ROCKET RANCH

The Nuts and Bolts of the Apollo Moon Program at Kennedy Space Center

Jonathan H. Ward

Springer

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Frank Bryan (NASA) deserves to be at the top of my list, both because he was the first KSC Apollo/Saturn worker I met and because he has been a consistent source of information and encouragement during the research and writing process. You'll see Frank's name frequently throughout this book, for good reason. As one of the go-to troubleshooters for the launch vehicle operations directorate throughout the Saturn era, Frank found himself in the middle of more interesting situations than you can possibly imagine. Frank spent many hours going over my drafts to ensure that I correctly represented the technology. Frank is conducting his own research and gathering the names of the people seen in photos from the era. I encourage you to visit the NASA Alumni League-Florida Chapter's webpage if you, a friend, or a family member worked on the space program. See http://nalfl.com/?page_id=2441 for more information.

Fred Cordia, one of the senior managers on Rockwell's S-II stage, likewise took painstaking time and effort to immerse me into the life of a launch vehicle stage contractor. One of the serendipitous joys of writing this book was putting Frank and Fred back in touch with each other for the first time in many years.

NASA launch vehicle test conductor Norm Carlson was initially skeptical of me and quickly became a dear friend. He made many phone calls and opened many doors on my behalf, for which I am very grateful. I regret not having finished this book in time for him to see it before he passed away. He will always have a special place in my heart.

What an honor it has been to get to know Ike Rigell, chief engineer and deputy director of launch vehicle operations during the Apollo era! I hope to see a book about this amazing man someday. Ike was with the Marines on Midway and Iwo Jima, played minor league baseball, served in Wernher von Braun's Missile Firing Lab, was instrumental in the launches of Explorer 1 and Alan Shepard…the list goes on and on. Ike is one of the most gentle and humble souls you will ever meet, and he is universally respected in the NASA community. I was honored to spend several days with him and thrilled that he agreed to write the foreword for this book.

From the spacecraft side of the house, Ernie Reyes (NASA) and John Tribe (Rockwell) merit my special thanks for their outstanding contributions, support, and friendship. John took me on a VIP tour of Kennedy Space Center and the Cape that was one of the best days I've ever spent. We went to places that I never dreamed I would see firsthand. It was the fulfillment of a lifetime of anticipation. Ernie can always be counted on for no-holds-barred and entertaining accounts of personalities and work practices. Both John and Ernie fact-checked my chapters on the spacecraft facilities. I could not have written this book without their contributions.

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Dave Mohr provided fascinating insights into the technology of the launch systems at Kennedy Space Center. Tim Burk supplied me with some of the first documents I had seen on the electrical support equipment at KSC, and he stimulated my interest in learning more about launch operations. Bill Sawchuck has been a longtime friend and resource on badges and people at the Cape. Ivan Blejec shared advice and many source documents with me as well.

Thank you to Jerome Bascom-Pipp and J. L. Pickering for making so many NASA images available to me. These gentlemen saved me countless hours of trolling the Internet for the "perfect" picture. Thanks also to the good folks who scanned the NASA images for the online Apollo Image Gallery and Apollo Lunar Surface Journal.

On April 22, 2013, my good friend the Rev. Meghan Froehlich said to me, "You need to write a book." I was non-committal, as I couldn't imagine what I would possibly write a book about. Little did we know that she planted a seed that day that insisted on being cultivated. Special thanks to Holly Williams for coaching me through the book writing process and keeping me from feeling overwhelmed. Without her, I might still be trying to get started. Thanks also to Martin Impey, Rick Swegan, W. David Woods, Francis French, Colin Burgess, and Susan Roy for their encouragement and sage advice during the writing and editing process. Their books have places of honor on my shelves. I appreciate the support provided by Emily Carney, Rebecca McWhirter, and other members of the Facebook "Space Hipsters" group. Thanks also to Maury Solomon and Nora Rawn at Springer for their excellent advice and patience with a new writer navigating the publication process for the first time.

And of course, I am grateful to my wife, Jane Gwyn Ward, for letting me cover every flat surface in the house inches deep in technical manuals, flow charts, and photos. She never doubted that I needed to write this book. She gave me complete freedom to pursue it, without question or complaint, even agreeing that I put aside any income-producing work for a year while I researched and wrote. She took many trips to the Space Coast in Florida when she could have asked to go some place more fun. After listening to so many stories about 1960s technology, she suggested that this book be subtitled, "How Cavemen Went to the Moon."

And many thanks to you, kind reader, for your curiosity about Kennedy Space Center and the days of Apollo and Saturn. All of the people I interviewed were deeply grateful that there are people interested in the Apollo era and what went on at KSC. You honor them and their legacy when you read this book. I hope that my writing conveys some of the thrill I experienced in hearing their stories.

This book is dedicated to the nearly 24,000 men and women of Kennedy Space Center who assembled, tested, and launched America's Apollo/Saturn missions.

About the Author

American author Jonathan Ward spent several years of his childhood in Japan, but he considers the Virginia suburbs of Washington, D. C., to be his hometown. Although he has a wide variety of interests and has worked in many fields, space exploration is his lifelong passion. His joy of bringing the space program to life for the general public began in high school, when he served as a volunteer tour guide at the National Air and Space Museum during the Apollo 15 and 16 missions. He continues his public outreach today, as a Solar System Ambassador for the Jet Propulsion Laboratory, as a frequent speaker on space exploration topics to interest groups and at regional conferences, and as an author for Springer-Praxis. Jonathan is also a frequent contributor to online space exploration forums.

Jonathan brings a unique perspective to his writing that marries a systems view of the topic, fascination with the technology, passion for space exploration, and deep respect for the people who make it all happen. He holds an MS in Systems Management from the University of Denver and a BS in Psychology from Virginia Commonwealth University. He is professionally certified as an executive coach by the International Coach Federation and serves on the adjunct faculty at the Center for Creative Leadership. His professional experience includes extensive work with leadership teams and several years with Boeing on the Space Station Freedom program.

Jonathan and his wife Jane now reside in Greensboro, North Carolina. He is fiercely proud of his two grown children and their families, and he wishes they lived closer to him. He maintains a web site at www.apollo-saturn.com to document his research on the Apollo era at Kennedy Space Center. He collects and restores artifacts from the Apollo era, including several control panels from the Firing Rooms. Jonathan also notes that he might possibly be the only current author about manned spaceflight who has appeared on two GRAMMY-winning albums, which were recorded during his years as a Bass II section leader, soloist, and eventually president of The Washington Chorus.

Foreword

I'm honored to introduce this book about our Apollo and Saturn team at Kennedy Space Center. You will learn the inside story of what it was like to be part of Project Apollo at KSC, what I consider to be the greatest achievement in human history. I'm convinced this story is a winner, one that needs to be told.

We are a product of our environment. In the Apollo days, we had great leaders, we had smart people who were willing to try new things, and we took responsibility for making bold decisions. That's what made Apollo succeed.

When President Kennedy made his challenge on May 25, 1961, the NASA organizations were on the level of a mom-and-pop grocery store. And the next day, we suddenly had to be General Motors or Walmart. Fortunately, we had strong leaders at each NASA Center: Bob Gilruth, Wernher von Braun, Kurt Debus, and others. Of course, they all had their own ideas, and they fought for them fiercely. But we had strong NASA management in Washington. Jim Webb was one of the best administrators we ever had. He knew how to work the Congress, he knew how to work the executive branch of the government, and he knew how to get resources.

Webb called in Dr. George Mueller, who brought in General Sam Phillips as program manager. When you were a program manager, you got money. And if you got the money, you got the power. Dr. Mueller and Gen. Phillips drew up a plan, and they told each NASA center, "Here's what you're going to do, and this is the way we're going to do it."

There'd still be some infighting, but they worked it out. With the time pressure we were under, we couldn't get a committee together and study the situation for months. They had a 5-hour meeting in Washington one day and decided, "Here's how we're going to the Moon." And what is the flight hardware, the booster going to look like? And von Braun had some strong ideas on that. And then you had to design that hardware and write contracts. And how are you going to launch that baby? That's where Dr. Debus figured out what the Launch Complex 39 should look like. We had people like Don Buchanan at KSC to do the design work. He was one of the sharpest guys out there. It all worked beautifully.

And I can't say enough about Rocco Petrone, the director of launch operations for Dr. Debus. I am not sure many people know or appreciate what Rocco meant to the success of the Apollo Program, but we never would have gotten to the Moon on time, or maybe never got there at all, without Rocco. I attended Rocco's staff meeting every morning and I observed what he did to shape up not only KSC but also Houston and Huntsville. A lot of evenings, I don't know how it happened, but I'd end up in Rocco's office, and Rocco would sit there and just talk about the whole program. He had vast knowledge. If there were problems they were having back at the factory with the command module, or the S-II, or the engines or whatever, Rocco knew as much or more than the guys at Houston or Marshall. If you were straight up with him that you didn't have all the answers, that's okay—just go get them. But you should never try to fool him. Chances were that he already knew more about a situation than you did.

When we started off, we had advantages we weren't aware of. We were all young. In the space exploration business, that's a tremendous advantage, because when you're young, you're not afraid of failure like you are when you're older. That's true of an organization and of a person. I've got two little great-grandchildren. They try to walk around. They tumble, and we all laugh. It doesn't bother them. They get up and try again. And now here I am, and I want to get to the top of the stairs. To me, that's a challenge. And I think Man is like that. Early Man always looked to the stars. In the early space days, we were trying to get up that next step, and we weren't afraid. We failed, and we'd pick ourselves up and try again.

On *Redstone 3*, the rocket went up a few feet, crashed down, and blew up on the pad. That's when you learn. You don't learn a whole lot if everything goes like the book. We learned and regrouped and went ahead. I think that was a tremendous advantage. When you're young, you accept responsibility.

When we started out, there was no paper. The countdown procedure was maybe three sheets of paper. And we didn't pay much attention to that! We'd say, "Milt, turn your gyros on when you're ready." As the program grew, we accumulated more paper and bureaucracy. You reach a point in your growth when you've got to make a big decision, and you start to worry: "How am I going to look if this fails?" The fear of failure makes you form a committee. The worst thing you can do is to get a committee to make a decision that should have been made quickly.

When we started NASA, there was no set of rules or regulations. They didn't exist! And so you did things sometimes where you didn't know any better if there was a regulation against it or not, so you just went ahead and did it.

At the end of my space career, I was with USBI for about 10 years. One of the last things I remember was that we wanted to build a concrete pad that we were going to put a trailer on where we hot-fired the gas generators. The environmental impact statement for that tiny little pad took months. I'll bet you there was more paper generated on that pad than there was to buy the land for Kennedy Space Center.

Apollo was built with 1960s technology, with relays, stepping switches, and moving parts. Moving parts by their nature are less reliable than solid state. Some of us still remember the old car radios with vacuum tubes. In earlier missiles, we had tape recorders.

And it's still amazing to me that we had so many countdowns and such a success with the Saturn, because we had relays and moving parts everywhere.

We were the first, as far as I know, to do checkout and launch work with automation. It's no exaggeration to say that in the early days, our computer was down more than it was up. It could be downright dangerous, because it had a failure mode where it would issue about half its commands when it shut down. We really fought that thing. In the first Saturn V countdown demonstration test that we tried, it took us 17 days to finally get the green lights to say yeah, we could have launched. It was amazing that we could get the subsequent countdowns off on time like we did.

Just seven and a half years after President Kennedy said, "Let's go to the Moon," Frank Borman was circling the Moon and reading from the Book of Genesis. Seven and a half years! In the atmosphere during Apollo, you just thrived on problems, and you had pride that you could accomplish things that at first seemed impossible. It was a real can-do attitude. Now we're talking about maybe going to meet an asteroid sometime about 2030. In my opinion, we've lost something along the way. I think this is a nationwide issue, not limited to space exploration. You couldn't do Apollo today. I think it would be totally insurmountable. We don't have the attitude and perseverance that it took to make it happen back then.

When I grew up, there was a woman that was our cook and housekeeper. And every time I went back home to Alabama, I'd go and see Johnnie Mae. The first time I went back home after *Apollo 11*, I went to see her, and she was in her front yard with a lot of people. She pulled me aside and said, "Mr. Ike, I want to talk to you. I want you to tell me about how you all faked that thing about going to the Moon! I know the Lord, if he wanted somebody up there, He'd have put them there! Now I want you to tell me how you all did that!" I said, "No, it's real!" She said, "No, no. You tell me! You can trust me, you know me!" I said, "Johnnie Mae, it's real!" And we went back and forth like that. And she never would believe me. And it's one of the regrets I have, that not long after that exchange, she died. And I sometimes wish I'd made up some fake story, because she died thinking that I didn't trust her enough to tell her the truth.

But it was the truth. We really did put men on the Moon.

We recently had the 60th anniversary of the launch of the first Redstone, August 20, 1953. I remember standing outside after the gantry moved back on that Redstone. It was 5 ft in diameter, 70 ft tall, and I was thinking, "Man, this thing is too big to fly! They'll never get this off the ground!" And 15 years later, Frank Borman is circling the Moon. The following summer, Neil Armstrong is walking on the Moon. It's incredible! You can't hardly conceive it.

As the years go by, the memory of what Kennedy Space Center did in Apollo is fading away. I appreciate Jonathan's enthusiasm for documenting a part of our space history that has not been told. I suspect it would never be told without Jonathan's effort because, let's face it, time is running out. I'm 91 years old now. These days, I go to too many funerals of good friends and hard workers from KSC, people who never asked for or got recognition for doing everything it took to launch the best space vehicle that ever flew. It's time they got their due.

I always tell people that I never worked a day of my life at the Space Center. I think that if you enjoy what you're doing, it's not work. This book tells the story about people who enjoyed what they were doing, and did it really well.

Titusville, FL, USA
September 2014

Isom A. "Ike" Rigell
Launch Vehicle Operations
Kennedy Space Center

Preface

My earliest memories include my fascination with space. I have always been consumed by the love of space travel, rockets, and astronomy. As a child of the mid-1950s, I had the outstanding good fortune to develop consciousness just as America's space program got off the ground. I watched TV coverage of Alan Shepard's first flight when I was 4 years old. I was a fourth grade student living in Okinawa when Neil Armstrong and Dave Scott's Gemini VIII capsule made an emergency landing nearby. In a very real sense, I feel like the space program and I grew up together.

The astronauts of that era were exceptional people in my mind. Although I sat in more than my share of cardboard box space capsule cockpits, I knew that my being overweight and colorblind meant that I would never actually fly in space. Even my 10-year-old self knew that it made no sense even to dream of being an astronaut.

But working in Mission Control or the Launch Control Center—that was a different story. I was fascinated with control panels, tubes, radios, knobs and switches, and indicators and dials. What could possibly be better than sitting at a console, wearing a headset, and pushing an important button at the critical moment?

Cape Canaveral and Kennedy Space Center seemed like a magical place, where huge rockets blasted off in the morning sun on epic journeys of exploration. I dreamed of going there, but our family travels never included Florida. My father, a career civil servant, participated in a management course that took him to NASA facilities at Langley, Houston, and Kennedy Space Center in August 1969. This was less than 2 weeks after the Apollo 11 astronauts had returned from the Moon. The Saturn V rockets for Apollo 12 and 13 were stacked in the Vehicle Assembly Building at KSC, being made ready for missions before the end of 1969 had Apollo 11 failed to make a lunar landing. Dad returned with slides of his brief trip, and I looked at them every chance I could. I would have traded anything to be able to make that trip with him.

Fast-forward to the spring of 1988. I had witnessed the *Challenger* disaster live on TV 2 years earlier. Now, as a 31-year-old, I was working for Boeing on a support contract the Space Station Freedom program. Just a few months on *Freedom* were sufficient for me to wonder how NASA's bureaucracy ever got a rocket off the ground. (And sure enough, *Freedom* never flew.) My family and I drove from the Washington, D.C., area to visit my now-retired father in Miami. On the way, we made a brief stop at KSC. The shuttle *Discovery* was still in its hangar, out of public sight, being prepared for its September return-to-flight mission. We saw the rusting remains of a Saturn V on display in the VAB parking lot. It was a difficult period to be a space enthusiast. Nothing seemed to be moving. Things feel very much the same today, as we wait for manned launches to resume—"someday soon"—from KSC.

Fast-forward another 15 years. With the advent of online auction sites such as eBay, I was astonished to find bits and pieces of actual Apollo-era hardware come up for sale. I developed a particular interest in Apollo-era access badges and items associated with the Launch Control Center at KSC. I felt compelled to research items to learn more about how they had been used and by whom. Every badge had a story to tell about someone with an interesting role during Apollo. Many of the items came from people selling off a deceased relative's estate. When I inquired about the person who had worn a given badge, I frequently received replies such as, "My uncle worked for NASA, but I have no idea what he did, and he didn't leave a diary or memoirs." I thought this was a crying shame.

I obtained a few control panels from the Apollo-era firing rooms. How could I possibly have foreseen as a child that such a thing would be possible—that I would actually have some of those control panels in my own hands? I located fellow collectors and learned about their relics. I put up a web site documenting some of my research into the Launch Control Center during Apollo days. I had the good fortune to begin corresponding with former NASA engineer Frank Bryan in late 2011, after Frank saw the web site. Frank was gracious enough to let me pick his brain about KSC hardware from the 1960s. His recollections provided intriguing behind-the-scenes insights into what it took to get the mighty Saturn V off the ground.

About the same time I met Frank, I briefly corresponded with Bob Sieck, who was a project engineer on the Spacecraft side of the house during Apollo, and who went on to become Director of Shuttle Operations. Bob was gracious enough to exchange letters with me and answer a few questions. The more I learned from Frank and Bob, the more I wanted to know, and the more I wanted to let everybody else know about the amazing work that was done at KSC in the Apollo era.

There are many outstanding books, most notably the classic "Moonport," which tell in exhaustive detail the history of the facilities at Kennedy Space Center. I would not presume to improve upon those books, but I also believe there are gaps that need to be filled. After all, it would be impossible to provide a full accounting of what 24,000 people did at KSC for the better part of a decade. At the other end of the spectrum are books that focus entirely on the "human" side of the story, usually told from one participant's perspective. They are filled with fascinating and humorous anecdotes, but they often leave the reader with the impression that "you really had to be there" to get the joke. Moreover, they lack a broader perspective of the myriad facets of work at KSC.

Given my background in systems management, what I really wanted to examine was how all the pieces fit together across KSC. How did the spacecraft, launch vehicle, and ground support equipment work together? How did the organizational structure support the work? What was it like to be one of 24,000 people working there—each worker relatively small in the overall scheme of things, yet still vitally important to the success of his or her particular component or process? The hardware and facilities were unlike any others on Earth, but they were useless without humans to run them. My story had to include both sides of that equation.

Armed with this idea, I asked Bob Sieck and Frank Bryan for their opinions. They both thought it was an interesting and workable approach. Then I took a big gulp and asked if they would be willing to introduce me to some of their colleagues so I could start filling in the blanks. After the first few interviews, everything snowballed. Every interview ended with the person saying, "Let me put you in touch with…"

My objectives were to put as much meat on the bone as possible, while keeping the detail at a manageable level, so that everything fit into one book. These turned out to be mutually exclusive goals. After reading my first manuscript, my wise editor at Springer advised me that a book over 700 pages long would prove too daunting for most people. She suggested that there were actually two books trying to emerge from this material. I resisted that notion at first, but she was correct.

This book and its companion ("Countdown to a Moon Launch: Preparing Apollo for Its Historic Journey") both focus on Kennedy Space Center during the Apollo era. Their topics are distinct and complementary. Each is complete in itself and can be read on its own. My hope is that you will find that both of them together tell an even more compelling story.

In researching these books, I devoured in excess of 1,200 source documents and conducted over 300 hours of interviews with more than 70 people. I know that I have only scratched the surface. Piecing everything together into a coherent saga was occasionally challenging but never frustrating. It was the most fun I've had in a long, long time. Other than seeing my kids become flourishing adults, I consider this work to be the most important and rewarding thing I've done with my life.

There are so many photos and figures I wish I could have included, but details in some photos and diagrams would be lost by shrinking them down to book size. My web site (www.apollo-saturn.com) contains supplementary information to accompany this book, and it will be kept up to date. There will also be a place to post errata and corrections for this book. Please visit the site and check back often!

So, that's the story of how this book came to be. I hope you will enjoy reading it, and that you will experience some of the joy I feel in celebrating wonderful people who accomplished amazing things at an incredible place in a magical time.

Greensboro, NC, USA Jonathan H. Ward

1

Introduction

FROM FISHING FOR MULLET TO SHOOTING THE MOON

On Monday morning, July 24, 1950, 12-year old Jim Ogle was on a small boat in the Banana River near South Merritt Island, Florida. He was cast netting for mullet to use for fishing bait. A strange crackling noise caught his attention at about 10:30. Looking up to the north, he saw a contrail taking off from the ground and extending out over the ocean. He wasn't sure what it was he had witnessed, but he knew it was unusual.

The front page of the next morning's *Cocoa Tribune* was full of excited news about the previous day's events. Jim learned that he had witnessed the very first rocket launch from Cape Canaveral. Wernher von Braun and his Missile firing lab team from Alabama had come to the Cape to launch *Bumper 8*, a V-2 rocket with a WAC Corporal missile bolted on as the upper stage.

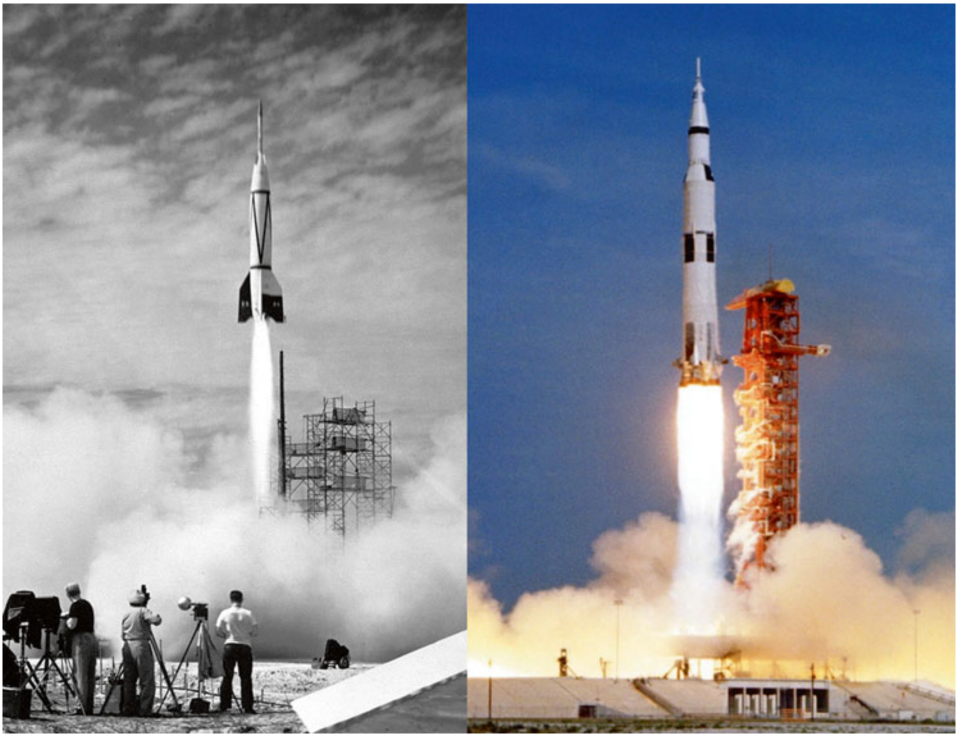
The young boy could not possibly have imagined that less than 19 years later, he would be manning a console in the Launch Control Center during the launch of *Apollo 11*, playing an integral part in mankind's first attempted landing on the Moon (Fig. 1.1).

WHY A BOOK ABOUT KENNEDY SPACE CENTER DURING APOLLO?

More than 45 years after it first landed on the Moon, America struggles to define its future in outer space. The United States spearheaded the development of the International Space Station, an amazing feat of technological prowess and international cooperation, and yet it currently lacks a vehicle for taking its own astronauts to visit the scientific outpost that it built. People argue over which long-term goal the country should pursue in space. Is it Mars? If so, when? What role will astronauts play? Isn't it cheaper to send robotic probes?

Without a vision of where we are going, a strategy is meaningless, and the intermediate steps are difficult to rationalize. Should we go to an asteroid, or should we first set up a Moon base? We cannot develop a long-term goal in space because we do not have the funding, and the country is unwilling to provide funding if there is no long-term goal. Years go by, money is spent, and progress is difficult to quantify. How do you measure progress when there is no goal?

J.H. Ward, *Rocket Ranch*, Springer Praxis Books, DOI 10.1007/978-3-319-17789-2_1



1.1 *Left*, *Bumper 8* becomes the first rocket launched from Cape Canaveral on July 24, 1950. Just 19 years later and a few miles to the north, some of the same rocketeers sent *Apollo 11* on its historic journey to the Moon. *Source*: NASA/Ward

In frustrating times, people passionate about space exploration understandably look back to the good old days of America's early space program. The country pursued an audacious goal set by a charismatic young president. We were in a struggle to win the hearts and minds of the world by showing that our approach to life was more productive than that of the Soviet Union. We launched a new space mission every other month throughout much of the 1960s, each flight more daring than the last. The race to the Moon spurred new technological advances and changed the way we thought of ourselves.

We remember most vividly America's larger-than-life astronauts. Their pictures were in magazines, newspapers, and on television. We knew their names and personalities. Those of us who followed the missions on TV remember seeing occasional scenes of the inside of Mission Control at Houston, or of the fiery launches of the Saturn V rockets from Kennedy Space Center. But would many of us have been able to recall the name of anyone in Mission Control, had it not been for the 1995 movie, *Apollo 13*?

A more difficult question for the ardent space buff is: Can you remember the names of anyone who worked at Kennedy Space Center? Pad Leader Guenter Wendt's name might come up, but again primarily because he was briefly mentioned in *Apollo 13*. But for whom did Guenter work? Did you know he wasn't a NASA employee? Who was in charge at Kennedy Space Center during the Apollo era? No, it wasn't Wernher von Braun. What really went on at Kennedy Space Center other than launching the rockets?

The fact of the matter is that the eyes of the world were on the astronauts and Mission Control but except for launch day, the public rarely heard of or saw what went on at Kennedy Space Center.

HOW THIS BOOK IS ORGANIZED

This book's intent is to provide a glimpse of what it was like to work at Cape Canaveral and Kennedy Space Center during the Apollo era. There are many other wonderful books that cover the missions themselves, the role of Mission Control in Houston, or the Apollo/Saturn flight hardware. Rather than trying to re-tell what has been better told elsewhere, we will concentrate on the story that has not been told as often—a behind-the-scenes look at the facilities and people at KSC that made it possible for a mission to get off the ground in the first place.

The book has three primary sections. Chapters 2 and 3 give an historical context for the Apollo/Saturn program at Cape Canaveral and Kennedy Space Center in the early days, from 1960 up through the *Apollo 1* fire. We will first briefly review the story of how Kennedy Space Center came into being and its relationship with the two other major centers that managed parts of the Apollo program. This history will shed some light on the distinct organizational cultures at KSC and how they affected day-to-day work. We'll briefly explore life at Launch Complexes 34 and 37 on the Cape and the challenges of implementing new technologies. Then we will discuss the most infamous test during the Apollo era, the "plugs-out" test that claimed the lives of the three *Apollo 1* astronauts on January 27, 1967. You will read first-hand accounts from people who were in the blockhouse and control room, and also hear from the brave men who fought the fire on the launch pad to try to rescue the astronauts. This tragedy deeply affected everyone who worked on Apollo/Saturn, whether or not they were on duty that day.

The middle section of the book moves us to Launch Complex 39, America's Moonport. Chapters 4 through 6 describe the amazing facilities where the Apollo spacecraft and the Saturn launch vehicle came together and were tested. We will take a detailed look at the groundbreaking use of computers for checking out the Apollo and Saturn V and controlling operations at the launch pad.

We roll out to the launch pad in the final section of the book. Chapter 7 describes the incredible structures and technologies of KSC's Saturn V launch facilities. Chapter 8 orients us to the many hazards at the launch pads and provides first-hand accounts from KSC employees about what it was actually like to work in this strange and dangerous place. We will close the book with workers' personal reflections on their experiences in the Apollo program.

This book is a companion to the author's *Countdown to a Moon Launch: Preparing Apollo for Its Historic Journey. Countdown* follows the launch processing flow for Apollo/Saturn missions at KSC, from shipment of the stages to Kennedy through assembly and test, culminating in launch. While both books can be read independently, the information is complementary. The book you're holding is the "where, and what" of Kennedy Space Center; *Countdown* provides the "how and why." Core to both books is the recognition of the "who"—the people who made it all happened.

24,000 PERSPECTIVES

The challenge in putting together a book about Apollo and Saturn is that so much has already been written about the program. However, many of the books focus on the missions after launch and the astronauts. These books don't tell us how things really got done on the ground, before a mission even got to the launch pad.

Another missing theme from accounts about Apollo and Saturn is what the day-to-day life and work entailed at Kennedy Space Center in the 1960s. What was it like to work at the launch pad on a Saturn V? What did all those people in the firing room do?

This is not a book about larger-than-life leaders or daring astronauts. This is a book about what happened on the assembly and checkout floor, inside the mobile launcher, or on the umbilical tower 400 ft above the launch pad.

The people who were actually there will do most of the talking in this book. You will hear their experiences described in the first person, told by the people who did the work. We have done our best to include perspectives of people who worked for NASA or a contractor, who were engineers or technicians, who ran tests or conducted operations, who worked on the launch vehicle or the spacecraft or the support organizations. More than 70 Apollo-era workers from KSC contributed directly to this book through interviews, personal written records, photographs, diagrams, and drawings. These sources represent a cross-section of the people who tested and launched the Apollo/Saturn missions.

Most of these men and women are in their seventies or eighties now, and a few are in their nineties. Wherever possible, their recollections have been fact-checked and married up to official versions of events. Trust that any disagreement is likely due to the perspective of the person recalling the incident.

One of the constants of NASA, then and now, is that people use a lot of acronyms and abbreviations in their conversation. The terms can be confusing to grasp, but they actually make conversation clearer and more concise. It is simply easier to say "SCAPE suit" than "self-contained atmospheric protective ensemble." I have tried to limit the use of acronyms to the most common ones, and they are all spelled out in Appendix A.

Many of the people interviewed for this book not only worked during the Apollo/Saturn era but also continued on through a large part of the space shuttle program. That these people are able to recall Apollo with such clarity, despite 40-plus intervening years and 135 Space Shuttle missions, speaks to the powerful impressions made by their experiences with Apollo/Saturn.

My sincere hope is that you will get a feel for what it was like to work in amazing facilities on the biggest rocket that the United States has ever flown, when there was intense pressure to beat the Russians and an impossibly tight deadline, when dedication to a challenging goal was enough to keep people working 12-hour shifts for months without a break. You will hear some incredible stories about successes and things that didn't go quite as planned. The illustrations include some well-known photographs from the period, as well as diagrams from hard-to-find sources. Unless specifically captioned otherwise, all illustrations in this book were extracted from NASA public domain photographs or diagrams from NASA manuals.

Prepare yourself for a journey back to the 1960s and 1970s, when ordinary people in an extraordinary place were creating the future every day.

2

Setting the Stage for Apollo/Saturn, 1960–1966

"I believe that this nation should commit itself to achieving the goal, before this decade is out, of landing a man on the Moon and returning him safely to the Earth. No single space project in this period will be more impressive to mankind, or more important for the long-range exploration of space; and none will be so difficult or expensive to accomplish.

We propose to accelerate the development of the appropriate lunar spacecraft. We propose to develop alternate liquid and solid fuel boosters, much larger than any now being developed, until certain which is superior. We propose additional funds for other engine development and for unmanned explorations – explorations which are particularly important for one purpose which this nation will never overlook: the survival of the man who first makes this daring flight.

But in a very real sense, it will not be one man going to the Moon – if we make this judgment affirmatively, it will be an entire nation. For all of us must work to put him there."

– Excerpt from the "Special Message to Congress on Urgent National Needs," President John F. Kennedy, May 25, 1961

The president's challenge came at a time of tremendous change for the world, the nation, and the space program. NASA was still a relatively young agency, but it had already launched an American into space, and it was already at work on the next generation of spacecraft and launch vehicles, respectively called *Apollo* and *Saturn*, when the president made his first public push for a lunar landing program.

This chapter provides some context on the early years of the Apollo and Saturn programs. We will take a brief glimpse at the Cape and Kennedy Space Center, the early launch sites and technology, and the people and organizations who were embarking on years of countless overtime and untold pressure in preparation for one of mankind's greatest technological achievements.

J.H. Ward, *Rocket Ranch*, Springer Praxis Books, DOI 10.1007/978-3-319-17789-2_2

THE CAPE AND KENNEDY SPACE CENTER

The U. S. military had been launching rockets from Cape Canaveral since July 1950. Managed by Patrick AFB about 20 miles (32 km) to the south, Cape Canaveral Air Force Station (CCAFS) was a convenient location for the military to test its rapidly evolving missile program in the 1950s and 1960s. Seaside launch pads allowed sometimes-balky, and always dangerous, missiles to fly out over the ocean, minimizing the risk to the civilian population.

In the early and mid 1950s, Wernher von Braun ran the Missile Firing Lab in the Army Ballistic Missile Agency (ABMA). Von Braun and his team trucked their missiles from ABMA in Huntsville, Alabama to the Cape for test flights, borrowing bunkers and launch pads from the air force. The ABMA became Marshall Space Flight Center (MSFC), with von Braun as the center director, when NASA was created in 1958. The Missile Firing Lab became NASA's launch operations directorate (LOD), managed remotely by MSFC. The LOD was responsible for running NASA's launches at the Cape.

The pace of rocket testing continued to accelerate, and NASA saw that it would be more efficient to manage its launch operations locally in Florida rather than remotely from Alabama. Von Braun designated one of his deputies and long-time associates, Kurt H. Debus, as director of the newly-named Launch Operations Center (LOC) when it spun off from MSFC in 1962. Debus was renowned for his deep technical knowledge of all aspects of rocket systems and launch technologies. Debus' headquarters were in Cocoa Beach, while all operations associated with assembling and launching rockets were conducted at CCAFS (Fig. 2.1).

When President Kennedy issued his challenge to go to the Moon by the end of the decade, NASA was already activating Launch Complex 34 (LC-34) at CCAFS for the unmanned Saturn *SA-1* launch scheduled for September 1961. Construction was also underway on LC-37, just to the north of LC-34, to handle the launches of NASA's planned second generation of unmanned Saturn rockets. LC-34 and LC-37 would be the free world's largest launch complexes at that time. And yet even before construction was complete, von Braun and Debus clearly knew that even these two complexes were insufficient to support the lunar program, which centered on the rocket eventually known as the Saturn V.

The scope of the challenge to reach the Moon required building more and vastly larger facilities than Cape Canaveral could support. Early NASA projections showed that perhaps 50 launches a year[1] might be needed to ensure that the United States reached the Moon by 1969. Von Braun and Debus realized that the existing launch facilities at the Cape could not be expanded to handle the numbers and sizes of the rockets needed to send men to the Moon. NASA needed a new "moonport."

In July 1961, after considering many other alternative sites, NASA began acquiring land on Merritt Island, adjacent to and lying to the north-northwest of CCAFS, to support the LOC and the lunar program. NASA dubbed this new site the Merritt Island Launch Annex (MILA).

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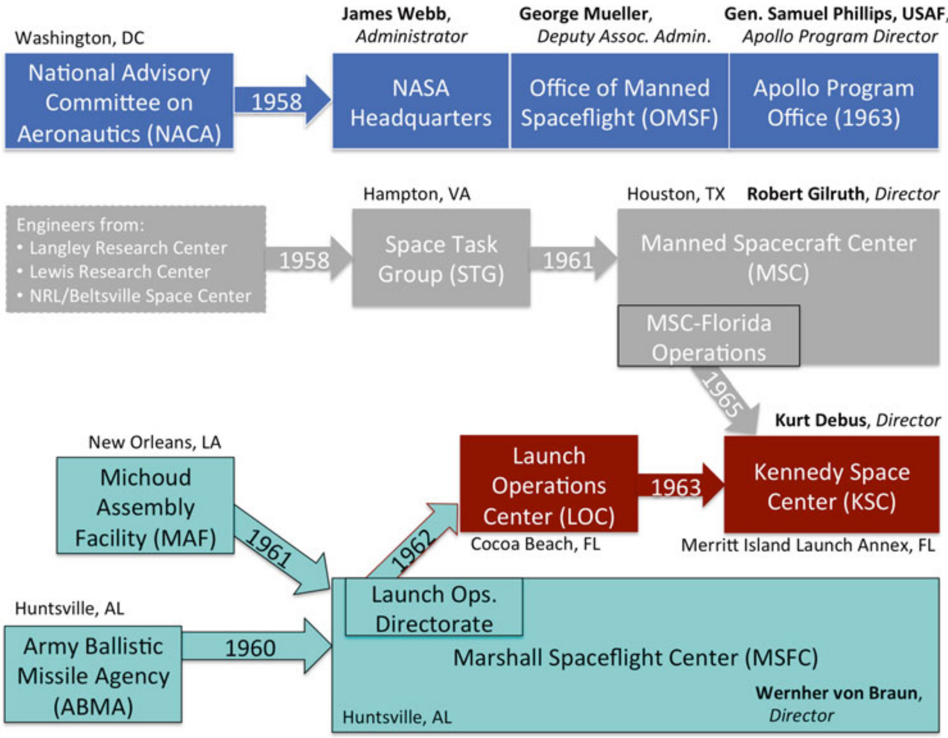
[1] This estimate was based both on von Braun's conservative test approach and the original *Earth-orbit rendezvous* (EOR) mission strategy for reaching the Moon. EOR required two rocket launches within a day or two for a single Moon mission.

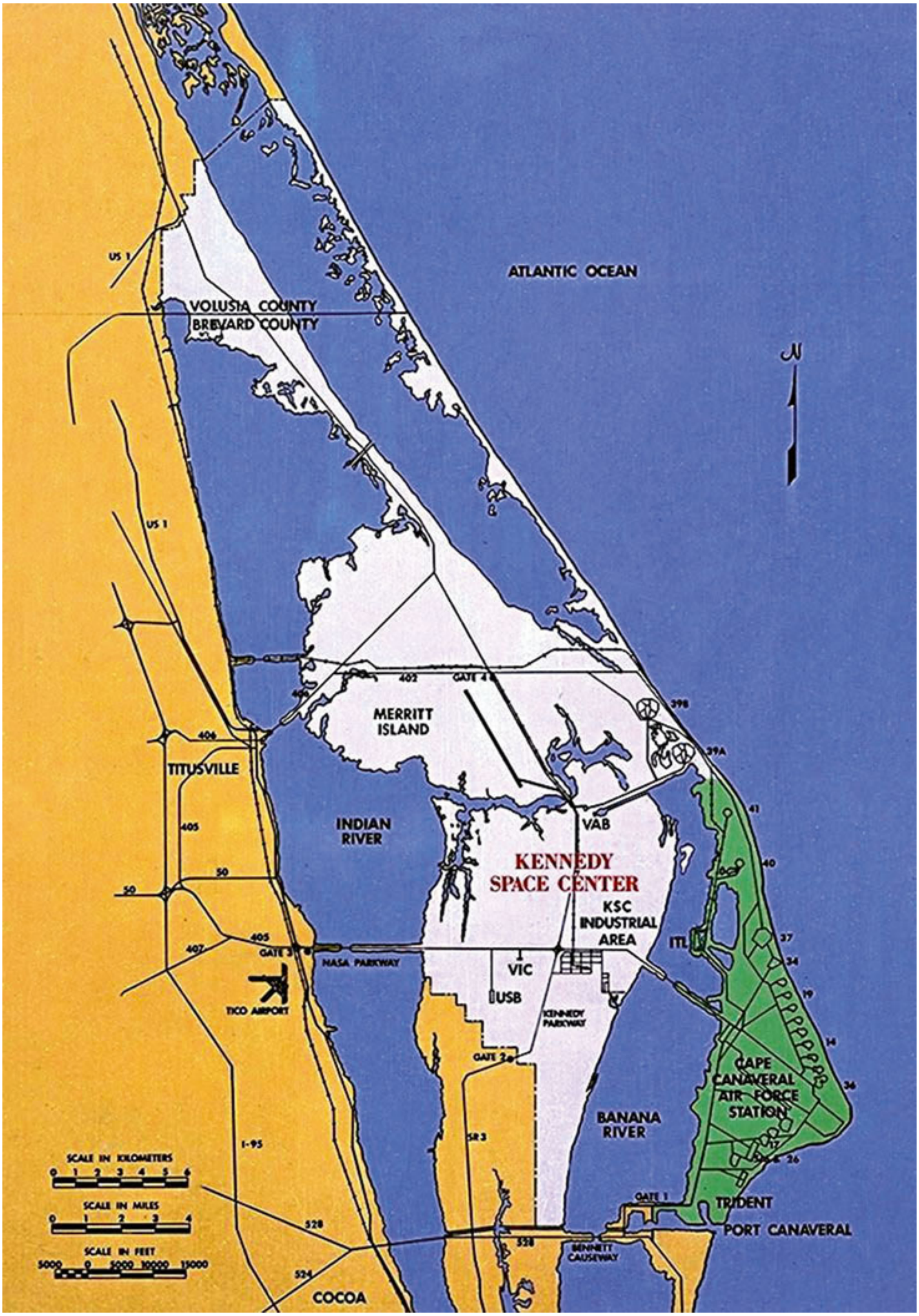


2.1 The evolution of the NASA organizations with primary responsibility for the Apollo/Saturn program. *Source*: Author

A week after the assassination of President Kennedy in November 1963, Lyndon Johnson's executive order changed the collective name of the LOC and MILA to the John F. Kennedy Space Center (KSC). At the same time, Cape Canaveral Air Force Station was renamed the Cape Kennedy Air Force Station (CKAFS). It would retain that name into the early 1970s. Because the name eventually changed back to Cape Canaveral Air Force Station, we will refer to it as Cape Canaveral, or CCAFS, throughout this book.

The distinction between KSC and Cape Canaveral can be maddeningly confusing. KSC and Cape Canaveral/Cape Kennedy are not the same entity. KSC is a NASA organization and a NASA site. Cape Canaveral is a USAF installation managed by Patrick AFB. The air force leased launch pads and other facilities and provided support operations to NASA, and continues to do so today.

So, KSC and CCAFS were and are distinct and different. The newscasters of the 1960s did nothing to help alleviate the confusion when they referred to Kennedy Space Center as "Cape Kennedy." And even nowadays, it is not unusual to hear astronauts or people from other NASA centers talk about "flying out to the Cape," when they in fact mean that they are traveling to KSC. It is no small wonder people still confuse these installations (Fig. 2.2).



2.2 Map showing the relationship of Kennedy Space Center (*white*) and Cape Canaveral Air Force Station (*green*). *Source*: NASA/Ward

LC-34 AND LC-37 AND THE LAUNCH OPERATIONS DIVISION

Launch Complexes 34 and 37 (referred to in conversation simply as "34" and "37," and collectively also referred to as LC-34/37) were designed specifically for the Saturn C-1 family of rockets. The C-1 was one of many conceptual configurations for the Saturns, using an S-I first stage and an S-IV second stage. Von Braun pitched the Saturn to the U. S. military in the 1950s, but the air force decided to use its own missiles. The Saturns became the first launch vehicles built by von Braun's team strictly for civilian use. LC-34 was the first CCAFS launch pad totally dedicated to NASA missions, and Kurt Debus proudly referred to it as "the world's first launch complex build solely for the peaceful exploration of space." (Fig. 2.3).

LC-34 and LC-37 were located at the north end of CCAFS. Since the Saturn launch vehicles were more than twice the size of any rockets previously launched at the Cape, the facilities at LC-34 and 37 also dwarfed all previous CCAFS launch sites. In the CCAFS industrial area, several miles away, were the hangars and trailers housing the rapidly-growing NASA and contractor staffs. Debus and his launch vehicle team were primarily in the E&L building. Spacecraft operations resided in hangar S. Some stage contractors were in hangar AE, and the data and telemetry station were in hangar D.

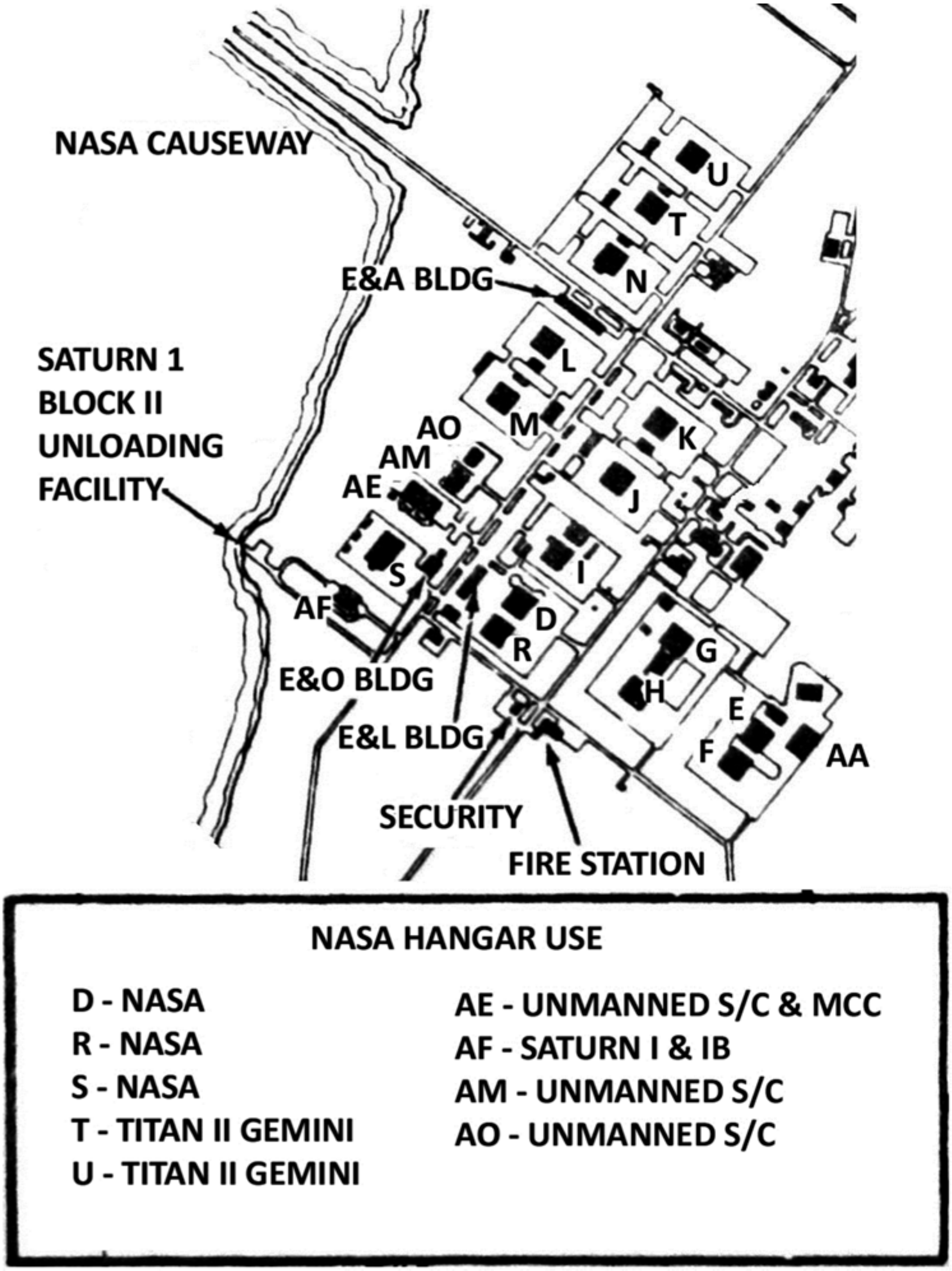
LC-34 and LC-37 were designed for fixed operations. This meant that the vehicle stages were delivered to the launch pad, where they were hoisted atop the launch pedestal, assembled, tested, and eventually launched. The service structure, a mobile tower with mechanized work platforms, rolled into place on rails to facilitate assembly and servicing of the launch vehicle on the pad. Automated equipment inside the blockhouse and under the pad checked out and launched the vehicle (Fig. 2.4).

LC-34 was approximately 40 acres (16 ha) in total area, surrounding a raised concrete launch pad 400 ft (120 m) in diameter. A 30 ft (9 m) tall launch pedestal sat in the middle of the launch pad. Its circular opening was ringed at the top by a water deluge system, and it also housed the holddown arms and support arms upon which the launch vehicle rested. An automatic ground control system (AGCS) facility, located underneath the launch pad, housed the electrical support equipment and half of the ground computer system (Fig. 2.5).

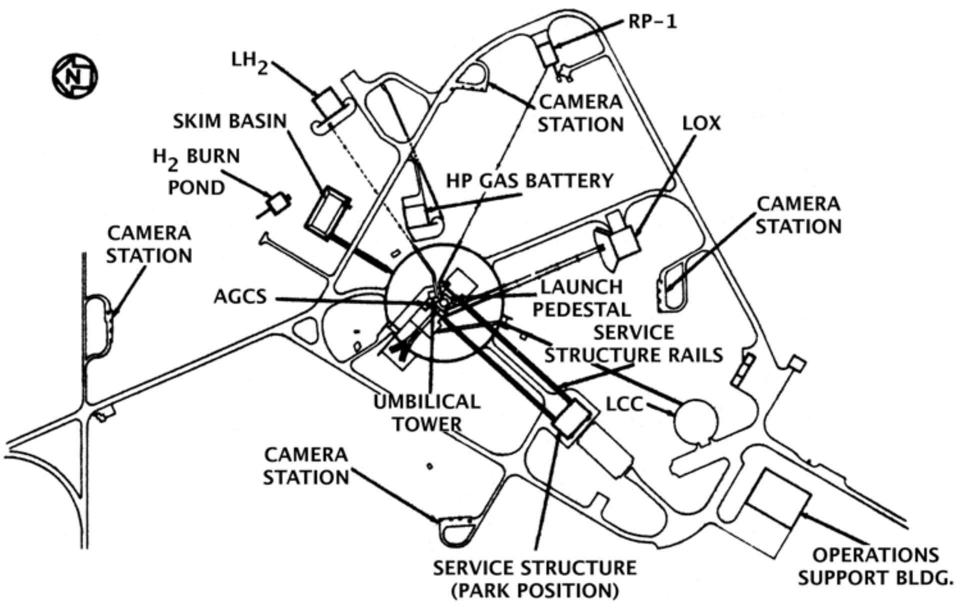
To erect the launch vehicle onto the pad, the 310 ft (94 m) tall, self-propelled service structure moved into place on rails from the southwest. It straddled the launch pedestal, and had vertically adjustable and fixed service platforms. The service structure was moved back to a parking position about 600 ft (182 m) from the pedestal before launch. A flame deflector, also mounted on rails, was moved into position under the pedestal shortly before launch (Fig. 2.6).

NASA added an umbilical tower to the pad beginning with the *SA-3* mission. The 240 ft (73 m) tall tower, immediately to the northeast of the pedestal, supplied propellant, electrical, pneumatic, and data connections to the launch vehicle from the pad.

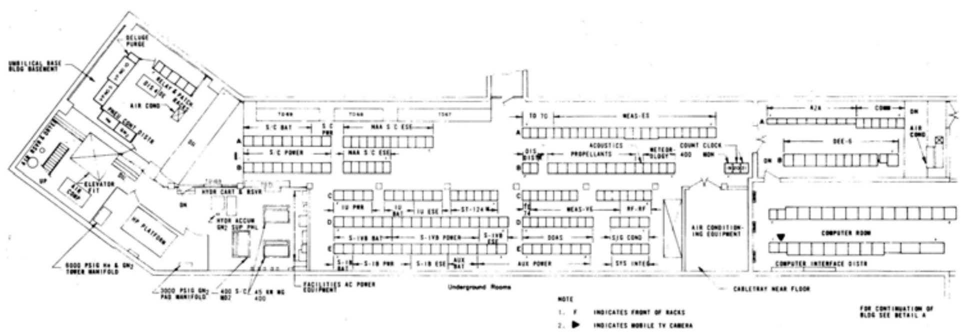
An igloo-shaped blockhouse sat about 1,200 ft (360 m) SSW of the launch pad. Its first floor contained telemetry and computer equipment. The second floor was a firing room that housed about 150 engineers and test conductors. There were no windows in the blockhouse. Observers monitored activities on the launch pad using periscopes and a closed circuit TV system (Figs. 2.7 and 2.8).



2.3 Diagram of the CCAFS industrial area hangars and buildings in use by NASA in mid-1967. *Source*: NASA/Ward



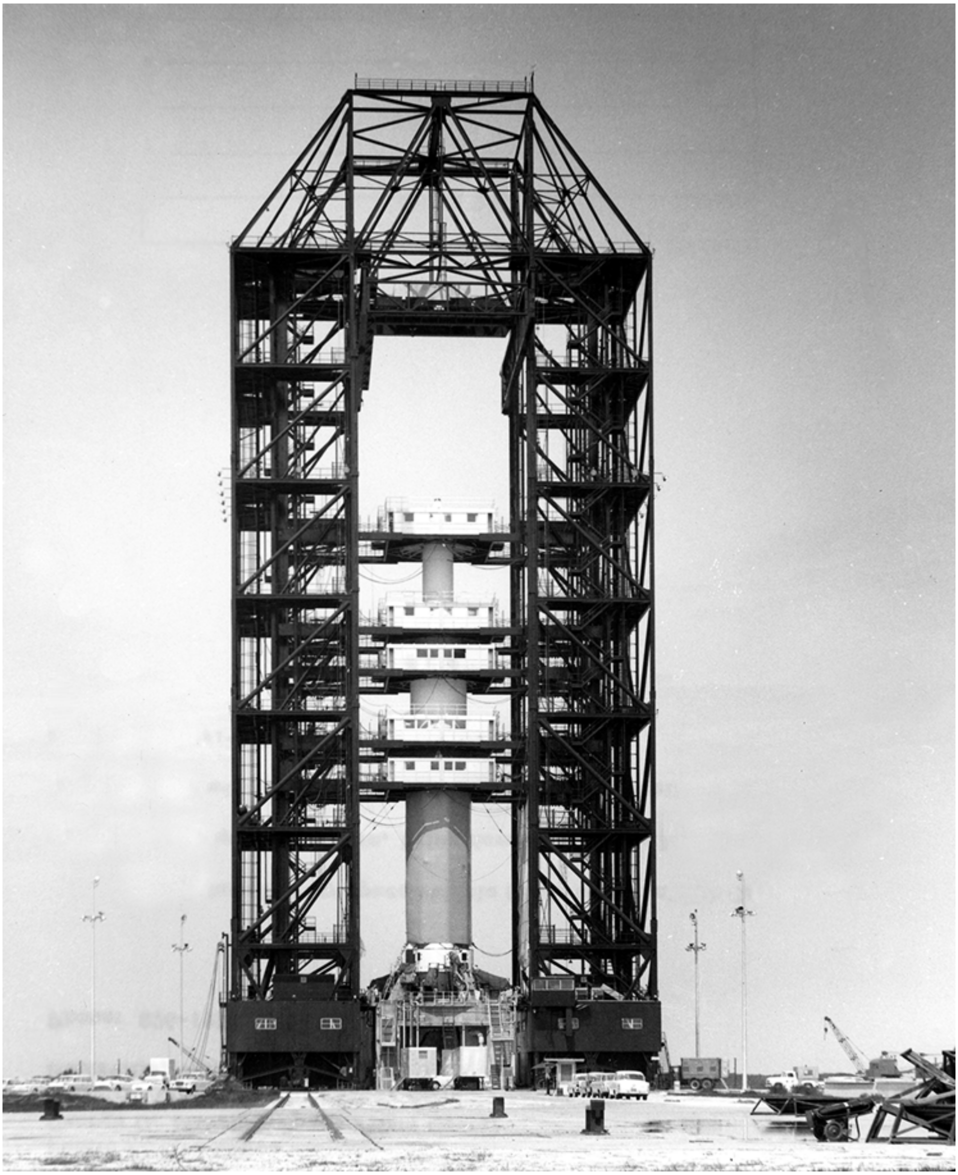
2.4 LC-34 pad facilities during the Apollo/Saturn era. *Source*: NASA/Ward



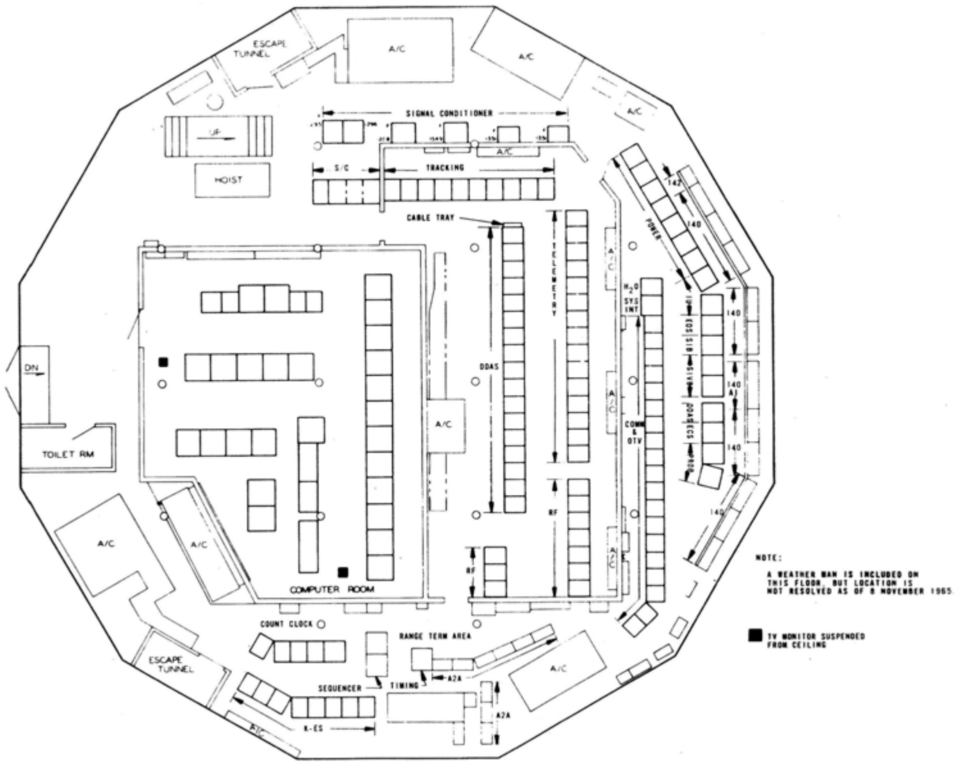
2.5 Diagram of the underground automatic ground control system (AGCS) facility at LC-34. The AGCS equipment was similar to that which would be installed in the pad terminal connection rooms and mobile launchers at LC-39. *Source*: NASA/Ward

Storage and pumping facilities for propellants (LOX, LH_2, and RP-1) were situated around the pad perimeter and connected to the pad via cross-country pipelines. High-pressure gases (nitrogen for purging, helium for LOX bubbling, and oxygen for crew cabin ventilation) were also stored in the vicinity of the pad.

The first four rockets launched out of LC-34 were the Saturn I Block I. Each was essentially an S-I first stage with a dummy second stage. The first Saturn, *SA-1*, lifted off from



2.6 The first Saturn, *SA-1*, during servicing on the launch pad. A protective shroud surrounds the vehicle to shield it from the elements. There was no umbilical tower for the early missions, and the inverted-U shaped service structure was later substantially modified to support the Saturn IB. *Source*: NASA/Jerome Bascom-Pipp

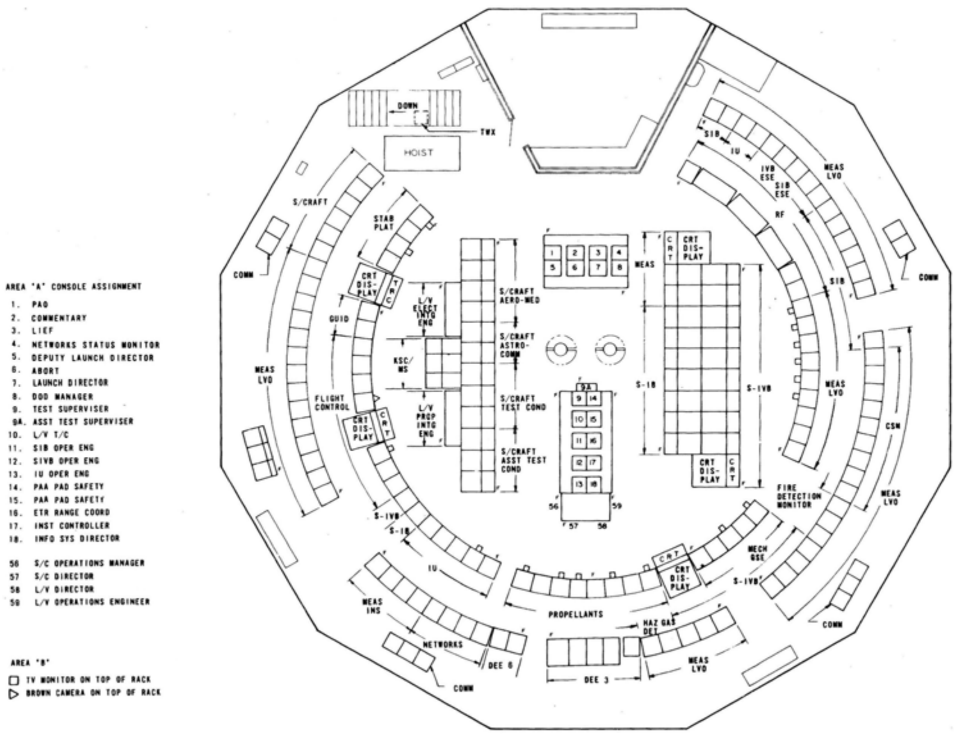


2.7 Layout of the first floor of the LC-34 blockhouse, as of November 1965. This floor housed telemetry and computer equipment, and had the only bathroom in the blockhouse. *Source*: NASA/Ward

LC-34 at 10:06 a.m. on October 26, 1961. Officials gave the mission a 75 % chance of getting off the launch pad, and only a 30 % chance of completing its brief mission (first stage burn followed by detonating a water tank in the dummy second stage at 60 miles altitude). These probability assessments seem dismal in today's environment, but they were considered realistic in the early days of the space program (Fig. 2.9).

Nervous that damage from a launch pad explosion could render LC-34 unusable for as much as 1 year, NASA sought to lower the program risk by building another Saturn launch complex. LC-37 was initially designed as a backup for LC-34. LC-37 was also intended to accommodate the evolving and growing Saturn I family of launch vehicles. The first four Saturn missions launched from LC-34 while LC-37 was under construction. Appendix B provides some particulars about these missions, as well as all flights of Apollo and Saturn hardware.

LC-37 was designed with two launch pads, pads 37A and 37B. Each pad had its own launch pedestal, AGCS, and umbilical tower. The pads shared the complex's blockhouse, service structure, propellant facilities, and high-pressure gas facilities. Two launch pads



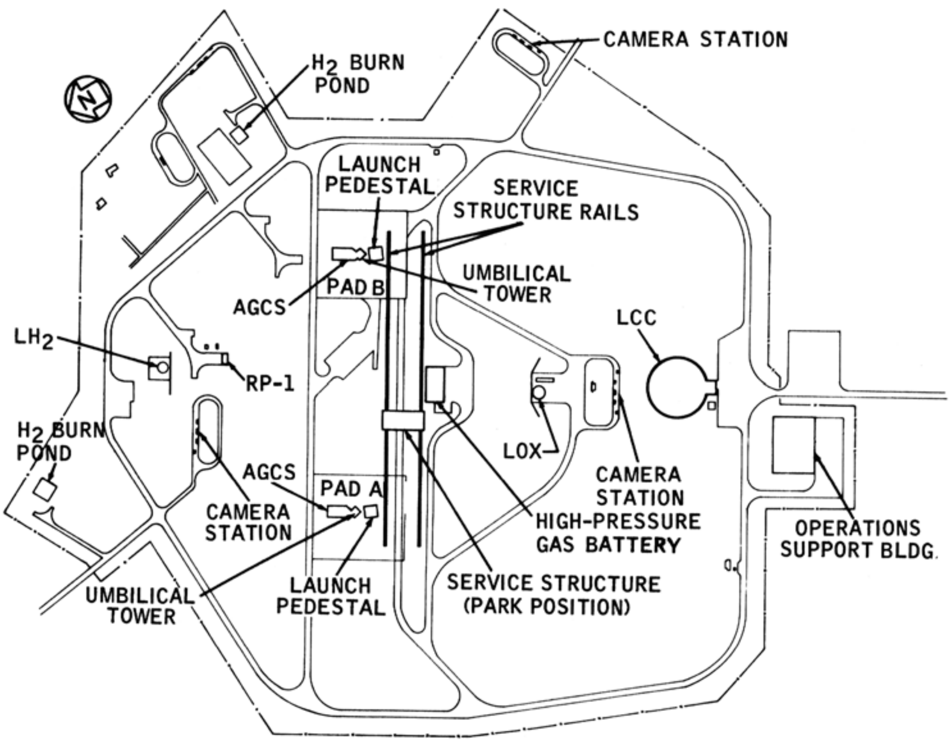
2.8 Layout of the second floor firing room in the LC-34 blockhouse in 1965. The spacecraft test conductor functions were moved to the ACE room at the Manned Spacecraft Operations Building on KSC the following year. *Source*: NASA/Ward

enabled faster turnaround on launch processing, as it could take a month or more to refurbish a pad and its equipment after a launch. The two pads also provided another level of insurance against a launch pad explosion potentially jeopardizing the launch timeline. NASA built the umbilical tower for LC-37A, but the pad was never activated. NASA determined that the money would be better allocated toward renovation of LC-34 and construction of LC-39 for the Moon landing program.

LC-37 was of greater size and complexity than LC-34, as it was to host the Saturn I Block II missions. Block II included the new six-engine S-IV second stage, which used high-energy liquid hydrogen (LH_2) as fuel. As gaseous hydrogen boiled off from the S-IV second stage of the Saturn during tanking operations, it was collected and piped several hundred meters to a burn pond within the launch complex. Here, the highly explosive waste gas was bubbled up through water and burned off, well away from the launch pad (Fig. 2.10).

NASA claimed that at the time of its construction in 1963, the service structure for LC-37 was the world's largest wheeled vehicle. It featured four elevators, ten movable platforms, nine fixed platforms, and weatherproof enclosures that could envelop and protect the vehicle and spacecraft on the pad. The service structure was 300 ft (92 m) tall and weighed 9.4 million lb (4,263 t). It could withstand hurricane force winds (Figs. 2.11 and 2.12).

2.9 Blockhouse personnel during the launch of *SA-1*, October 27, 1961. *Source*: NASA/Ward



2.10 Diagram of LC-37 facilities in the Apollo/Saturn era. Pad A was never used; all launch operations took place on pad B. *Source*: NASA/Ward

2.11 *SA-5* being stacked on pad 37B. Three of the service structure's clamshells enclose the vehicle, and two are open. The LC-34 service structure is visible in the background at right. *Source*: NASA/Jerome Bascom-Pipp

2.12 Harold Pyles (*right*) monitors operations in the control room of the LC-37 service structure. The structure moved between pads A and B on rails. *Source*: NASA/Ward

The blockhouse for LC-37 was similar to, and larger than, the LC-34 blockhouse. The increased complexity of the ground support equipment for the uprated Saturn and its new second stage necessitated more control consoles and test engineers.

President Kennedy visited the complex and saw the *SA-5* rocket on the launch pad 1 week before he was assassinated. The launch of *SA-5* on January 29, 1964 inaugurated LC-37B, and many workers at the pad privately dedicated the flight to the slain president's memory. Four months later, *SA-6* was the first flight of a boilerplate Apollo spacecraft aboard a Saturn launch vehicle (Fig. 2.13).

While *SA-5* through *SA-10* test and launch operations were underway from LC-37 from mid-1963 into mid-1965, LC-34 was renovated to accommodate the next generation of the Saturn family, the Saturn IB. The Saturn IB featured an uprated first stage (the S-IB) and a new, longer S-IVB second stage. The S-IVB sported an advanced J-2 engine that was 2.5 times as powerful as all six engines combined on the earlier S-IV stage. The Saturn IB was the first combination of stages that was powerful enough to place an actual Apollo spacecraft into Earth orbit. The first Saturn IB with a "production" command/service module was *AS-201*, which launched from LC-34 on February 26, 1966. It ushered the way for two more unmanned tests before the first manned Apollo flight, *Apollo 204* (also known as *Apollo 1*), which NASA hoped to get off the ground by late 1966.

2.13 George Mueller briefs President Kennedy on the status of the Apollo program in the LC-37 blockhouse, November 16, 1963. The large rocket model is *SA-5*, which was on the launch pad at the time of Kennedy's visit. In the front row of the audience are (*left* to *right*): George Low, Kurt Debus, Robert C. Seamans, Jr., James E. Webb, Kennedy, Hugh L. Dryden, Wernher von Braun. Out of picture to the right: major general Leighton I. Davis and senator George Smathers. *Source*: NASA/Jerome Bascom-Pipp

THE SPACECRAFT ORGANIZATION COMES TOGETHER

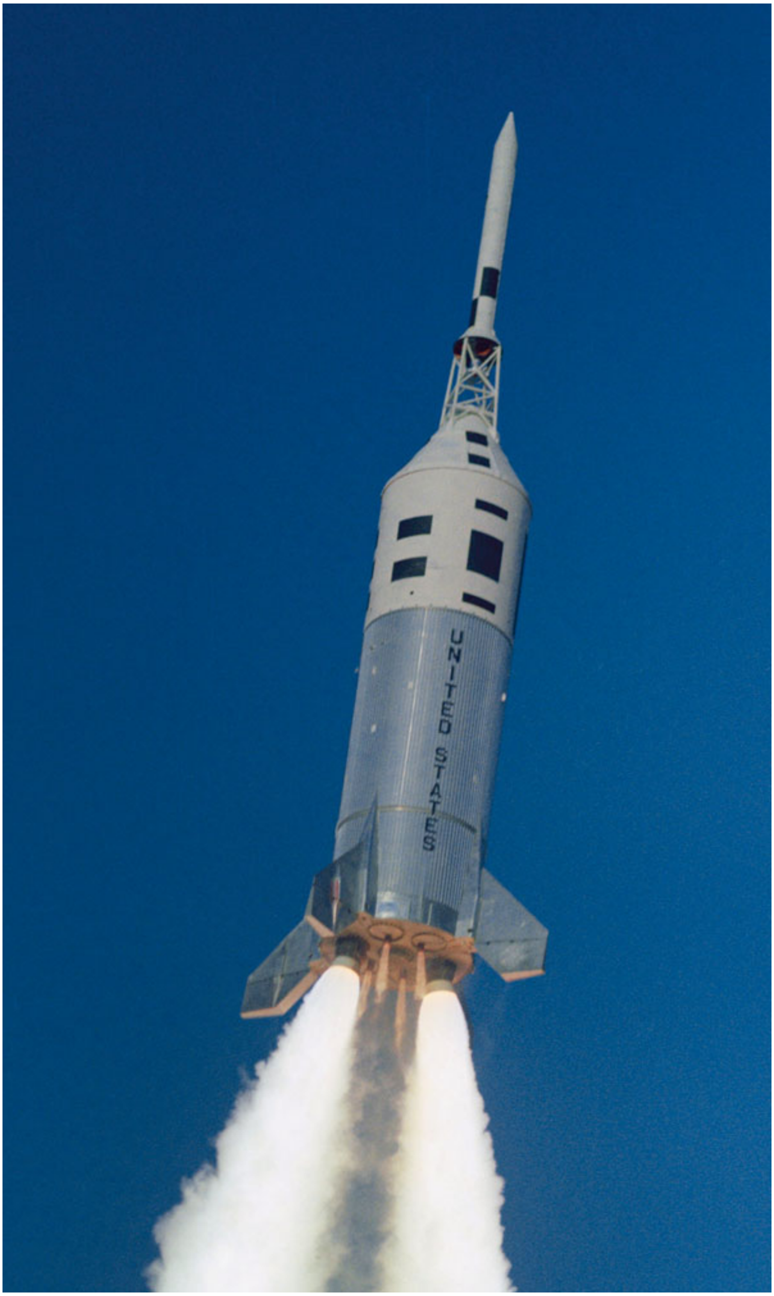
As the launch vehicle organization gained confidence with the Saturn boosters and the new launch facilities, the spacecraft operations organization was busy preparing for the first flights of Apollo hardware. NASA spacecraft personnel at the Cape were employees of the Manned Spacecraft Center-Florida Operations (MSC-FO), and they reported to MSC in Houston. Like project engineer Jackie Smith, many of them gained their experience in spacecraft processing on the Mercury program, and later in Gemini, before moving on to Apollo. Most of the spacecraft personnel worked out of hangar S on the Cape, until KSC's Manned Spacecraft Operations Building (MSOB) was commissioned in 1965.

A cadre of spacecraft operations personnel supported the Little Joe II and pad abort test program, which tested the Apollo launch escape system and the capsule's parachute system. NASA originally intended to conduct these tests at the Cape, but the Cape's facilities were fully booked with other high-priority launches. MSC instead ran the test program from the army's White Sands Missile Range in New Mexico.

Little Joe II launches and the Apollo pad abort tests ran from 1963 through 1966. Many of the spacecraft operations personnel who would eventually work together throughout the

2.14 Pad Abort Test 1, November 7, 1963, White Sands Missile Range. The pad abort tests verified the ability of the launch escape system to pull the Apollo capsule rapidly to safety from the launch pad. *Source*: NASA

Apollo program first came together as a team at White Sands. Welby Risler, Paul Donnelly, George Page, Ted Sasseen, Clarence "Skip" Chauvin, and Ernie Reyes were among those who worked together on the Little Joe II program and continued their association when they returned to the Cape. For example, George Page offered Skip Chauvin the lead spacecraft test conductor role in Apollo processing based on Chauvin's outstanding performance in the Little Joe II program (Figs. 2.14 and 2.15).



2.15 Little Joe II test flight A-002, December 8, 1964, White Sands. Little Joe II tested the launch escape system's performance in rescuing the Apollo capsule during flight. *Source*: NASA/J. L. Pickering

OPERATIONS AT LC-34 AND LC-37

NASA's operations grew tremendously in maturity and sophistication during the lifetimes of complexes 34 and 37. Construction and operation of the facilities was a learning experience for everyone involved, as nothing of this scale and sophistication had ever been built.

The Cape's launch schedule itself posed challenges as LC-34 was under construction. It seemed like there was at least one rocket launch every week from one of the many launch pads on "Missile Row." Roy Tharpe spent his high school years in the Cape area, and his first job was as a construction worker at LC-34. He recalled watching a launch of an air force Titan I missile on July 1, 1960 from LC-20, immediately to the south of LC-34 (Fig. 2.16):

> *It was the first launch off of that pad. I was a surveyor. I borrowed the transit, and I set it up on a platform 12 ft up in the air, and I had a nice clear view of that Titan. It lifted off the launch pad and made an immediate left, heading straight towards me. I'm looking through this transit, and I see it lay over, and next thing I know, I'm looking nose cone to eyeball. No joke! It's 5 miles away, but it's coming right at our area on complex 34. It was heading right for me. I jumped down 12 ft and rolled, and stood up. And when I stood up, range safety – and I never knew anything about range safety – they exploded it. The next thing that hit me was the sound waves and then the heat waves. Almost knocked me over! Stuff was flying all over, launch debris was everywhere, and fires had started. My concern was my brother, who was also out there working about 100 yards closer than me. I ran over and found him, and he was A-OK.*

J. R. "Dick" Lyon began his career at the Cape with MSC-FO. He was tasked with collecting the design requirements for the spacecraft support systems at LC-34 and 37. He recalled that no one seemed to know anything about how to do it or who to talk to. Two co-op students were assigned to help him. He said, "The three of us worked through the summer to start putting things together: ground systems interfaces, laying out the launch pad for all the servicing systems that went there. Service structure—how did you have to build it, how were you going to run pipes up the service structure to valve boxes that serviced each of the systems that loaded it with fuel and cryogenics and air, and all that good stuff." The expertise he gained through that work for LC-34 led to his performing the same role for LC-37 and LC-39.

The massive scale of the launch facilities meant that some practices learned at other pads just would not work in this new environment. For example, an endless-belt manlift system to take workers up and down at the pad was scrapped early on, because it injured at least one worker. Norm Carlson said, "I rode it one time. That son-of-a-bitch was real scary. They did away with it after probably 45 days. I couldn't believe that NASA safety allowed that thing."

Chuck McEachern recalled that at LC-34, catwalks with handrails on both sides extended from the service tower to the launch vehicle during the assembly and test phase. During the launch countdown, as preparations were made to move the service structure back from the pad, all the handrails were removed. However, this was prior to the final walk-down of the launch vehicle. He said, "So to get to the vehicle, you had this 3-ft wide

2.16 "Missile Row" on Cape Canaveral, November 13, 1964. Launch Complex 36 A/B is in the foreground. The Vehicle Assembly Building is under construction at *upper left. Source*: NASA

platform, with no handrails on either side, that you had to walk across, more than 100 ft up in the air. The first time I did that, I did it on all fours!"

In 1964, Frank Bryan had recently transitioned to the Saturn program from the Atlas/Centaur program. His boss, chief engineer Ike Rigell, was familiarizing Bryan with Saturn *SA-6*. The two began performing a walkdown of the LC-37 service structure, starting at the top level and working their way down one level at a time. The test supervisor announced over the PA system that all personnel to clear the area immediately, as the launch escape motor was being delivered to the tower. Rigell and Bryan decided to take the elevator down to get off the service structure quickly. Bryan said,

> *I walked over to the elevator door. There was a metal box with the cover off and a button beside the door, and I assumed it was the call button and pushed it. At that*

moment, I realized something was wrong, since I heard large valves moving and the structure shaking the instant I pushed the button. A hissing sound came from the spray nozzles around the structure. A second later, red rusty water from the structure deluge system was spraying everywhere. Ike came up and said we needed to get off the structure – there must be an emergency somewhere since the water was on. I told him I had turned it on by mistake.

We got off the structure, drove back to the blockhouse, and went inside covered with rusty water. The test supervisor, Don Phillips, was on the PA system announcing that he was trying to find the emergency. I told Ike we should tell him I turned it on. He said, "You tell him."

I found a plastic toy fire chief's hat on my desk the next morning. I spent the next few weeks trying to live it down.

Like Bryan and Rigell, other NASA engineers and technicians who came from the Explorer, Juno, Jupiter, and Redstone programs brought their experience to Apollo/Saturn. They were used to working directly on the vehicle and ground systems. NASA management decided early in the Apollo program that rather than expanding the government workforce to meet the demands of the program, NASA could staff the Apollo program more flexibly by making the launch vehicle and spacecraft contractors responsible for all hands-on work with the vehicles. NASA's role going forward would be strictly advisory and managerial—no more turning wrenches, tracing wires, or getting one's hands dirty if you were a civil servant. This transition was hard for many NASA workers to make, especially ones who prided themselves on their technical prowess.

There were still times in the early days at LC-34/37 when it seemed more expedient for a NASA engineer just to step in and do something under the radar, rather than take the time to explain a procedure to a contractor. For example, Ed Fannin, who was at this time already moving into a leadership role in the mechanical and propulsion systems division, recalled a situation at LC-37 where he jumped in to fix a pressure regulator on one of the Saturn's engines:

Our lead tech at the time, Joe Lendle, had asked this guy to go up and secure our 750 regulator for launch, setting it to a proper pressure and removing the gauge, wiring it down. Joe says, "I sent that Chrysler guy in there, and he backed it the wrong direction with the handle." He hands me this regulator-adjusting handle and a couple of little parts. I had spent three months at Marshall in their components test lab, and we had used that regulator on the Redstone, which also had a Rocketdyne engine. I knew that thing like the back of my hands. I said, "I can probably put that thing back together."

I went in, had to take a light in with me, with the parts, got them in the proper order, and threaded the thing back. Tom Marsh was in the blockhouse. I said, "Tommy, tell the instrumentation guys not to pay any attention to the recorder that shows the 750 pressure, 'cause I'm going to be playing with this thing." I knew that if I could pop the internal pressure relief, set it to 750, and then back it off real quick, and it popped, it was okay. So I did that about three or four times, and told Joe that it was ready to secure. And we flew it. I never did tell my boss! It was either me make that fix or scrub the launch, which we obviously didn't want to do.

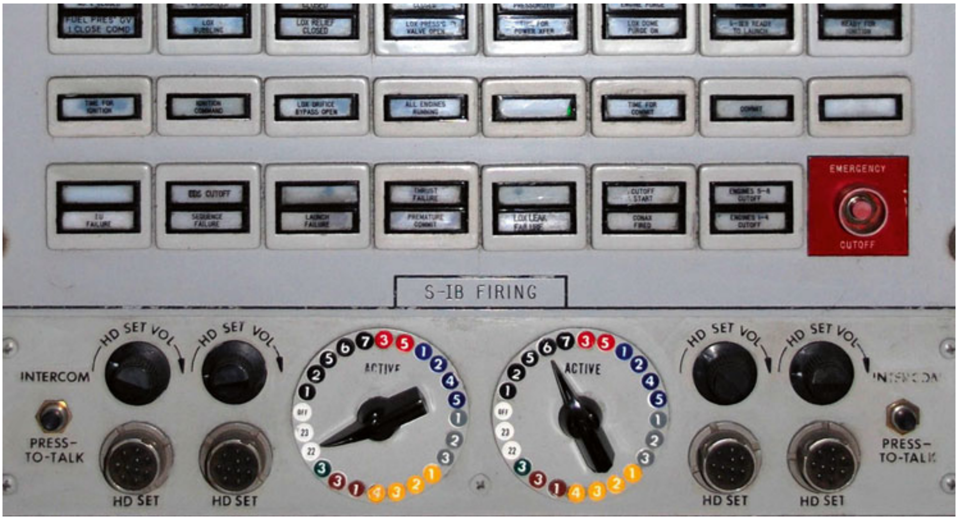
Formal procedures were still evolving, while an aggressive launch schedule demanded to be met. Procedure changes during tests were redlined into the documents as tests were underway. Quick thinking solved problems, saved time and money, and allowed launches to move ahead. For example, the vacuum-jacketed, cross-country LOX pipelines were prone to developing air leaks on occasion. Spotters watching the launch preparations through the blockhouse periscopes could see plumes of oxygen vapor escaping from the pipelines. Leaks threatened the quality of the LOX being delivered to the launch vehicle. Rather than scrubbing the launch to repair the pipeline, someone devised a quick temporary fix. The fallback team would go out to the leak site with a package of Kotex sanitary napkins and a bucket of water. The crew soaked a napkin in water and then slapped it onto the leaking part of the pipe, where it froze solid instantly and sealed the leak. After the launch, the VJ line could be more permanently repaired.

Not having fully-reviewed and documented procedures did come back to bite the team on occasion. Launch director Rocco Petrone found a red *remove before flight* streamer lying on the launch pad during his walkdown before one launch countdown. The tag was not numbered, so there was no way to tell where it had come from on the vehicle, or if there were still more missed tags somewhere on the vehicle. That incident resulted in a procedure for numbering and logging all red tags throughout the space vehicle. In another foul-up, the launch of *SA-5* was scrubbed on the first attempt because someone had not removed a blind flange (a plate without an opening) from the LOX replenish lines. That circumstance led to Debus instituting a new concept, the countdown demonstration test (CDDT). CDDT was a full dress rehearsal of the entire countdown, to catch and eliminate all the procedural bugs before the actual launch countdown.

As a sidebar to the blind flange incident, NASA public affairs officer Jack King recalled an additional constraint that was brought to NASA's attention prior to the next attempt at launching *SA-5*:

> *The Audubon Society comes to me and says, "We want you to be aware that nearby on pad 34 is a nesting ground for the roseate spoonbill, an endangered species. If you can help us, we would appreciate it." I checked into it, and certainly there is a roseate spoonbill, which is the ugliest thing you'd ever want to see waddling around. But when he takes flight, it's the most magnificent thing you'd ever want to see.*
>
> *We go to the final readiness check for another attempt at the launch. Rocco is chewing ass left and right about that blind flange: "Are you sure you're ready?" and turning around and going through the whole goddamn thing, making sure everybody is reporting in. The atmosphere is really tense. Finally he says, "Anything else?" And I said, "Yeah, Rocco, uh, it was brought to my attention that the roseate spoonbill…" I was afraid he'd throw my ass out of the meeting, particularly the mood he was in. It turned out to be fine. He actually listened to me.*
>
> *What we did to keep the Audubon Society happy: Just before we closed the pad, we drove two security cars with their "silent screamer" around the pad in the hopes that you'd scare the birds away. And I'm happy to report that, after the launch, there was no roseate spoonbill fricassee at the launch pad.*

A strict protocol governed communications during tests and countdowns at LC-34/37. Tip Talone served as the communicator between the blockhouse and the Huntsville



2.17 *S-IB Firing* console with a typical LC-34/37 OIS panel at *bottom*. Up to four test engineers could plug in headsets and monitor two active intercom channels. *Source*: Author

Operations Support Center (HOSC) at MSFC. The HOSC provided technical support and troubleshooting if requested by staff at the Cape. Otherwise, the HOSC was in listen-only mode during tests. Talone said (Fig. 2.17),

> *They couldn't talk to us from Huntsville; they could only listen on the command channel. We didn't want any interference, so they were blocked from talking. But there was an open two-way channel that I could patch them into there whenever there was troubleshooting going on. Our comm system had designations by color and number. Channels were red, black, green, blue, yellow, and then 1-2-3-4-5, and each of those colors was assigned to a discipline. The command channels were all in the black. So if someone said, "Go to yellow 5," you had a little switch dial that you clicked around. We didn't have a whole lot of television cameras on the pad back in those days. The test engineers could make requests, "We'd like to look at the launch umbilical," so I'd switch them over to that.*

KSC LEARNS TO USE COMPUTERS

NASA's fears about Saturn launch pad explosions never materialized. In an era where launch vehicles such as Atlas and Titan were experiencing failure rates in excess of 40 %, Saturn's perfect launch record was quite an accomplishment. This was at least partly due to the groundbreaking use of computers for automating the test and checkout process. This section provides a brief overview of the state-of-the-art computer systems NASA employed in spacecraft and launch vehicle processing beginning with Apollo/Saturn.

NASA used computers to automate the launch vehicle test, checkout, and launch processes for the first time at LC-34 and LC-37. In NASA's earlier launches at the Cape, the blockhouses were adjacent to the launch pad. Test engineers in those blockhouses sat at consoles clustered by systems or functions, and they operated and monitored their vehicle or ground support systems via control panels at their consoles. There were hundreds of switches, lights, and meters on the consoles in a blockhouse or firing room. Prior to the Saturn program, each of those switches connected to a wire that ran out to the pad to perform an operation on the vehicle or pad system. When that operation was performed, a response was returned back to the firing room via a hardwire connection. That response lit a lamp near the switch, informing the engineer the function was completed.

As launch vehicles became larger and more powerful (and more dangerous), blockhouses had to be moved farther from the pad. The explosive potential of the Saturn V rocket at LC-39 meant that the Launch Control Center needed to be 3.5 miles (6 km) from the launch pad. This was too far for control signals to be carried on direct wire connections between the vehicle and the equipment in the firing room. The only option was a computer linkup. NASA started perfecting this technology at LC-34/37.

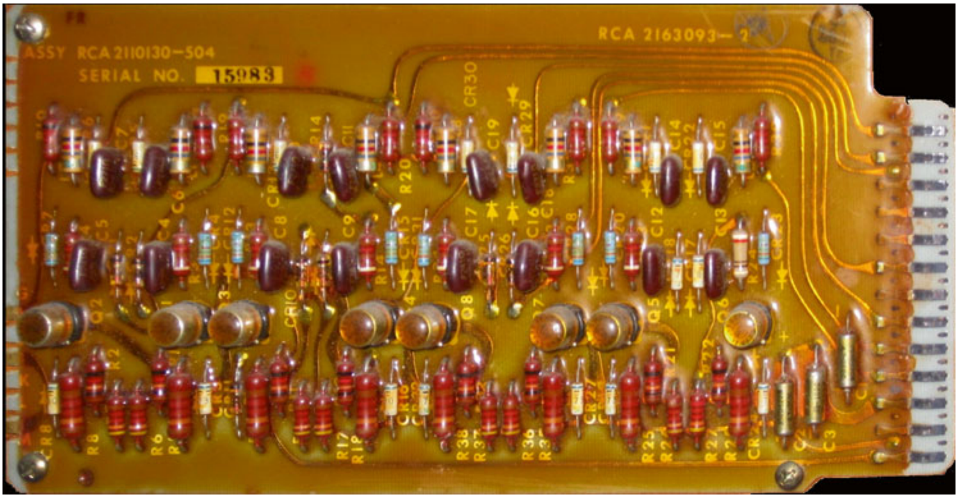
During the course of the Saturn program, NASA procured computers for use in launch vehicle checkout at the Cape and KSC. These were located as follows:

- LC-34: Libratol 500 drum-based computer to monitor vehicle parameters during launch preparation for the first four Saturn I Block I launches, *SA-1* through *SA-4*. This system was uninstalled after *SA-4*.
- LC-37: Two RCA 110 computers, one in the blockhouse and one in the underground AGCS facility below pad 37B. Each computer had 4K words of core memory. These computers supported the unmanned Saturn I Block II launches, *SA-5* through *SA-10*. LC-37's computers were upgraded to the RCA 110A model for the launch of *Apollo 5*.
- LC-34: Two RCA 110A computers, one in the blockhouse and one in the pad 34 AGCS. The RCA 110A was similar to the 110, but had 32K of core memory and 32K of drum memory. The LC-34 computers supported the unmanned *AS-201*, *AS-202*, and *AS-203* Saturn IB launches, the checkout of *Apollo 1's* launch vehicle at the pad, and the *Apollo 7* mission.
- LC-39: Eight RCA 110A computers, one in each of the four firing rooms, one in each of the three launcher/umbilical towers (LUTs), and one in a lab in tower D of the VAB. These were used for all Saturn V launches and Saturn IB launches for Skylab and the Apollo-Soyuz Test Project.

The paired RCA computers were officially known as the *Saturn launch computer complex* or the *Saturn ground computer complex*, but were usually just referred to in conversation as "the one-ten" or "the one-ten-A."

Each 110A computer was constructed from over 3,000 printed circuit module boards. These module boards had discrete components (resistors, diodes, capacitors, and transistors) but no integrated circuits. Twenty-four boards were connected together into a nest, and the nests were wired together to form the computer.

Core memory consisted of boards with small ferrous magnetic rings with hand-woven wires running through every ring. Each ring represented one bit of data. Each *word* of data



2.18 RCA 110A circuit board with four "flip flops." The eight cylindrical objects (labeled with "*Q*") are transistors (Courtesy of Frank Penovich). *Source*: Penovich

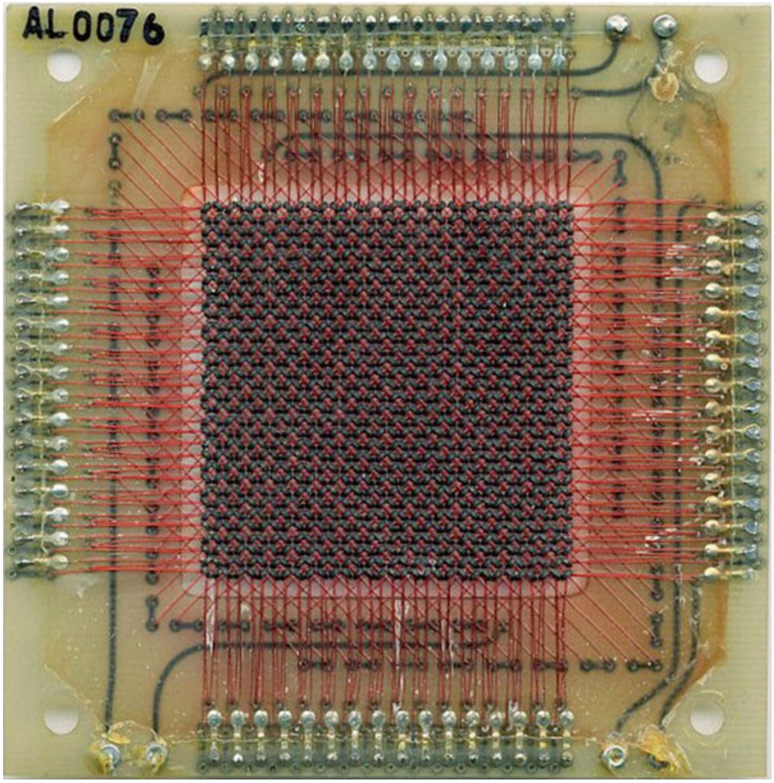
on the RCA 110A was 25 bits. With 32,768 words of memory, the RCA 110A had over 819,000 of those tiny rings. Memory was nested together in *core stacks*, each of which required 60 circuit boards to operate and read the memory. Each core stack resided in the middle of four nests of circuit boards (Figs. 2.18, 2.19, and 2.20).

Frank Penovich, a former RCA employee hired by NASA, was responsible for implementing and operating the ground computer system at the Cape. He said:

> *Software programmers can fill up any computer. That's the axiom of computers. We were the same. At Complex 37, the first time the computer was used for checkout, we had a 4,000-word memory, and that's it. And every launch, they were coming up with a new operating system and loading it. It scared the hell out of me. Can you imagine doing a Saturn checkout with 4,000 words of memory? But it always seemed to work. It blows my mind that we were able to do that.*
>
> *Then we went to the S-IB at Complex 34. Our 110As had 32,000 words of memory, and 32,000 words of drum memory. Again, it was always filled up. As a test was run, each software program was brought in off of external devices and then run. The operating system was what was loaded in the main computer.*

Growing Pains

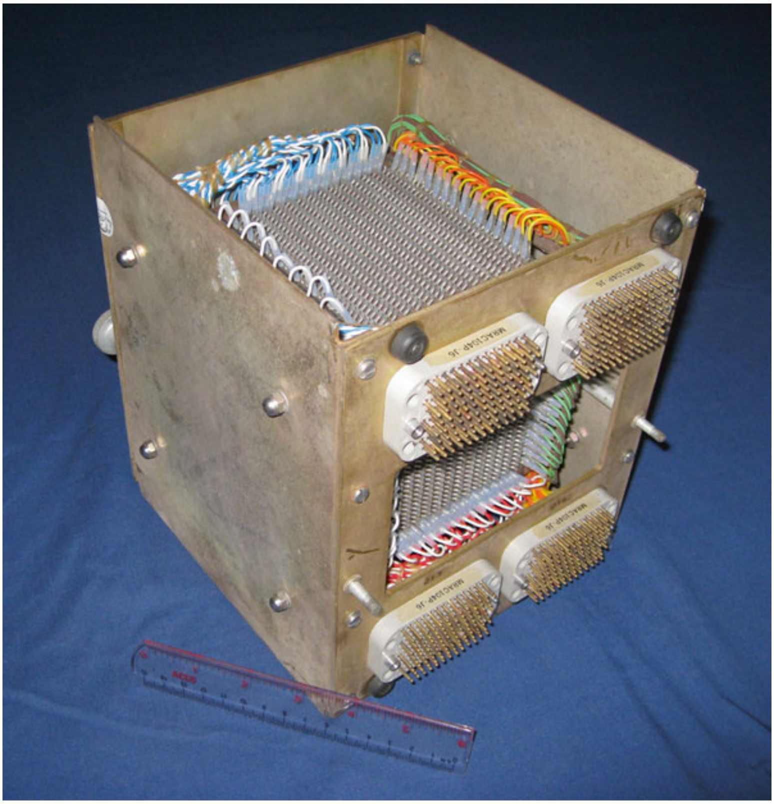
From 1964 onward, NASA's commitment to using computers for launch vehicle processing meant that the launch vehicle could only be powered up, checked out, or processed when the computers were operating. Except for emergency functions needed to place the vehicle in a safe configuration, all commands from the firing room had to go through the computer. Engineers did not trust computers to carry out critical test operations. This was



2.19 A magnetic core memory board, of the type used in Apollo flight computers rather than the RCA 110A. This board could store 256 bits of information (Author's collection). *Source*: Author

particularly painful in the rough first year or so of operations of the RCA system. When the computer crashed, it stopped the data link between the control center and the vehicle and launch pad. Engineers could not perform any test work for an hour or more, until the computer came back up and the link was re-established. Penovich gives great credit to NASA senior management for sticking with the decision to use computers through very tough times.

Ike Rigell recalled: "The early 110 had an unsettling failure mode. One time, it stopped and issued about half the discrete outputs. [Andy] Pickett and Fannin and those guys would start yelling. Pickett said one day, 'I'm going to get an axe and smash that computer!' They had a point—it was dangerous. We'd complain to Huntsville, and they thought we were over-playing it. Their manager, Lee James, made a personal trip down here. I took him out to 34. There was a PA loudspeaker right outside the blockhouse, and as soon as we got out of the car, we heard, 'The computer is no longer supporting.' I said, 'Lee, we hear that all day long!'"



2.20 An RCA 110A core memory stack of 4,096 words of storage. Physical size is approximately 7.25 in. wide × 8.5 in. high × 7.25 in. deep (18.4 cm × 21.6 cm × 18.4 cm). The RCA 110A had eight of these core stacks, for a total of 32K words of memory (Courtesy of Frank Penovich). *Source*: Penovich

After 1 week of working night shift, NASA test conductor John Twigg made an entry in his logbook that read, "The Saturn ground computer complex does not work any better in the dark."

The computer's flakiness created tension and led to finger pointing between RCA (the computer manufacturer), IBM (the computer programmer and operator), and NASA. RCA was unhappy that IBM was awarded the contract for operating and maintaining the equipment; IBM was upset about running another manufacturer's balky hardware. Rigell said that Apollo program manager Gen. Sam Phillips had to call a meeting with senior leaders from IBM, RCA, Huntsville, and KSC to resolve the management problem and stop the bickering.

Penovich said that the RCA 110 problems went on for almost 6 months. Troubleshooting a breakdown would identify a single module board as the culprit. NASA would send the board to RCA for repair, only to have RCA claim that they could not find anything wrong with it. Then NASA tried removing suspect boards and putting them into another computer to have the boards fail twice before they were sent for repair. And yet, even boards that failed twice would still come back with paperwork from RCA documenting that there was nothing wrong with the board.

The problem turned out to be cracked solder joints caused by a tough, varnish-like conformal coating on the boards. The coating protected the boards from humidity and the corrosive salt air of the launch site. While it prevented some problems, the coating had unintended consequences. Penovich explained:

The heart of the problem was that the conformal coating had a negative coefficient of expansion. Normally, when something warms up, it expands. When this coating got warm, it actually contracted.

Metal expands quite a lot when it gets hot. Almost all of the electronic module boards had transistors on them. The transistors were little metal "cans" with three wire leads coming out the bottom of the can and running through the other side of the board, where they were soldered.

When the computer was powered up, each transistor warmed up, and its leads would start to expand. Without the conformal coating, the transistor would simply rise up off the board a little to allow for the lead expansion. However, the conformal coating was keeping the transistor pushed down. In fact, with the negative coefficient of expansion of the conformal coating, as the transistor leads were expanding, the conformal coating was actually pulling the transistor closer to the board. Since the can couldn't go up, there was only one place for the transistor leads to go, and that was down through the board, which made the leads push through the solder joints on the other side.

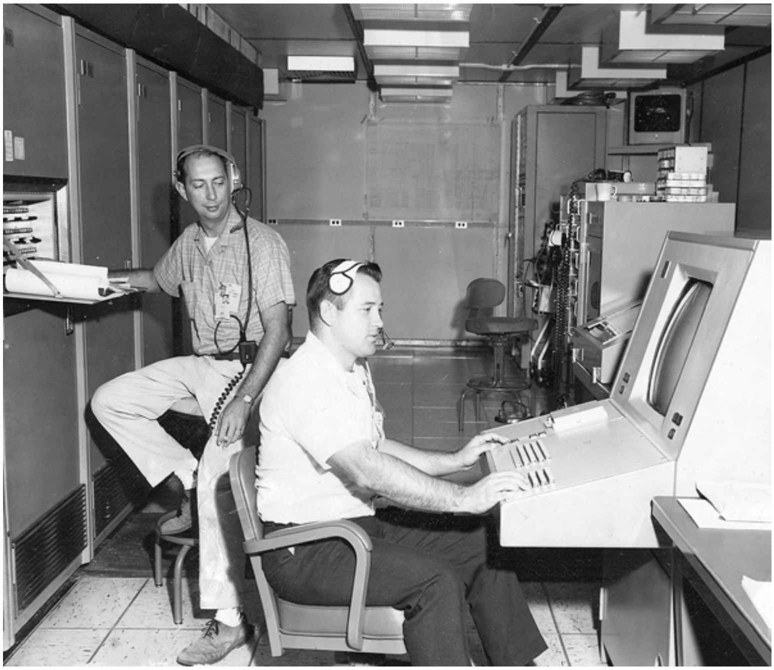
It wasn't anything that happened fast. At first, a little crescent moon-shaped crack would start at the bend of the lead. The crack would then progress down the bent-over part of the lead until it reached the end of the lead. It took months of expansion and contraction of the transistor leads to finally break away from the board, and even then a joint would only fail intermittently.

The fix was not easy. First, the transistors had to be removed from every board. The tough conformal coating had to be cut off around each transistor on both sides of the board. A new transistor was installed with protective *tubletts* over the bent wires, giving the transistor wires the opportunity to flex without breaking away from the board. Penovich continued:

There were from five to ten transistors on every module board, each transistor with three leads on it, and there were about 3,000 module boards in a computer system. So there were 45,000 to 90,000 transistor joints going through the expansion and contraction process every time a single computer was powered on and off – and remember, there were two computers operating in tandem. It was a hell of a problem.

No one seems to know who discovered that the problem was cracked solder joints, but if they hadn't found it, who knows if we would have gotten off the ground. But despite all the hardware problems we had, it's amazing to report that the computers never caused a launch scrub. They delayed tests, but never a launch.

With its hardware issues finally resolved, engineers could start to capitalize on the features of the ground computer system. Far from being a rudimentary computer, the RCA



2.21 NASA's Harold Schneider (*left*) and Bob Register in a computer room, probably the one in the AGCS under pad 37B, during checkout of *SA-5*. This mission was the first to use the RCA 110 for Saturn ground testing. *Source*: NASA/Penovich

110A had many advanced features for its time. For example, its data channels provided for independent data transfer directly to and from the computer's memory, leaving the central processing system free to run applications software. It could monitor 2,048 discrete inputs and outputs separately from whatever test program was being executed. This was a huge advantage in vehicle checkout because of the thousands of measurements that would eventually be needed to check out a Saturn V (Fig. 2.21).

Appendix C summarizes the RCA 110A's advanced features. The chapter on the Launch Control Center describes the operations of the RCA 110A system during tests and launch countdowns.

The ACE System for Spacecraft Checkout

While launch vehicle operations was shaking out its RCA computers, spacecraft operations was activating its own computer system, the acceptance checkout equipment for spacecraft system (abbreviated as ACE-S/C or simply ACE, and pronounced like the playing card). The GE-built ACE system was managed from the Manned Spacecraft Operations Building in the industrial area at KSC. ACE came online at KSC when the MSOB opened in 1965.

Four ACE rooms housed the consoles for running and monitoring tests of the Apollo spacecraft, whether the vehicle was in the MSOB undergoing initial checkout, at the

Vehicle Assembly Building, or at the launch site. Spacecraft operations test conductors and test engineers managed spacecraft tests and launches from the ACE room; they were not stationed in the LC-34/37 blockhouses or LC-39's firing rooms.

The chapter on spacecraft operations facilities provides a more detailed description of the ACE system and how it supported spacecraft test and checkout.

Hangar D and the Central Instrumentation Facility

Debus' launch vehicle team was almost fanatical about gathering every possible piece of data about the performance of the Saturn and its ground support equipment during tests. The data was often extremely valuable, especially in diagnosing what went wrong with vehicle components or systems during flight. However, the increasing size and complexity of launch vehicles led to a corresponding increase in the amount of data to be collected.

Most of the vehicle data was preserved as pen squiggle tracings on strip chart recorders during the early days of operations at LC-34/37. Many of these recorders were in launch vehicle's data office and telemetry station in hangar D on Cape Canaveral. It seems almost impossible to believe, but each major test or launch generated 50 miles (80 km) of strip chart paper that had to be collected and analyzed—and this was just for the launch vehicle!

Roy Tharpe, who by the early Saturn program was working as an instrumentation specialist, said that the immense volume of data required was a direct consequence of von Braun and Debus' building-block approach to launch vehicle testing. Performance of each component, down the level of individual valves and servos, was tested and recorded separately to provide traceability throughout the buildup process. Tharpe and his colleagues used magnets to hang the strip charts in the data display area of hangar D for review by engineers after tests.

Tharpe collected the 50 miles of strip chart recordings after launches and took them to reproduction to be copied. Planes flew in to the Cape at launch plus 6 h and launch plus 12 h to collect the copies of the launch data and take the copied charts to Huntsville and Houston for further analysis.

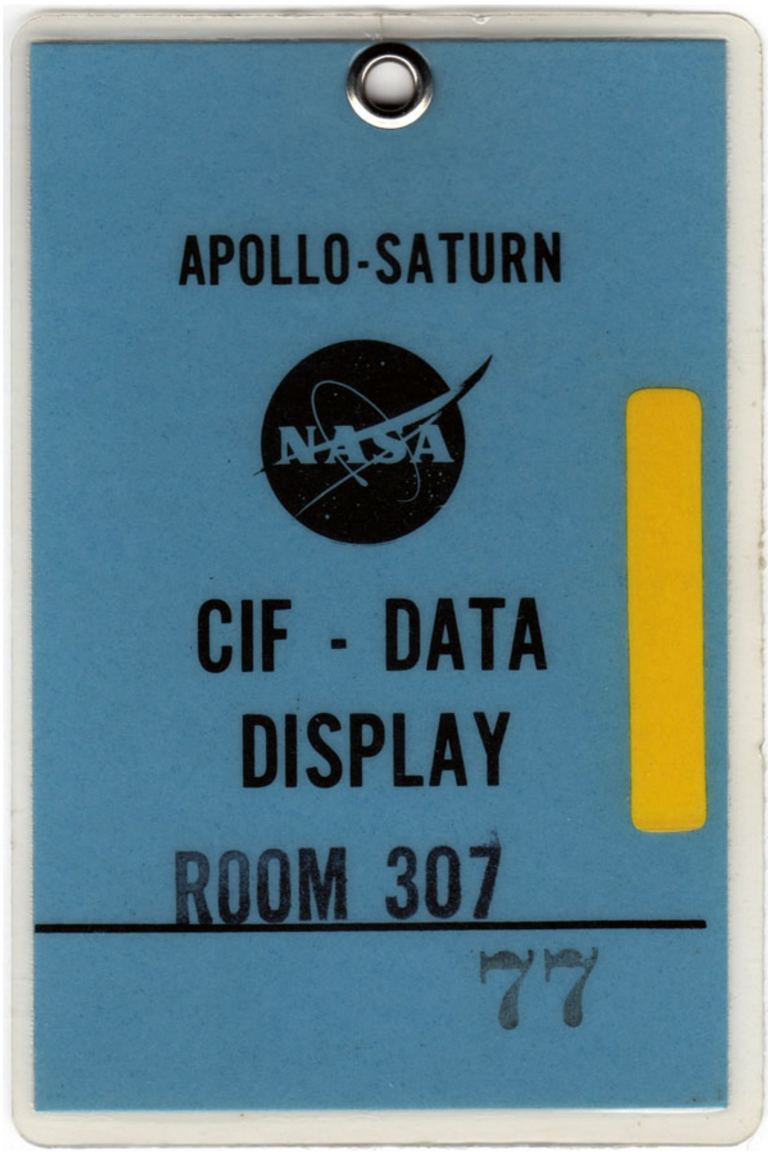
The practice of recording all vehicle data on strip charts was clearly inadequate to deal with the thousands of measurements that would be taken during a Saturn V launch, especially since strip charts could not provide information about rapidly-changing data. NASA designed KSC's central instrumentation facility (CIF) to house the complex of computer and data reduction systems necessary to receive the telemetry from the space vehicle and record it in real time. The main CIF office and computer facility was a three-story building adjacent to KSC headquarters. The CIF came online in 1965 and replaced NASA's hangar D offices. A sister facility, the CIF antenna site, was approximately 2.5 km north of the main CIF building on KSC. The antenna site was in an area devoid of other buildings, minimizing radio interference and providing the CIF antennas a clear view of the launch complexes and early stages of the boost phase of a mission.

Designed in the days when computers filled entire rooms and required a great deal of cooling, the CIF was built with offices around its periphery and computer rooms in the core of the building. The main CIF computer was a GE-635, and Scientific Data Systems designed the digital acquisition systems. Quite advanced for its time, the GE-635 was actually two computers, one prime and one backup, sharing a common data core (Fig. 2.22).

2.22 CIF central computer complex (rm. 205) in 1967. *Source*: NASA/Ward

2.23 CIF data presentation and evaluation room (rm. 307) in 1967. *Source*: NASA/Ward

Dozens of engineers monitored overall tests and launch countdowns from the data presentation and evaluation room (rm. 307), one of the largest rooms in the CIF. Tharpe described rm. 307's role as a backup for the firing rooms during launch: "The Germans were great about having backup systems. In the event that something was to go wrong with the systems in the Launch Control Center, we had hardline capability from the CIF to the launch vehicle to the LCC back to the CIF. So those consoles were just as active, and they could be interactive on a command if something was to happen in the LCC. We had systems engineers and folks sitting in rm. 307, and it was the backup to run the booster." (Figs. 2.23 and 2.24).



2.24 Access badge for CIF rm. 307 (Author's collection). *Source*: Ward

During overall tests, the Saturn's systems status was telemetered over hardline to the CIF for monitoring. Data relayed over radio from the spacecraft went to the Eastern Test Range and from there to the ACE rooms in the MSOB (Figs. 2.25 and 2.26).

2.25 CIF telemetry station (rm. 291), November 1, 1965. *Source*: NASA/Ward

2.26 CIF control room, October 5, 1966. *Source*: NASA/Ward

DIFFERENT ORIGINS, DIFFERENT HARDWARE, DIFFERENT CULTURES, COMMON GOAL

The paths of the staffs of launch vehicle operations and the spacecraft operations did not often cross during the course of day-to-day business. The cultures of the two organizations reflected their origins and the nature of their work. Launch vehicle people and spacecraft people were simply two different tribes.

The distinctive cultures of the launch vehicle and spacecraft organizations played out in many ways. Part of the difference was work scheduling, attributable to management directive. For example, spacecraft operations worked three shifts a day, 7 days a week up through *Apollo 11*. Although this was an expensive way of working, it was necessary to keep up with the demands placed on them to get their spacecraft ready while incorporating almost non-stop changes from Houston.

On the other hand, Hans Gruene, launch vehicle operations director, came from the cost-conscious German school of management. He decreed that work in his directorate would be scheduled so that it could be accomplished in one shift. His deputy, Ike Rigell, said, "Dr. Gruene said we'd have one shift wherever possible. We'd stay until we finished a test, or work a second shift for modifications. In launch vehicle, we always had the first team doing the work, and those guys in spacecraft didn't always have the first team. The handoffs caused them some trouble sometimes."

Rigell was referring to communications issues that could arise resulting from the handoff between shifts in spacecraft processing. Working three shifts kept personnel fresher, because each person worked fewer hours, but the need to transition work from one shift to the next introduced potential for errors or miscommunication if the handoff was not carefully managed. Neither way was necessarily better or worse; it was a matter of how you learned to cope with the demands and get the job done.

The following table summarizes some of the realities of day-to-day operations in the two groups:

Factors affecting launch vehicle culture	Factors affecting spacecraft culture
Primarily interfaced with Marshall Space Flight Center	Primarily interfaced with Manned Spacecraft Center
MSFC built its own launch vehicles in-house in early days	Contractors always designed and built manned spacecraft
Each stage test-fired for full mission duration before shipment to KSC	Factory acceptance tests with lots of "traveled work" needing to be addressed at KSC
Relatively few modifications to booster stages after delivery to KSC	Nearly constant changes based on results of most recent mission; modifications up to the day before launch in some cases
Many contractors for launch vehicle stages	Two primary contractors for spacecraft modules
Everything was big; massive rockets that could be worked on from inside; propellant loading at thousands of gallons per minute	Relatively small spacecraft; most testing work was done outside the vehicle; delicate propellant loading process in small quantities at a time over the course of a week
Astronauts rarely involved until tests at the launch pad	Astronauts constantly involved, even before the hardware reached KSC

Factors affecting launch vehicle culture	Factors affecting spacecraft culture
By management directive, work scheduled for no more than 1–2 shifts per day, 5 days per week, except during hazardous operations or major tests spanning multiple days	24/7 operations—3 shifts per day, 7 days per week
Most work performed on the launch pad or in the firing room	Work performed in the Manned Spacecraft Operations Building, at the launch pad, and VAB
Testing operations controlled from the blockhouse at LC-34 or LC-37 (later the LC-39 firing rooms)	Testing operations run from the ACE control room in the MSOB in the KSC industrial area

An "us versus them" attitude inevitably evolves in teams within any large organization. Because of the division of responsibilities, launch vehicle and spacecraft people rarely interacted with each other in their day-to-day activities, especially at the working level. In the case of Apollo, their physical separation amplified the incredibly intense time pressure and stress that everyone at KSC experienced in the time leading up to *Apollo 11*.

The rivalry between the two groups was generally good-natured, with an underlying (if usually unspoken) respect for each other's technical accomplishments. Surprisingly, even a few minutes of conversation about Apollo/Saturn with veterans of the program can still bring the old rivalries to the surface again, feelings that have persisted for 40 years or more.

One group's unawareness of the other group's management directives sometimes translated into misperceptions about the motivations—and even the intelligence—of people in the other group. One group perceived the other as lazy and one saw the other as disorganized.

In the heat of the moment, people sometimes missed opportunities to put themselves in the other guy's shoes. A casual observation taken out of context could turn into an unflattering assessment of the other group. For example, one launch vehicle person recalled going to see Dick Proffitt, a NASA spacecraft engineer, in his trailer at the launch complex. He said, "On Dick's blackboard was written these words: 'Having lost sight of our goal, let's redouble our efforts. Let's grab the ball and run! It's speed that counts, and not the direction.' Even if it was a joke, as far as I was concerned, that fit the spacecraft organization to a damn T!"

How launch vehicle viewed spacecraft	How spacecraft viewed launch vehicle
Spacecraft people are really disorganized. That's why they had to have a second shift and third shift, so in three shifts they could get one shift's worth of work done.	The launch vehicle guys don't work as hard as we do. They get all tests scheduled at the prime time on first shift, because that's easier for them. They don't even have headlights on their cars!
They're just the payload, a little-bitty hood ornament on the vehicle. We've got millions of pounds of high explosive ready to blow up if we don't do everything perfectly.	Those guys are the "big dumb booster." It's just a bunch of engines and fuel tanks. It only has to run for 15 min, but our spacecraft has to work perfectly for 2 weeks.
Without our launch vehicle, they couldn't go anywhere.	Without our spacecraft, there wouldn't be any need for their booster.

Revisiting these attitudes is not intended to throw any fuel on the fire. Rather, the rivalry was just a fact of life at the Cape, and ultimately it never seemed to get in the way of getting the job done. It is crucial to remember that both of these organizations were highly successful, they accomplished their missions with an astonishingly high degree of perfection, and they recognized each other for their accomplishments and the excellence of their end product.

Perhaps not surprisingly, the NASA centers also developed attitudes about each other in the course of working together. These assessments also color the comments one hears even today.

What KSC thought about Huntsville and Houston	What Huntsville and Houston thought about KSC
Those designers don't have any idea what it actually takes to do the work.	We don't understand what the big fuss is. We ship perfectly good vehicles to KSC. All they have to do is bolt them together, fuel them up, and fire them off. It should be "ship and shoot."
We have practical experience, but they ignore us. We tell them that what they designed for us won't work, but they won't believe us until it's too late.	We're the real rocket scientists. Those guys at KSC are a bunch of plumbers and electricians.

After identifying some of these differences in worldview, it is vital to note the points on which everyone agreed, and these were by far the most important. These shared attitudes enabled NASA to overcome tremendous challenges and caused the president's dream to be realized.

- The goal of landing on the Moon is crucial to our country's world leadership role. We must beat the Russians.
- We will make it happen by the end of the decade.
- I am personally responsible for the quality of the work I do. I expect the best from myself, and I expect it from my coworkers.
- I am 100 % dedicated to my job. I will do whatever it takes to get the job done in my area of responsibility. I will work long hours without complaint, and I expect to be on call when I'm home so that I can help out in any way I'm needed.

The bottom line is that KSC in the 1960s was staffed by human beings working under incredible pressure. Any personal differences or attitudes were more than overcome by their shared commitment to a challenging goal.

When asked what he thought about the people at KSC, astronaut Dick Gordon said, "My impression of the whole operation was the confidence that we astronauts had in those people. They were some of the best, I think, that there ever were. Every time we interfaced with them, we enjoyed it, because we had so much confidence in their ability."

THE PEOPLE

The employees in the contractor and NASA teams at Kennedy Space Center came from diverse backgrounds. Some brought deep experience gained in other high-tech missile programs for the military. Others were fresh out of engineering school.

As mentioned previously, many NASA personnel found their way to KSC via Marshall Space Flight Center or the Manned Spaceflight Center, where they worked on programs predating Apollo/Saturn. Some of the launch vehicle contractor engineers and technicians came to the Saturn program from the air force's missile programs such as Atlas or Hound Dog. Many of Grumman's technicians brought expertise they developed while working on aircraft and submarines.

Many other people who worked on the Apollo program came to NASA straight from college. In the 1960s, NASA was hiring all the engineers it could attract. NASA engineer Bob Pound described how he and his friend found jobs at KSC:

> *My buddy Charlie and I were finishing up our degrees in math and physics from a small college in Georgia, and the combination of those two was something that NASA allowed to be called an "engineer." We decided we'd apply for a job, so we got in our car one day and came down here to the Cape and went to the visitors' information center. That was actually a badging station, but we didn't know that. We thought that maybe it was the space center, because we'd never been down here. The lady behind the counter said, "Can I help you?" We said, "Yeah, we came down here looking for a job." She said, "With what company?" We looked at each other and we didn't even know that there were a lot of companies down here. We thought it was all NASA. That's just how naive we were. So she asks, "Do you have an appointment?" And we said, "No, we just drove down." She said, "Let me make a call."*
>
> *We were sitting off to the side and listening to her on the phone, hearing her say, "No, they're here. They're sitting here right now." She made a few more phone calls, and finally people at the headquarters building called her back and said, "Send them in and we'll show them around."*
>
> *Two or three people took us around to different parts of the operation. They asked us, "Where do you think you would like to work?" I picked ground instrumentation systems in the CIF, the central instrumentation facility. Charlie picked the ACE, the automated checkout for the spacecraft, the Apollo capsules. We hadn't even graduated at that time. We came back home, and within a week, we each got a telegram. They offered us both a job as a GS-7, which was $7,729 a year. We thought that was great, because that was a little bit more than schoolteachers were making at the time.*

Beverly Merrilees, a recruiter in KSC's manpower office during the 1960s, was not surprised to hear this story. She said, "We had was almost unlimited funding. We could hire anybody that would come, so we were going to all of the engineering colleges all over the country, and recruiting electrical and mechanical engineers for the most part. We were hiring a lot of people sight unseen. We would send a college recruiter out to a school, and a lot of times it was just based on someone's grades and their major and if they wanted to come. Back in the early 1960s, the Cape was not a place families wanted to come especially. Cocoa Beach was pretty wild and crazy."

Ida Reyes agreed that living in the Cape area was hard for families in the early days. The closest shopping was in Orlando, more than an hour away by car. There were not enough doctors, medical facilities, or schools in the vicinity to accommodate the rapidly growing population. JoAnn Morgan's husband taught music at a local public school, which had to run two full shifts of classes per day.

PUTTING IT ALL TOGETHER: LAUNCH DAY AT LC-34/37

The true test of KSC's people, technology, and processes always came on launch day. More than 150 test engineers, test conductors, and management personnel crammed the blockhouse, each one monitoring a critical system or component on the vehicle or the ground support equipment. Starting with the *SA-6* mission (also known as *AS-101*), the first Saturn launch to fly a boilerplate Apollo spacecraft, a few representatives of the spacecraft operations organization joined the launch vehicle staff in the blockhouse.

The blockhouse's massive blast door was shut and locked a few hours before the scheduled liftoff. The staff was sealed inside and would remain there until the launch was scrubbed, the vehicle was safely off the launch pad, or a launch pad explosion had died down enough that it was safe to leave the building.

Workers shared the sole bathroom inside the blockhouse. There were at most one or two women working on launches at LC-34/37, and someone needed to stand guard at the bathroom door when they were using the facilities.

Frank Penovich recalled that conditions were not altogether spartan in the blockhouse: "When we had launch day at 34/37, we'd have a big food spread on desks up against the wall, and we'd bring ham and turkey and all sorts of lunchmeat and potato salad. It would all be laid out there, almost like a party."

Tensions mounted in the firing room as the countdown progressed and the test supervisor and test conductors ran the show. When the Saturn's first stage engines ignited less than 400 m away, everyone knew it. Norm Carlson said, "Even despite all the concrete over you, you could feel the vibration and hear the rumble." Launch commit was given, and the vehicle lifted off. All eyes turned to the black-and-white TV monitors to follow the flight of the vehicle (Fig. 2.27).

Spacecraft engineer Charlie Mars recalled that his first experience watching a launch from inside a blockhouse was particularly frightening:

> *They put me and [W. M.] "Bucket" Milikin out there as the blockhouse interface for the launch vehicle and the command and service module for the first launch that involved a command module. When the damn thing launched, Bucket and I were sitting in the row with the launch vehicle guys all around, and the test supervisor was draped over that periscope. All of a sudden at liftoff, every light in the blockhouse went off. The emergency lights came on. We heard this* WAA-o-WAA-o-WAA-o *and looked up at these black-and-white TVs, and you could tell it was flames. We felt the rumble. We thought that the missile had blown up and hit the blockhouse.*
>
> *Bucket and I were fighting each other to get the hell under that damn console as fast as we could. We were sitting under there, looking at each other. Then I look out,*

2.27 Kurt Debus points to a monitor in the LC-37 blockhouse shortly after the launch of *A-104* (SA-8), May 25, 1965. To Debus' right (with head resting on his hand) is G. Merritt Preston. Hans Gruene is crouching in front of Wernher von Braun, and Eberhard Rees is leaning in. Von Braun's wristwatch, the wall clock, and the countdown clock behind Robert Moser (under periscope) indicate that this photo was taken about 4-1/2 min after launch. *Source*: NASA/Ward

and nobody's excited but me and him. Everybody's looking up. So we kind of sneakily got up and back into our chairs to see what the hell had happened. Well, it turned out they had routed some major power cables right at the pad, and it when the missile fired, it burnt the cables in two. Then the Doppler alarm went off when the rocket launched, which was a standard thing, but we didn't know about it. And the TV was pointed at the hydrogen burn pond. When we got those three things in our brains all at the same time, we thought, "Catastrophe!"

PREPARING FOR MANNED APOLLO/SATURN MISSIONS

Kennedy Space Center and the rest of NASA ramped up quickly in the early and mid-1960s. As Ike Rigell noted in the foreword for this book, the Apollo program forced NASA to go from being a mom-and-pop organization to a highly sophisticated operation almost overnight. So now we have had a peek at NASA's first Apollo/Saturn launch facilities and the technologies and people that supported launch operations. With work underway on Launch Complex 39 a few miles to the north, NASA finished out the Mercury program and ran the Gemini program while building LC-34 and LC-37 and launching 13 unmanned flights of early Saturn and Apollo technology.

The unbroken string of successful launches from LC-34 and LC-37 instilled confidence with the ground systems and the Saturn launch vehicle. However, there were persistent concerns about the flightworthiness of the Apollo spacecraft. Pressure mounted to push the envelope, as the end of the decade loomed larger every day. It was perhaps inevitable that mistakes would be made along the way, and risks would be overlooked or downplayed in the haste to meet the president’s challenge. There would be dire consequences for the program and for an astronaut crew as a result.

3

The *Apollo 1* Fire

PREPARATIONS FOR THE FIRST MANNED APOLLO MISSION

The Gemini program was in full swing when Apollo/Saturn test flights got underway at Cape Canaveral. After ten successful launches of the unmanned Saturn I launch vehicle in the preceding years, NASA followed with three unmanned launches of the new Saturn IB rocket in 1966. Across the Banana River at Kennedy Space Center, Launch Complex 39 was being activated for the first launch of the Saturn V rocket, America's ride to the moon. The Saturn V *AS-500F* facilities integration vehicle was rolled out to pad 39A in May to begin shaking out the new launch facilities.

With 3 years remaining in the decade, NASA and its contractors were under tremendous pressure to get the Apollo program off the ground. NASA began preparing at LC-34 for the first manned flight of the Apollo command/service module. The mission was officially designated *AS-204* or *Apollo 204*. Its flight crew dubbed it *Apollo 1*. The crew's name for the mission was inconsistent with Mercury and Gemini flight numbering; it probably should have been called *Apollo 4*, as there had already been three flights of Apollo/Saturn hardware before this mission. The crew commissioned a spacesuit patch with the *Apollo 1* mission name, but NASA's access badges retained the official designation.

The Saturn IB launch vehicle had been proven in the unmanned flights, but the new and highly complex Apollo spacecraft was behind schedule. There were doubts about its quality and whether all the bugs had been worked out of its systems. Many of the new technologies in the Apollo spacecraft (such as fuel cells) had only recently been tested for the first time in the Gemini program. As 1966 progressed, the target date for the *Apollo 1* launch moved from the fourth quarter of 1966 to February 21, 1967.

North American Aviation delivered spacecraft CSM-012 to Kennedy Space Center on August 26, 1966. At the time it was delivered, there were 164 incomplete engineering changes on the vehicle. An additional 623 engineering orders were issued in the months after the spacecraft arrived.

The spacecraft went through checkout in the relatively new Manned Spacecraft Operations Building at KSC. Spacecraft operations personnel and the *Apollo 1* astronaut crew tested the spacecraft in the MSOB's new altitude chamber. October 18 saw the first altitude test of a manned spacecraft in the chamber, but the test had to be cut short because

J.H. Ward, *Rocket Ranch*, Springer Praxis Books, DOI 10.1007/978-3-319-17789-2_3

3.1 Gus Grissom enters the *Apollo 1* CM for a manned altitude run in the MSOB on October 18, 1966. Roger Chaffee is behind Grissom. Ed White stands off to the *left*. *Source*: NASA/JSC

of a problem depressurizing the chamber. During the altitude runs, the CSM's cabin was pressurized with a 100 % oxygen atmosphere. Several manned and unmanned altitude chamber tests were needed to clear problems and work off the astronaut *squawks*—issues and discrepancies that concerned the crew (Fig. 3.1).

The command module was removed from the altitude chamber on October 29 and moved to integrated test stand 1 in the MSOB high bay. Testing operations continued to uncover problems with the spacecraft. The service propulsion system's propellant tanks were removed from the Apollo service module on November 1 and taken to LC-16 for testing. New tanks were installed on the service module on November 11. The entire SM was carted to LC-16 for pressure checks on November 13. On November 15, the SM went back into the altitude chamber. The CM joined it in the altitude chamber on November 19. The CM's environmental control unit was replaced. There were water/glycol leaks in the environmental control system in late November, and tests were suspended until the system was cleaned up and repaired.

Right behind CSM-012 in the process flow in the MSOB were CSM-014, intended to fly the second manned Apollo mission, and CSM-017, scheduled to fly on the unmanned first test flight of the Saturn V in 1967. With three spacecraft in flow, spacecraft operations test and assembly teams were on duty 24 hours a day, 7 days a week to process those spacecraft and get the *Apollo 1* spacecraft ready to move to the launch pad. Christmas Day was the only day off granted to spacecraft operations personnel in the last half of 1966. The back-up astronaut crew performed a sea-level altitude run on December 29 and 30. All workers were given a holiday on January 1, 1967.

Finally, the command and service modules were joined in the MSOB on January 3, 1967. They were then mated to the spacecraft/launch vehicle adapter on January 5. Two new reaction control system quads were installed on the service module on January 6. Later that day, the spacecraft was hoisted onto a trailer and towed across the causeway to Launch Complex 34 (Figs. 3.2 and 3.3).

TESTS AT THE PAD

In early August 1966, while tests were underway on the spacecraft in the MSOB, the three major components of the Saturn IB launch vehicle (S-IB first stage, S-IVB second stage, and instrument unit) arrived at LC-34. Eight fins were bolted to the base of the S-IB stage. The stages and IU were stacked on the pad's launch pedestal. Checkout of the power, electrical networks, telemetry systems, and mechanical systems were conducted on each stage. The integrated Saturn IB launch vehicle underwent combined systems tests such as electrical mating checks, power transfer tests, guidance and control tests, sequence malfunction tests, and tests of the emergency detection and emergency destruct systems. All of these tests aimed to run to ensure that the Saturn IB would be ready for the Apollo spacecraft once it arrived from the MSOB.

The spacecraft arrived at LC-34 from the MSOB on the afternoon of January 6, 1967. It was hoisted by the gantry crane and mated to the instrument unit on top of the launch vehicle. The service structure's environmental panels were closed, protecting the upper portion of the launch vehicle and the spacecraft from the elements. Work platforms were moved into position around the SM (adjustable platform A7) and CM (adjustable platform A8) (Figs. 3.4 and 3.5).

Checkout operations shifted into high gear, with 13 major tests planned before the scheduled launch in February. Most of these checked how the spacecraft and launch vehicle (jointly referred to as the space vehicle) operated as an integrated system and how they interacted with the ground support equipment.

This was also a shakedown of the whole test and checkout process itself. No one had ever launched a manned Apollo/Saturn vehicle before. Everyone fully expected—even hoped—that the first run-through of the test and checkout process would uncover bugs or deficiencies in the vehicle, the ground systems, and the procedures. NASA certainly preferred to find and correct problems with the space vehicle while it was on the ground rather than in flight. Ironing out problems with the ground systems and procedures at this point increased the likelihood that the launch countdown would go smoothly in February. Even though hiccups were expected, the tests were grueling and frustrating. Breakdowns repeatedly caused activities to come to a halt.

Marcus Goodkind, who had just wrapped up his role as a Gemini test conductor for the Martin Company, was a friend of *Apollo 1* command pilot Gus Grissom. Goodkind recalls

3.2 The *Apollo 1* command and service modules are mated for the final time on the south integrated test stand in the MSOB high bay, January 3, 1966. *Source*: NASA/Jerome Bascom-Pipp

that Grissom told him in mid-January 1967 that "Apollo is all screwed up," and Grissom tried to convince him to come work on Apollo. Goodkind said that because Martin was not a contractor on the Apollo/Saturn program, Grissom's suggestion meant that he would have to leave his current employer. He was not sure he wanted to do it. Grissom replied,

3.3 The *Apollo 1* spacecraft convoy approaches LC-34 on January 6, 1967. *Source*: NASA/Jerome Bascom-Pipp

"I understand that, but this program's really in trouble. We could really use you over here." Grissom implored him to consider the change and offered to make some contacts on his behalf.

The space vehicle went through six integrated tests in its first 2 weeks at the launch pad. Some of these included a spacecraft/launch vehicle malfunction detection test and the "space vehicle integrated test with umbilicals connected," commonly called the *plugs-in overall test*. The first run of the plugs-in test on January 20 went well, with no significant problems. A repeat of the test on January 25 took 24 hours, due to problems with the ACE test computer system for the spacecraft and a problem in the launch vehicle's instrument unit.

JANUARY 27, 1967: THE PLUGS-OUT OVERALL TEST

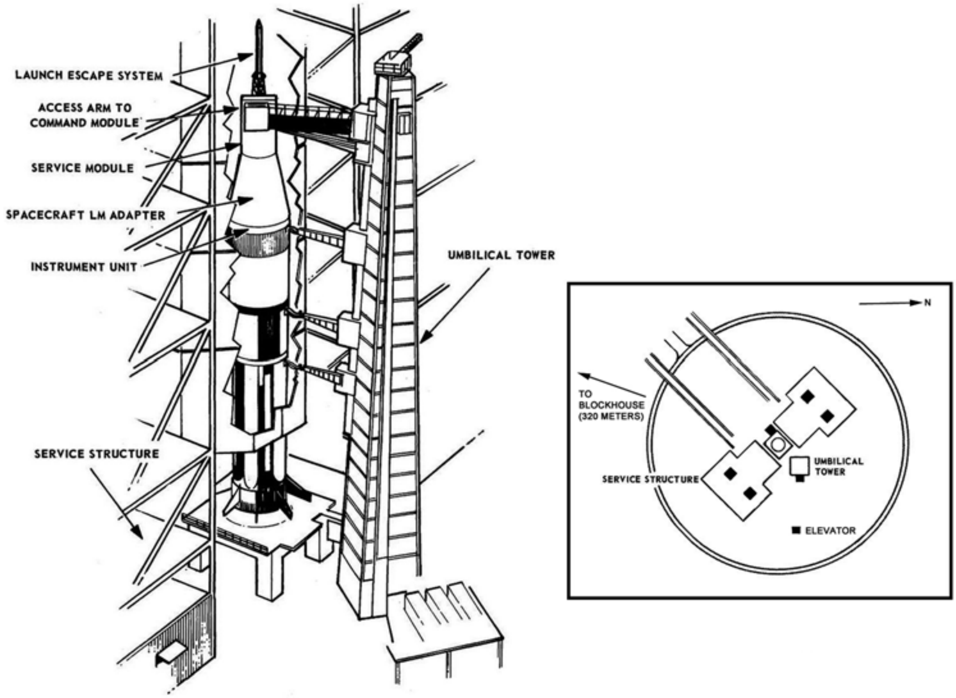
The final scheduled test before the countdown demonstration test was the "space vehicle integrated test with umbilicals disconnected," also referred to as the *plugs-out overall test*. The test's intent was to demonstrate all space vehicle systems and operational procedures in a configuration as close as possible to flight conditions. It was scheduled to begin on Friday, January 27, at 1:00 pm Eastern Standard Time.

The test would begin with a simulated countdown that started a few minutes before liftoff. At the time of liftoff in the test procedure, the umbilicals for the space vehicle would be ejected, and the spacecraft would be on simulated fuel cell power for several

3.4 The LC-34 crane hoists the *Apollo 1* spacecraft for stacking on the AS-204 launch vehicle. The rocket is hidden by the protective enclosures of the service structure. *Source*: NASA/Jerome Bascom-Pipp

hours of flight time. Much of the boost protective cover, including the portion that went over the crew hatch, would be in place over the CM. The crew was scheduled to practice an unaided egress from the capsule at the end of the test. Because there were no propellants or explosives on the vehicle, it was not classified as a hazardous test. No emergency or rescue crew was required to be present.

Grissom, senior pilot Ed White, and pilot Roger Chaffee donned their spacesuits and began pre-breathing oxygen. Standard launch procedure for American spaceflights was for the crew to breathe pure oxygen beginning when they suited up for a mission. Astronauts carried portable oxygen ventilators from the suit-up room to the transfer van



3.5 Schematic of AS-204 launch vehicle and *Apollo 1* on the launch pad, showing the positions of the service structure and umbilical tower. During testing on the pad, the service structure completely surrounded and enclosed the space vehicle. *Source*: Author's modification of NASA diagram

and onto the spacecraft. When the cabin hatch closed, the spacecraft cabin was pressurized with pure oxygen to slightly above sea level pressure to prevent atmospheric nitrogen from entering the cabin and potentially get into the astronauts' bloodstreams. After liftoff and during ascent into orbit, the cabin pressure gradually reduced to 5 psi (34.5 kPa). Having a pure oxygen environment in the spacecraft precluded the astronauts from developing decompression sickness (the bends) from nitrogen coming out of solution in their blood as the cabin pressure decreased. An oxygen-only system simplified the design of the spacecraft as well (Fig. 3.6).

Cabin pressurization for this test was similar to the procedures used in Mercury and Gemini spacecraft, and despite the inherent huge increase in potential flammability that the pressurized oxygen environment presented, the test did not qualify for hazardous classification. After all, the spacecraft had just gone through four altitude chamber runs with a pure oxygen atmosphere in the cabin without issue. Although many upper-level managers subsequently denied knowledge of the test conditions, no one involved at any level of management appears to have stopped to contemplate exactly how hazardous such an environment could become.

3.6 Gus Grissom (*right*) and Roger Chaffee cross the swing arm from the umbilical tower to the White Room prior to the plugs-out overall test, January 27, 1967. *Source*: NASA/JSC

MONITORING THE TEST FROM THE ACE ROOM

Problems with the spacecraft started almost from the outset of the test. Grissom complained of a smell "like sour milk" when his spacesuit's hose was connected to the spacecraft's oxygen supply. NASA spacecraft test conductor Skip Chauvin placed a direct-line call on the black phone about Grissom's complaint to Ernie Reyes, the NASA crew chief for the vehicle, who was working in a trailer near the launch pad. Reyes called a test team out to the pad to sample the air flowing through the system. The pad crew sampled the air supply by tapping into the oxygen system from outside the spacecraft, which did not affect or interrupt the ongoing plugs-out test. Nothing unusual was found in the air supply that would account for the smell that Grissom reported. Reyes relayed the findings to Chauvin at about 4:00 pm.

A high oxygen flow inside the cabin triggered the master alarm several times during the afternoon. The cause of this problem was never identified or resolved, and it was not considered serious enough to stop the test. Most frustrating was a communications problem between the spacecraft, the LC-34 blockhouse (where the test supervisor and launch vehicle test team were conducting the overall test), and the ACE control room in the MSOB (where the spacecraft test team was conducting tests). Communications were so garbled that it was difficult at times for people to understand what the astronauts were saying in the cockpit. One of the procedural breakdowns uncovered in this test was that there was no one person responsible for resolving the communications issue. This was precisely the type of process problem the tests were designed to find, so they could be addressed and corrected before the actual launch countdown. The test was halted for about 50 min for troubleshooting.

John Tribe, lead engineer for North American Aviation's reaction control systems group, was covering for one of his engineers in the ACE control room that day. Tribe recalled the events of that afternoon:

> *Skip could communicate directly with the crew; the rest of us could listen to them but only talk to them through Skip. NAA's test conductor Hank Kuznicki was supporting Skip.*
>
> *At about 6:00 pm, Skip suggested we go ahead with a planned simulated RCS static fire while we were waiting to clear up the communication issues. In the actual countdown, we would be test firing the RCS thrusters prior to flight. This test would merely be a simulation of the RCS firing, since we had no propellants on board. It would be an opportunity to cycle through the switching and obtain a time hack on the operation. I initiated the test, working with Skip and Gus Grissom. It was uneventful. Unknown to me at that time, it would be the last functional action on the part of the* Apollo 1 *crew.*
>
> *More communication problems caused another hold after we had finished the simulated static firing test. This obviously frustrated Grissom, causing him to grumble and say, "How are we going to get to the Moon if we can't even talk between three buildings!" Both he and Ed White thought that no one could hear them because of the break-up in communications, and Grissom added a final "Jesus Christ!"*
>
> *At 6:30 pm, we were still holding at T-10 minutes in the terminal countdown while the communications problems were being addressed. I was filling the down time by writing a test preparation sheet to conduct some RCS command module isolation valve heating tests the next day. In parallel with the plugs-out test, I was having Bruce Davis, an electrical technician who was working out on the CM level at pad 34, evaluate where to install temperature sensors on the spacecraft valves. This did not affect any operations for the plugs-out test. All the RCS closeout panels had been removed from the outside of the CM, exposing the tanks, valves, and plumbing in the pork chop area of the command module. The pork chop area was the volume around the base of the CM between the pressurized cabin and the heat shield. Bruce had been reaching through those open panels into the interior area, checking potential access for installing the temperature sensors. When the last countdown hold started, I told Bruce to take a break.*
>
> *With the hold continuing, I was concentrating on the RCS work and was unaware of events happening in the CM that became evident after the subsequent data review. According to the data recorded by the instruments and noted in the accident report, right about 6:30 pm, the biomed data from the crew, together with guidance and navigation accelerometer indications, increased oxygen flow, and live microphone sounds, all pointed towards movement inside the capsule. This stopped at 6:30:45. At 6:30:55, 10 seconds later, a significant voltage transient occurred in the CM's AC bus 2.*
>
> *In the ACE station, my first indication of a problem occurred at 6:31:05, a further 10 seconds after the voltage spike. It was one of the astronauts, possibly Grissom,*

with an exclamatory remark that sounded like "Fire!" I turned to Dave Stewart, the stabilization and control engineer who was sitting at the next console over from me in the ACE room, and said, "Did he say, 'Fire'?" Before Dave could answer, astronaut Roger Chaffee shouted, "We've got a fire in the cockpit!" We listened in disbelief, not fully comprehending what we were hearing, when there was a last garbled transmission from Chaffee that sounded like "We've got a bad fire – get us out – we're burning up!" followed by a scream of pain and then silence. This last transmission finished at 6:31:22.

Chauvin said, "As best I recall, I was the last one to talk to them. That time was so confusing, there was so much noise from the crew, and I'm not understanding them…and it wasn't until I looked up at our black-and-white monitor in the ACE room, that I got a feel for what was going on."

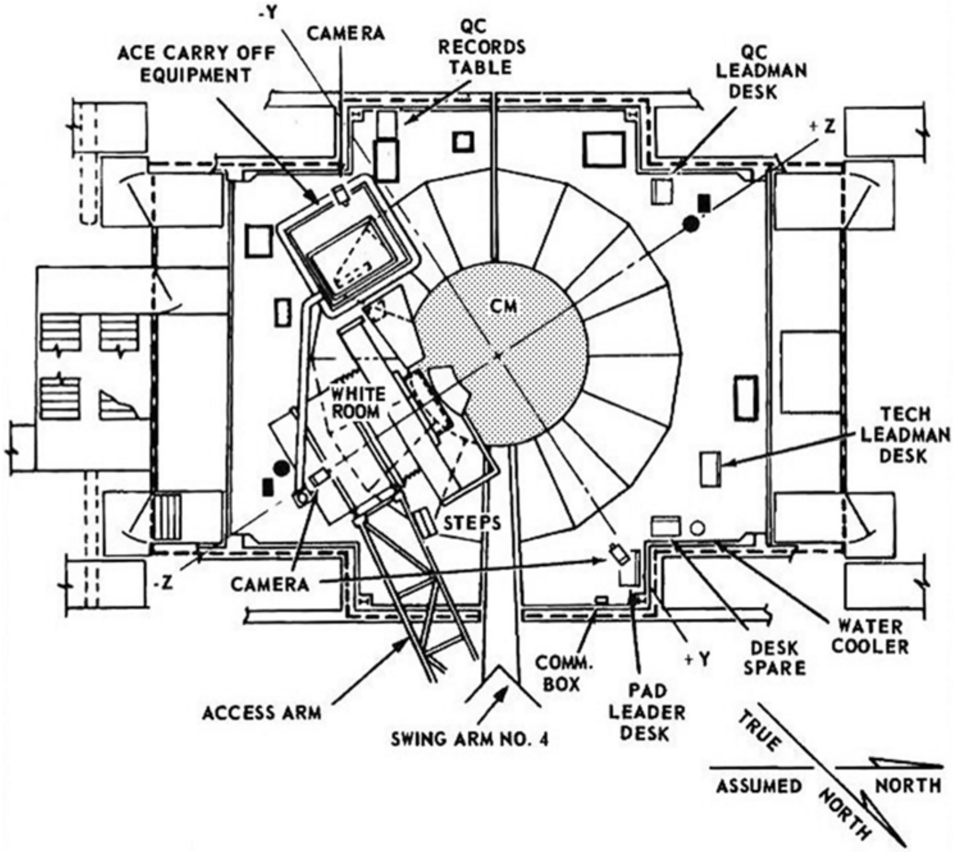
FIGHTING THE FIRE

At the launch pad, North American Aviation personnel on the command module level (A8) of the service structure included pad leader Don Babbitt, with Jess Owens, the mechanical systems engineer responsible for the hatch, beside him. Near them were Jim Gleaves, the mechanical lead technician for that shift, Jerry Hawkins, a supporting mechanical technician, and Steve Clemmons, another mechanical technician who was monitoring the oxygen supply test set up that fed oxygen to the spacecraft. The flight tanks were empty for the test, so a special test unit and external oxygen cylinders were required. L. D. Reece and Dale Hickenbottom were quality control inspectors on this level, and Bruce Davis was an electrical technician there. Although there were several other NASA and NAA personnel also in the area at the time, the people named above played the significant roles in what was about to happen. John Tribe and Ernie Reyes provided most of the following account of the actions on the pad, with inputs from some of the men who were involved (Fig. 3.7).

The terminal count for the plugs-out overall test required the flyaway electrical umbilicals to be released from the vehicle at T-0. The mechanical technicians were standing by on the A7 (service module) level to pull the cables that released the umbilicals' locking mechanism, and to catch the umbilicals to prevent any damage as they fell. This activity would occur approximately 10 min after the count picked up again.

Only Babbitt, as pad leader, was required to be on a headset, through which he could communicate with the ACE room. However, it was standard practice for workers in the area to listen to the command channel on the operational intercom system (OIS) speaker boxes placed around A8 and A7. This way, all personnel in the area were generally aware of what was transpiring on the command channel, even though they were not directly participating in the test.

In the spacecraft's 100 % oxygen environment, whatever caused the initial spark needed very little flammable material for ignition, and there was plenty around. The lower part of the spacecraft cabin had a trap netting to stop debris and floating items in zero G from lodging under areas that were difficult for the crew to reach. There were many patches of Velcro fastened to nearly every available open area on panels throughout the CM. This Velcro was installed both by design and at the crew's request to permit convenient



3.7 Diagram showing the relative positions of adjustable platform A8 on the service structure, the White Room, and the swing arm at the time of the *Apollo 1* fire. Astronauts crossed the swing arm from the umbilical tower to enter the White Room. The pad crew could also walk up steps from the A8 platform to get to the White Room entrance. On launch day, everything in this diagram would be rolled away from the pad except for the swing arm, White Room, and spacecraft. *Source*: Author's modification of NASA diagram

attachment of articles in zero G. Both the netting and the Velcro, especially its adhesive, were highly flammable and provided the transport mechanism for the fire.

Most of the support people on the working levels heard the cry, "Fire!" on the OIS speakers, followed by Chaffee's anguished cry, "We've got a fire in the cockpit!" These support personnel had been expecting an announcement to begin a planned crew emergency egress at the completion of the simulated countdown, but they all knew that this was neither the time nor the expected announcement. Babbitt, immediately recognizing the seriousness of the cry, yelled, "The spacecraft's on fire! We've got to get the men out!" His headset suddenly went dead, as did all the other communication boxes on level A8. He had to run out and across the swing arm to the umbilical tower to find a working comm unit in an effort to talk with the blockhouse and the ACE room.

Meanwhile, Hawkins headed toward the White Room. He suddenly realized he would need the T-handle wrench to retract the locks in the boost protective cover that was installed over the double hatch of the CM, and he backtracked to the lead man's desk where the tool was kept. Clemmons tried to get an answer as to what to do with the oxygen supply system but was stymied by the lost OIS connection. He joined Hawkins in recovering the tool.

Meanwhile, Gleaves again yelled, "Let's get the crew out!" and passed Hawkins as he backtracked to get the key. Gleaves jumped up the two stairs from the A8 level onto the swing arm. He turned right and started to enter the White Room, when he heard a *whoosh* as the spacecraft's cabin pressure relief valve blew. This valve was located just below the spacecraft hatch and was set to relieve the cabin pressure at about 20 psia (138 kPa). Almost immediately he saw a flash in the cockpit through the window in the BPC hatch, leading him to believe something very dangerous was imminent. Fire flashed up the interior left-hand wall of the cabin and across the ceiling, and the cabin pressure increased rapidly.

Gleaves turned and hastened back out of the White Room, and at that moment, the pressure buildup caused the CM cabin to rupture. It was only about 15 s after the first report of fire. The last transmission from the astronauts also occurred at about this time.

A pressure wave of heated air and combustibles slammed Gleaves into the White Room isolation door. This door would only open toward him, making it difficult for him to get it open quickly and get onto the swing arm, away from the fire and smoke. Once he had it open and could breathe the clear air on the swing arm, Gleaves gathered his senses and returned into the smoke- and fire-filled White Room.

When the spacecraft's pressurized cabin ruptured, the flames shot through the pork chop area and flared out through the open panels where Bruce Davis had recently been working. The flames went up the side of the command module, dangerously close to the solid-propellant rocket of the launch escape system. Had the fire reached much higher, the flames could have ignited the propellants in the LES, which would have incinerated everyone and everything on top of the launch pad.

After the cabin ruptured, the brief second stage of the fire began inside the cabin. This was the period of greatest conflagration, due to the forced convection from the rush of gases through the ruptured pressure vessel. The swirling flow scattered firebrands throughout the cabin, completing the spread of fire. The intensity at this point was evidenced by the burst and burned aluminum tubing in the oxygen and coolant systems found during the investigation at the floor level in the cabin.

Sheets of fire with burning fragments burst forth from the ruptured pressure vessel into the pork chop area of the command module and out the open access panels around the spacecraft periphery. The flames burned both pad leader Babbitt and Owens, threw Babbitt backward into his desk, ignited papers on the desk, and started numerous other small fires. Smoke filled the area, and flames licked up around the spacecraft (Figs. 3.8 and 3.9).

Owens became enveloped in smoke. He was nursing superficial burns and well aware of the live launch escape motor over his head. His first reaction was to back out the side door of level A8. Outside in the fresh air, he caught his breath. As he turned to re-enter, he suddenly realized he was trapped behind a one-way door. The elevator, his only route down, had been locked out. The locked elevator was either a planned action in support of the emergency egress test or perhaps an emergency action from the blockhouse.

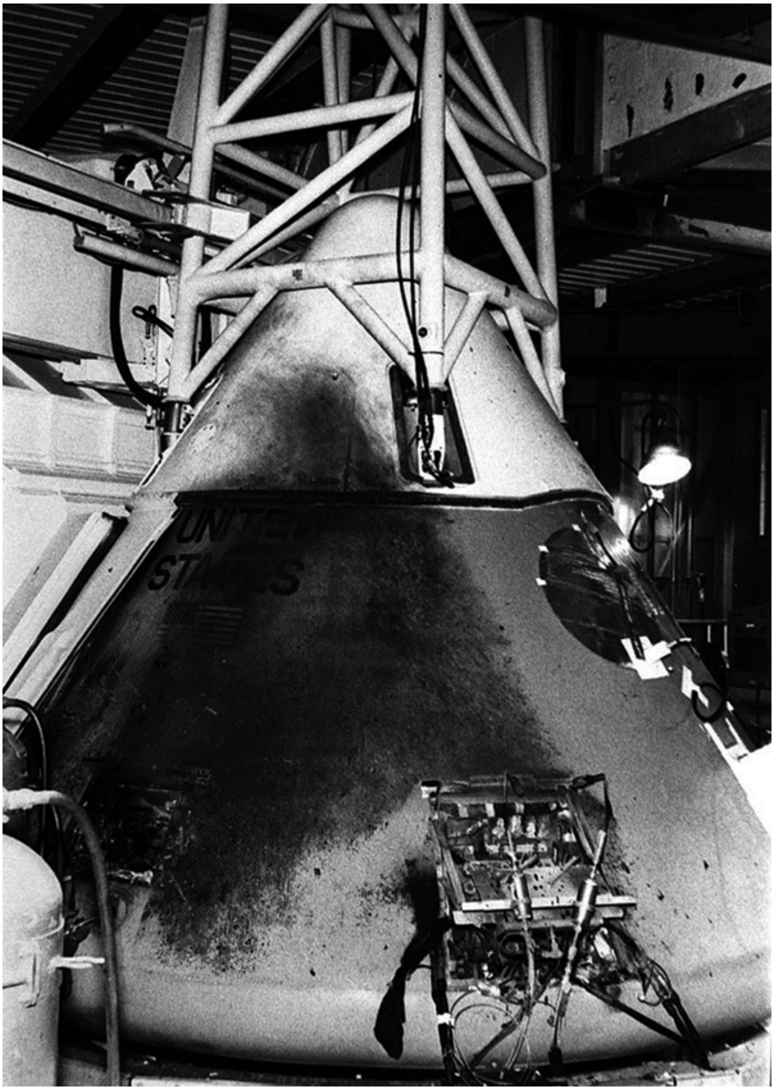
3.8 Fire damage to the pad leader's desk. *Source*: NASA/Ward

In a fully reactive and automatic mode, most of which he could not remember afterward, Owens climbed over the rail and clambered down the external structure. Reaching a lower level, he took stairs down to the ground. Once on the ground, he found a functioning phone and called his supervisor, Chuck Stephens, to tell him of the fire. His climb down the external structure was quite an accomplishment, even for a former steel worker.

Meanwhile, Babbitt had joined Gleaves in the White Room. Gleaves was trying to remove the BPC barehanded, since it was only attached by two latching fingers in the upper corners for the test. As Gleaves reached under the BPC, the flames still emerging from the open access panel below the BPC burned his hands. Hawkins arrived with the lock retraction tool and a fire extinguisher to kill the remaining fires. The BPC section over the hatch was removed and set aside. With the BPC off, the fire and smoke that the cover had deflected downwards below the White Room were now directed into the face of the rescuers. This reduced the visibility in the White Room to near zero and made it almost impossible to breathe.

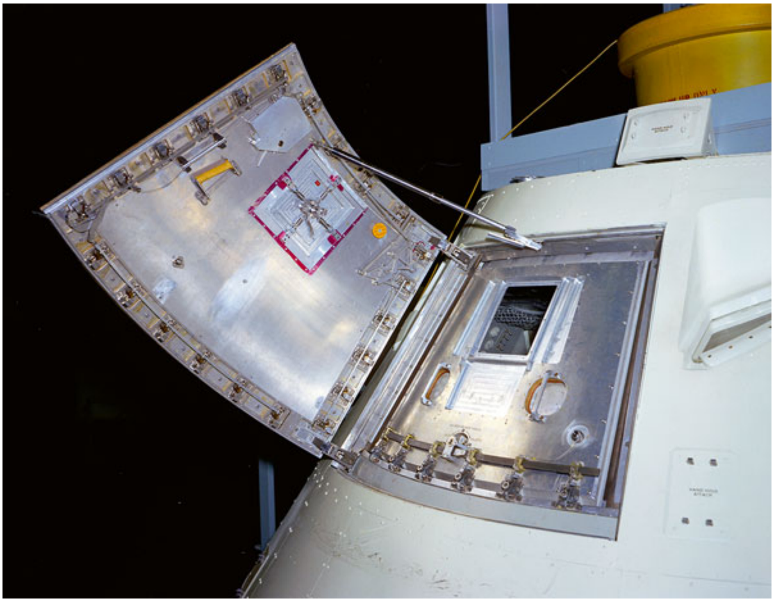
Clemmons, out on the A8 level, was still worrying about the oxygen supply. Should he secure it to prevent feeding the fire? Or was it still providing needed oxygen to the crew? He also had experienced the blast of flame from the spacecraft and the burning material being shot out through the open access panels. One item that struck him was a piece of white nylon, which he recognized as a part of an astronaut suit. It was a sobering indication to him that if the suits had been breached, the crew must be in serious trouble.

Dale Hickenbottom activated a large wheeled fire extinguisher on level A8. He was trying to suppress the many minor fires on the level and ensure no flames were reaching the LES. He seemed to be getting the fires under control. Clemmons, with no contact established to the ACE control room, decided the best bet would be to leave the panel oxygen flowing and go help out in the White Room.



3.9 *Apollo 1* spacecraft after the fire, as seen from near the pad leader's desk. The White Room is at *left. Source*: NASA/Ward

Meanwhile, support came from other areas. Technicians Journey, Schneider, Howard, McConnell, Belt, and Metcalf arrived with gas masks and fire extinguishers. Henry Rogers of NASA, who had been coming up to A8 on one of the service structure elevators when the fire occurred, gave Hickenbottom a smock to wrap around his face. All these support personnel had been delayed and frustrated by the limited access to A8, where most of the doors were for exit only and did not permit quick entry.



3.10 *Apollo 1* hatch design, showing outer structural hatch (*open*) and inward-opening cabin hatch (*closed*). *Source*: NASA

Clemmons met Babbitt outside the White Room. Babbitt shouted, “Jim’s down! Get him out!” Clemmons found Jim Gleaves lying on the floor, overcome by the dense pungent smoke. Despite Gleaves’ protests, Clemmons dragged him out into the clearer air on the swing arm. While Clemmons was on the swing arm, he yelled down to personnel who were swarming out of trailers at the ground level, “The spacecraft’s on fire! We need help—fire extinguishers and Scott Air-Paks!” The lack of elevators and the non-functional OIS severely retarded rapid communications and support.

The third stage of the fire was characterized by rapid production of high concentrations of carbon monoxide that filled the cabin as the last of the oxygen was depleted. Heavy smoke formed. As the fire diminished from lack of oxygen, the atmosphere inside the cabin became lethal. Localized burning continued around the environmental control unit close to where the fire is believed to have started, as failed oxygen and glycol lines continued to supply oxygen and fuel to the fire.

L. D. Reece brought another fire extinguisher into the White Room. He and Jerry Hawkins had the fires suppressed and were now working on the spacecraft outer hatch. Although the fires had died out, the smoke had turned black and noxious. The men could only work for brief periods without backing out to grab some fresh air. Gleaves quickly recovered, and with Clemmons, Hawkins, and Reese set up a rotation—two on, two off—to remove the structural hatch. They again burned their hands in the process, before they started on the even hotter inner hatch. Someone had brought in gas masks, which unfortunately were intended to only protect against toxic hypergolic fumes, not smoke. With the filter cans removed and the inlet tubes close to the floor, the masks helped with the breathing problem but not with visibility (Fig. 3.10).

Clemmons and Hawkins were working on the inner spacecraft hatch when it finally released. As designed, the hatch began to drop down vertically into the CM. When the hatch cracked open, another wave of black smoke belched into the White Room. The hatch would not drop fully; unknown to the rescuers, it was blocked by the body of astronaut White. The blocked hatch only allowed limited access to the interior. Neither Clemmons nor Hawkins could get more than their head and shoulders into the opening, and they could make out nothing inside. Visibility was zero in the blackened, smoke-filled crew compartment.

Gleaves came in and told the others to stand back. He kicked the hatch, causing it to drop farther and permit more access. Reece, armed with his largely ineffective gas mask, climbed into the spacecraft. The other men held his ankles in case he needed to get out immediately. The blackness and smoke made it impossible for him to determine anything at first. A wheezing sound that he thought was human caused him to remove his gas mask, only to realize that the noise was the oxygen still flowing through the failed suit lines. He later said that the sound would haunt him until the day he died. He was sure initially that someone must still be alive in that black chaos. When he finally determined that all three astronauts were beyond help, he backed out through the hatch, crying, “They’re dead, they’re all dead!” Tears rolled down his cheeks.

As the smoke cleared, Grissom’s empty couch could be seen on the left, in the 170° position—essentially horizontal—with the harnesses and foot restraints released. Grissom’s electrical adapter cable was disconnected from the communications cable, and he was lying supine on the floor of the CM with his head below White’s headrest and his feet on his own couch.

White’s couch was in the 96° position, with the back horizontal and the leg pan in the raised position. The buckle releasing the harness straps was not opened. However, the straps and belt were burned and torn apart, believed to be as a result of White’s exertions to open the hatch. White was lying transverse across the CM just below the level of the hatchway.

Chaffee’s couch was in the 264° position, with the back horizontal and the leg pan down. All restraints were disconnected, and Chaffee was supine on his couch. His test procedure lay beneath him, relatively unburned.

Steve Clemmons estimated that the pad crew had the last hatch off in just over 3 min from the start of the fire. The entries of the technicians attempting to determine the crew status, together with a follow-up entry by the pad leader, Babbitt, took a couple more minutes. Babbitt put his headset on and made an announcement to Skip Chauvin and the test supervisor in the blockhouse, George Page, at 6:36 pm: “I can’t begin to describe to you what it’s like…” He used this phrase rather than say over the open OIS net that the crew were dead. In the ACE room, everyone knew by his words that the crew was lost.

Firemen and doctors arrived shortly after the technicians opened the hatch. Once the doctors had confirmed that all three of the crew were dead, the firemen struggled, without success, to remove White’s body. Melted materials on the couches and the astronaut suits made it very difficult to move the astronauts. The doctors confirmed to the blockhouse that the crew was dead. It was decided to leave the crew as they were until all the necessary photography of the accident scene had been completed. No further activity in the CM would occur until later that evening.

SHOCK AND GRIEF

Every person on duty that evening was profoundly affected by what happened that day on the launch pad. The universal feelings were those of shock, horror, and utter helplessness.

John Tribe said:

> *In the ACE station, we were stunned. Skip could raise no one on the net. We knew that something dreadful had happened. I rose from my seat and went to the wall phone in the ACE station and called my wife. I told her that we'd had an accident on the Cape, but I was fine and not to worry if I was much later than planned getting home. After I replaced the phone, Dave Stewart picked it up to make a similar call. He asked me what was wrong with the phone. He couldn't get a dial tone; it was dead. I looked around and saw a security guard locking the door of the station. The KSC emergency response procedure was in work, and all affected areas were locked, sealed, and isolated.*

Several years after the accident, Rich Robitaille became the supervisor of one of the engineers who was manning a console in the ACE room during the accident. Robitaille said, "One of the guys who worked for me later on was on the power console, and he saw the glitch—the first indication that there was a problem. He was an electrical engineer, and he saw the short. It took years for him to recover. He never forgot it."

Frank Bryan was on duty in the LC-34 blockhouse during the test. His boss, Ike Rigell, was at a design review on the west coast at the time the accident occurred. Rigell and Bryan recalled the events of the evening:

> Rigell: *The night of the fire, you called me, and you spoke very low and quietly, "I can't tell you, but we've got a serious problem here." I said, "What is it, Frank?" You said, "I can't say, I can't say." You weren't supposed to make any outside calls, but you called me. You did say something about the spacecraft. I said, "Frank, are we [launch vehicle operations] involved?" I was thinking that maybe it was the emergency detection system or something. I couldn't sleep after your call. But you guys were locked in. You don't remember talking to me?*
>
> Bryan: *I was in a total state of shock. There was absolutely nothing we could do about it. We were totally helpless, the Saturn crew. We tried to think of everything we could do, and there was just nothing. You could listen to them yelling in the spacecraft. On the TV, you just saw smoke coming up around the Apollo. Deke Slayton was there in the blockhouse. He was the astronaut lead. I remember seeing him cry when he realized fully what had happened.*

Some people were so devastated by the feeling of helplessness while witnessing the accident that they refused to work on test teams again. JoAnn Morgan was on duty earlier in the day, but had been sent home by her boss about 2 h before the accident. She said:

> *Jim Coonce, my boss, relieved me at 4:30 pm because I'd been there since 6:30 that morning. Jim was in the blockhouse when the fire occurred and the astronauts died. Thank God it was Jim, and not me. I probably would have never gone back. That would have probably ended my career. Joe Smith from my office was there with him. Joe*

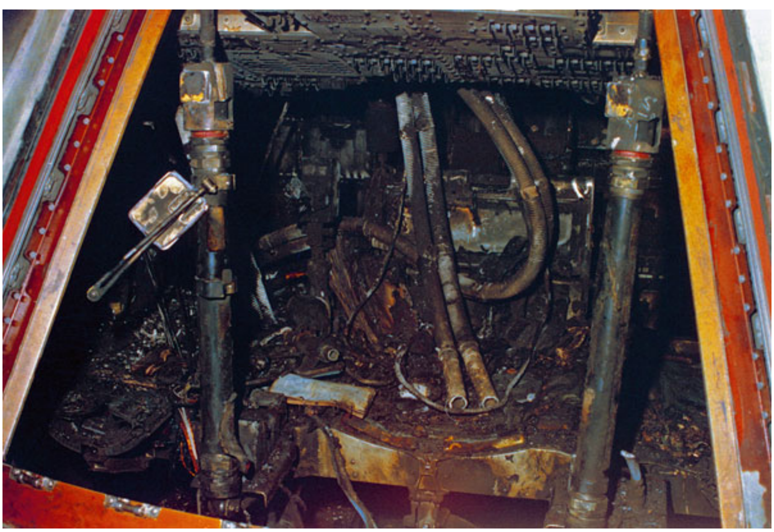
never wanted to sit on a console again the rest of his life. In fact, that probably had a lot to do with why I later got sent to the firing room and became the first woman to work on the launch team in launch control for Apollo, because Joe could never work a console again. It just devastated him to be there, to hear it, and to have to be part of that whole first twenty-four hours locked in the blockhouse while the investigation started. It was a nightmare for all of those people.

James Ogle was manning an S-IVB instrumentation console in the blockhouse that day. He said: "I was really young and impressionable. I really thought it was the end of the space program, to be honest with you. It took them 18 months to get people back into space again. It wasn't just me. I know that everyone in the blockhouse, and the whole nation, thought that was a horrible way to die. I had nightmares. I also thought, 'That's the end of my job. What am I going to do now?'"

LOCKING DOWN

The blockhouse and the ACE room were locked down. John Tribe said, "In the MSOB, while we trying to gather our thoughts, we realized that something was in motion. Security came through the control room and collected all the procedures and smarts books that we always had with us on station. We were shepherded over in a bus to LC-34. The pad was a sea of lights, ambulances, and fire and security vehicles. We looked up at the A8 level and knew that what remained of spacecraft 012 and the three astronauts was still there."

Ernie Reyes had gone home at the end of his shift that afternoon. He was called back in to work to perform an excruciatingly difficult task that began at 12:30 am and took about 90 min (Fig. 3.11):



3.11 *Apollo 1* capsule interior after crewmen were removed. *Source*: NASA

As the NASA crew chief, I had lived with that ship since California. When I got to the pad that night, the ship was like a fireplace. I had to go in there and help remove the bodies from the cabin. We had to disconnect the hoses, move the hand controllers, separate the suits from the couches, and move the men from where they had expired.

I will never forget having those crewmembers in my arms that night. These were good friends that you've argued with, you've been working with them. It's like a military crew chief in Vietnam or Korea, having to pull out a burned crewmember when one of the sorties was over.

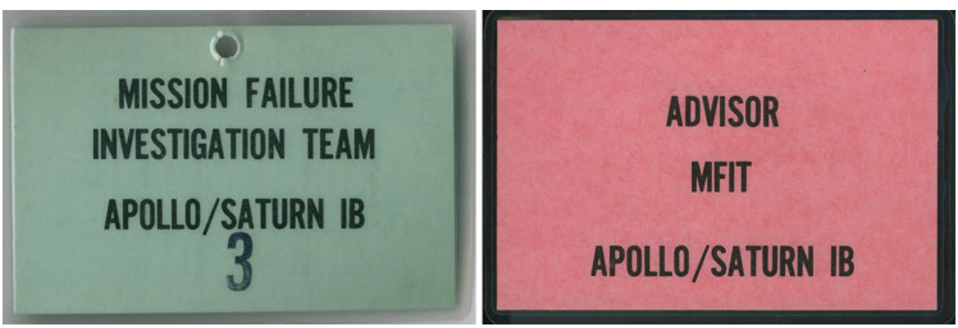
Meanwhile, in the pad 34 blockhouse, the investigation was already underway. Tribe said that the ACE team was taken to the ready room at the pad, where everyone was interrogated on tape as to actions, memories, involvement in the test, and so on. They were released at about 2:30 am and instructed to return at 6:30 that morning.

Charlie Mars was not involved in the *Apollo 1* mission, but he was pressed into service that night to stand guard over the data in the MSOB:

My boss came to my house after dark. He said, "We've had an accident. Put yourself on call." I got a call at 3:00 in the morning, saying, "Go to the data room. There's a guard there. He knows you're coming. You're our data room guy until we can get all this settled."

Over in the MSOB, security had taken everything from the ACE room and piled it up. They put everything from the ACE room in our data room on the southwest corner of the second floor – all the strip chart recordings, the audio recordings, all the procedures – everything the guys had was put in there and locked up, and they posted a guard outside of the room.

I got there, and the guard lets me in. All the strip charts were laid out on these big boards so we could check on them. I'm going over the data and listening to the voice tapes to make sure it's all intact, and I hear this racket in the hallway around 6:00 or 6:30 in the morning. I walk out in the hall, and here comes a bunch of guys from MSC: Dr. Ralph Langford, who I knew, and a planeload of mostly NASA and some Rockwell guys, ten or twelve of them. I tried to put myself between the guard and the other wall, and I said, "Ralph, what are you doing here?" He said, "We're going to



3.12 *Apollo 1* mission failure investigation team member and advisor badges (Author's collection). *Source*: Ward *look at the data!" I said, "I don't think you are. They have not formed a review board yet, and until they do, nobody's going to get in here." And he started to walk toward me. I felt this arm move me out of the way, and the guard put himself between me and them, and put his hand on his gun! That scared the shit out of me. I was thinking, "Oh God, he's going to shoot Ralph!" He just stood there, and he didn't say anything. Never said a word. I felt like it went on for minutes. It was probably seconds. Ralph turned around and just stormed through the people that were with him. He was very hot-tempered.*

The guard sat back down. After everybody left, I asked him, "Would you really have shot him?" He said, "No, but I didn't want him to know that."

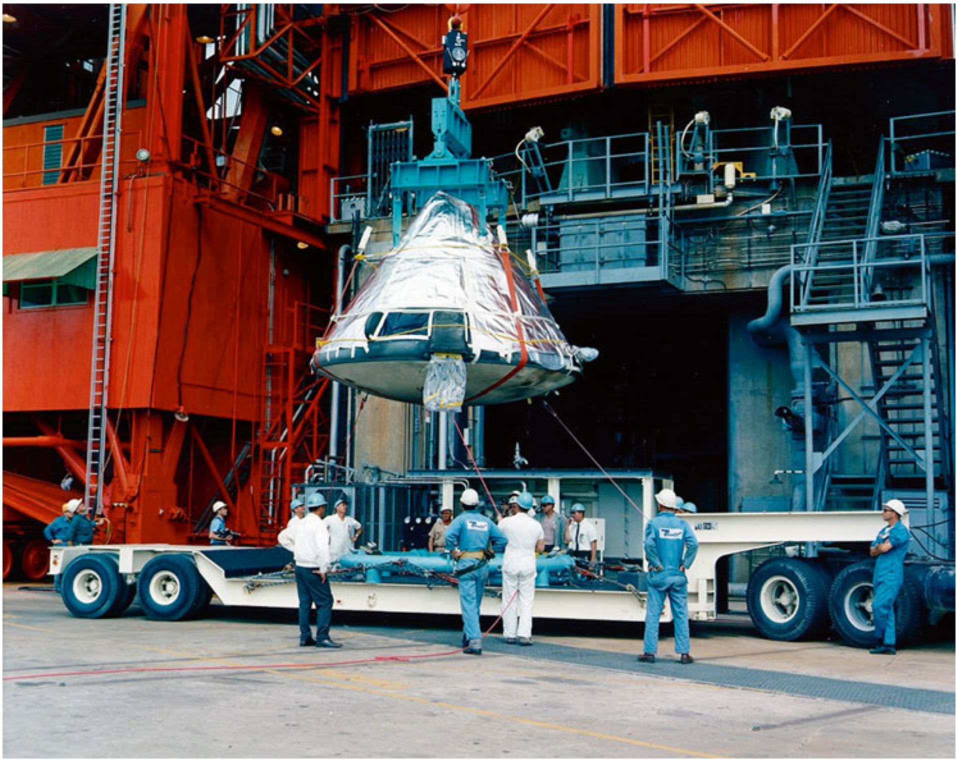
NASA assembled a mission failure investigation team and convened an accident investigation board. The launch escape system was unbolted from the top of the capsule. Fire investigators carefully examined the interior of the command module. The environmental control system and crew couches were inspected in place, removed, and taken offsite. The main control panels were removed and taken to the pyrotechnic installation building (PIB). Because its internal hull had been ruptured, the command module was not structurally sound. When the CM was de-stacked on February 17, it was lowered from the pad supported by straps rather than the usual handling fixture. The CM was taken to the PIB and disassembled. Spacecraft 014, originally intended to fly the second manned Apollo mission, was also taken to the PIB and disassembled. The configuration and construction of the two capsules were compared, piece by piece, wire by wire (Figs. 3.12 and 3.13).

All of the data generated during the plugs-out test was carefully scrutinized. James Ogle said:

Our S-IVB stage was right under the capsule. It seemed like that for about a year, we would re-run the magnetic tapes and get all the telemetry off them from that test. We'd look at all these measurements on the 8-pen strip chart recorders – there'd be 15 or 20 charts full of the measurements. We did that I don't know how many times. When it was over, there was a building over by blockhouse 34 where they used to string up the data: "Okay, we've got to go look at the data again for the fire." And we did that five or six times. Nothing changed. You're looking for glitches, anything that we could have done, sitting underneath them at the time, that could have potentially maybe set up the fire, because a lot of wiring came down from the command module.

LESSONS LEARNED

The precise source of the electrical spark that caused the fire was never pinpointed. The board determined that the fire spread rapidly because of the pure oxygen atmosphere and the flammable items (such as Velcro and paper) in the spacecraft. It also determined that the large number of engineering changes still open at the time of the test demonstrated that the spacecraft configuration was still evolving, that documentation and test procedures had not caught up with the current state of the vehicle, and that carry-on equipment and other items had not been adequately checked for suitability in a test environment.



3.13 The remains of the *Apollo 1* command module are lowered onto a trailer, February 16, 1967. Much of the spacecraft cabin interior has already been removed for analysis. *Source*: NASA/Kipp Teague

The board noted that the organizations responsible for the planning, conduct, and safety of this test failed to identify it as being hazardous, and there were no procedures or contingency preparations to enable crew escape or rescue from a fire inside the spacecraft. There were no emergency teams attending the test. Even the design of the access platforms around the spacecraft hindered the ability to fight the fire.

The board also found that there was one major and one minor revision to the operational checkout procedure for the test less than 24 hours before it began. There were differences between the test procedures being used by the ground crew and the in-flight checklist. Although the board noted that these changes did not contribute to the accident, the late revisions prevented the test team from being fully familiar with the test procedure before they ran the test. The board recommended that test procedures and changes be published, reviewed, and distributed far enough in advance of tests that personnel could be fully prepared to participate.

NASA decided not to fly any manned missions with the Block I Apollo CSM (the configuration used for *Apollo 1*), which was only capable of solo, Earth-orbital missions. NASA concentrated its efforts at improving the Block II CSM, the model that would fly missions to the Moon, and bringing it into service as soon as possible.

NASA, Rockwell, and Grumman thoroughly examined all aspects of the command/service module and the lunar module to eliminate fire hazards and protect wiring. Rockwell designed a new, outward-opening hatch for the CM. The spacecraft cabin atmosphere for pre-launch testing was changed from 100 % oxygen to a 60 % oxygen/40 % nitrogen mix to reduce support of combustion. In the cabin before launch, astronauts would still breathe pure oxygen through their suit loops, which were pressurized above atmospheric pressure to prevent nitrogen from seeping into their air supply.

Test procedures were scrutinized to identify and eliminate unnecessarily unsafe conditions. Training and configuration controls were increased and strengthened. Inspections were added across every aspect of the spacecraft. Additional ground safety precautions were implemented to provide emergency fire and medical personnel on site, appropriate emergency breathing and firefighting equipment on the spacecraft levels, and improved access to and from the swing arm, elevator, work platforms, and White Room.

Ernie Reyes summed up the resolution of every person involved with *Apollo 1*:

> *You feel, "God dang it! I've got to do better, so that this never, ever happens again!" And that's one of the things that I had inside of me, that said, "I will do everything humanly possible to see that this will never, ever happen on my watch."*
>
> *And then I became very strict, that I could laugh, I could tell stories, and we could jive around with the guys all the time. But when it came to that ship, that capsule, and that work effort, it was going to be ship-shape. It was going to be first class. And I never forgot that.*
>
> *It was not just me; it was everybody that was working out there, the test team of forty-some people that were in the ACE room when it happened, the people in the blockhouse, everyone at KSC. They all took that oath, no matter whether they said it out loud or to themselves.*

APOLLO MOVES AHEAD

NASA kept moving forward. The first test flight of the Saturn V took place on November 9, 1967, about 9-1/2 months after the fire.

Apollo 1's AS-204 Saturn IB launch vehicle was undamaged by the fire. NASA unstacked the booster and moved it to LC-37B. On January 23, 1968, almost exactly 1 year after the *Apollo 1* fire, the AS-204 launch vehicle flew the *Apollo 5* mission, the first test flight of the lunar module in low Earth orbit.

Marcus Goodkind remembered Grissom's request for him to move to the Apollo program. After the accident, Goodkind said to his wife, "Surely I can't turn Gus down now." He negotiated a transfer to Grumman to work on the lunar module. Goodkind went on to become the Grumman LM test manager for *Apollo 11's* LM-5, better known to the world as *Eagle*.

NASA put its first manned Apollo capsule, *Apollo 7*, into Earth orbit on October 11, 1968. Wally Schirra, Walt Cunningham, and Donn Eisele had been the backup crew for *Apollo 1*. They put *Apollo 7's* improved Block II CSM through its paces, flying a ship that was much safer because of the sacrifice of their colleagues. The mission proved the capability of the rebuilt Apollo spacecraft and started the countdown to a lunar landing.

There were 14 months remaining in the decade in which to meet President Kennedy's challenge.

John Tribe summed up the optimism and determination of KSC's workers: "The lives of Grissom, White and Chafee were not lost in vain. The Moon was still within reach."

Astronaut Cunningham told the author: "Every once in a while, they show a picture of Launch Complex 34 during *Apollo 7*, and a picture now, and it's sad. The air force guys run the tour of that launch complex out there, and the only thing they emphasize is that people got killed there. But it was really the *birthplace* of Apollo, and we ought to be emphasizing that we got Apollo off the ground from there."

4

The Spacecraft Assembly and Checkout Facilities

We move now from Cape Canaveral to start our exploration of Kennedy Space Center proper. First on our tour will be the facilities that supported Apollo spacecraft assembly and checkout.

THE WORLD OF SPACECRAFT OPERATIONS

KSC's spacecraft operations directorate was responsible for assembling, testing, and checking out the Apollo spacecraft prior to launch. For nine of the manned Apollo missions, each spacecraft consisted of two vehicles (the command/service module and the lunar module), and each of these vehicles was comprised of two separate stages or modules. Spacecraft operations personnel also checked out the scientific payloads that were to be carried to the Moon and integrated these experiments with the spacecraft.

Spacecraft operations' work primarily took place in three locations. These were the Manned Spacecraft Operations Building (MSOB or MSO Building), the Vehicle Assembly Building (VAB), and the launch pad. During the hectic period from 1967 through the middle of 1969, three Apollo spacecraft were typically in flow simultaneously for three different missions, with one—and sometimes two—spacecraft in each of these locations.

THE MANNED SPACECRAFT OPERATIONS BUILDING (MSOB)

The MSOB was the home base for spacecraft operations. The lunar module and the command/service modules were received, assembled, and thoroughly tested here. The spacecraft vehicles spent about 3 months in the MSOB before being transferred to the Vehicle Assembly Building for stacking on the launch vehicle. The MSOB housed most of NASA's and the contractors' key spacecraft engineers and the spacecraft test conductors. The ACE computers and control rooms in the MSOB managed the checkout of the spacecraft components at KSC, whether the spacecraft was in the MSOB, VAB, or at the launch pad.

Some early NASA documents referred to the MSOB as the Operations and Checkout Building (O&C), but that was not how most people referred to it during the Apollo program.

J.H. Ward, *Rocket Ranch*, Springer Praxis Books, DOI 10.1007/978-3-319-17789-2_4

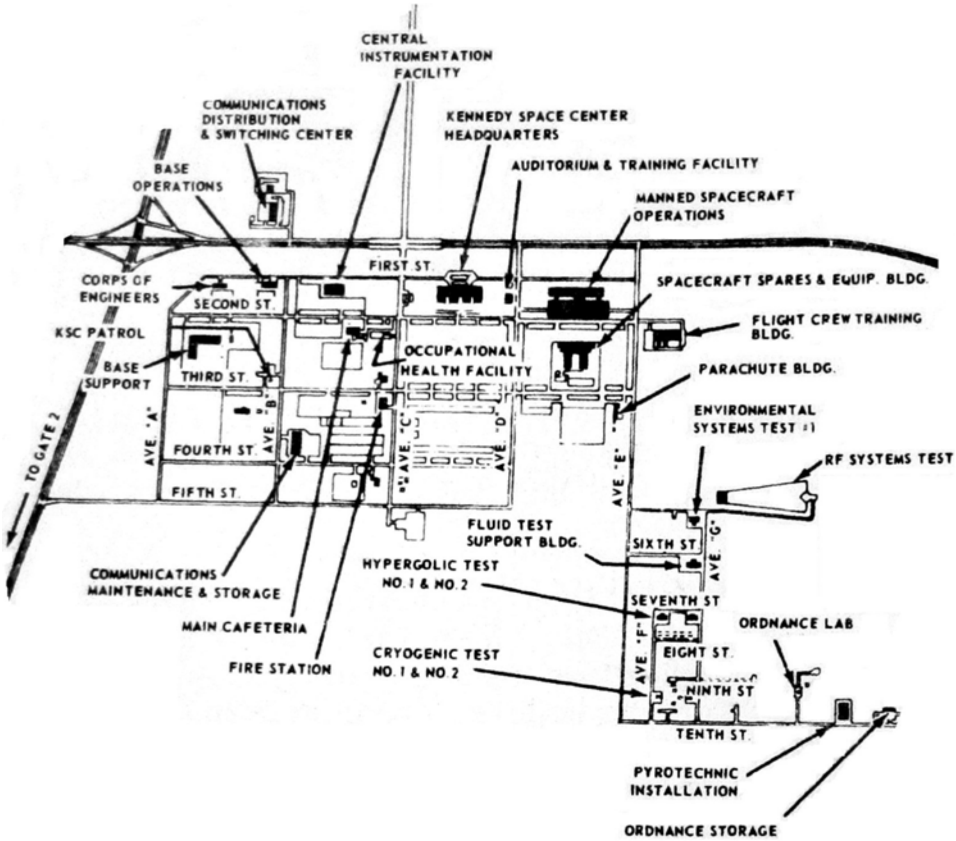
The MSOB got its name from being the administrative office of Manned Spacecraft Center-Florida operations (MSC-FO). The building retained its name after MSC-FO became KSC's spacecraft operations directorate in 1965. After the Apollo era, the building was formally designated as the Operations and Checkout (O&C) Building.

Construction on the MSOB began in 1963, and it was fully operational in 1965, just in time to process the first unmanned Apollo missions. The MSOB was located in KSC's industrial area, east of the KSC headquarters building on NASA Parkway, and 5 miles (8 km) south of the VAB (Figs. 4.1 and 4.2).

The distance between operations facilities complicated the lives of spacecraft managers, engineers, and technicians, who might have to work on three vehicles that were in various phases of the processing flow in different locations. Engineers and technicians had to drive or be shuttled between the MSOB to the VAB and the launch pad, sometimes several times a day. On the challenge of managing staff in spacecraft processing from his office in the MSOB, John Tribe noted:

> *From the '66 to '69 timeframe, I had engineers working in the MSOB, the HMF* [*hypergolic maintenance facility*], *LC-34, LC-37, LC-39A, LC-39B, and the VAB. I had to locate people at every one of those sites, because we had ground support equipment or the spacecraft at all of those sites. We even had people on LC-16 doing hot-firing tests of the service propulsion system. From a supervisory point of view, it was a nightmare, trying to work out the people and what shifts they were supporting, what tests they were supporting, and just trying to keep up geographically with all these different facilities scattered over a pretty big area.*

4.1 MSO Building (foreground) in 1964. The next two buildings in the distance are KSC administration headquarters and the CIF. *Source*: NASA/Ward

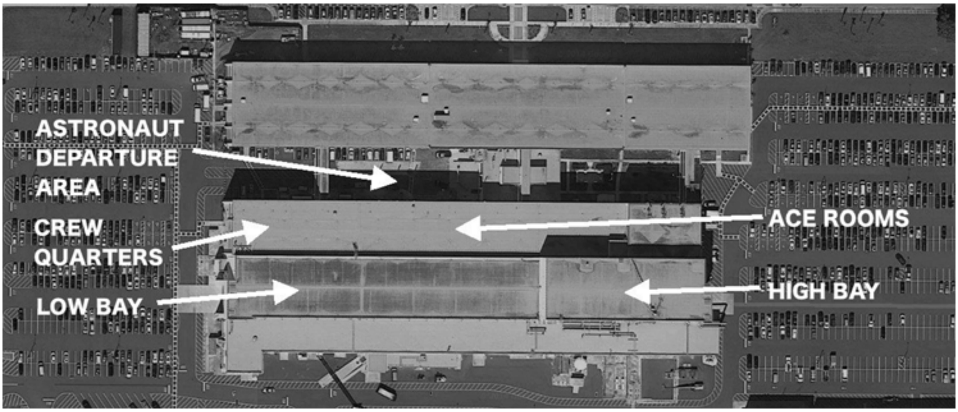


4.2 Map of the KSC industrial area from 1967, showing many of the facilities used in spacecraft processing. *Source*: NASA/Ward

The MSOB underwent continuous modification and addition during its first 5 years as the Apollo program intensified. The MSOB consisted of two parallel wings, joined by three crossovers that spanned a paved central parking and receiving area. The major assembly and checkout action took place in the larger, south wing of the building. This wing housed:

- The low bay and high bay, where spacecraft processing occurred.
- The astronaut crew quarters and suit-up room on the third floor.
- The acceptance checkout equipment (ACE) control rooms and computer complex.
- Laboratories and clean rooms.
- Various mechanical, electrical, and parts stores that supported the assembly and checkout process.
- Power and gas facilities.

The north wing of the building, referred to as the administrative and engineering (A&E) area, had offices for contractors and NASA engineers and QC technicians, senior executives, and other managers. The offices of Rocco Petrone, Paul Donnelly, Ike Rigell,



4.3 Overhead view of the MSOB. *Source*: NASA photograph scanned and annotated by author

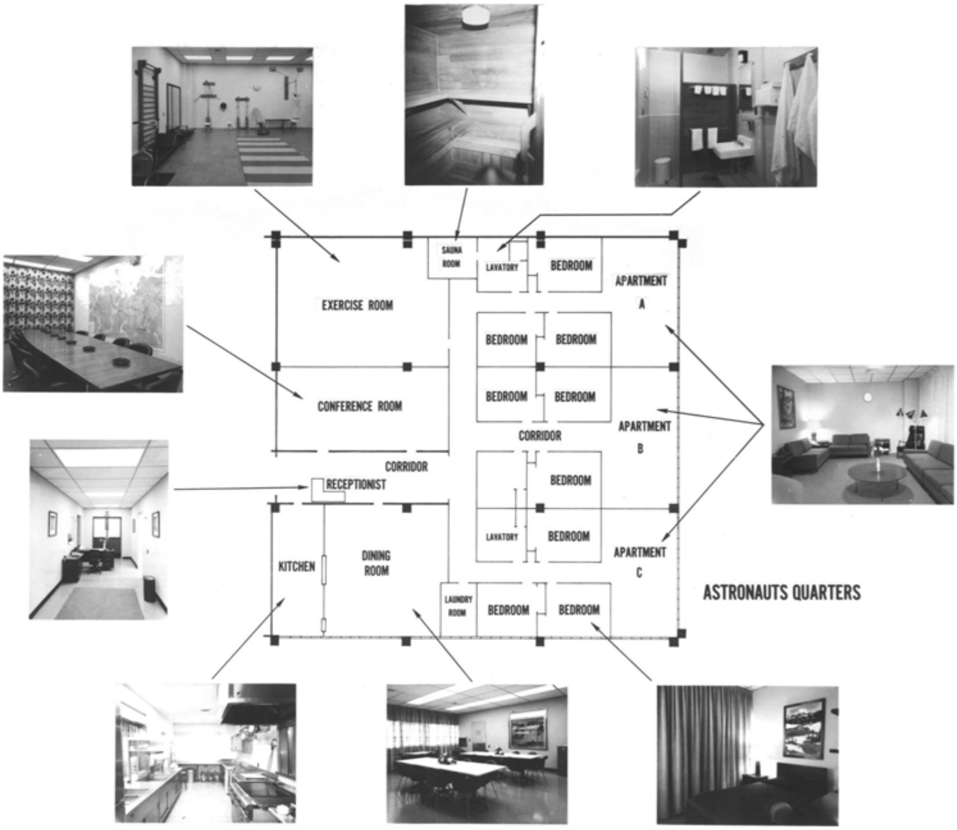
John Williams, George Page, and Ted Sasseen, among others, were on the second floor. Grumman and NASA QA occupied offices on the first floor, and Rockwell had offices on the third floor. The cafeteria and a large mission briefing room that seated 300 people were located in a large crossover area between the two wings of the building (Fig. 4.3).

The MSOB was a hive of activity 24 hours a day, 7 days a week throughout much of the Apollo program. Ernie Reyes recalls doing a badge check one day that indicated there were about 750 people working just in the operations and checkout area of the MSOB. Technicians, engineers, and inspectors for Grumman and Rockwell comprised the bulk of the people on duty. NASA QC inspectors, project engineers, operations engineers, and test conductors supervised the activities. Boeing rover technicians and engineers, scientists for the lunar experiments packages, Bendix crane operators and safety personnel, IBM and GE staff managing the ACE room equipment, managers, astronauts, and miscellaneous other support personnel were also on the scene, making the MSOB a very busy place.

The Astronauts' KSC Home Base

Astronaut crews working at KSC lived in the astronaut quarters at the west end of the third floor of the MSOB's south building. The crew quarters afforded them a private place to relax or prepare for upcoming missions. There were three apartments in the crew quarters, each apartment with three bedrooms (Fig. 4.4).

Living in the MSOB made it convenient for the astronauts to participate in spacecraft tests when required. It also enabled them to drop in on the activities on the work floor to see what issues were cropping up with their spacecraft. Astronauts were intimately involved with their spacecraft throughout the assembly and test process. Support crew astronauts kept a handle on day-to-day issues that arose in testing. Prime and backup astronaut crews came to assembly and test areas for altitude tests, crew compartment fit and



4.4 Astronauts' quarters in the west end of the MSOB. *Source*: NASA/Ward

function checks, and other activities that required their direct participation. Their presence was a reminder to the spacecraft personnel that human lives were dependent on the quality of their work.

Astronauts had reserved parking spaces in the central paved courtyard. The comings and goings of the red, white, and blue Corvettes, leased to the astronauts by Jim Rathmann, caught everyone's attention. One engineer said: "Our windows overlooked the astronaut parking area. We would start work at 7:00 in the morning, and we would see them arriving in the parking lot from their evening activities and heading up to the crew quarters, getting in from a night of partying. It was a different life for them!"

The astronauts ate their traditional steak-and-eggs breakfast in the crew quarters on launch day, before moving down the hall to the suit-up room. After donning their spacesuits on the third floor of the MSOB, astronauts took the elevator to the ground floor and departed the south wing into the central courtyard, where the *Astrovan* was waiting to ferry them to the launch pad (Fig. 4.5).

4.5 Astronauts conduct a C^2F^2 (crew compartment fit and function) test with the new *Astrovan*, August 1968. NASA security specialist Steve Tatham is at *left. Source*: NASA/Ward

The Assembly and Test Area

When people see photographs of the Apollo spacecraft assembly and test process, at KSC they mistakenly assume that these photos were taken in the VAB. Much of the south end of the MSOB was a large open bay that ran the entire 650-ft (198 m) length of the building. The bay was divided into two major processing area. The low bay was on the west end, with a ceiling about 60 ft (18 m) above the work floor. The high bay was about 80 ft (24 m) tall on the east end of the checkout area. The bay was referred to as the "assembly and test (A&T) area" in some documents and as the "operations and checkout (O&C) area" in other documents. In informal conversation, spacecraft operations personnel referred to either the MSOB low bay or the MSOB high bay. A service and utility tunnel ran the length of the building underneath the work floor. Off the south side of the bays were shop rooms, parts storage, and tool cribs for use by spacecraft technicians.

Welby Risler, one of the original pioneers of NASA, was responsible for the design of the operations and checkout area. The specifications and layout were required at a time when the Apollo spacecraft had not yet been designed, and the tactics for landing on the Moon were not yet decided. Risler said:

> *I was told that we had to come up with the basic requirements for the operations and checkout building for Apollo. The first thing that I asked them was*, "*How many times*

will we be launching to go to the Moon?" The official answer that they gave me: Once a week. I told my buddy, "They're crazy!" The boss said, "No matter how big you think, you won't think big enough!" I was given a lot of latitude in making decisions.

We were originally told that it was going to be a direct flight to the Moon and landing there. In other words, there would be the three big boosters that they made in Huntsville, but we were going to have one rocket that was going to slow the command and service modules down and land on the Moon's surface. There would be four outrigger things that would come out. I told my friend that it would be top heavy – and I could just see that thing falling over!

I figured out that landing rocket would be about 30 feet, and add to that the height of the service module and the height of the command module and the height and the launch abort rocket was very similar to what we had on Mercury. That's what we said we needed for the high bay.

NASA realized early in the program that a direct landing with the CSM was infeasible, as it required far too much weight to be decelerated and landed on the lunar surface. Instead, a separate lunar module would make the landing while the CSM stayed in lunar orbit. This reduced the Apollo spacecraft components to a more manageable size and weight. Risler continued:

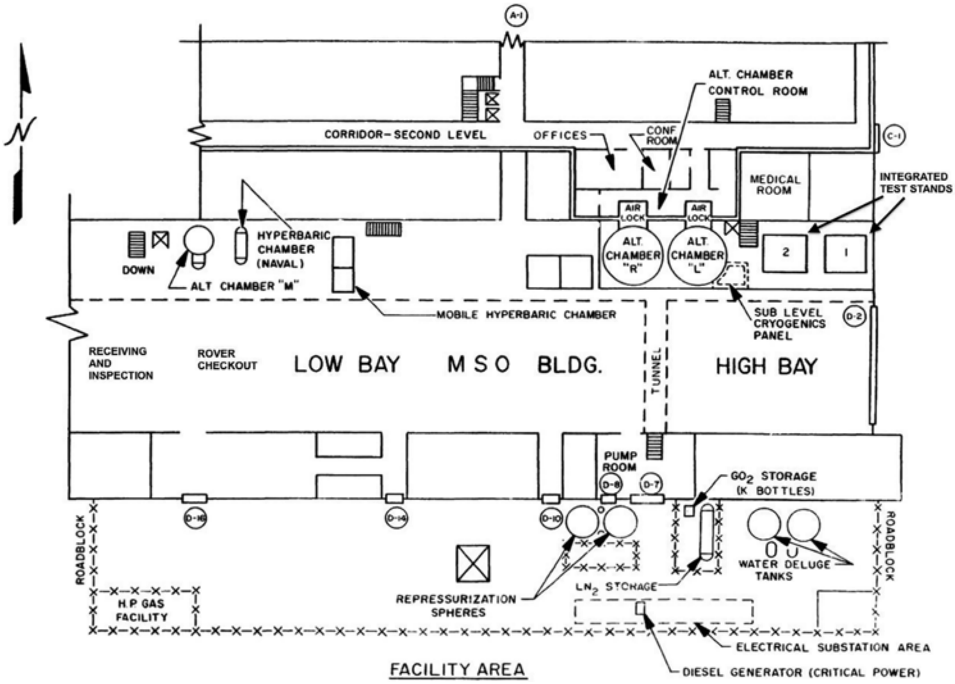
When I heard that, I called up the A&E people right away, and I said, "Cancel the high bay!" They said, "You don't know much about the government, do you? Once you start building something, it costs you more to cancel it than if you just went ahead and built it." But it worked out fine, because the LM that we came up with, and the SLA that they put it in, was just the same height as the landing rocket. So the high bay turned out perfect, you know!

The low bay, which was mostly open space, was where the lunar module's stages arrived and were inspected, and where the LM was checked out. The command and service modules came in through the doors at the east end of the high bay. At the conclusion of the checkout process in the MSOB, the assembled spacecraft exited the building through large rising-panel doors at the east end of the high bay.

Three small altitude chambers lined the northwest wall of the low bay. Two hyperbaric chambers (one on loan from the U. S. navy and one portable chamber) could be used to stabilize astronauts in case of an emergency decompression during an altitude chamber test with the spacecraft. The white-painted chamber M was a holdover from the Mercury and Gemini programs. Russell Lloyd said:

It was the Mercury chamber that was originally over in hangar S [*on CCAFS*]. *We used it for Gemini 3 to dry the heat shield. Spacecraft wanted it as part of their testing. They wanted to vacuum-dry the heat shield so they could take core samples and see how the ablative material was working.*

During the Apollo program [Apollo 14 *and* 16], *the astronauts performed some experiments with electrophoresis on board the CSM, trying to make purer insulin for treating diabetes. It's a process where you induce an electrical current into a liquid and cause it to segregate into the various components. We tested their electrophoresis unit in Chamber M with an astronaut in there. That was the only time it was used on a manned basis.*



4.6 Diagram of the MSOB assembly and checkout area. *Source*: Author's adaptation of NASA diagram

At the northeastern corner of the high bay were two large integrated test stands (the square boxes numbered "1" and "2" in Fig. 4.6) with several levels of work platforms that could be folded down around the spacecraft or flipped up out of the way. The CSM and LM went through final assembly and were mated to the SLA in the integrated test stands (Figs. 4.7 and 4.8).

The low bay and high bay also contained a number of movable test stands and work fixtures. Some of these will be discussed in more detail in the section on spacecraft processing.

Altitude Chambers L and R

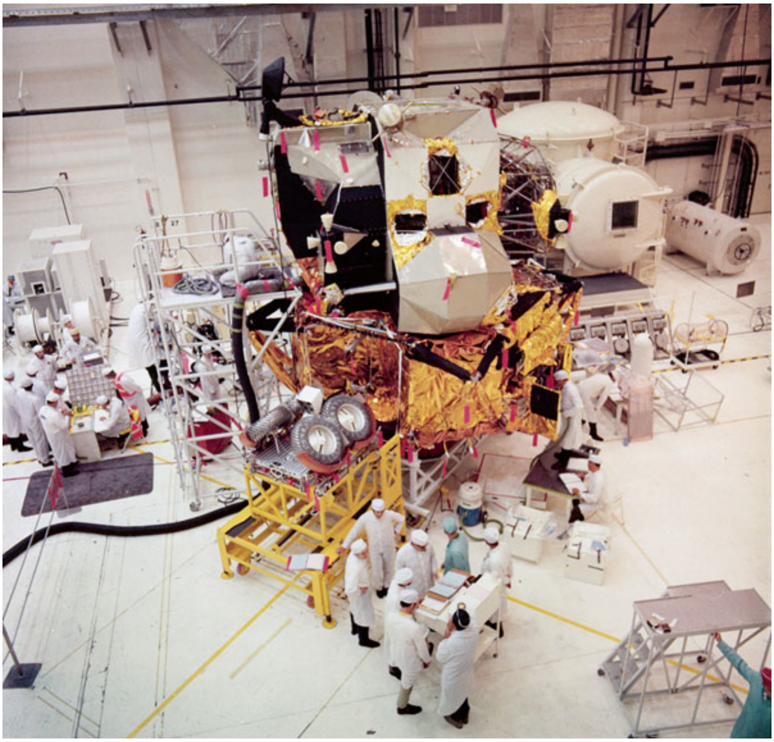
The most distinctive features of the high bay were two cylindrical altitude chambers along the north edge, immediately to the west of the integrated test stands. These two chambers were officially designated as the *Apollo altitude simulation system*, but were never referred to that way in conversation. The chambers were about 59 ft (18 m) tall, 33.5 ft (10 m) in diameter, and were made of ½-in. (13 mm) thick stainless steel. A set of stainless steel spiral stairs was welded into each chamber's interior wall. Each chamber had ten observation ports and a set of double airlocks (Fig. 4.9).

The altitude chamber control room was situated between the airlocks for the two chambers on the second floor of the MSOB. From here, operators could control the chambers'

4.7 The *Apollo 15* CSM has been removed from altitude chamber L and is being moved into integrated test stand 2, at *left* in this photo of the MSOB high bay. There, technicians will install the high gain antenna and the service propulsion system engine bell (in the *red cover* to the *left* of the CSM). *Source*: NASA/Jerome Bascom-Pipp

interrelated systems. These included the systems for depressurizing the chamber, maintaining vacuum, cryogenics, oxygen chilled water, valve air and instrument air, gaseous nitrogen purge, water deluge, air conditioning, instrumentation, fire detection, and electrical power distribution. Many of the systems for both chambers that related directly to spacecraft testing could be controlled by the NASA spacecraft test conductors in the ACE control rooms.

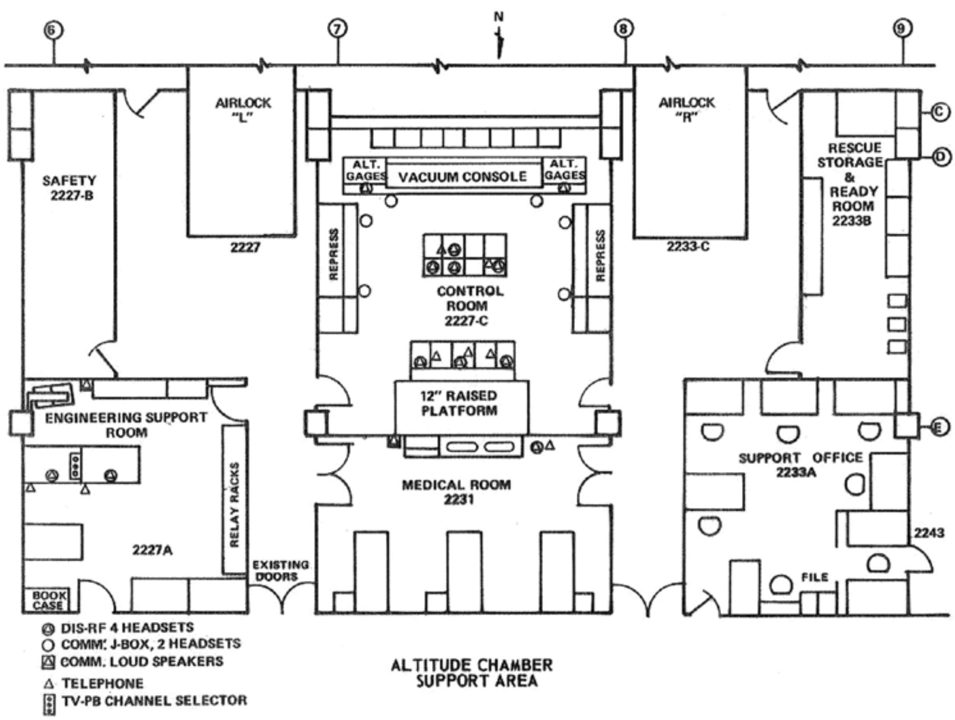
Ernie Pyle, the Bendix complex operator, was responsible for the activities of the operations staff in the altitude chambers and control room. Unmanned tests in the altitude chamber required 18 controllers with 2 backup personnel for each 12-hour shift. Manned altitude runs required 36 controllers per shift, with a minimum backup team of 1 rescue team member and 2 operations personnel (Figs. 4.10 and 4.11).



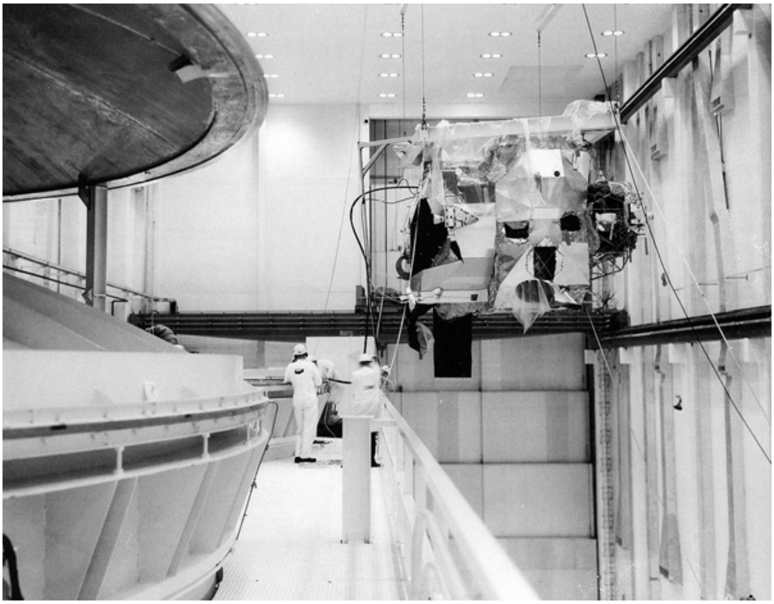
4.8 Fit check of the *Apollo 15* lunar rover and lunar module in the MSOB low bay. Note the Mercury-era altitude chamber M (with *square* porthole) behind the LM, and the naval hyperbaric chamber at *upper right. Source*: NASA/Jerome Bascom-Pipp

4.9 Altitude chambers R (at *left*) and L, 1966. *Source*: NASA/Ward

4.10 Altitude chamber control room. *Source*: NASA/Ward



4.11 Diagram of altitude chamber support area, MSOB second floor. *Source*: NASA/Ward



4.12 The inverted ascent stage for LM-3 (*Apollo 9*) is about to be lowered into chamber L for a docking test with the CSM. The lid for chamber L has temporarily been placed on supports atop chamber R. *Source*: NASA/Jerome Bascom-Pipp

Looking out (southward) from the control room onto the high bay, the eastern altitude chamber was designated chamber L (for left) and the western one was chamber R (right). The CSM spent the majority of its time in the MSOB inside chamber L. Much of the LM buildup and test occurred in chamber R.

Each chamber had a large circular lid that rested on a gasket. The cover had to be lifted off the chamber by the overhead bridge crane in order to move a spacecraft into or out of the chamber. Russell Lloyd noted (Fig. 4.12):

Each lid weighed 27.5 tons. The three cranes in the building were rated at 25 tons. A little bit of a design glitch there, not communicating between the two design organizations. Our design group at KSC did a total analysis of the cranes so they could be upgraded. There was enough safety margin built into them so they could be upgraded to 27.5-ton cranes so we could lift the lid.

We'd lift the lid off and set it on the adjacent chamber, take the spacecraft in or out, and then put the lid back on it. That the lid came completely off was one of the things that concerned our safety organization at one time. They were concerned that if we over-pressurized the altitude chamber when we were bringing it back to sea level, then the lid might take off like a Frisbee. But we demonstrated to them that one-half psi would just barely lift the lid on its metal guideposts, and it would wobble there like the lid of a boiling pot until the pressure dissipated. There was no way to blow the lid off.

Air could be evacuated from only one chamber at a time. The process of bringing a chamber up to simulated altitude (i.e., decreasing the pressure inside the chamber to the equivalent of near-space environments) started by using the vacuum system to pump air out of the chamber. While the chamber was being lowered in pressure, the cryogenics system and the valve air and instrument air systems removed humidity and other vapors from the air, so that there would be no moisture to freeze out onto delicate spacecraft systems. The chilled water system removed heat from the vacuum and depressurization systems as they worked to bring the pressure down. Once the chamber reached the appropriate simulated altitude, the main pumping system was turned off, and another subsystem held the chamber at the required pressure. At this point, if required for a test, the main vacuum pumping system could then depressurize the other chamber.

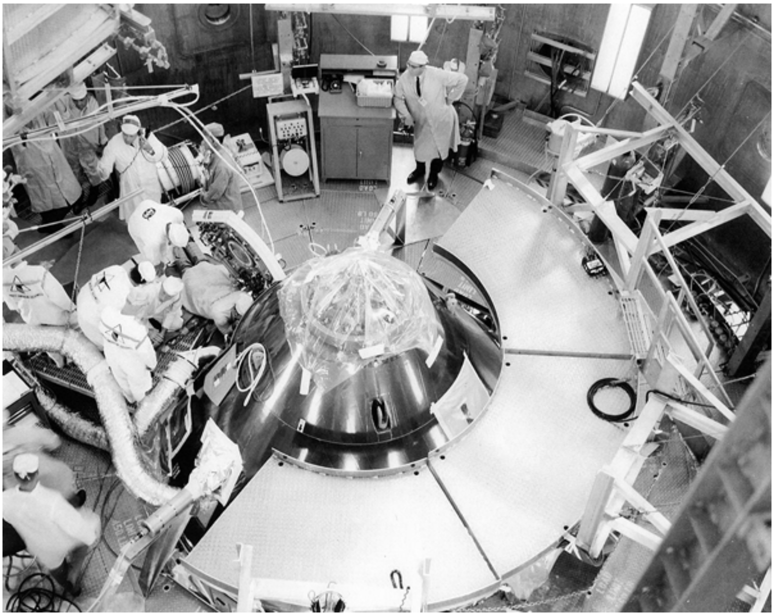
Although the altitude chambers could not achieve a perfect vacuum, they could be depressurized to an equivalent altitude of more than 250,000 ft (76 km) over the course of an hour. Apollo spacecraft testing occurred at a maximum simulated altitude of 210,000 ft (64 km) to verify spacecraft systems performance in near-vacuum conditions.

At the end of a test, re-pressurization with dry air brought the chamber back to an equivalent altitude of 25,000 ft (7.6 km) to equalize the chamber pressure with the airlocks. Then the chamber was brought slowly back the rest of the way to sea level pressure. Re-pressurization time was normally from 16 to 30 min, but could be pushed to 2 min in an emergency.

The altitude chambers were installed in 1965 but were not man-rated until 1966. They had to undergo another man-rating certification after modifications in 1968. Lloyd said that there was an unpleasant surprise during the initial testing of the chambers:

> *Our source of air for re-pressurization was spheres that were outside the building. They were about 20-ft.* [*6 m*] *diameter spheres that we pressurized to 285 psi* [*1,965 kPa*] *with air. The spheres were made out of carbon steel – I guess to save money – rather than stainless steel. Most of the piping and the chamber itself were made out of stainless steel. In hindsight, I guess we should have realized that the spheres were sitting there in the Florida environment. They weren't painted on the inside. Unknown to us, there was surface rust on the inside of the spheres.*
>
> *Early on, we did an emergency re-pressurization test of one of the chambers. Suddenly, we had a big red cloud in the altitude chamber. It was blown full of rust. It just settled on everything in there. And of course we had to do a very thorough cleaning. But it was good that we found that out when we did, because it would have been pretty bad if we had a spacecraft in there. As it's coming back down in altitude, the ambient air is brought into the command module by vent valves. So the rust would have actually been sucked into the command module. It would've been a terrible mess. After that, we put dryers on the spheres, and we kept them pressurized at all times so that ambient air didn't get in there. We're in the worst salt-spray area on the east coast of the United States. Corrosion is a major problem at the space center, something we always try to watch out for.*

The altitude chambers were convenient places to install, test, and modify or replace various parts of the spacecraft during the checkout process. A chamber's internal floor could be rotated through a full 360° range of motion as needed. Work platforms flipped up out of the way or folded down around the spacecraft (Fig. 4.13).



4.13 A CSM undergoing checkout in chamber L. Flip-up platforms partially encircle the CM. The tubular devices taped to the CM at *lower left* and *upper center* are test equipment and interfaces to the ACE system. *Source*: NASA/Jerome Bascom-Pipp

The chambers were used for spacecraft tests through the Apollo-Soyuz Test Project in 1975, following which they were both deactivated, and all their equipment was removed. One chamber was used as a convenient location for launch pad personnel to practice using an access device for the space shuttle's Spacelab module. Chamber R was reactivated in 1997, and new vacuum equipment was installed to support the testing of International Space Station modules starting in 1999. The chamber was deactivated again following completion of ISS assembly. When the O&C high bay was completely gutted and turned over to Lockheed Martin for the Orion program, the altitude chambers were left in place but without any support equipment.

The altitude chambers at KSC could simulate near-vacuum conditions, but they lacked the capability to simulate solar heating in deep space. A large thermal vacuum chamber at the Manned Spacecraft Center in Houston was able to simulate both conditions. The first manned test of a Block II CSM was in June 1968, in a weeklong simulated mission (*2TV-1*) in Houston's thermal vacuum chamber A. This mission was "flown" by astronauts Joe Engle, Vance Brand, and Joe Kerwin. The profile of this mission was different than the altitude chamber runs at KSC. Altitude runs at KSC's MSOB were generally no more than a day's duration and only simulated part of a mission. *2TV-1* lasted a week and simulated an entire Apollo mission, from launch to landing. Vance Brand recalled that the crew compartment was kept at normal mission pressure (5 psi, or 34 kPa) and was never fully depressurized during *2TV-1*. Spending a week inside the capsule on the ground inside an altitude chamber posed other logistical challenges. Brand said, “We had a one-G toilet in there. It overflowed and broke down in the middle of the mission. We were using rags cleaning that up. We were pretty happy to be doing it, though. We felt that any kind of progress was good back then.”

COMPUTERIZED SPACECRAFT CHECKOUT: THE ACE SYSTEM

The acceptance checkout equipment for spacecraft system (abbreviated as ACE-SC or simply ACE) facilitated the test and checkout of the Apollo spacecraft at KSC. Four ACE rooms were on the third floor of the MSOB, two each for the CSM and LM. CSM rooms were mirror images LM rooms, and a CSM room and a LM room were paired with a common wall separating them. In a given test, one pair of CSM and LM rooms was prime, and the other pair served as backup. At times when several missions were in flow, one pair of ACE rooms could be dedicated to one mission and the other pair to the other mission.

The ACE ground station (often referred to simply as the “ACE station”) was spread across a computer room, control rooms, and a terminal facility room. ACE carry-on equipment and peripheral equipment was co-located with the spacecraft or ground support systems being tested, either on the checkout floor, at the VAB, or at the launch pad.

The ACE computer room housed the computer complex, parts of the command system, the data acquisition and decoding equipment, some of the alphanumeric CRT display system, diagnostic equipment for the ground system, and other peripheral equipment. Two CDC-168 computers formed the heart of the computer room. One computer was designated as the digital command computer, and it processed the commands from the control rooms to the spacecraft and interfaced with the ground support equipment. The other computer was the data processing computer, which drove the data displays in the control room and controlled the peripherals.

At KSC, the ACE computer room was on the fourth floor of the MSOB. It was connected by a wideband video transmission system to the VAB, Launch Control Center, and the launch pads. The ACE computers and the RCA ground control computers for the Saturn V shared limited connections (dedicated input/output registers and priority interrupts). The ACE computer also interfaced with the guidance computers in the command module and the lunar module.

The computer system was state-of-the-art when it was designed (the first ACE station went live at North American’s Downey plant in 1964). It could fulfill its initial requirements: command and response testing of individual systems, monitoring several hundred parameters in real time, providing special processing to display about 400 spacecraft parameters in real time, recording all commands and raw pulse-code modulated data, digitally recording out-of-limit parameters, and recording some test data on strip chart recorders. This was all done with 8,192 words of magnetic core memory per computer. The two ace computers shared a memory core of 24,576 words (Fig. 4.14).

As the Apollo program progressed—in fact, even before KSC’s ACE system was fully implemented in 1965—it became clear that the ACE computer system could not keep up with demands of ever-increasing complexity in systems testing. The computer’s processing speed was barely able to cope with the real-time data being received. Even more critically,

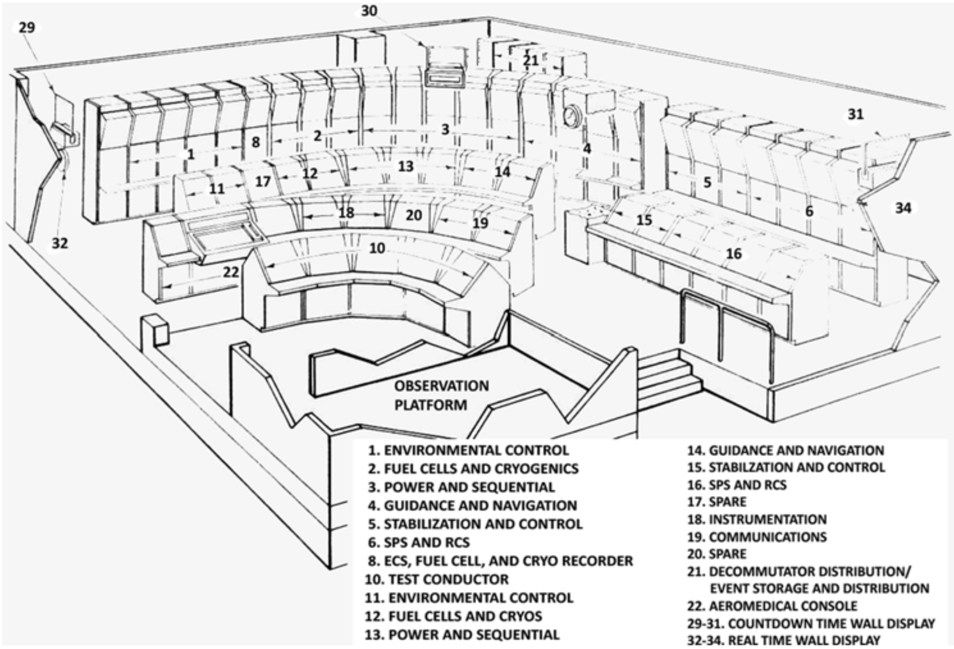
4.14 Jackie Smith (with drawn-in Mickey Mouse ears, courtesy of Ernie Reyes) in the MSOB ACE computer room. *Source*: NASA/Ernie Reyes

a lack of memory began to impede the ability to run complex tests. KSC requirements exceeded the ACE system's memory capacity by 1966, and KSC had no budget to buy more memory. The ACE system software and test procedures had to be re-written to conserve memory space as much as possible. This threatened to cause severe schedule impacts, since test operations had to be stopped every few minutes to dump the data stored in memory before loading the next test program and proceeding.

Given that computer memory is essentially a free commodity in the twenty-first century, it seems ludicrous now that it took KSC nearly 2 years to get the budget approval to procure an additional 24,000 words of memory storage for KSC's ACE computers. The hardware for this single memory upgrade cost more than $60,000 in 1965 dollars (equivalent to more than $450,000 in 2015). One could not simply plug in new computer memory, either; once the additional memory was installed, the system software had to be modified to use the new memory capacity.

The terminal facility room contained the interfaces and patches between the remote ACE test equipment, the computer room, and the control rooms. The terminal facility also housed the time code generator for the real-time displays in the ground station, a countdown generator to drive the countdown clocks, and portions of the command system and the CRT display drivers.

The ACE control room (frequently referred to as the ACE room) was the spacecraft operations directorate's equivalent of the firing room in the Launch Control Center. Each ACE room in the MSOB was divided into two main sections. The test conductors (usually one or two from NASA and two from the contractor) sat at consoles on a raised



4.15 Typical layout of an ACE room in the MSOB. The CSM and LM rooms were mirror images of each other. *Source*: NASA/Ward

platform in one corner of the room, and immediately behind them was a glassed-in observation area. This part of the room was analogous to the mission management area of the firing room. The observation area spanned the two adjoining ACE rooms (Fig. 4.15).

The main section of an ACE control room had about 50 consoles and strip-chart recorders arrayed in three concentric arcs. Many of the consoles had CRTs that displayed real-time test data in alphanumeric format. Other analog and digital displays provided subsystem-level information supplementing the information presented to the engineers on the CRTs. The test conductors received summary-level information at their consoles.

During a full-scale test for either a CSM or an LM, approximately 50 people staffed the ACE ground station at KSC. An engineer and a specialist monitored and controlled the equipment in the terminal facility room. Eleven engineers and technicians manned the computer room. About 35 people staffed the control room. The system test conductor and test project engineer sat at the elevated test conductor consoles, where they could observe all of the operations in the control room. Test engineers were stationed at the consoles for their functional areas and systems. Senior engineers generally sat at the low consoles in the center of the room, while the test engineers they were directing stood at the various vertical consoles along the wall (Fig. 4.16).

Bob Sieck noted that, "The rules were, when you went into the ACE control room, you sat at a console and put a headset on. If you didn't have a job that required a headset, you didn't belong in the control room." Sieck added that the staffing in an ACE room for a test might include representatives from the design center (MSC), the spacecraft computer

4.16 ACE room 1 at KSC, shown here likely staffed by GE employees in a posed photo, February 16, 1967. *Source*: NASA/Ward

(IBM), the ACE equipment (GE), as well as KSC engineers from NASA and either Rockwell or Grumman personnel.

Shown below are the subsystems groups and the number of people typically assigned to control and monitor each subsystem:

- Instrumentation (*Inst*)—2
- Communications (*Comm*)—2
- Environmental control system (*ECS*)—5
- Fuel cell and cryogenics (*FC&C*)—4
- Power and sequential (*Pwr & Seq*)—7
- Guidance and navigation (*G&N*)—4
- Stabilization and control (*Stab & Cont*)—3
- Propulsion and reaction control (*Prop & RCS*; the CSM team referred to this station as *SPS & RCS*)—6
- Biomedical console (*BMC*)—2

The Quick-Look Data Station

The ACE system was too slow to capture and display some critical information in real time. A few enterprising engineers from NASA, Rockwell, and GE cobbled together the quick-look data station (QLDS) from surplussed hardware. The QLDS was a room with wall-to-wall high-speed data recorders, located on the second floor of the MSOB, the floor below the ACE rooms.

OTHER KSC SPACECRAFT SUPPORT SITES

Supporting all the assembly and checkout work in the MSOB was an array of fabrication and modification shops. Grumman technician Dick Koralewicz recalled: "A lot of technicians that worked out there never even saw the rocket. We had a place we called the mod shop that made all kinds of stuff. If they needed a bracket or something else, we had a full shop back there. We used to fabricate tubing. We had all these pressure panels, and we were constantly repairing them or making them down there. We had a hose shop where we made hoses, sent them out, got them all cleaned. We had a battery shop."

Grumman's Gilroy Chow remembers, "Bobby Myers, who we always called, 'Mod Shop Bob,' was a friendly guy who would make all the ground support test equipment. There was always somebody needing some kluge, a Rube Goldberg contraption, to try something to test something. You'd run over to the mod shop and ask Bobby, 'Can you make this?' As long as it was GSE, you didn't have a problem. If it was for flight, that was a different story. That didn't happen in the mod shop."

Two KSC sites, the hypergolic maintenance facility (HMF) and the RF systems test facility, were originally intended to play a major role in Apollo spacecraft processing. As late as October 1965, it was envisioned that much of the initial spacecraft checkout flow would occur in these buildings. After the spacecraft components arrived at the Cape's skid strip, the plan was that they would first go to the HMF for initial inspection and leak checks. Next, the modules or stages would be sent to the RF systems test facility for electrical systems tests. Then the modules would be transported to the MSOB for altitude runs and final assembly and checkout. Once the Apollo program got into full swing, management decided to centralize all spacecraft assembly and testing in the MSOB.

RF Test Facility

The RF systems test facility, located east of the MSOB in the KSC industrial area, was an unusual structure. The building was initially used to test radio frequency communications systems on the Gemini spacecraft. During Apollo, it was used for testing various devices on the spacecraft that transmitted or received RF signals.

To avoid RF interference, the building was a *timber tower*, with no metal connectors longer than 6 in. (15 cm). The spacecraft or systems being tested were turned to face the communications facilities on Cape Canaveral. KSC design engineers needed to devise a radio-transparent and weatherproof protection scheme for the sensitive components. The solution was a "baby buggy cover," fiberglass arches with canvas stretched across them. A winch could retract the cover so that a spacecraft could be placed on top of the tower. The tower and cover assembly was nearly 70 ft (21 m) tall.

Some subsystems of the Apollo spacecraft, such as the LM's landing radar system, were sent to the RF test facility for checkout after they arrived at KSC. Following this testing, the subsystems were integrated into the spacecraft at the MSOB.

Hypergolic Maintenance Facility

The hypergolic maintenance facility was located in the fluid test complex at the southeastern end of KSC's industrial area, well away from office buildings and other inhabited areas because of the dangers posed by hypergolic propellants and engines. The HMF supported testing of the hypergolic engines on the Apollo spacecraft. The HMF had two test large bays that were originally intended to hold stages or modules during initial checkout. The fluid test complex housed two hypergolic test buildings, a cryogenic test building, and a fluid test support building.

The fluid test complex was never fully utilized during Apollo. After processing the first several unmanned Apollo spacecraft, NASA determined that testing performed in the HMF was redundant; the same tests could be performed on the spacecraft at the launch pad.

The Super Guppy

NASA's B-377-SG *Super Guppy* airplane flew the modules for the Apollo spacecraft, as well as the S-IVB stage and the instrument unit of the Saturn V, from their respective manufacturing and test facilities to KSC for final assembly and test (Figs. 4.17 and 4.18).

The *Super Guppy* was specially built for NASA in 1965 by modifying the fuselage of a C-97J Turbo Stratocruiser, the military version of Boeing's 377 Stratocruiser. Its predecessor was the somewhat smaller *Pregnant Guppy* (also based on the Boeing 377), which carried Titan II missile stages from Baltimore to CCAFS for the Gemini program. Aero Spacelines, Inc., built and operated the *Guppy* aircraft for NASA. Because of its lengthened fuselage and increased diameter, modified wings and tail, and more powerful turboprop engines, the *Super Guppy* was able to carry larger and heavier loads than the *Pregnant Guppy*. The front end of the plane's fuselage was hinged along one side. The entire forward end of the plane swung open fully, enabling cargo to be inserted directly into the cargo hold without passing through a door.

The plane required a very long takeoff roll when fully loaded with cargo. Workers at Bethpage said that they held their breath every time the *Super Guppy* took off from the relatively short Grumman airstrip with a LM on board. The plane's weight was so critical

4.17 Aero Spacelines B-377-SG *Super Guppy*. *Source*: NASA/Ward

4.18 The *Apollo 9* command and service modules arrive at Cape Canaveral on the *Super Guppy. Source*: NASA/Jerome Bascom-Pipp

that the *Super Guppy* had to take off from Bethpage with only enough fuel to reach an airfield in New Jersey, where it would then be fully fueled for the flight to CCAFS. Andrew Nawracki of Grumman recalled, "The whole ground would shake when the Guppy powered up. It would just barely clear the fence at the end of the runway. I wouldn't want to have had a home at the South Oyster Bay Road end of the runway, because that plane just barely cleared some of the TV antennas!"

The *Super Guppy* landed with its cargo at the *skid strip* landing field on Cape Canaveral Air Force Station.[1] The spacecraft modules were offloaded onto a cargo trailer and towed across the Causeway to the MSOB. The S-IVB and IU went from the skid strip to the VAB.

Air cargo carrier technology changed by the end of the Apollo era. The command and service modules for the Apollo-Soyuz Test Project were shipped to KSC aboard a Lockheed C-5A *Galaxy*, which at the time was the USAF's newest cargo carrier airplane.

THE DANGEROUS WORLD OF SPACECRAFT TESTING

Spacecraft test and checkout included not only working on the Apollo spacecraft itself, but also testing the spacecraft's subsystems. These tests could be particularly hazardous when they involved propulsion systems, which was why the HMF was in a remote location.

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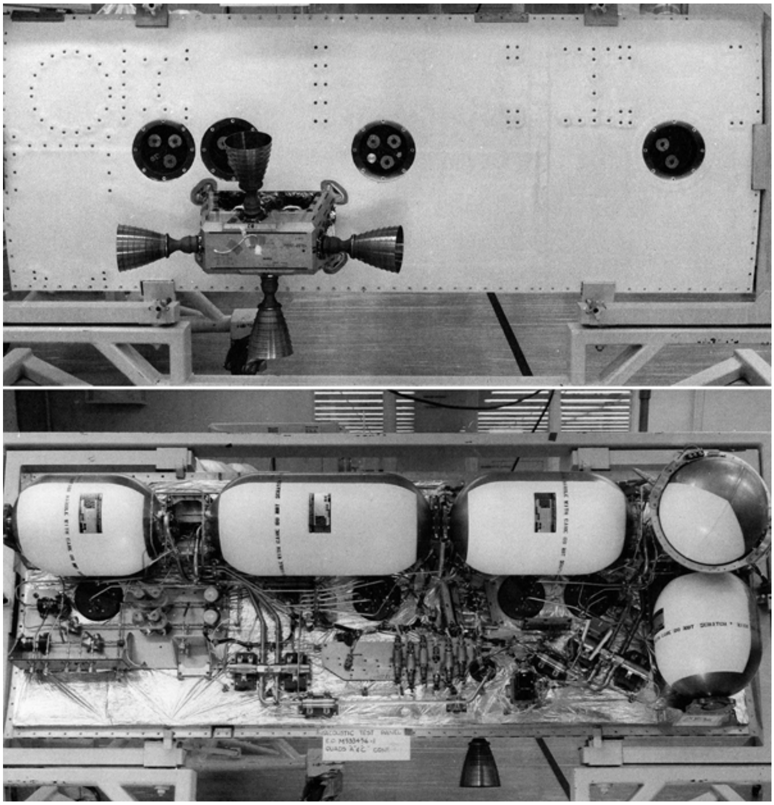
1 The CCAFS airstrip was called the Skid Strip, because it was the landing place for SM-62 *Snark* cruise missiles tests. The *Snark* lacked wheeled landing gear, so it was supposed to skid to a halt on the runway at the conclusion of test flights.

4.19 Early SM RCS quad testing in a KSC warehouse before HMF completion, 1965. From *left*: Bill Hopkins, Seymour Siegel, Hank Miller, John Tribe, and Jim Gleaves (Courtesy of John Tribe). *Source*: Tribe

The first CSM flight hardware was due to be delivered to KSC in October 1965. While awaiting delivery of the CSM, North American decided to send a service module quad (set of four reaction control system engines) and a set of CM RCS engines to KSC for testing that summer. This would enable the team to test the checkout facilities, equipment, and procedures, so that all would be ready once the production spacecraft arrived. The HMF had not yet been completed, and North American set up a test area in the corner of a warehouse behind the MSOB (Figs. 4.19 and 4.20).

Initial checkout of the test equipment revealed problems almost immediately. These included overly complicated quick-disconnect fittings, a gauge that read in 8-psi (55 kPa) increments instead of the customary multiples of 5-psi, and output regulators that did not permit smooth application of pressure. Test equipment was re-designed and replaced, and then it was time to test some of the spacecraft components. The necessity of paying close attention to requirements and procedures quickly became evident. John Tribe was working on the test team for North American. He recalled:

> *One of our limitations was not to open the high-pressure helium isolation valves to lock up the regulators unless the helium tank pressure was less than 300 psi (2.1 MPa). If we had high pressure in the tank, we had to back-flow the regulators to preclude shocking the relief valve burst discs that protected the tank from overpressure. Our NASA engineer, Joe Battaglia, didn't see the necessity of "wasting time" with the back pressurization work, and he directed that the valves be opened.*



4.20 Service module RCS quad panel exterior (*top*) and interior. From *left*, the white tanks are the secondary and primary oxidizer tank, primary fuel tank, helium tank, and the secondary fuel tank (below the helium tank). Each service module had four of these quad panels (Courtesy of John Tribe). *Source*: Tribe

The simultaneous bang of the two relief valve burst discs rupturing emphasized to all concerned that we had better pay attention to the specified requirements. If we had blown those discs on real flight hardware, it would have required new relief valves to be brazed in as replacements – a significant task.

We progressed through the quad checkout in our temporary facilities until we were told we could move to the HMF. There we struggled to get the new facility and its ground support equipment activated. Meanwhile, our resident Downey engineer, Glen Torrey, checked out our test console, which was newly modified to incorporate the table lash-up that we used in the warehouse. As he nervously tweaked the regulator up to crack the internal relief valve, he was a prime candidate for a prank. Someone dropped a metal trash can lid behind him onto the metal cell floor grating. A noise like that, when you're expecting the sudden bang of a relief valve, was not good for one's state of health.

The test team now moved on to test-firing the engines the RCS quad. The team loaded the propellant tanks with hypergolics and carefully brought the helium tank to flight pressure. Tribe continued:

> *Now it was time to count down to the single thruster firing. The ACE room in the MSOB was manned and, for the first time, a* C-START *pre-programmed control sequence would be entered into the ACE system to fire the thruster for the predetermined 2 seconds. The test was conducted from the local control room at the HMF, and the ACE room was directed to send the signal to open the helium isolation valves. Nothing happened. The signal was sent and acknowledged, but no valve function occurred. The valves were stuck closed due to their higher delta pressure. Joe Battaglia stormed out of the control room and was next seen down in the test cell, armed with a mallet. There, with a few well-directed taps, he persuaded the sticky valves to open. They weren't going to argue with him while he was in that mood.*
>
> *Back upstairs, we picked up the count and proceeded down to T-0. The thruster went bang; a quick flash of fire, a little residual vapor from the oxidizer propellant, and it was all over. What an anti-climax after such a long and painful period of preparation!*
>
> *That evening, as the last of the engineers was leaving the cell, he noticed a puddle of residual fluid in the up-firing thruster. It smelled suspiciously like monomethylhydrazine. We couldn't leave what appeared to be a leaking thruster valve in that condition. We needed to isolate the manifold and blow out the residual fuel. Although the ACE station was shut down by now, one of the NASA ACE engineers said he could actuate the thruster valve from an ACE carry-on unit. Armed with specific instructions as to which thruster and which valve, he set up the suitcase. When all was set he sent the command as we waited anxiously peering in the cell door. WHOOSH! A big red cloud flashed from the down-firing thruster. Wrong thruster; wrong valve. We rapidly decided to call it quits for the night.*

It was now time to try out the procedure with the CM test article in the building's next cell. This involved firing all six thrusters for a longer, 20-s burn. Tribe continued:

> *Again using the C-START in the ACE station, we counted down to zero, and the first thruster burst into life. Instead of the almost negligible flame that we saw from the quad thruster (a Marquardt engine), the CM thruster (an ablative Rocketdyne model) sent out a long shaft of fire that grew even longer as the 20-second firing continued. It looked like a blowtorch, and pieces of the ablated thrust chamber added to the pyrotechnics. As the program worked through the six thrusters, we realized that twenty seconds was probably too long, especially since each thruster fired in a different direction (roll, yaw, and pitch; clockwise and counterclockwise), and some of these flames were pointed right at the facility cabling.*
>
> *At the behest of the control room, the engineer in the ACE station was hastily attempting to safely terminate the firing sequence. By the time he'd figured it out, the cell was a mass of smoke from charred cables. We were concerned that there might be major damage to our new facility.*
>
> *Luckily, the damage was slight, and we moved on to prepare the cells for the imminent delivery of spacecraft 009 hardware. We had all cut our teeth on some real and – thankfully – forgiving flight-type hardware before we started on the real thing.*

Another test at the HMF in December 1969 was aimed at automating the very long and arduous manual process for loading the ten helium tanks that pressurized the CSM's propellant systems. The original process was so tedious because as helium was loaded into the relatively small tanks, compression of the gas caused it to heat, which violated the specified upper limit for the tank's temperature. The operator had to wait for the tank to cool down before he could load more gas, which again heated the tank. The process had to be repeated until the tank was at the required temperature and pressure.

Rockwell engineer Larry Whitacre managed this complex process from the ACE room for the previous Apollo launches. He had to select each of the six loading valves manually with an R-START, a pushbutton switch group of four valves per module, and a function command for each of the four selections. While Whitacre was an acknowledged expert in the process, one tank or another would invariably spike over the temperature limit. Violating the specification required generating a waiver to the OMRSD requirements document, which required justification and approval at upper management levels every time the limit was violated. Everyone saw the need to resolve the helium loading issue permanently.

NASA's Warren Lackie worked with Whitacre to develop a flowchart that reduced the manual process to a series of action steps based on valve positions, temperatures, pressures, and times. The ACE computer was sufficiently fast to run the six systems at once and stay within limits. GE used the ADAP routine to code the flow chart into a test program. All looked good, but the process could not be simulated; it had to be tested during actual flight servicing.

NASA and Rockwell assembled the required test equipment and a set of orifices in the ground support equipment that would restrict the helium flow. Tribe described the test setup (Fig. 4.21):

> *Lackie led a test team with support of Glen Torrey and RCS lead engineer Marty Cioffoletti in a test in a small lab room in the HMF. The test equipment consisted of an assortment of small pressure vessels, including a spare CM RCS tank and a similarly sized fiberglass tank with a bladder inside. Les Beecher, a Bendix support technician, provided the second tank. He was supposed to have hydrostatically pressure-checked the tank prior to its use. Beecher also proved a louvered steel "coffin," left over from the Gemini program, which would act as a safety enclosure for the tanks during the test.*
>
> *On December 19, 1969, the team started manually loading the tanks in the coffin. The team intended to pressurize the tanks to 4,500 psi (31 MPa) to verify that the orifices in the supply line would control the rate of pressurization to stay within the temperature limits. When the system reached a pressure of 4,410 psi (30 MPa), the team was startled by high-pitched pinging noises coming from the coffin. Ciofoletti immediately realized that a rupture was imminent, and he made a mad dash for the door. He did not make it. The old Fiberglas tank failed with a deafening explosion that reduced it to millions of particles. These escaped the coffin through the louvers and filled the room with an iridescent snowstorm. The overpressure from the explosion sheared the interior concrete block wall in the room, blew out the window, and tore apart the ceiling panels. Even the liquid nitrogen tank outside the building was*

4.21 Rockwell CSM propulsion group engineers, 1971 (Courtesy of John Tribe). *Source*: Tribe

moved several feet. A technician who rushed into the room fell over Torrey, who was on his hands and knees.

The personnel were in shock, covered in sparkling particles, ears ringing, eyes stinging, and beginning to appreciate that they were lucky to be alive. They were rushed to the KSC dispensary to be checked out. Even though their eardrums were not ruptured, all of the men suffered permanent hearing damage. Torrey said that since the event, he always had a hard time hearing higher frequencies, especially women's voices. (He said that could be a good thing or a bad thing, depending on the circumstances.)

The results of the test were:

- *Three partially deaf engineers who never again volunteered to perform any special pressurization tests*.
- *Les Beecher of Bendix was fired*.
- *The orifices did their job*, *and combined with Larry Whitacre*'*s software*, *allowed a much more controlled helium loading procedure to be used starting with* Apollo 13 *in April 1970. This was the first automatic loading of a fluid or gas on an Apollo spacecraft*, *although it came at a price*.

These are just two examples of the kinds of work that went on behind the scenes in spacecraft operations. Later in this book, we will learn more about the hazards of working with hypergolic propellants in the close confines of the launch pad. Readers interested in more detail about spacecraft test operations will find them in the author's companion volume to this book, noted in the References section.

5

The VAB and the Mobile Launcher

We now shift gears from the world of spacecraft operations, and travel 5 miles north to enter Launch Complex 39 and the world of launch vehicle operations. During the course of the next three chapters, we will take a tour of the assembly facilities for the Saturn V, examine the Launch Control Center, and prepare to move out to the launch pads (Figs. 5.1 and 5.2).

THE VEHICLE ASSEMBLY BUILDING

The launch vehicle spent most of its time at KSC in the Vehicle Assembly Building (VAB, pronounced "vee-ay-bee"). The VAB was the cornerstone of Kurt Debus' concept for a facility that would enable processing of multiple missions at the same time, facilitating the rapid turnaround in launch operations needed to ensure a Moon landing by 1970. The VAB provided a weatherproof area for assembling and testing launch vehicles. The VAB also provided a safe haven to which rockets could be returned from the pad if a hurricane threatened the Cape.

The VAB was originally called the "Vertical Assembly Building," and it was referred to as such in early Apollo/Saturn plans and documents. The building's name was officially changed to the "Vehicle Assembly Building" on February 3, 1965, to reflect its role in both current and future programs. Some people took a while to adjust to the name change, but at least the acronym remained the same.

The VAB is located adjacent to the turning basin, a widened extension of a canal leading to the Banana River. Barges carrying rocket stages and other large equipment were towed through the Banana River and then down the canal into the turning basin. There, they unloaded their cargo for the short ride by trailer across the road and parking lot to the VAB (Figs. 5.3 and 5.4).

The VAB has two main sections, the low bay area and the high bay area. The adjoining sections are bisected by a 92-ft (28 m) wide transfer aisle, which runs the length of the building. The low bay, at the south end of the building, is where the launch vehicle stages entered the VAB. There were eight checkout cells in the low bay, four on each side of the aisle, where the S-II and S-IVB stages were removed from their transport trailers, rotated vertically, and checked out. Four of the checkout cells had systems to simulate the

J.H. Ward, *Rocket Ranch*, Springer Praxis Books, DOI 10.1007/978-3-319-17789-2_5

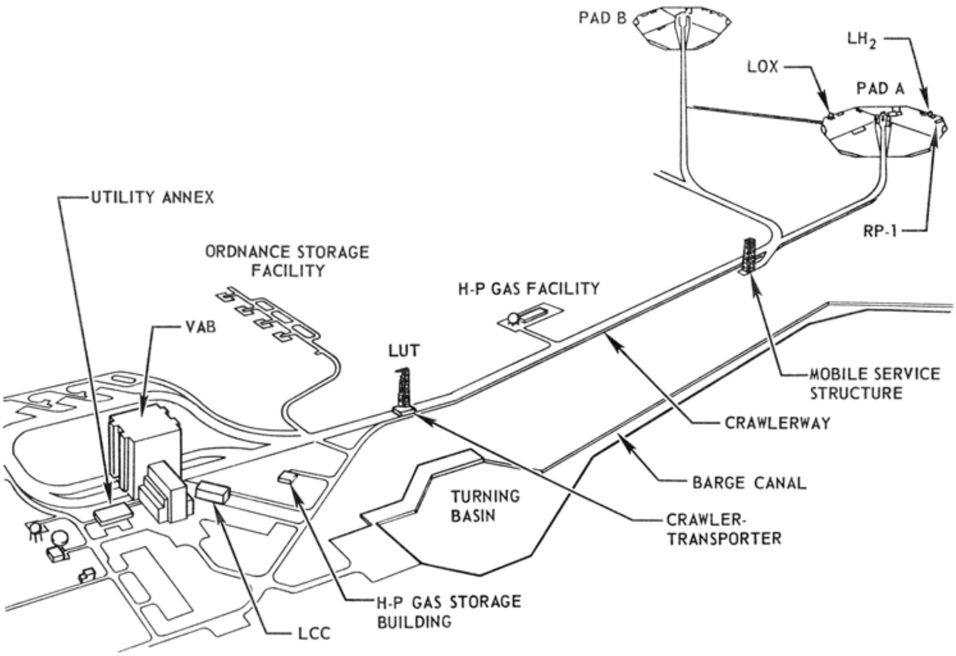
5.1 Launch Complex 39 in the spring of 1973. In the distance, the Skylab orbital workshop sits on pad A (right); the *Skylab 2* space vehicle and the mobile service structure are on pad B. *Source*: NASA

interactions between stages and the Saturn's instrument unit. The low bay cells were occasionally used to store stages that were not being processed (Fig. 5.5).

The north section of the building contained four high bays, two on each side of the transfer aisle. Each of the high bays could accommodate a Saturn V stacked on top of a mobile launcher. Initial designs for the VAB included provisions for six high bays. As it was, only three of the four high bays were activated for Apollo/Saturn.

High bays 1 and 3, whose outer doors faced the launch pads, were the ones most frequently used in Apollo/Saturn missions. High bay 2 was used for stacking *Apollo 10* and the Skylab Orbital Workshop; *Apollo 13*'s launch vehicle was also stacked here, and then rolled around to high bay 1 for final processing after *Apollo 11*'s mission. High bay 4 was used for storage or ad hoc projects (Fig. 5.6).

Superlatives cannot adequately describe the VAB. Words and photographs simply fail to convey the feeling of being inside the building. At the time of its construction, the VAB was one of the largest buildings in the world by volume. The VAB roof was the highest point above sea level in Florida for several decades. American movie cowboy Roy Rogers toured the VAB in the late 1960s, and was said to have remarked, "This sure would hold a lot of hay, wouldn't it!" Without a frame of reference, it is difficult for someone to get a



5.2 Overview of Launch Complex 39 facilities during the Apollo era. *Source*: NASA/Ward

feel for just how big the space inside the VAB really is. Each one of the four high bays could hold the Statue of Liberty, complete with its pedestal (Fig. 5.7).

The VAB was and is a no-nonsense, industrial facility. Upon checking in through security, one enters a cavernous space with lattices of girders and crossbeams extending from the concrete floor to a ceiling that is so high up it is difficult to discern. Visitors inevitably gasp when they enter the building.

The VAB is too voluminous to be air-conditioned. Air-handling equipment recirculates the building's air about once an hour. Some of the high bay doors are left partially opened to improve airflow within the building. This ventilation strategy comes at a peculiar cost, however. Turkey vultures make a nuisance of themselves by flying into the VAB, roosting high in the ceiling, and chewing on cables. NASA installed netting over the high bay doorways to thwart the vultures, who soon learned that they could perch on the doors and sidle around the netting to get into the building. NASA occasionally has to bring in rangers from the nearby wildlife refuge to trap the vultures. Caged vultures are taken down via elevator. John Tribe noted that while the vultures are relatively calm in cages, they do not react well to elevators, exhibiting a tendency to projectile vomit.

The elevators can be troubling enough to humans, even when one knows what to expect. The elevators ascend and descend at 600 ft per minute (3 m/s), fast enough that one's ears pop several times in the 20 s that it takes to move between the 16th and 34th floors. A glass-walled elevator in each tower afforded spectacular views of a Saturn V stack in the high bay.

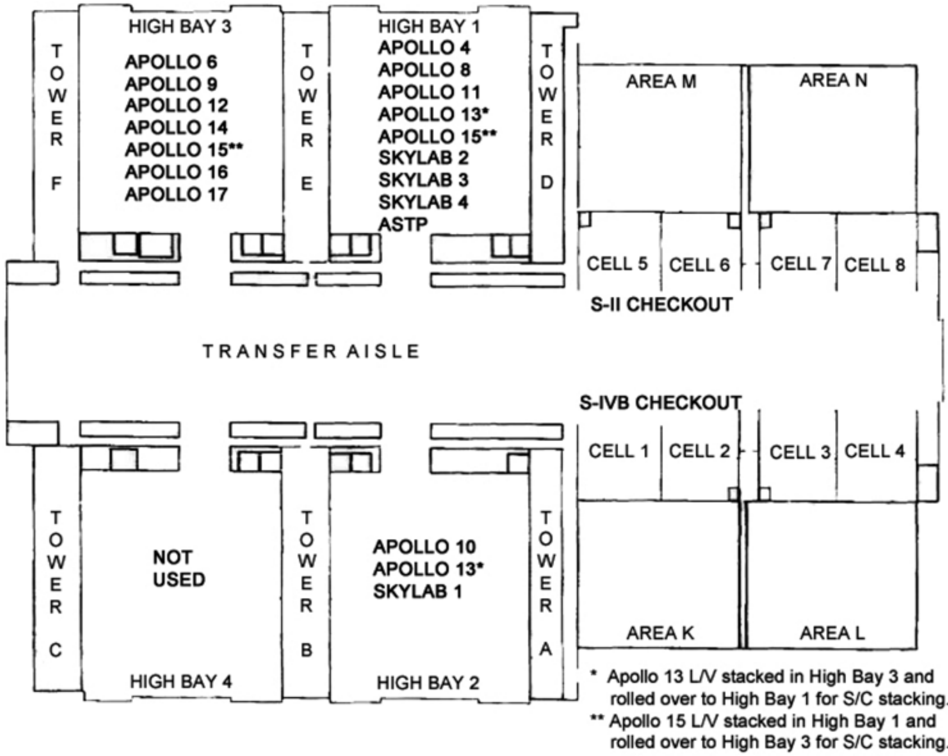
5.3 The Vehicle Assembly Building and Launch Control Center during the rollout of the AS-500F facilities integration vehicle rollout. Two launcher/umbilical towers are under construction to the north of the VAB. *Source*: NASA

The ceilings are high enough that clouds can form in the high bays if conditions are right. While long-time legend holds that it can rain inside the VAB, a full-fledged rain shower probably never happened. However, Fred Cordia remembers feeling raindrops when inside the building during his years on the Apollo program.

Office towers adjoined the high bays and the low bays. Most of the contractors who worked on the stages of the Saturn V had offices in the VAB, as did many NASA technicians, engineers, and managers. Offices for contractors were located adjacent to the areas where their stages were being processed. JoAnn Morgan's information systems work group moved into the VAB before construction was complete; the elevators only ran as high as 16th floor at the time. She recalls: "I had to walk all the way up to the top! There's a penthouse up there [on the 34th level]. Man, did I have skinny legs back then! You had to take your equipment with you and your procedures. Everything was stacks of paper."

Fred Cordia's office was on the 16th floor. He recalls:

There was a catwalk at the 16th floor level and there was another one at the 34th level, at the spacecraft level. Other than that, there was just ironwork up there. Walking across the 16th floor level was a thrill, initially, because you could look straight down.



5.4 Floor plan of VAB, showing where Saturn V stages and Apollo/Saturn missions were processed. *Source*: Author's adaptation of NASA diagram

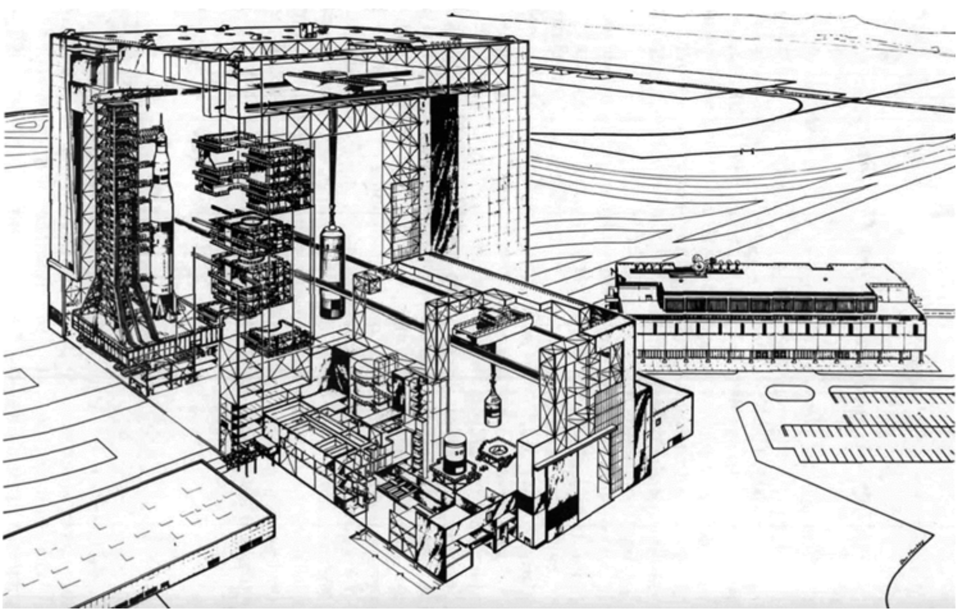
You eventually got used to that. I always would walk in the middle of the catwalk. I didn't want to be any place where I could look straight down. The walkways across the high bay were enclosed in lattice metalwork, so you couldn't lean over the edge and fall; it would contain you. But going across that one on the 34th level…boy, you really had to want to do that in order to make yourself do it.

The VAB was not a female-friendly place to work. IBM's Lori Fore recalled that the company's dress code at the time required women to wear fashionable skirts or dresses, which had very short hems in the 1960s. It was not uncommon for men to hang out underneath catwalks or stairwells and ogle the women walking overhead (Fig. 5.8).[1]

---

[1] Few, if any, workplace conduct rules governed sexual harassment and hostile work environments in the 1960s. This was especially true in the "man's world" of the launch pad. Liaisons between coworkers or between bosses and subordinates were not uncommon. Couples sought out-of-the-way areas, thinking they could not be seen. Unknown to them, some of the spots were covered by the operational TV system, and their trysts were observed on closed-circuit TV. One woman earned the nickname "Periscope Thelma" [name changed to protect her identity] because her romantic encounters in the LC-34 parking area were observed via the periscopes in the blockhouse.

5.5 AS-208 (*Skylab 4*) stages in storage in checkout cells 3 and 4 in the Low Bay of the VAB, November 15, 1971. *Source*: NASA/Jerome Bascom-Pipp



5.6 Early NASA cutaway diagram of the VAB. Ironically, high bay 4 (*upper left*) was the only one not used during the Apollo/Saturn era. *Source*: NASA/Ward

5.7 Space vehicle test supervisor Don Phillips escorts actor Gregory Peck and his wife Veronique on a tour of the VAB, March 7, 1969. Peck is wearing a "Marooned" badge; the movie was being filmed in the KSC area at the time. *Source*: NASA/Ward

5.8 Frank Penovich's office in the VAB, showing furniture that any civil servant from the 1960s would recognize (Courtesy of Frank Penovich). *Source*: Penovich

The VAB interior was very noisy. Cordia said that during thunderstorms, "it was like sitting inside a bass drum." Frank Penovich had to contend with other sounds in his office: "My office was on the third floor of Tower D, which is the southeast tower of the VAB. My desk was about 10 ft below the 0 level of the LUT [launcher/umbilical tower].

5.9 A sense of scale of the VAB: 5,500 workers from KSC, and the marching band from Satellite High School, are seated in the transfer aisle in the VAB. This was a welcoming ceremony for the crew of *Apollo 17*, February 20, 1973. *Source*: NASA/Ward

Every once in a while, a God-awful loud noise would occur. I could envision something very big falling off the LUT tower, crashing, rolling off the deck of the LUT, coming through the wall, and landing right on me or my desk. More than once, I flat took off running for the door. I am not a nervous person, but some of those noises were really loud."

At the height of the Apollo program, nearly 3,000 people worked inside the VAB, although Bob Sieck noted that the VAB was the administrative home to about 10,000 people. Traffic jams at the start and end of the workday were horrendous (Fig. 5.9).

The VAB roof affords spectacular views of the launch pads of LC-39 to the east and the Cape to the south. On a clear day, one can see the city of Orlando, about 45 miles (72 km) to the west. At the end of the space shuttle program, contractor employees who were being laid off were asked what one place on KSC they would most like to see before they left. The overwhelming choice was the VAB roof. Flying paper airplanes off the VAB roof has been a popular (but not officially sanctioned) activity since the building opened. On a day with good thermals, it can take more than 30 min for a paper airplane thrown from the roof to hit the ground.

KSC held a celebration when the final beam was about to be installed on the VAB roof. Workers at KSC were invited to sign their names on the beam. It is still visible to savvy visitors who have access to the upper reaches of the VAB and know where to look (Fig. 5.10).

5.10 KSC director Dr. Kurt Debus signs the last beam to be installed in the VAB. Gerald Autry (Boeing-TIE) notes that his own signature is at the top of the beam just above where Debus is signing. *Source*: NASA

Cranes

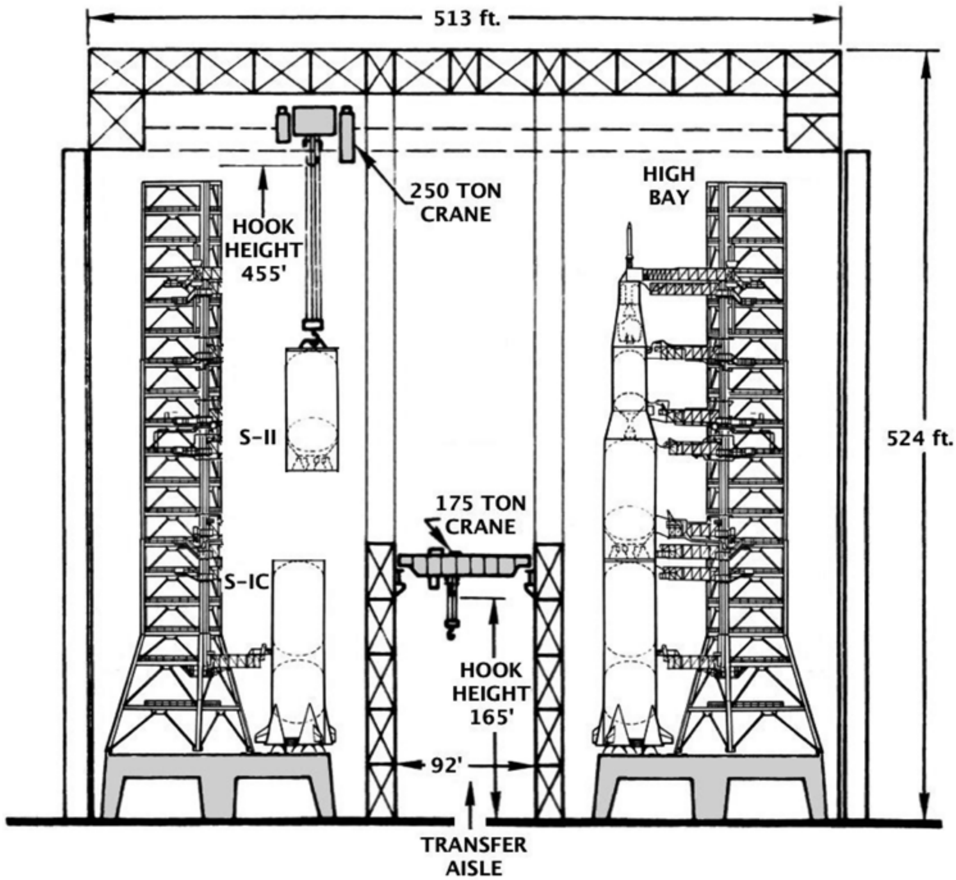
There were 141 lifting devices of various sorts in the VAB during the Apollo years. The smallest were 1-ton mechanical hoists. Three large cranes were the workhorses of the VAB. A 175-ton (159 t) Colby crane ran the length of the VAB north and south along the transfer aisle. It had a hook height of 165 ft (50 m). Two 250-ton (227 t) Colby bridge cranes ran east-west across the transfer aisle between high bays, one between high bays 1 and 2, and the other between high bays 3 and 4. The cranes had a hook height of about 455 ft (138 m). They lifted the various stages of the launch vehicle from the VAB floor and hoisted them into position onto the launch vehicle stack (Figs. 5.11 and 5.12).

Ed Fannin said that the operators helped design the crane requirements based on their first-hand experience in stacking rockets: "One of our handling guys, Henry Crunk, had been through it all, from Redstone, to Mercury/Redstone, to Jupiters, to Saturns. When it came to requirements for the 250-ton crane in the VAB, he told the designers, 'I want to be able to touch an egg without breaking it.'"

Crunk's requirement actually became part of the certification process for the Bendix crane operators, as described by Russell Lloyd (Fig. 5.13):

Even though they were 1960s vintage, those 250-ton cranes were some of the best cranes I've ever come across, because the guys on the controls could what we call "float" the load. They knew exactly how much control stick to put in that they could actually release the brake on the crane and the load would just stay there.

One of the demonstration tests we did for crane operators was to put an egg on the VAB floor. We had a test ballast tank, and we would fill it with water, up to 250 tons. Then the operator would have to take that test weight tank over the top of an egg and set it down with enough pressure so that you couldn't pull the egg out,



5.11 Cross-section of the VAB showing cranes servicing the transfer aisle and the high bays during stacking operations. *Source*: Author's adaptation of NASA diagram

but he couldn't crack the shell, either. That's the precision that you had on that. We'd set a can of spray paint on the ground, and he'd bring the ballast down and operate the nozzle of the spray paint can. That was part of our proficiency demonstration for our crane operators.

During the Shuttle program, they went to heavier solid rocket boosters. They decided the 250-ton cranes were not adequate, so they purchased two 325-ton cranes. Of course, their controls are more modern. If you wanted to go up or down one-thousandth of an inch per second, you can dial that in. And it'll just move almost imperceptibly, visually. But in Apollo, it was all operator skill.

To give the reader a sense of scale, a 250-ton crane can lift approximately 30 full-grown African elephants at once.

Lloyd noted that one of the instances of artistic license in the movie *Apollo 13* was in the scene showing the stacking of a stage in the VAB. The stage came down, and there was

5.12 Author's photo from November 2011 showing the relationship of the transfer aisle crane (right) and a high bay crane. The "diaphragm" (opening) into high bay 3 is clearly visible. To provide a sense of scale, the low end of the diaphragm is 165 ft (50 m) above where the author was standing on the VAB floor. *Source*: Ward

a loud *clang* as it came to rest on the stage below it. "No clang," said Lloyd. The stacking operation was much more delicate (Fig. 5.14).

Crane operators rode in cabs that hung just under the crane, allowing them to look all the way down to the floor. To reach the cab, an operator rode an elevator to the 16th floor, took another elevator to the upper reaches of the VAB, and then walked across a gangway just below the ceiling. Lloyd said that it was "an interesting view from up there."

5.13 The water-filled ballast tank was still in use for VAB crane operator training as of August 2013. *Source*: Ward

Work Platforms

Each active high bay had a set of work platforms mounted on rails protruding from opposing walls. After a stage was stacked on the mobile launcher in the high bay, the work platforms for that stage were extended into position and mated together around the launch vehicle. The platforms could extend or retract in 10 min (Fig. 5.15).

The work platforms afforded access to the inter-tank and interstage areas of the launch vehicle while it was in the VAB. This facilitated checking of connections between stages and integrated testing of the launch vehicle.

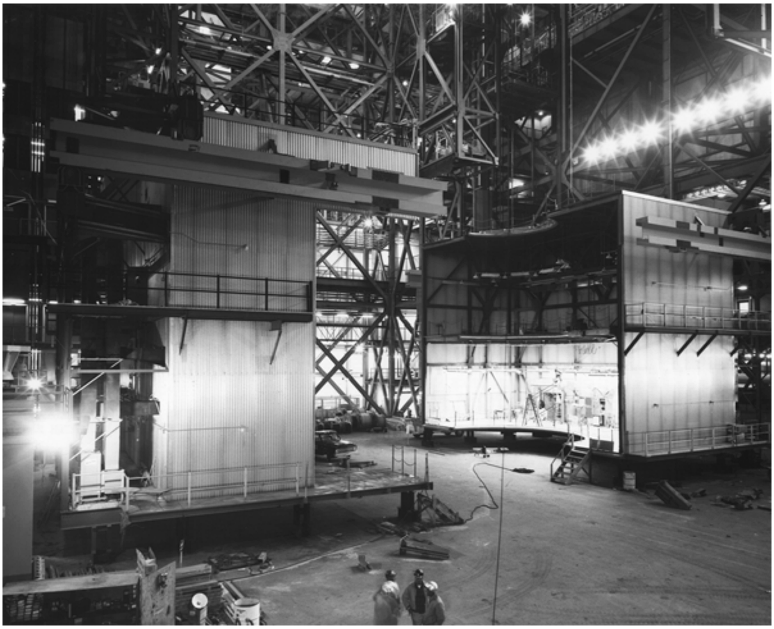
5.14 View from a high bay crane cab looking down into the transfer aisle, February 13, 1968.
Source: NASA/Jerome Bascom-Pipp

Circular yellow rubber bumpers with black "zebra stripes" lined the edges of the cutout that surrounded the launch vehicle. The yellow circles were warnings. Ernie Reyes said: "You were not to get any closer than that yellow line to the flight hardware unless you had an authorized piece of paperwork to do something official. If not, you keep the hell away from that vehicle. No signing your name, dropping your pencil, dropping your tool."

Fred Cordia noted that even though tools had to be tethered when working on the vehicle once it was stacked, there was a very real risk to the vehicle and to people below if objects were dropped from the upper levels. Tethering tools definitely slowed work down, but the added safety more than made up for any inconvenience.

Activating the VAB

In 1965 through 1967, launch operations for the unmanned Saturn IB missions were underway at Launch Complexes 34 and 37 on the Cape. At the same time, NASA and the launch vehicle contractors were preparing the VAB to support processing of the new Saturn V. Activating the checkout facilities in the low bay took nearly 1 year. The activation



5.15 High bay work platforms under construction on the VAB floor. Tracks along the upper sides of the platforms helped roll the platforms into place around the vehicle. *Source*: NASA/Ward

process entailed not only getting the facilities ready, but also thinking through the test processes, designing checkout equipment, writing procedures, and training and certifying the engineers and technicians in the work they would perform once the launch vehicle stages began arriving.

Rich Robitaille recalls:

Everybody had their own control panels in low bay and their own area for checking out their particular stage. The first part of my job was, before the first one of our stages even got there, how do you want your panel to look in front of you? What makes sense? What kind of switches do you want? What kind of meters do you think you'll need? And you worked with people that designed the panels, and they put the panels together.

I started helping put the panels together. Whether you were electrical or mechanical, you more or less did the activation of the low bay control center by writing some procedures simulating that you've got a stage out there. In the low bay, there was no computer – it was all done with wires. Before the stage arrived, you would take a simulator, or you would have a little box that would send signals to the wiring, and it was all wired in the low bay. The hydraulics people had to monitor the pressure of the hydraulic system, so they had kind of a unit that would simulate the stage, and then it would fire back, and the meters would come on. Check all the meters, check all the switches…you would turn this switch on to open up a valve, and the simulator would say, "yes, the valve is open," and it would send back the pressure.

During activation, you wrote procedures for that process. It got you used to writing procedures, because guys like me never wrote a procedure in our lives before this. You learn how to read schematics and how to write procedures, and you're starting to get set up.

I worked 50 to 60 hours a week in activation. I was running back and forth from the Launch Control Center and into the mobile launcher when we had problems with wiring. A connector was disconnected, just little things like that. We spent almost a year just in activation.

THE LAUNCHER/UMBILICAL TOWER

Another innovation in the world of Apollo and Saturn was the mobile launcher (ML) with its attached umbilical tower. The mobile launcher's base was a mammoth, steel plate-over-girder, box-like structure that covered nearly half an acre (0.2 ha). It was 160 ft (49 m) long, 135 ft (41 m) wide, and 25 ft (8 m) deep. The mobile launcher's most prominent feature was the 380 ft (116 m) umbilical tower, described below, which was mounted on and rose from the north end of the launcher deck. The launcher and tower were collectively called the launcher/umbilical tower (LUT, pronounced "lutt") and weighed 10.6 million pounds (4.8 million kg) (Fig. 5.16).

The mobile launcher and launch umbilical tower were technically two different parts of the structure, the launch umbilical tower being attached to the north end of the mobile launcher deck. However, in the vast majority of interviews with workers from KSC for this book, the terms launcher and LUT were used interchangeably to refer to the overall structure. Further adding to the confusion, the abbreviation ML was used in some documents and badges, and LUT in others, to refer to the overall structure. The launchers were repurposed for the Space Shuttle program; the umbilical towers were removed, and the launchers were re-designated *mobile launch platforms* (MLPs).

Rockets were typically assembled one of two ways in other launch vehicle programs. One method was to assemble the rocket stages horizontally in a building, cart the rocket on a trailer out the launch pad, and then raise it into vertical position at the pad. This is similar to the technique used to assemble missiles such as the Atlas and Titan II. The other approach was to stack the rocket vertically, directly on the launch pad. This technique was used for Saturn launches at LC-34 and LC-37 at the Cape, including *Apollo 1* and *Apollo 7*.

LC-39 operations employed a novel approach. The vehicle was erected vertically on the ML inside the VAB, and the vehicle and launch platform were then carried out to and mated to the launch pad. Establishing and debugging the connections between the umbilical tower and the vehicle inside the VAB significantly reduced the amount of time the vehicle was exposed to the elements at the launch pad. Removing one LUT from the pad immediately after a launch, and then moving another vehicle and its LUT onto the same pad, enabled a rapid turnaround between launches. This approach also minimized the risk that an explosion at a launch pad would impact the launch schedule. With two identical launch pads available, the LUT and vehicle for the next mission could be set up on one pad while the other pad was being repaired.

For the Apollo/Saturn program at LC-39, NASA built three LUTs and two launch pads. This facilitated the complex choreography of processing three missions at a time during

5.16 The crawler begins to climb the ramp to pad A with LUT 1 and the *Apollo 11* space vehicle. *Source*: NASA/Kipp Teague

the critical period of late 1968 through mid-1969, when rapid turnaround was needed to give the best odds of landing on the Moon by 1970. Here is an example of the elaborate moves performed in late 1968 and 1969 (Fig. 5.17):

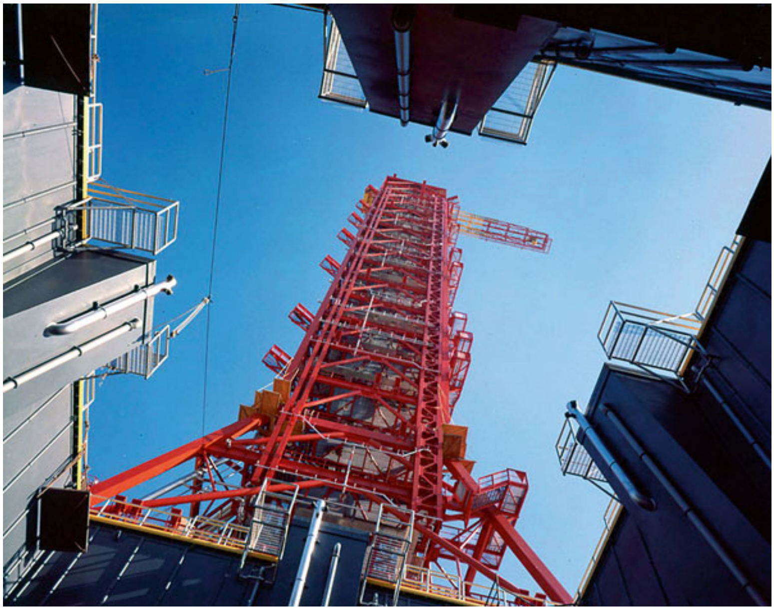
- December 1968—*Apollo 8* launches from LUT 1, which is on pad A. *Apollo 9* is being stacked on LUT 2 in high bay 3. *Apollo 10* is being stacked on LUT 3 in high bay 2.

5.17 Badge authorizing access to all three mobile launchers (Author's collection). *Source*: Ward

- January 1969—LUT 1 returns to high bay 1 to be prepared for stacking *Apollo 11*. *Apollo 9* on LUT 2 rolls out to pad A. *Apollo 10* processing continues on LUT 3 in high bay 2.
- March 1969—*Apollo 9* launches off of LUT 2 on pad A. *Apollo 10* rolls out to pad B on LUT 3. *Apollo 11* stacking is underway in high bay 1 on LUT 1. LUT 2 returns to high bay 3.
- May 1969—*Apollo 10* launches from LUT 3 on pad B. *Apollo 11* rolls out to pad A on LUT 1. *Apollo 12* stacking begins on LUT 2 in high bay 3. LUT 3 returns to high bay 2.
- July 1969—*Apollo 11* launches off of LUT 1 on pad A. *Apollo 12* stacking continues on LUT 2 in high bay 3. *Apollo 13* stacking is underway on LUT 3 in high bay 2, then the stack is rolled around into high bay 1.
- September 1969—If *Apollo 11* had not landed, *Apollo 12* would have launched from pad B for a second landing attempt.
- November 1969—If *Apollo 12* failed to land, *Apollo 13* would have launched from pad A for a third landing attempt.

Mobile Launcher

The mobile launcher was subjected to the most extreme heat and acoustic environment imaginable during a launch. The Saturn V's F-1 engines protruded into a square opening called the vehicle engine compartment (also known as the engine exhaust chamber or the flame hole), which was 45 ft (14 m) on each side and went straight through the launcher. The engines blasted the launcher with the full force of their fury from the 8.9 s between ignition and liftoff, and throughout the additional 10 s that it took the vehicle to clear the launch tower. Although much of the Saturn V's exhaust went through the engine compartment to the launch pad's flame trench (commonly known as the flame bucket) in the initial seconds after ignition and liftoff, the launcher deck still bore the brunt of the S-IC's power. Temperatures on the deck approached 3,000 °F (about 1,650 °C) during liftoff and the Saturn V's slow ascent past the umbilical tower (Fig. 5.18).



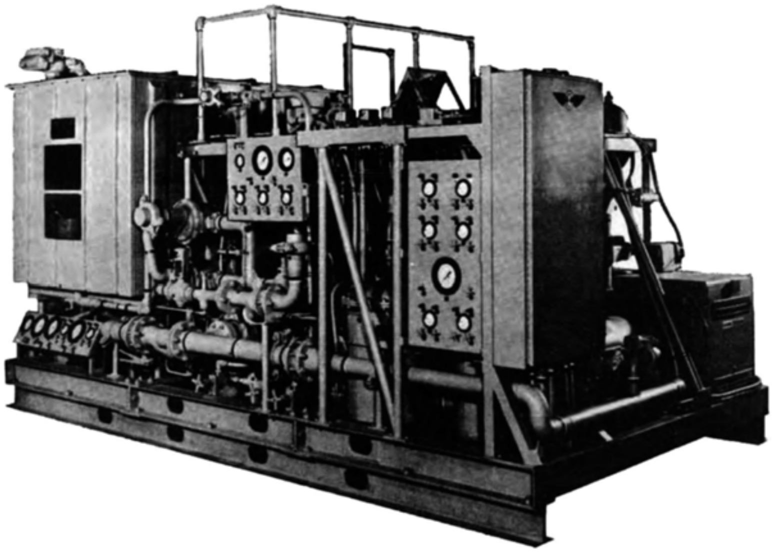
5.18 View of the umbilical tower from inside the flame compartment. The swing arms have not yet been installed on the tower. *Source*: NASA/Ward

The noise of the engines at the launcher deck was estimated at about 190 dB, or up to 2.5 million watts per square meter. To mitigate the risk of acoustic pressure damaging the Saturn V as it built up thrust on and rose from the launcher, water was flooded across the launcher deck in launches after AS-501 (*Apollo 4*).

Some of the structures on the launcher deck, such as the tail service masts and the first 10 ft (3 m) of the umbilical tower, were painted with an ablative coating. As the launch vehicle began its ascent and the heat from the engines was most intense, this coating was designed to burn off, carrying away some of the heat of the launch blast and thus protecting the tower and other structures.

The mobile launcher had three levels of launch support equipment. Level 0 (zero) was the upper deck surface. The two levels (A and B) inside the launcher were partitioned into equipment compartments. These compartments contained equipment such as the RCA 110A ground launch support computer and test sets, the propellant tanking computer system, hydraulic systems, pneumatic and propellant lines, air conditioning systems, electrical power supply, water system, and support systems for the various stages of the Saturn V. These systems controlled other launch equipment based on signals received from the Launch Control Center via computer connection or by hardline. Appendix D illustrates the layout of the mobile launcher and describes some of the equipment in the various compartments.

The interior of the mobile launcher was like a submarine or battleship. Walls were steel plate, the handrails along stairwells were steel pipe, and there were hatches at the entrances to some compartments. There were airlocks at two exterior doors, one each leading



5.19 One of the hydraulic power units, typical of the types of equipment in levels A and B inside the launcher. *Source*: NASA/Ward

into the west side of level A and B. At 16 places around the upper deck, 5 ft by 8 ft (1.5 m by 2.4 m) recessed hatches provided access to equipment in the launcher interior.

Russell Lloyd described the interior of the launcher (Fig. 5.19):

The base of the LUT was like a big ship. It had big hatches, and at the launch pad, it was actually pressurized to keep any gases from coming into the base of the LUT. Just getting into the base of the LUT was difficult. You had to go into in via a certain pathway, because there were only two airlocks to get in. There was a flapper valve; you'd equalize the pressure between the hallway and the airlock, and you closed the door behind you and another flapper valve to equalize the pressure between the compartment and the airlock. You could then enter the compartment. There were passageways all the way around the interior.

There were hatches on some rooms depending on what was in that compartment. Some of them didn't have a lot of equipment in them. Rooms like 14AB were just basically pipe chases. Other rooms were all equipment racks. One room was a big electrical power substation. Another had the hydraulic charging unit.

Room 1B was really noisy, very loud. It had the equipment that provided hydraulic pressure to the swing arms. You weren't allowed in there without hearing protection when it was in operation.

How could sensitive equipment in the launcher, like the RCA 110A computer, survive the harsh effects of a Saturn V blasting off less than 100 ft away? Part of the heat of launch was attenuated by heat shields lining the engine compartment and the girders supporting the four hold-down arms. Shock-mounted floors and spring supports under some cabinets in the compartments ensured that critical equipment experienced vibrations of less than ±0.5 g. Acoustical insulation added to electronics compartments ensured that the interior noise level did not exceed 92 dB during launch. This is about the same volume as a motorcycle at 20 ft (6 m). JoAnn Morgan said: "We had gotten so much good vibration data early on in the program with the prior missions, and we also got a lot of good data at Complex 34 and 37. That was a big help for understanding what forces were going to be exerted on the equipment. Then it was a matter of putting it in racks, figuring out how to protect that equipment, and making sure that we didn't have to replace a lot of that stuff after launches, too."

The ventilation systems kept the launcher interior slightly pressurized (by 0.1 psi or 0.75 kPa) relative to the outside environment. An air conditioning system served only those areas inside the launcher that needed to be kept cool, such as the computer room or electronics racks. "Cool" was a relative term. The computer room had to be maintained at 76 ± 2 °F (24.4 ± 1 °C) when the computer was operating. The rest of the interior of the LUT could be stiflingly hot, especially when it was sitting in the sun at the launch pad.

Umbilical Tower

The umbilical tower was an open girder structure attached to the north end of the mobile launcher. Its connections between the launch pad and the space vehicle supplied fuel, LOX, electrical power, computer control, pneumatics, communications, and other services. It also afforded access to the vehicle interior for servicing and for crew entry into the command module. Nine service arms extended from the tower to the Saturn V, carrying umbilicals that attached to connection plates at various locations on the space vehicle.

The umbilical tower had fixed platforms at regularly spaced intervals from its base. These were referred to by the height of the platform in feet above the launcher deck. For example, LUT level 240 was 240 ft (73 m) above the launcher deck. The first two levels of the tower were 30 ft (9 m) apart, and higher levels were spaced 20 ft (6 m) apart.

Stage-peculiar ground support equipment, provided by Marshall Space Flight Center or by the stage contractors, was located throughout the tower. Most levels held equipment and consoles for checking out and servicing the vehicle as well as providing local controls for some functions. Permanently installed ground support equipment such as control consoles, valving complexes, and electrical and control distributors were located at levels where service arms attached to the LUT. Closed-circuit television cameras were stationed at critical locations throughout the tower.

Above the uppermost service arm was the viscous damper system. This trapezoidal structure could be folded up flat against the side of the LUT or lowered into horizontal position and clamped to the launch escape tower on the spacecraft. The damper system restricted the degree to which the space vehicle could wobble during rollout or while sitting at the launch pad. The damper restricted horizontal movement to 4 in. (10 cm), even during high winds. On the AS-500F facilities vehicle, the damper system attached to the vehicle at the S-II/S-IVB interstage (Figs. 5.20 and 5.21).

A hammerhead crane topped off the tower. The crane was rated at 25 tons (22 t) close to the tower and 10 tons (9 t) farther from the tower. The crane could swing from side to side, and its trolley could move back and forth along the length of the crane arm. This allowed workers to raise equipment beside the LUT or the mobile service structure and then manhandle it into position at the appropriate level.

5.20 The viscous dampening system is the trapezoidal structure (arrowed) extending from the umbilical tower to the base of the launch escape system. The damper bar reduced vehicle sway during rollout and in windy conditions at the pad. *Source*: NASA/Ward

5.21 S-II/S-IVB damper system in use on AS-500F at the launch pad. The dampers are the two thinner arms at center (*arrowed*). *Source*: NASA/Ward

Two high-speed elevators ran from level 340 to level B inside the launcher. These elevators traveled at 600 ft (183 m) per minute. They could be operated from within the elevator cab, and could also be controlled remotely from the Launch Control Center in the event of an emergency.

Cabling and pipework ran up the sides of the tower. The pipework routed LH_2, LOX, hydraulic fluid, and gases from the pad to the vehicle. The cabling included electrical distribution, computer data, and communications. Much of the cabling was MI (mineral-insulated, copper-clad) to protect it from the harsh environment of the launch pad and ensure reliability during launch operations.

Swing Arms

Nine service arms extended from the launch tower to the Saturn V. They were more commonly called *swing arms* because they swung quickly back to the tower at liftoff to make way for the Saturn V as it powered past. The swing arms provided access to the vehicle from the launch tower and also carried the umbilical cables and piping from the tower to the vehicle (Fig. 5.22).

The swing arms were open latticework construction. They were huge, averaging 22 metric tons in weight, 35–45 ft (11–14 m) long, and wide enough to drive a Jeep across. Hayes International manufactured the swing arms. It was a tremendous technical challenge to design and build such massive equipment that could move out of the way rapidly and reliably, adjust its speed depending on whether there was an assisting or retarding wind blowing, not smash into the tower, stay in place after being retracted, and survive the forces of a Saturn V launch. Initial testing was done at KSC, then the arms were sent to Huntsville to work the bugs out before the swing arms came back to KSC to be installed on the LUTs.

Each swing arm was classified as either *pre-flight* or *in-flight*. Pre-flight arms retracted before ignition of the Saturn V's engines; in-flight arms disconnected when the vehicle began moving. Other than the command module access arm (arm 9), the pre-flight arms were closest to the launcher deck, these being the arms that needed to be well out of the way of the wide base of the Saturn V when it first started moving. In the event of a launch hold or recycle, the CM access arm (arm 9) and the S-IC intertank arm (arm 1) could be moved back into position and reconnected by remote control from the firing room.

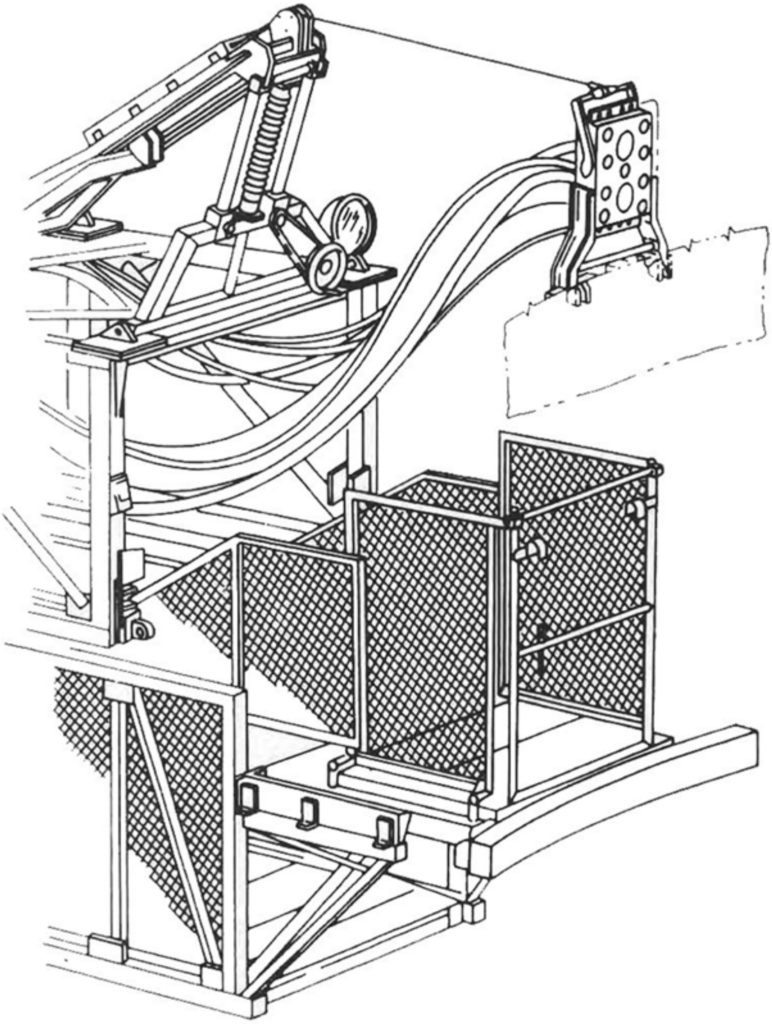
Metal grate walkways led from the umbilical tower across the swing arm to the Saturn V. Platforms could be extended on rollers from the end of some swing arms to meet hatches in the side of the Saturn V. Engineers and technicians could then walk across a swing arm and access platform to enter certain areas of the Saturn V. These included the intertank area of the S-IC, the interstage areas (for servicing the engines on the S-II and S-IVB), and the instrument unit.

Except for the command module access arm and the S-II aft arm (arm 3), each swing arm had an umbilical carrier with an array of cables and piping that terminated in an umbilical plate. The umbilical plate attached to a matching receptacle on the exterior of the space vehicle.

A more detailed description of each swing arm and its function is shown Appendix D (Fig. 5.23).

5.22 A spectacular view of the LUT and swing arms during the *Apollo 14* space vehicle rollout, November 9, 1970. *Source*: NASA/Jerome Bascom-Pipp

Most of the in-flight swing arms employed a redundant umbilical plate ejection system to be absolutely certain that the umbilicals disconnected and the swing arms retracted at liftoff. The mechanisms were extremely complicated. They failed occasionally in testing, but they worked flawlessly at every launch. The primary ejection mechanism was to fire a burst of gaseous nitrogen at 750 psi (5 MPa) to the locking mechanism on the plate and the push-off pistons within the carrier. If that method failed for some reason, a completely mechanical process came into play. Although slightly different secondary release methods were used on the swing arms, they all involved a process in which the umbilical plate followed the rocket as it moved upward, which tightened a lanyard, which in turn moved levers or cams to disengage the locking mechanism. Hydraulic and pneumatic systems then rotated the arm back against the tower.



5.23 Diagram of the vehicle end of the S-IC forward swing arm (arm 2). At top right are the umbilicals and the connection plate to the launch vehicle. The swing arm walkway and extension platform to access the interstage are at bottom. *Source*: NASA/Ward

Environmental Chamber (White Room)

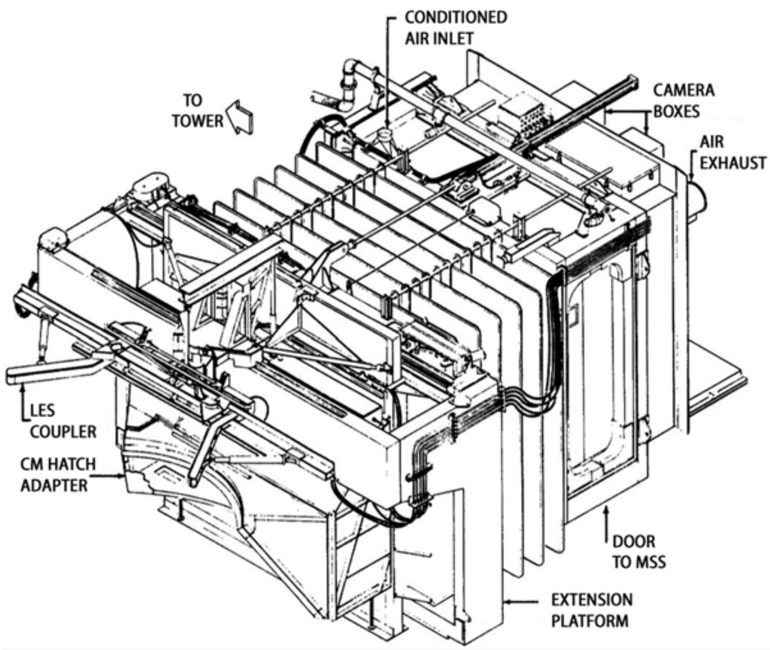
The environmental chamber (universally known as the *White Room*) was mounted on the end of swing arm 9. It provided a controlled work area adjacent to the command module, and was the platform from which astronauts entered the CM for tests or missions. The White Room could accommodate no more than about six people, and even that was a tight fit.

There were two ways to access the White Room. During test and checkout of the vehicle, when the mobile service structure was at the pad, a door led to the White Room from the

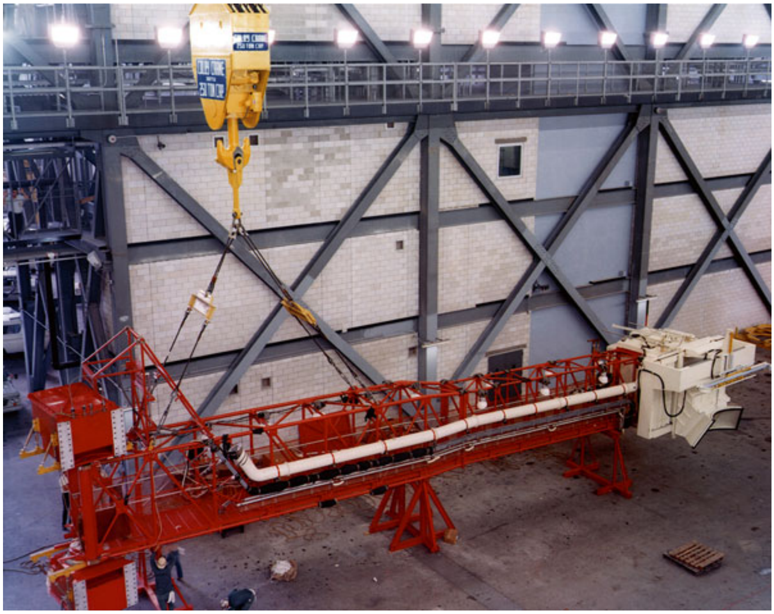
MSS' enclosed CM-level work platform. Most spacecraft operations personnel entered the White Room this way. The other method was to go up the umbilical tower and walk across swing arm 9. People who were uncomfortable with heights did not take this route unless there were no other options available.

The main chamber of the White Room contained the equipment needed to support the flight crew prior to launch. An extension platform, with a pneumatically retractable floor, bellows assembly, and hood adapter, connected the main chamber with the CM. The extension platform was held in place by a coupler that connected to the base of the launch escape tower. A soft rubber seal on the hood adapter surrounded the CM hatch opening. It was held in place by the LES coupler and panels that could be quickly removed. Firefighting and crew rescue equipment was positioned close to the spacecraft entrance. Still cameras, movie cameras, and OTV cameras mounted in the White Room provided a visual record of the activities inside.

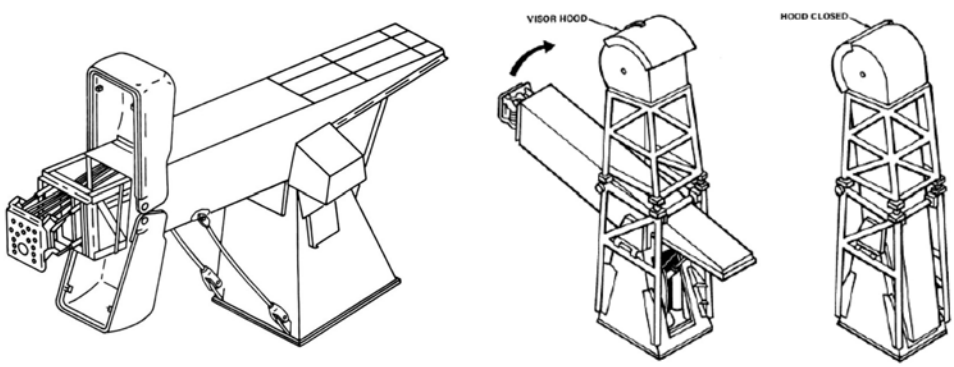
The White Room stayed in place at the capsule until the astronauts were on board and the closeout crew was done with their business. At T minus 43 min, the White Room was partially retracted to a position about 5 ft (1.5 m) from the CM. If necessary, the White Room could be reconnected to the CM within about 30 s from this position. At T minus 5 min, swing arm 9 was fully retracted. Swing arm 9 was attached and hinged differently than the other swing arms. When the swing arm retracted, the White Room opening pointed 180° away from the Saturn V at liftoff. This minimized launch damage and contamination inside the White Room (Figs. 5.24 and 5.25).



5.24 The White Room was attached to the end of swing arm 9, which the astronauts crossed to enter the capsule. Spacecraft workers could also enter the White Room via a door from platform 4C on the MSS. *Source*: Author's adaptation of NASA diagram



5.25 Swing arm 9 and White Room (at lower right) being checked out in the VAB prior to attachment to the LUT, 1966. *Source*: NASA/Ward



5.26 Tail service mast. At left, the original design used during *Apollo 4* and *6* launches. From *Apollo 8* onward, the TSMs were redesigned so that the connection plate rotated up into a protective hood at vehicle liftoff. *Source*: Author's adaptation of NASA diagrams

Tail Service Masts

Three tail service masts (TSMs) were mounted on the platform at LUT level 0. They functioned like swing arms, in that they carried umbilical connections for fuel, electrical, pneumatic, and hydraulic lines to the aft section of the S-IC stage, and they swung up and out of the way at launch (Fig. 5.26).

The umbilicals in all three TSMs disconnected from the vehicle at liftoff. A hydraulic system rotated the TSMs to a vertical position before the F-1 engines rose above the launcher deck. As a backup precaution, the TSMs were counterweighted such that they would rotate to vertical on their own if the hydraulic system failed. In the first two Saturn V launches, clamshell covers closed over the umbilical plates as the TSMs began rotating. After *Apollo 6*, the TSMs were slightly redesigned because launch damage to the interface plates was more severe than anticipated in the early Saturn V launches. A hood into which the TSMs rotated replaced the clamshells.

Holddown Arms

Four holddown arms served as vital connections between the LUT and the Saturn V, although they did not have umbilical hookups to the vehicle. The holddown arms were massive pieces of machinery that secured the Saturn V to the launcher deck. The vehicle base was held with a force of 700,000 lb (3.1 MN) at each arm. This force, combined with the weight of the fully-fueled Saturn V, was sufficient to keep the rocket on the pad until all of the S-IC engines were running at full throttle and the launch commit signal was given. Each arm was 6 ft by 12 ft (1.8 m by 3.6 m) at the base and weighed 18.5 tons (16.5 t). They were numbered I (east), II (north), III (west), and IV (south). These numbers corresponded to the quadrant numbers painted on the first stage of the Saturn V (Fig. 5.27).

5.27 Still frame of *Apollo 11* launch, just before the bottom of the engines cleared the opening of the flame compartment. Ice falls from the side of the Saturn V, a cable from the S-IC to the holddown arm cover pulls its cover shut, and the tail service mast rotates into its protective hood. *Source*: NASA/Ward

Engine Servicing Platforms

Engine servicing platforms were installed on the LUT while it was inside the VAB. The S-IC's engines protruded down into the cavernous engine compartment on the LUT and were thus hard for servicing technicians to reach. The mobile launcher level servicing platform and the S-IC engine servicing platform enabled Rocketdyne technicians to service the engine area, install engine skirts, or replace engines while the Saturn V was in the VAB. A similar servicing platform was used at the launch pad. Winches on the launcher deck could raise or lower the engine servicing platform and one F-1 engine through the LUT's engine compartment. The portable engine installer could remove the engine from the servicing platform and load a new one into the platform. Prior to the stack rolling out to the launch pad, the servicing platforms were lowered down through the launcher and moved out from under the LUT (Figs. 5.28 and 5.29).

The Milkstool

The first several Saturn IB missions flew from Launch Complexes 37 and 34. These launch pads were deactivated after *Apollo 5* and *7*, respectively. Looking forward to the Apollo Applications Program (which later became Skylab), NASA knew that it would have a continuing need to launch Saturn IB rockets in the early 1970s, after the Moon landing was accomplished. The question became where and how NASA would process and launch these Saturn IB missions. A Bellcomm study determined that it was more cost-effective to modify one of the LUTs to launch Saturn IBs for the Skylab program from LC-39 than it

5.28 The S-IC engine servicing platform was installed in the LUT before the S-IC stage was erected. The platform was removed before rollout by lowering it through the LUT's flame compartment. *Source*: NASA/Ward

5.29 The F-1 engine installer during a test with a dummy F-1 engine in the VAB. The truck and engine drove under the LUT, and then the installer raised the engine into the servicing platform. *Source*: NASA/Ward

was to maintain LC-34 or LC-37 and continue to run them in parallel with the LC-39 operations.

The challenge with launching a Saturn IB from LC-39 was primarily one of scale: LC-39's LUTs were too big for the Saturn IB. With its smaller S-IB first stage and lacking the S-II stage completely, a Apollo/Saturn IB space vehicle was significantly shorter than a Saturn V, so it did not align with the swing arms on the LUT. Rather than building a new umbilical tower on the LUT, the solution was to raise the Saturn IB up off the launcher deck. After the flight of *Apollo 11*, LUT 1 was taken out of service and modified to support Saturn IB launches. NASA built a structural pedestal, dubbed the *milkstool*, onto LUT 1's deck. The milkstool lifted the smaller S-IB stack's Apollo spacecraft, S-IVB stage, and instrument unit to the same height above the launcher deck that they would have been on a Saturn V. Unneeded swing arms were removed or repurposed. A new access bridge from the utility tower connected with the milkstool's upper platform. Launcher accessory equipment was removed from LC-34 and LC-37B and installed on the milkstool deck (Figs. 5.30 and 5.31).

5.30 Milkstool launch platform for Saturn IB vehicles under construction on LUT 1 in the VAB. *Source*: NASA/Ward

5.31 Fit checks with the milkstool and the *Skylab 2* Saturn IB launch vehicle, 1972. *Source*: NASA/Jerome Bascom-Pipp

6

The Launch Control Center and Firing Rooms

All launch facilities at Cape Canaveral featured a launch pad located near a hardened blockhouse that contained a launch control room. As launch vehicles grew larger and became more sophisticated, and as their explosive potential increased, the Cape's launch complexes incorporated larger blockhouses that were increasingly farther from the launch pad.

The blockhouse at LC-5/6 (site of Alan Shepard and Gus Grissom's Mercury/Redstone launches) was only about 300 ft (91 m) from the center of the launch pads. A large window in the blockhouse faced the pad. In contrast, the huge blockhouse at LC-34 (site of the Saturn IB launches up through *Apollo 7*) was more 1,800 ft (550 m) from the center of the launch pad, and there were no windows. The explosive potential of a Saturn V mandated that the launch control center be at least 3 miles (4.8 km) from the launch pad.

To meet the aggressive launch schedule necessary to put men on the Moon by the end of the 1960s, NASA needed a novel approach to assembling, testing, and launching multiple rockets. Kurt Debus' insight into addressing the issue was a Launch Control Center (LCC) with four separate firing rooms, located at a safe distance from the launch pad. Each firing room could be dedicated to the test and checkout of a single mission, regardless of whether the rocket was in the VAB or at the launch pad. This enabled NASA to have up to four Saturn V missions in flow at any given time.

This chapter explores the LCC and how it was organized. We will touch on the innovative computer technologies and the intricate network of electrical support equipment that enabled several hundred engineers to control and test all operations of the Saturn V and its supporting facilities.

THE LAUNCH CONTROL CENTER

The LCC is the command center for the checkout and launch of rockets from Launch Complex 39. The LCC is adjacent to the VAB and connected to it by an enclosed walkway bridge (Fig. 6.1).

The first floor of the LCC contained an entry lobby and support functions including a cafeteria, the communications control room (CCR), and the complex control center (CCC).

J.H. Ward, *Rocket Ranch*, Springer Praxis Books, DOI 10.1007/978-3-319-17789-2_6

6.1 The Launch Control Center (foreground) and the VAB during the *Apollo 11* rollout. *Source*: NASA

The CCR housed the equipment supporting the operational intercom system (OIS) and the operational TV system (OTV).

The CCC was in room 1P9 of the LCC, immediately to the left after one entered the front door of the building. The CCC had consoles similar to those in firing rooms, but they controlled all the ground systems (high-pressure gas distribution systems, air conditioning and pressurization, pad catacombs, pad terminal connection room, power distribution controls, LUT and VAB elevators, etc.).

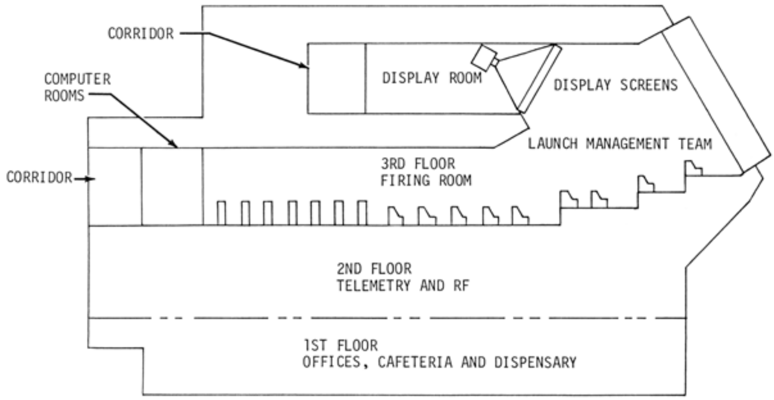
Telemetry, tracking equipment, and instrumentation equipment occupied the second floor of the LCC during the Apollo era. IBM and the stage contractors operated 45 racks of telemetry checkout equipment in room 2P10.

The third floor of the LCC was devoted to the firing rooms, computer rooms, and conference rooms. The fourth floor contained offices and equipment for the large Eidophor projector displays in the firing rooms. The firing rooms were the heart of the LCC, and we will spend the bulk of this chapter discussing their layout and operation (Fig. 6.2).

FIRING ROOMS

All of the familiar Apollo launch film footage showing people sitting in a cavernous room in front of rows and rows of control panels was taken in the firing rooms. The firing rooms were active for much more than launches, however. They were the nerve centers for launch vehicle checkout activities at LC-39. They contained control, monitoring, and display equipment for automated testing and launch of the Saturn V. Personnel stationed in the firing rooms ran all of a stage's tests from the time it was stacked on the LUT through launch.

Many people are under the impression that the firing room was the same room as the mission operations control room (MOCR) in Mission Control. This misperception has



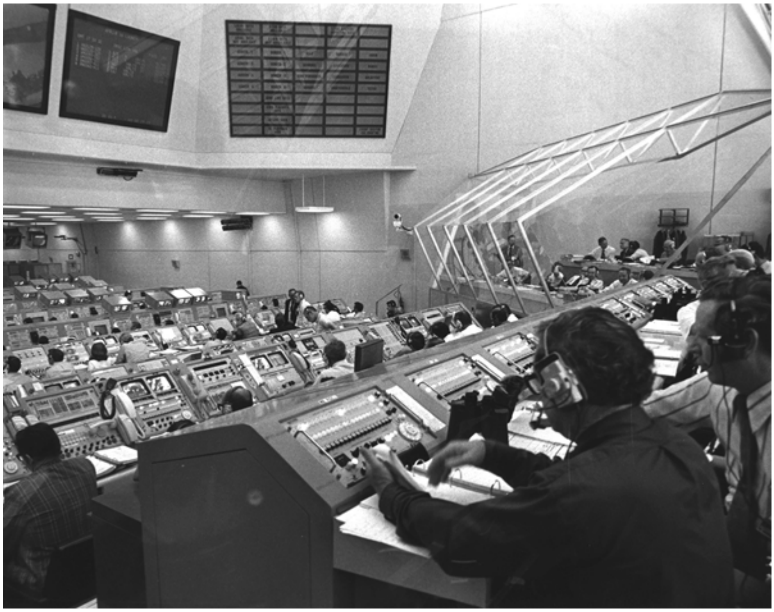
6.2 Cross-section of the Launch Control Center illustrating how the firing rooms fit into the overall building plan. *Source*: Author's adaptation of NASA diagram

been repeatedly reinforced, even in otherwise excellent documentaries about Apollo. Nothing will make a KSC worker more upset than someone asking him or her about working in Mission Control!

Notwithstanding the fact that the firing rooms were in Florida and the MOCR was in Houston as of the early Gemini program, the two facilities were of vastly different size (each of the four firing rooms was about ten times the size of the MOCR), and they served very different purposes. The firing rooms controlled all the testing, preparation, fueling, and launch of the vehicle, up to the moment of liftoff. The moment the umbilicals pulled away from the vehicle, the firing room's role in a mission was essentially complete, except for the range safety function and safing pad equipment. The firing room had no control over the vehicle once the umbilicals disconnected. Within 10 s of liftoff, the vehicle had cleared the launch tower; Mission Control in Houston took complete control from that point forward in the mission (Figs. 6.3 and 6.4).

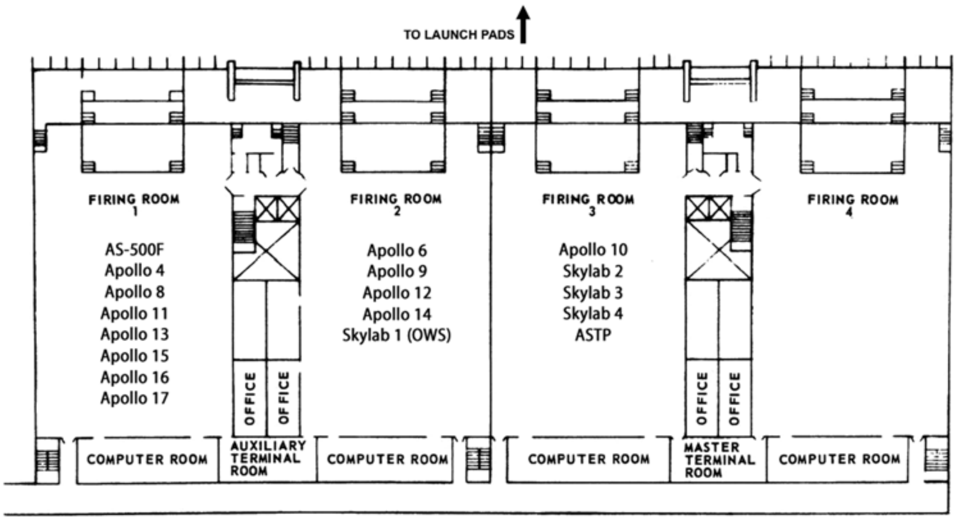
The firing rooms were analogous to the control rooms in the blockhouses at LC-34 or LC-37, built on a much larger scale. There were about 450 consoles in an Apollo-era firing room at the Launch Control Center. Astronaut Dave Scott told the author: "Comparing it with Gemini, the difference was astounding. It never ceases to amaze me. When I was on Gemini VIII, we spent a lot of time at the Cape. One weekend, Neil [Armstrong] says to me, 'Hey, they're building the Apollo launch center and the firing room—let's go have a look.' The Gemini launch control center had about 20–24 consoles, and that was pretty big compared to Mercury. So we drive over and they're building the VAB, and we go up into the VIP room and look down at the firing room. 450 consoles. We said, 'We'd better go back! It ain't gonna work! No WAY it's gonna work!'"

The four firing rooms in the LCC corresponded to the four high bays in the VAB. When the complex was designed, Debus' idea was that each firing room could oversee the check-out of a Saturn V in one of the VAB's high bays, with up to four in process at once. Strictly speaking, each firing room was connected to a single LUT during processing for a mission, and that LUT could either be in the VAB or at the launch pad. The key concept was that



6.3 Ike Rigell (foreground) monitors the final half-hour of the *Apollo 16* countdown in firing room 1, April 16, 1972. *Source*: NASA/Jerome Bascom-Pipp

6.4 The mission operations control room in Houston's Mission Control Center during an *Apollo 16* EVA. Do not confuse this room with the KSC firing rooms! *Source*: NASA/J. L. Pickering



6.5 Four firing rooms filled the third floor of the LCC. Firing room 1 was most frequently used one during the Apollo program. *Source*: NASA/Ward

each firing room would be dedicated to a single Saturn V throughout that vehicle's processing flow at KSC, through stacking, checkout, and launch. After a mission launched, the LUT returned to the VAB for refurbishment, and it and firing room were then assigned to another mission whose processing flow was about to begin.

After LC-39 was designed and while construction was underway, NASA determined that only three launch vehicles would be in flow at a time. Therefore, only three LUTs were built, and only three high bays in the VAB were activated for launch processing. Firing room 4 was re-purposed to serve as a management information and control room where the status of LC-39 activation and mission processing flows were tracked and managed.

Firing room 1 was the first to be activated. It controlled the test of the AS-500F facility vehicle and the checkout and launch of the AS-501 (*Apollo 4*) mission. Firing room 2 was activated for the next Saturn V launch, AS-502 (*Apollo 6*). Firing room 3 came online to process and launch *Apollo 10*, but was not used again as a primary firing room until the processing of the Saturn IBs for *Skylab* and *ASTP* (Fig. 6.5).

Each firing room looked out to the LC-39 launch pads to the northeast through a 2-in. (5 cm) thick, laminated and tinted window that ran the entire width of the firing room. Electrically-controlled louvers could be closed over the window as a sunshade and for protection in case of an explosion on the launch pad. With its wide windows, the firing room also provided a convenient, climate-controlled place for VIPs to watch a Saturn V roll out to the launch pad.

One would think that a room filled with 450 electrical consoles, many of them with dozens of 28 V indicator lamps, would be very warm from the heat generated by all the electrical equipment. Engineer Bob Pound considered the opposite to be true; it was at times uncomfortably chilly in the firing room: "Keeping the area at the right temperature actually worked by adding heat into the cooled air, rather than cooling it down more. Of course, those computers needed a lot of cooling; they ran awful hot. To save energy, we'd let it run as cold as possible, because the chilled water came from the cooling towers out there by the VAB. They pumped as much cold as they could, and then to get it to the right temperature, they'd warm it up with heat from the consoles. We had to wear sweaters in there most of the time."

Looking out from the fourth floor over the firing rooms were glassed-in rooms that were originally intended as VIP observation areas. Instead, they became offices for the NASA test supervisors. Lead test supervisor Don Phillips occupied the office overlooking firing room 4; the other test supervisors shared the offices overlooking firing rooms 1 and 2 (Fig. 6.6).

Firing rooms 1, 2, and 3 had essentially identical layouts. The firing rooms were divided into separate areas that had specific operational significance. Each area was comprised of racks of consoles and displays. Two letters and a number designated a console's location in the firing room. The first letter was the area, the second letter was the row, and the number was the position along the row, numbered from left to right. For example, the *S-II engine 201* console was at position BA16: area B, row A, 16th console from the left.

Personnel *on console* in the firing room were identified by their operational intercom system (OIS) call sign. For example, the call sign for the test engineer manning the *S-II engine* console was C2EC.

The layout of the firing room was a physical manifestation of the management hierarchy. The following sections describe the function of each area and the roles of the personnel who occupied consoles.

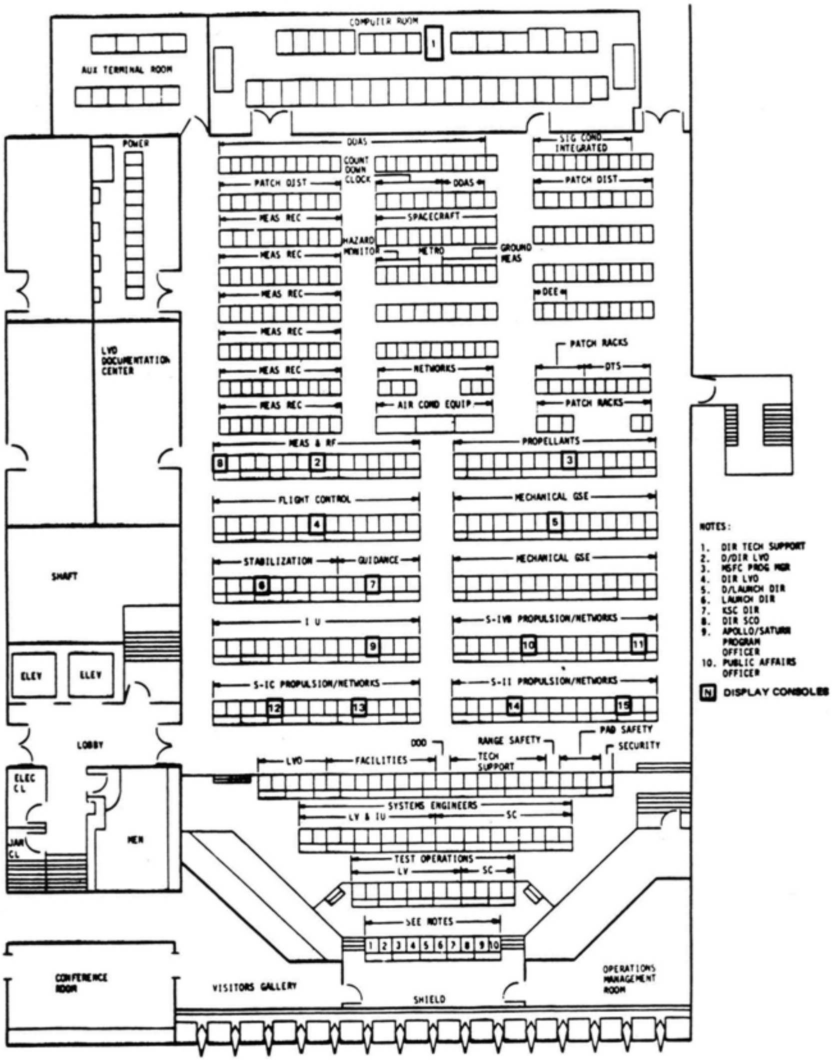
Area A

Area A was populated by the managers of the test and launch processes. Four rows of consoles stair-stepped down from the window. The higher the row in which a person sat in area A, the more comprehensive his or her job function and responsibility. Management personnel could look out over the entire firing room and monitor the activity.

Row AA (the uppermost row) was reserved for KSC and program management. Seated in this row were Ike Rigell, Hans Gruene, Kurt Debus, Rocco Petrone, Walt Kapryan, Robert Gray, John Williams, the public affairs officer, the Saturn program manager from MSFC, and the Apollo program manager from MSC.

Row AB was for the personnel who managed test operations. These included the space vehicle test supervisor, launch vehicle test conductor, and spacecraft managers from NASA, Grumman, and Rockwell. It is important to remember that the chief NASA spacecraft test conductors were stationed in the ACE rooms in the MSOB—not the firing room—during space vehicle tests and launches. Spacecraft operations had representatives in the firing room, but control of spacecraft testing resided solely in the MSOB ACE rooms.

Row AC was for the test conductors and systems engineers for the various launch vehicle stages, spacecraft operations managers, the astronaut representative and communicator (OIS call sign *Stoney*), and KSC chief of medical services.



6.6 Original plan for firing room 1 layout, May 21, 1965. Some positions in area A were reassigned prior to the start of Saturn V flights, but the overall layout remained consistent throughout Apollo. Detailed console assignment information is shown in Appendix E. *Source*: NASA/Ward

Row AD seated NASA managers for networks, engineering, guidance and control, mechanical and propulsion systems, instrumentation, and quality assurance; operations managers from the stage contractors and Bendix; instrumentation and communications controllers; and range safety, pad safety, and security.

6.7 *S-IB operations* panel from area A of the firing room. Chrysler's S-IB test conductor monitored the status of key discrete events on his stage from this panel. Note that there are no switches or controls (Author's collection). *Source*: Ward

The management personnel in area A monitored and directed tests and launches. OTV feeds and summary-level event displays on their consoles provided information, and they could monitor multiple channels on the operational intercom system during a test.

Off to the sides of area A were two triangular, glass-fronted rooms. With one's back to the main window in firing room 1, the room on the left was an observation room for VIPs and guests attending a launch. On the right was the operations management room (OMR, also sometimes referred to as the management support room or mission support room). Executives from NASA headquarters, other NASA centers, and the military observed and monitored launch activities here. George Mueller, Sam Phillips, and Wernher von Braun were among those who sat in the OMR during a launch.

Each contractor stage test conductor in area A monitored a *stage operations* panel with indicator lights showing the status of major systems on his stage. These displayed information similar to that on the large status board on the firing room wall, supplemented with additional information about range safety status on the stage (Fig. 6.7).

The VIPs and top brass in area A tracked the events of a test or launch via four large Eidophor projection screens mounted near the ceiling in the center of the firing room. The data on the screens was generated by the computer and the operational television (OTV) system (Fig. 6.8).

Two large status displays were mounted diagonally on the walls on either side of the Eidophor displays. The one on the left side displayed the status of key events in a test or countdown. Frank Bryan was responsible for implementing the key events display board, about which he said: "When we were designing the board, I picked a color for each light. My scheme was: green means you're go; yellow means something's going to happen and the light's going to go off before you get to launch; and red means it shouldn't be on—you've got a problem. We ran through the first test, when all management was up in the top row, and Ike [Rigell] came up to me and said, 'We're going to change that board. Every light up there is going to be green.' Management didn't like seeing yellow lights flashing."

6.8 Lead space vehicle test supervisor Don Phillips (*center*) talks with KSC security officer Sherman Evans during the CDDT for *Apollo 12*. Behind Phillips is Fleming Law of spacecraft operations. The large Eidophor projection screens above the firing room show operational television (*leftmost* display), data from discrete events, and a listing of programs being executed on the RCA 110A ground support computer. *Source*: NASA/Jerome Bascom-Pipp

The status board indicator lights for the *Apollo 11* mission are shown in the table below.

AS-506	LAUNCH SEQUENCE START	S-IC INTERTANK ARM RETRACTED	S-IC IGNITION	S-IVB ENGINE START
	S-IVB LOX TANK PRESSURIZED	S-IC ON INTERNAL POWER	COMMIT	S-IVB CUTOFF
RANGE SAFE	S-II LOX TANK PRESSURIZED	S-II ON INTERNAL POWER	LIFTOFF	
LAUNCH SUPPORT PREPS COMPLETE	S-IVB LH2 TANK PRESSURIZED	S-IVB ON INTERNAL POWER		ESE CUTOFF

(continued)

S-II PREPS COMPLETE	S-IVB PROPELLANTS PRESSURIZED	IU ON INTERNAL POWER	S-IC INBOARD ENGINE CUTOFF	
S-IVB PREPS COMPLETE	S-IC FUEL TANK PRESSURIZED	S-IC PROPELLANTS PRESSURIZED	S-IC OUTBOARD ENGINE CUTOFF	R F SILENCE
IU READY	S-IC LOX TANK PRESSURIZED	S-IC CARRIER K/O AND ARM RETRACT	S-IC/S-II SEP LOGIC ZERO	
S/C READY	S-II LH2 TANK PRESSURIZED	S-IC FORWARD ARM RETRACTED	S-II ENGINE START	TEST HOLDING
EDS READY	S-II PROPELLANTS PRESSURIZED	LSE READY FOR IGNITION	S-II CUTOFF	TEST COUNTING
S-IC PREPS COMPLETE	S-IC INTERTANK CARRIER RETRACTED	READY FOR S-IC IGNITION	S-II/S-IVB SEP LOGIC ZERO	EVENT SYSTEM CALIBRATING

The status display on the right side of the firing room showed which NASA ground stations in the spaceflight tracking data network (STDN) were receiving downlinked data. The tracking ships and stations on duty varied somewhat between missions. Shown below is the configuration of the board during the *Apollo 16* launch:

LOCAL DATA AVAILABLE	STDN DATA AVAILABLE		STDN STATION SUPPLYING DATA	
LOCAL DATA NOT AVAILABLE	STDN DATA NOT AVAILABLE			
SCREEN 1	SCREEN 1	MILA	MADRID	GUAM
SCREEN 2	SCREEN 2	BERMUDA	ASCENSION	HAWAII
SCREEN 3	SCREEN 3	USNS VANGUARD	CARNARVON	GOLDSTONE
SCREEN 4	SCREEN 4	CANARY	HONEYSUCKLE	TEXAS
	S-IVB LIVE DATA			
	S-IVB PLAYBACK DATA			
	IU LIVE DATA			
	IU PLAYBACK DATA			EVENT SYSTEM CALIBRATING

Area B

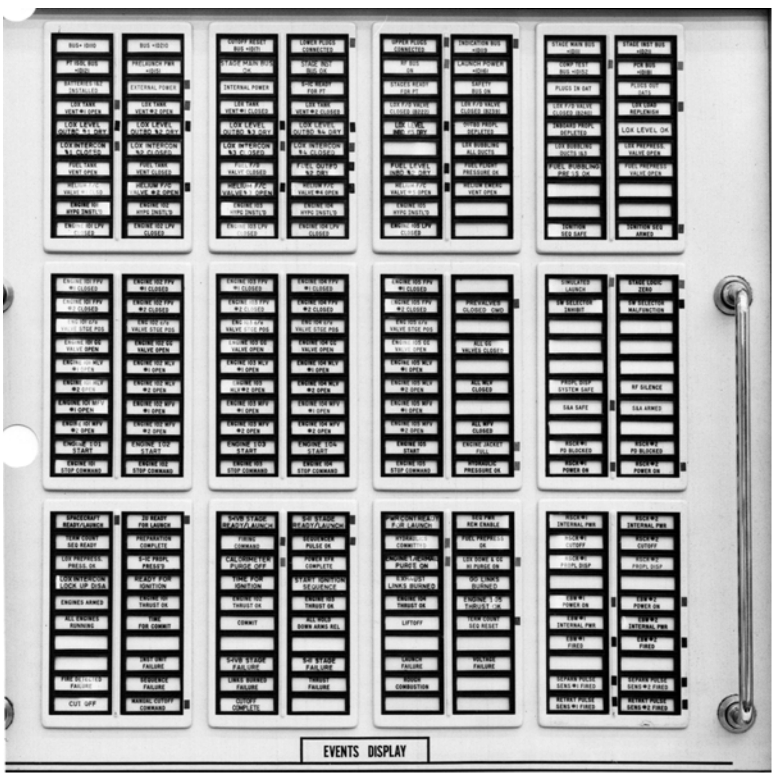
Area B covered the first five rows on the main floor level of the firing room. Here were the consoles from which engineers for NASA and the stage contractors directly controlled and monitored launch vehicle tests. The consoles provided inputs into and readouts from the ground computer, launch vehicle stages, ground support equipment, and electrical support equipment.

There were 30 consoles in each of the 5 rows of area B, 15 consoles on each side of the central aisle dividing each row in the area. The section for each stage (S-IC, S-II, S-IVB, and IU) had a printer for the digital events evaluator (DEE-6C) computer, and small OTV monitors sat on top of some of the consoles. Each side of every row had at least one computer terminal that could execute programs on the RCA 110A ground computer complex and call up formatted alphanumeric data on the status of certain systems. Consoles were grouped by stage or by function.

Many of the rows in area B had at least one large *events display* panel with dozens of indicator lights. These panels provided engineers with an overview of all the discrete commands issued to and the responses received from a stage and its ground support equipment during a test (Fig. 6.9).

Appendix E contains a detailed listing of the consoles in area B. The panels in each row were generally arranged and staffed by function as follows:

- Row BA, left side of the aisle (positions 1–15): S-IC propulsion and electrical networks. Manned by Boeing personnel. (Note: NASA engineers sat beside or behind the contractor engineers manning consoles throughout area B.)



6.9 An events display panel from the S-IC section of area B, row A. The indicators on this panel showed the status of more than 200 discrete events associated with the first stage of the Saturn V and its launch support equipment. *Source*: NASA/Ward

- Row BA, right side of the aisle (positions 16–30): S-II propulsion and electrical networks. Manned by Rockwell.
- Row BB, left side: Instrument unit networks, mechanical, and emergency detection system. Manned by IBM.
- Row BB, right side: S-IVB propulsion and electrical networks. Manned by McDonnell Douglas.
- Row BC, left side: Stabilization and guidance monitoring (theodolite, ST-124M inertial platform, and guidance computer). Manned by IBM.
- Row BC, right side: Service arms mechanical ground support equipment. Manned by Boeing.
- Row BD, left side: Flight control and IU measuring (engine gimbaling for each stage). Manned by IBM and stage contractors.
- Row BD, right side: Mechanical ground support equipment and launch accessories (tail service masts, holddown arms, environmental control system). Manned by Boeing.
- Row BE, left side: Stage RF measuring and tracking, Q-angle of attack. Manned by IBM.
- Row BE, right side: Propellant loading and propellant tanking computer system monitoring. Manned by Boeing.

After the success of the *Apollo 11* mission, firing room 3 was no longer needed to support lunar missions (it was the primary firing room only for processing *Apollo 10*). Firing room 3 was reconfigured to support launches of the Saturn IB for the Skylab manned missions and the Apollo-Soyuz Test Project. In the new configuration of firing room 3, the S-IC consoles on the left side of row BA were left in place and were not used. The S-II consoles on the right side of row BA were removed, since there was no S-II stage on the Saturn IB. Some S-II panels were replaced by S-IB panels, which were manned by Chrysler engineers.

Area C

Area C was at the far end of the firing room from the window. There were eight rows of equipment racks, with two aisles dividing the area. The middle section of row CA was a large air conditioning equipment cabinet, which visually set off area C from the rest of the firing room. Strip chart recorders on the left and right sides of row CA faced toward areas A and B. Photos of the firing rooms during Apollo launches frequently show mission managers in row AA with binoculars in their hand or on their consoles. Ike Rigell said that launch managers used their binoculars to scan the tracings on the area C strip chart recorders from the other end of the firing room.

The consoles in area C controlled, measured, and recorded the status of various systems on the vehicle and at the launch pad as well as some of the support facilities such as the LOX and LH_2 farms. The last two rows of area C contained patch racks and patch distributors, the timing distributor from the countdown clock, signal conditioning equipment, and monitoring consoles for the digital data acquisition system (DDAS). The DDAS conveyed vehicle stage data and ESE data to the firing room and CIF for real-time monitoring on strip charts, indicators, and meters. DDAS data was also recorded to tape drives (Fig. 6.10).

6.10 Boeing electrical engineer Bill Heink at the LOX electrical systems control station in firing room 1, area C, during the *Apollo 8* countdown demonstration test. *Source*: Frame from NASA movie adapted by author

Areas D, E, and F

Area D was in a separate room off the back end of the firing room. This room contained the firing room's RCA 110A computer and its associated peripheral equipment (tape drives, drum storage, card punch and card reader, and line printer). Each firing room had its own dedicated RCA 110A computer. The Sanders display computer system was also located in area D.

Area E was separate room off to the left side of the firing room. It held power distribution and monitoring racks. Area F was a terminal equipment room at one back corner of the firing room. Each adjoining pair of firing rooms shared a terminal room.

The Woodshed

A launch vehicle documentation room was off to the side of each firing room. This room contained copies of all procedures, systems drawings, and other materials related to the launch vehicle and the ground support systems. It was affectionately known as the *woodshed*, where Rocco Petrone caucused his launch vehicle managers if problems arose during tests or launch countdowns.

Operational Intercom System (OIS)

The operational intercom system made it possible for test conductors, engineers, technicians, and managers to stay in contact with each other during a test, no matter where they were at KSC, or even at other centers and contractor facilities.

OIS-RF CHANNELIZATION LC-39

AS-508 & SUBS

LO 111 TEST SUPER. R C U	LV 121 L/V TEST COND. R C U	IN 131 DATA DISPLAY (CIF)	SF 141 PAD SAFETY	LV 151 IU TEST COND.	LV 161 S-IVB TEST COND.	LV 171 S-II TEST COND.	LV 181 S-IC TEST COND.	LS 211 CHIEF S/C TEST COND. U	LS 221 CSM PAD LEADER	LS 231 LM PAD LEADER	IS 241 PHOTO	IN 251 INST CONTROLLER	SO 261 SUPPORT CONTROLLER
TS 112 TEST SUPPORT CONTROLLER R C	IN 122 FAC & ENVIRON. MEAS C	LV 132 LAUNCHER SYSTEMS	LV 142 S/V PNEU. ECS	LV 152 IU MECH.	LV 162 S-IVB MECH. & ORD.	LV 172 S-II GND & STAGE PNEUM.	LV 182 S-IC MECH. & ORD.	LS 212 CSM STC U	LS 222 CSM TPE	LS 232 LM STE	LS 242 LM STC U	LS 252 LM TROUBLE SHOOTING	IS 262 INSL SUPPORT CONTROLLER
IN 113 OTV CONTROL ENG. C	LV 123 L/V FLIGHT CONTROL	LV 133 L/V OXIDIZER	LV 143 L/V FUEL	LV 153 IU FLIGHT COMP.	LV 163 S-IVB PROP. (STAGE)	LV 173 S-II PROP	LV 183 S-IC PROP	LS 213 CSM INST. U	LS 223 CSM EPS	LS 233 LM EPS	LS 243 LM INST.	IN 253 FACILITY & ENVIRON. MEAS.	SO 263 HPG GN 2 & HE PURGING
LV 114 L/V STAB. & LAYING C	LV 124 LSE ELECT.	LV 134 L/V PROP. ELEC.	LV 144 S-IC MEAS. & HGD	LV 154 IU ELECT. (STAGE)	LV 164 S-IVB GND. PNEUMATICS	LV 174 S-II ELECT. (STAGE)	LV 184 S-IC ELECT. (STAGE)	LS 214 CSM COMM. U	LS 224 CSM F/C CRYO	LS 234 LM RADAR	LS 244 LM COMM. U	IN 254 FACILITY & ENVIRON. MEAS.	SO 264 HPG MON. SYS.
SO 115 CRAWLER OP'S C	LV 125 L/V TROUBLE SHOOTING	LV 135 L/V TROUBLE SHOOTING	LV 145 L/V DDAS	LV 155 RCA 110A GND COMP.	LV 165 S-IVB ELEC. SYSTEM	LV 175 S-II GND ELECT.	LV 185 S-IC GND ELECT.	LS 215 CSM GEN	LS 225 CSM SCS	LS 235 LM SCS	LS 245 LM GEN	IN 255 FACILITY & ENVIRON. MEAS.	SO 265 HPG ELECT. CONT'S
LV 116 S-IC MEAS. C	LV 126 S-II LEAK DETECT.	LV 136 SERVICE ARM (MECH)	LV 146 IU MEAS. (GND)	LV 156 IU TM	LV 166 S-IVB STATUS MONITORING	LV 176 S-II TM	LV 186 S-IC TM	LS 216 CSM RCS SA	LS 226 CSM SPS SA	LS 236 LM RCS SA	LS 246 LM PROP.	IN 256 CIF TELEM. GND STA.	SO 266 O_2 FAC OPNS
IN 117 OIS CONTROL ENG C	LV 127 L/V TM R	LV 137 L/V RF R U	LV 147 CNTD'N CLOCK & DEE 6	LV 157 IU RF	TS 167 SUPPORT TROUBLE SHOOTING	LV 177 LV QAL	LV 187 S-IC RF	LS 217 CSM AERO-MED	LS 227 CSM ECS	LS 237 LM ECS	LS 247 SC Q/C	IN 257 CIF TELEM. GND STA.	IN 267 KSC TIMING
LV 118 SERVICE ARM MECH. C	LV 128 S-II MEAS.	LV 138 S-IVB DDAS & MEAS.	LV 148 IU MEAS.	LV 158 IU GND ELECT.	LV 168 S-IVB RF & TM	LV 178 S-II FLIGHT CONTROL & HYDRAULICS	188 PAGING	LS 218 CSM GSE	LS 228 CSM ACE	LS 238 LM ACE	LS 248 LM GSE	LO 258 TEST SUPER (BACK-UP)	LS 268 CSM TROUBLE SHOOTING

R = AVAILABLE TO ETR
U = AVAILABLE TO USB - MILA
SA = FOR TEMPORARY USE DURING SERVICE ARM OPERATIONS
C = AVAILABLE TO CRAWLER TRANSPORTER/MOBILE LAUNCHER BY MICROWAVE DURING TRANSFER OPERATIONS

APPROVED A. J. Griffin Jr. 1/22/70
LO/PLN

6.11 Matrix of active OIS channels during tests and launch countdown for *Apollo 17*. *Source*: NASA/Ward

Each major space vehicle and ground support system was assigned a primary OIS channel for communications during a test. The channel assignments were published in a matrix with each test procedure (Fig. 6.11).

Listening in on a loop was as simple as dialing in the number of the channel on an OIS communications panel and plugging in a headset. Most OIS stations located around KSC could be dialed into two channels, one that enabled the person at the station to talk on the loop, and a second channel that could be monitored (listen-only).

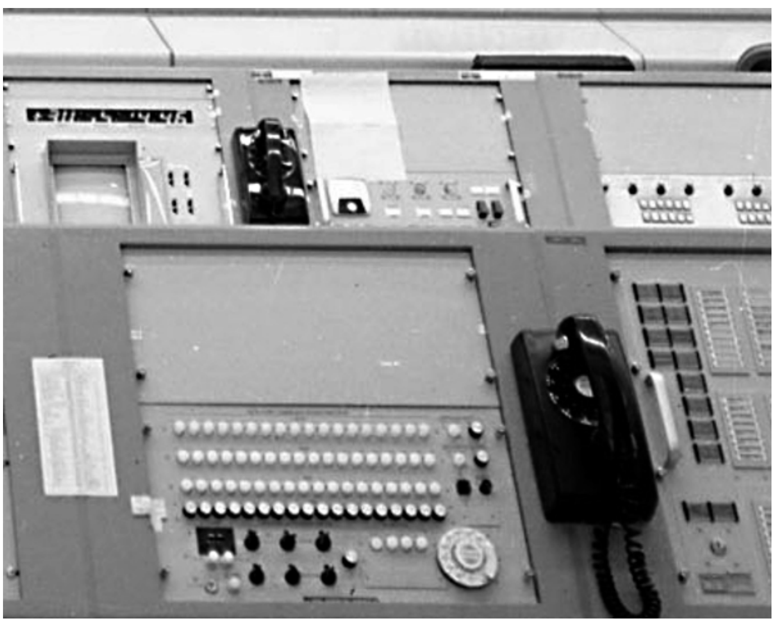
The OIS system was designed so that each test engineer could coordinate and talk with necessary people to perform his tasks while he listened in his other ear to his test conductor, who was on a separate intercom channel. The stage test conductor maintained contact with all of his stage test engineers, listening to them in one ear on one channel, while listening to the NASA test conductor in his other ear. This way, the entire population of test engineers in the LCC was closely linked in a very hierarchical manner to the NASA launch vehicle test conductor.

Shown in the accompanying photo is a typical OIS panel, one from area B of the firing room. The engineer sitting at the station was responsible for monitoring the pneumatic system that purged the fuel line for the auxiliary propulsion system on the S-IVB. We can see by the numbers on his OIS panel that for this test, he was active on OIS channel 125 (launch vehicle troubleshooting) as his primary loop, meaning that he was most likely involved in diagnosing and resolving issues on the Saturn V that had cropped up during the test.

He was also monitoring channel 161 (S-IVB test conductor), listening to any procedural call-outs in the test that were related to the S-IVB. Note that the four jacks on the panel enabled as many as four people to plug in their headsets at this station (Fig. 6.12).

Many of the manager and test conductor consoles in area A had large OIS communications control panels that could *side-tone* up to 18 channels at a time, listening in on the discussions among various teams during the test. Roy Tharpe said he was usually tuned into at least six different conversations at once, and he turned the volume for a channel up or down depending on the importance and relevance of what was being discussed on it at any given time. Lights on the console indicated which OIS channels were active (Fig. 6.13).

6.12 Typical OIS panel in area B of the firing room. *Source*: NASA/Ward



6.13 OIS monitoring panel from area A of the firing room. Management personnel could monitor many channels at once. *Source*: NASA/Ward

Each person with functional responsibility during a test was assigned a call station (call sign) that uniquely identified him or her on the net. Every test procedure included a list of the active call stations for that test. The test procedures included a call and response listing for actions during the test, specifying the call signs of the person responsible for initiating an action and the person who would respond that the action had been accomplished and verified. Many people kept a cheat sheet taped to their consoles, listing the call signs most relevant to their role in the test.

Call sign designations were relatively straightforward. The first letter of the call sign generally identified the location of the person (C was the launch control center, L was the launcher platform, P was the launch pad, U was the umbilical tower, etc.). The letter or digit in the second position sometimes referred to the vehicle stage (1 for S-IC, 2 for S-II, 4 for S-IVB, U for instrument unit), or the major function or system (L for launch vehicle operations, S for swing arms, P for propellants, etc.). The last two letters were usually abbreviations of the station's function (TC for test conductor, PU for propellant utilization, etc.). So, without the cheat sheet at hand, if one heard a callout for "C2PU" over the net, one could guess that this person was in the firing room and monitored the propellant utilization system on the S-II stage.

Conversation on the command channel of the net was strictly limited to what was called for in the test procedure. Launch vehicle operations instilled a level of discipline during test communications that forbade idle chatter. Tip Talone described the protocol for speaking over the OIS:

> *In any major test, the rule was – and it was a hard rule – you had "pro" words that you used when you came on the net to talk about something that wasn't in the procedure. You had to come on and sequentially say who you were by call sign, not by name. Names were forbidden. If you were the launch vehicle test conductor, you were CLTC. If you were the first stage engineer, you were the C1PE. You could recognize voices, obviously, but you used the call signs. But it was very disciplined.*
>
> *If you had a problem, your report had to be: "This is such-and-such, CLTC, calling on channel such-and-such." You had to be sure he was really on the command channel and not on his own channel, because we had a lot of channels. Then you'd say, "I've detected an increased pressurization in a regulator that seems to be creeping. Our plan is to do this and that, and we will report back to you in the next five minutes. Can we have channel 181 to do our troubleshooting on?" And Norm [Carlson, CLTC] would say, "Yep, you can have channel 181," and tell everybody on the command net and tell them who you wanted to help with troubleshooting. He'd say, "Call signs," and he'd rattle off the call signs the guy needed, "go to 181 and support troubleshooting." And of course he'd tell me, "You go to 181 and listen to what they're doing."*
>
> *The talk on the OIS was very stylized, so that there weren't any questions about what was really going on. There isn't any panic, and no one guy's working a problem that nobody else knew about. There were no wasted words, and we didn't want to jam up the command net in case somebody had a real problem.*

Houston, Huntsville, and the other NASA centers could be patched into the OIS network if the test called for their participation. Generally, these remote locations were only able to listen to the test progress; they did not have an active role during tests. They could talk on the problem resolution channels only if their advice was specifically requested. Skip Chauvin said, "They were strictly in a passive mode. They had all the data being shipped back to them, so they were essentially seeing the same things we were. At time we would maybe see a problem at KSC and somebody then says, 'Let's find out what Houston is seeing,' just as backup data. They were there, hand in glove."

Contractors were also listening in on tests and could pull in resources from the manufacturing facilities if needed. Rockwell's Fred Cordia said:

> *There was a backup firing room, the next one over, and they would listen in on certain comm nets and vehicle nets to ensure success. If your primary guy got in a tight spot, a support guy was just a flip of the switch away to talk to, to ensure that this was the right thing to do. They were on the net, but they were not to speak unless spoken to. We also had the design people on the West Coast plumbed into the network in a similar type of arrangement. They had a mission room in at the Rockwell facility at Seal Beach, and the key design people and so forth were there. They were listening only, but if you wanted to talk to one of them, you could.*
>
> *NASA had their own net back to Mission Control at Houston, they were piped in, and of course all the boosters came through MSFC, so NASA had a design crew back there who were plumbed in, listening in. We were all in synch. There shouldn't have been any surprises to anybody, anywhere, because as it was happening, everybody heard it on the net.*

Direct-dial telephone handsets were located near many of the consoles in the firing room, as well as at the pad, VAB, and other sites. To avoid having problems being broadly exposed before people were ready to talk about them with the broader test team, engineers sometimes made calls on their phones directly to a person rather than discussing the problem over the OIS. Dave Moja said:

> *If the stage people had a problem and they put it on the net, we'd hear about it, and people like Frank [Bryan] and I would hover around and try to "help" them. I say "help" with quotation marks, because sometimes we what we did wasn't helpful. So they would do what they called "black phone." They had phone connections out at the pad and in the launcher and wherever their equipment was, and when they were supposed to talk about problems on the intercom, sometimes they'd do a black phone thing, we called it. Actually it was to their benefit. Whenever I talked to them, I said, "Fine. If it isn't an integrated problem, I don't need to get involved in it," and I tried not to.*

Rocco Petrone disliked the black phone and discouraged people from using it. He wanted all problem-solving conversations to be in the open on the OIS. Frank Bryan recalled that, "Rocco insisted that you have your headset on. We'd have a problem, and I'd have a bunch of guys gathered. My phone had a long cord, and I could stretch it way over from my console to the other guys in my row. That was like a red flag to Petrone. He'd say, 'Get down there and get your headsets on. Let's talk about it on the loop so I can hear what's going on.'"

Finally, the OIS system was tied into a public address system around LC-39. Norm Carlson said, "There was a button on the test conductor console I could push, and just go ahead and talk in my headset like I was normally talking, but it would go on the OIS as well as the public address system. You could go just local in the firing room, or broadcast to all areas."

Operational Television

The OTV system allowed firing room staff to monitor hazardous or inaccessible operations throughout LC-39 from their consoles. OTV feeds could be viewed on up to 60 monitors at one time in the firing room. The feeds to each screen were controlled in the communications control room.

OTV cameras were placed in the VAB high bay work platforms 1 and 2 (5 cameras on each platform), the LUT (27 cameras on various levels), the mobile service structure (12 cameras), and pads A and B (12 cameras each). The LUT, MSS, and pad cameras could be pointed by remote control from the communications control room (Fig. 6.14).

THE LCC RAN THE SHOW

The ability to operate much of the launch pad equipment remotely during tests and countdown was a key innovation in the design of LC-39. The firing rooms controlled a vast network of relays, circuits, and electrical support equipment in the launch vehicle, LUT, and the launch pad. These systems distributed and executed commands from the RCA 110A computer complex to operate the ground support equipment and the launch vehicle prior to liftoff.

The LC-39 control system operated as two *complexes* of subsystems: the computer-DDAS-hardwire-terminal countdown sequencer complex, and the transfer-logic-distribution complex.

The Computer-DDAS-Hardwire-TCS Complex

Each control panel in the firing room had a dedicated function. Every panel had a designation, which was stenciled on the panel face, and every indicator light or switch was tied to a single discrete event. There was no automation in the panel, and no flexibility or possibility of multiple uses for a panel other than what was wired into the panel. Each panel was hardwired to the distribution racks in the back room. Any required configuration or functional changes after a panel was certified were made via jumper wires in patch panels in the back room. This was a practice carried over from the telephone industry (Figs. 6.15, 6.16, 6.17, and 6.18).

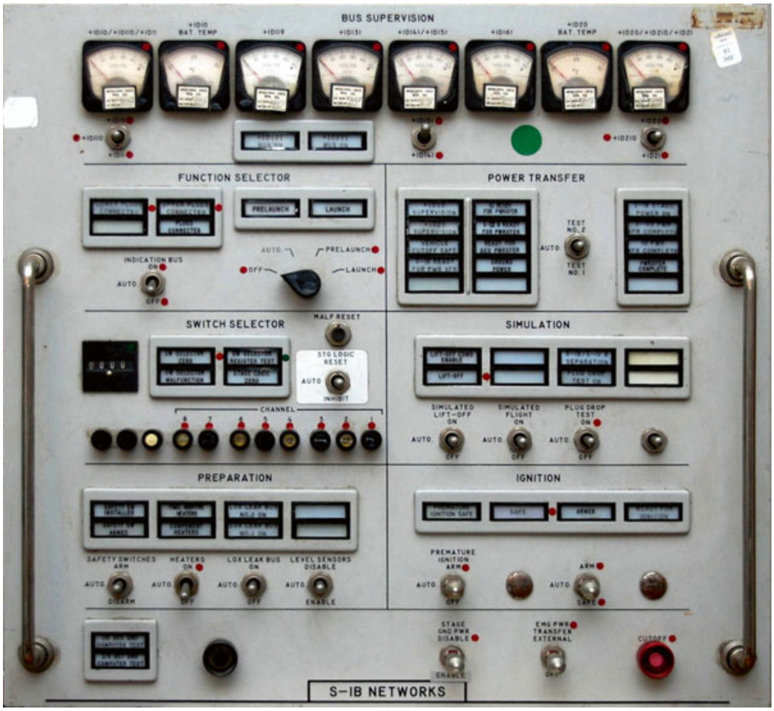
The Huntsville-designed firing room panels had two power sources that were looped to all of the switches and indicators. If a wire broke, the panel would still have a source of power. MSFC mandated this redundancy as a safety ground rule in control panel design.

Many of the test engineer control panels in area B sported analog meters and indicator lights to show the status of a particular system on the vehicle or the ground support equipment. Switches on panels commanded various test functions. Most of the switches had three positions: *ON*, *OFF*, and *AUTO*. *AUTO* was the preferred position, as it allowed the

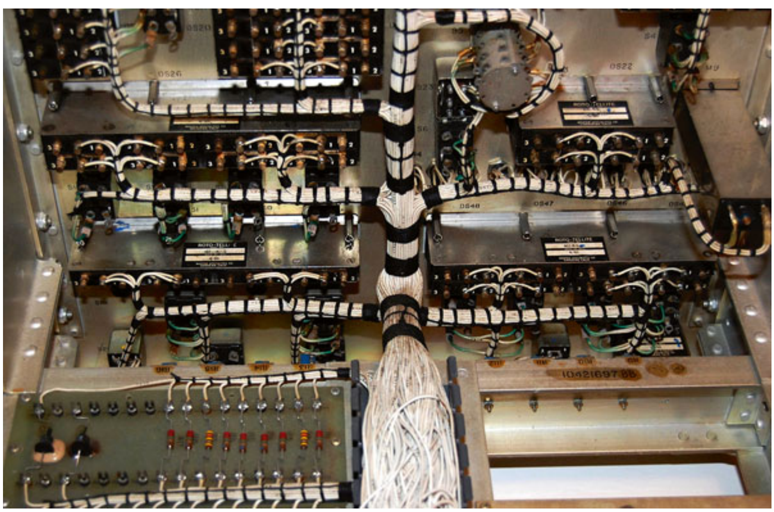
6.14 Operational television switching room in the LCC complex control center room. *Source*: NASA/Jerome Bascom-Pipp

RCA 110A ground control computer to execute a test program or function automatically. Moving a switch to the *ON* or *OFF* positions instructed the computer to energize or de-energize a circuit, immediately overriding the automated test program.

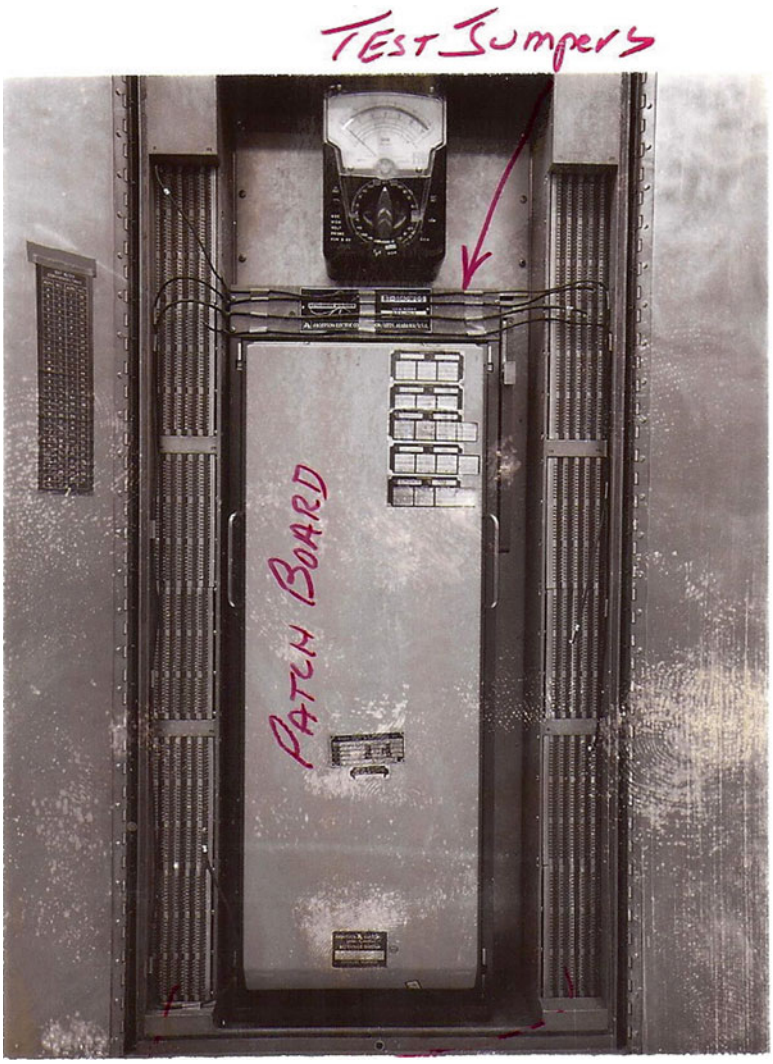
Switches on a few control panels were hard-wired to critical ground support equipment. These switches commanded functions that put the vehicle and GSE in a safe condition if



6.15 *S-IB networks* control panel, used in *Skylab 2*, *3*, *4* and *ASTP* tests and launches (Author's collection). *Source*: Ward



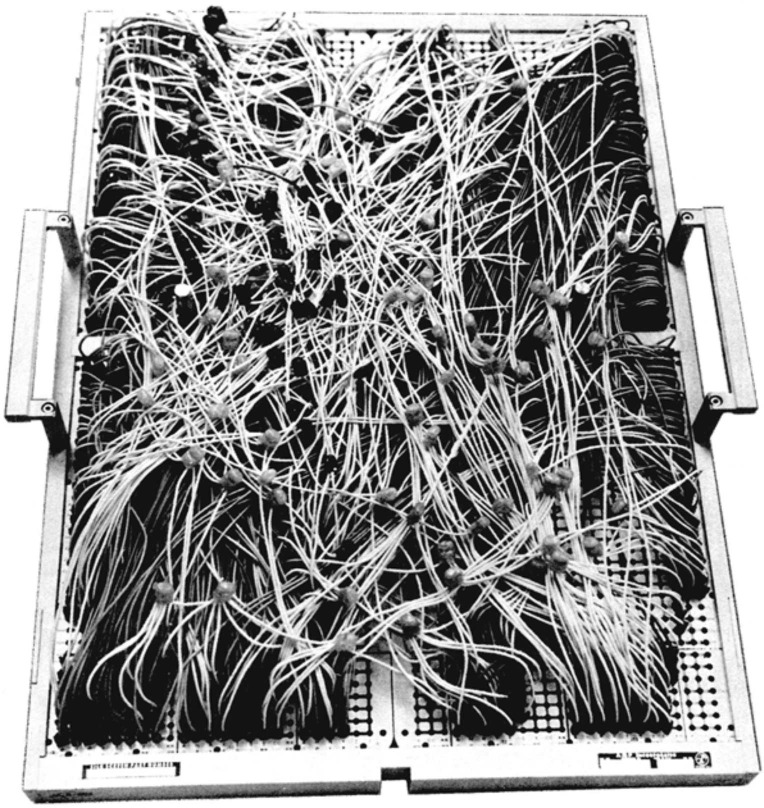
6.16 Back side of the *S-IB networks* panel in Fig. 6.15, showing the intricate wiring. Configuration changes were effected by installing jumpers in patch panels in the distributor racks in the terminal room rather than rewiring the control panel (Author's collection). *Source*: Ward



6.17 Typical patch distributor panel. Plugged into the back of each patch distributor were as many as 60 cables, each carrying 61 connections. The panels routed signals between the firing room, the RCA 110A computers, and the launch support equipment in the LUT and at the pad. Test points on the outside of the panel enabled engineers to test connections without opening the panel. *Source*: NASA/Frank Bryan

the computer malfunctioned, or if the cutoff command was issued in the event of a launch failure. For example, the *S-IB firing* and *S-IC firing* consoles had an emergency cutoff button that would immediately halt the automated terminal countdown sequence from T minus 3 min 10 s until *launch commit* at T-0. This red pushbutton can be seen in Fig. 2.15.

Fourteen computer control consoles were located throughout area B. A switch on a computer control console could initiate the operation of a single component or could start

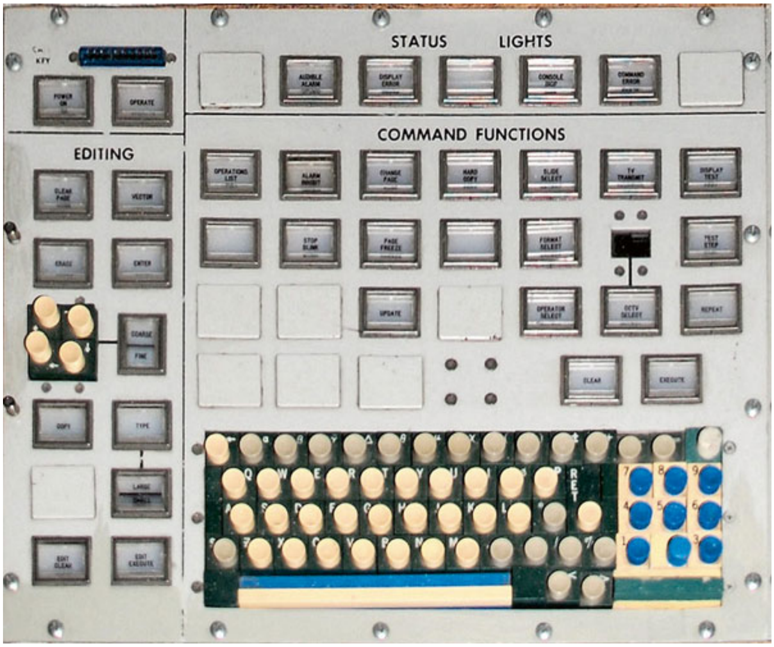


6.18 Patchboard of the type found inside patch distributor panels. Engineers reconfigured circuitry by moving the patch connectors rather than rewiring cables or equipment. *Source*: NASA/Ward

the execution of an entire computer program. The terminal operator first inserted a card key into the console to prevent an improper request to execute a program. Once a test routine was called up, the signal from the terminal went to the patch distributor in the firing room. The signal from the patch distributor was routed through signal conditioning equipment and then into the firing room's RCA 110A computer. The firing room's 110A communicated via hardline link to the 110A computer located in the base of the LUT (which was either in the VAB or at the launch pad). The LUT's computer routed its output through signal conditioning equipment in the LUT and then on to a relay rack for the appropriate stage of the launch vehicle or associated ground equipment. The signal then went to the terminal distribution equipment and a crossover distributor to communicate with sensors on the launch vehicle. The response was sent back to the 110A in the launcher and from there back to the 110A in the firing room, which then routed the information to the appropriate console for display.

All of the firing room console switches were read as discrete inputs by the firing room computer and transmitted over the data link to the LUT computer. The LUT computer would then send a discrete output to the launch vehicle or ground support system that corresponded to the console switch. The response from the vehicle or launch pad system was then sent back to the LUT computer, which in turn relayed it to the firing room computer, which lit an indicator lamp on the engineer's console. When a switch was thrown, the computer would immediately put that function in the condition the engineer wanted. The software being executed would suspend itself and stop sending any further commands. The engineer therefore had ultimate control of his system (Figs. 6.19, 6.20, and 6.21).

6.19 Sanders Associates display console. Area B of the firing room had 14 of these consoles, and there was one in the computer room in area D. These displayed computer program information and test data. *Source*: NASA/Ward



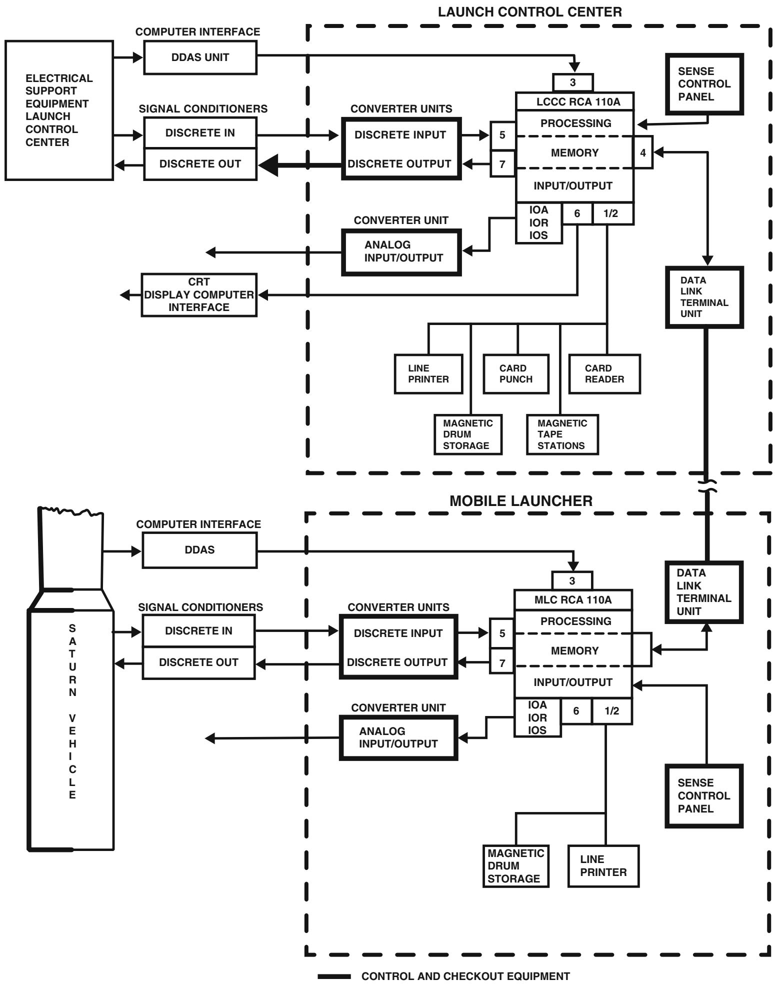
6.20 Keyboard used by test engineers in the firing rooms to execute test programs, request channel changes on the OTV system, or request printouts of data on the Sanders display screens (Author's photo). *Source*: Ward

Terminal Countdown Sequencer

The terminal countdown sequencer (TCS) was a solid-state device housed in the base of the mobile launcher. The TCS provided precisely timed outputs during the final countdown sequence to initiate actions in the electrical support equipment, which then commanded actions in the vehicle and ground support equipment. These included such functions as closing vents to pressurize the propellant tanks, switching from external to internal power, and sending the time-staggered ignition commands to each of the engines on the S-IC. These events happened so rapidly, and in such a critically timed sequence, that humans could not control the process manually.

Frank Bryan said: "The TCS was basically a clock that gave outputs. What the outputs did was controlled in the electrical support system relay logic. If you wanted something to happen at T minus 40 s, you'd take that timed output from the TCS and patch it into the patch panel, and then it would pull in a relay, and then you could do any number of things with that relay logic."

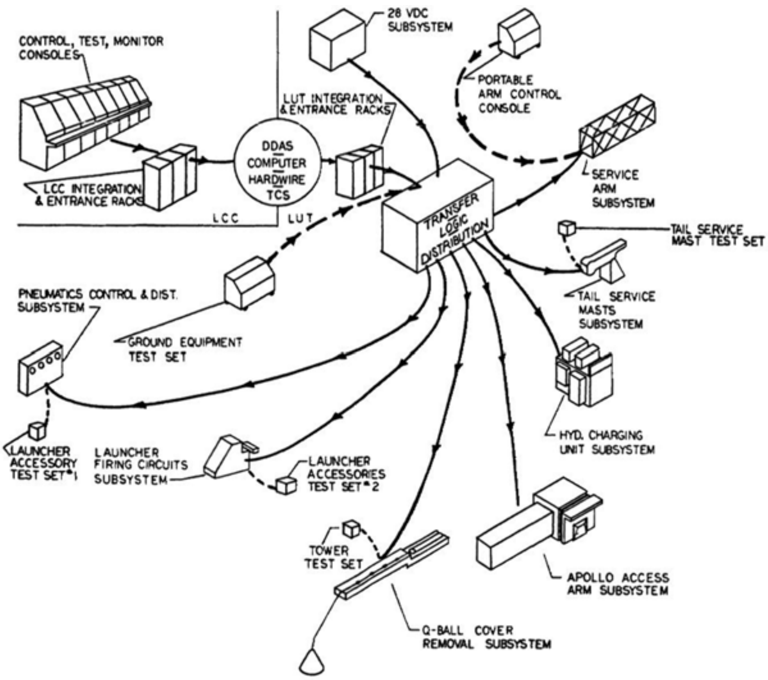
Relay logic acted like an extension of the TCS for controlling the ground support equipment and the launch vehicle. Rather than polling the state of each of the thousands of circuits in the system, the actions of ESE during terminal countdown was dependent on the presence or absence a few dozen interlocks.



6.21 Simplified diagram of the key elements of the Saturn ground computer complex system. *Source*: NASA/Ward

Some interlocks (such as *thrust failure*) could halt the countdown immediately. *Summation* interlocks were circuits that were energized only if a specified combination of other circuits was also energized. For any given interlock to be turned on, all of the prerequisite input circuits also had to be on. As an example, the *LV ready for launch* interlock was only energized if all of the individual stages had their *ready for launch* interlocks energized. One unready stage would prevent the countdown from proceeding past a decision point that required the presence of the *LV ready for launch* interlock.

Once TCS started the terminal countdown, it could only be stopped by a cutoff signal, either given manually or generated automatically by a missing interlock. In emergency situations, an override could allow the RCA 110A to provide discrete outputs to the



6.22 A portion of the electrical support equipment logic distribution system at LC-39. The RCA 110A computer system routed commands from the firing room to the LUT, where the distribution system then sent the appropriate signals to launch support equipment. *Source*: NASA/Ward

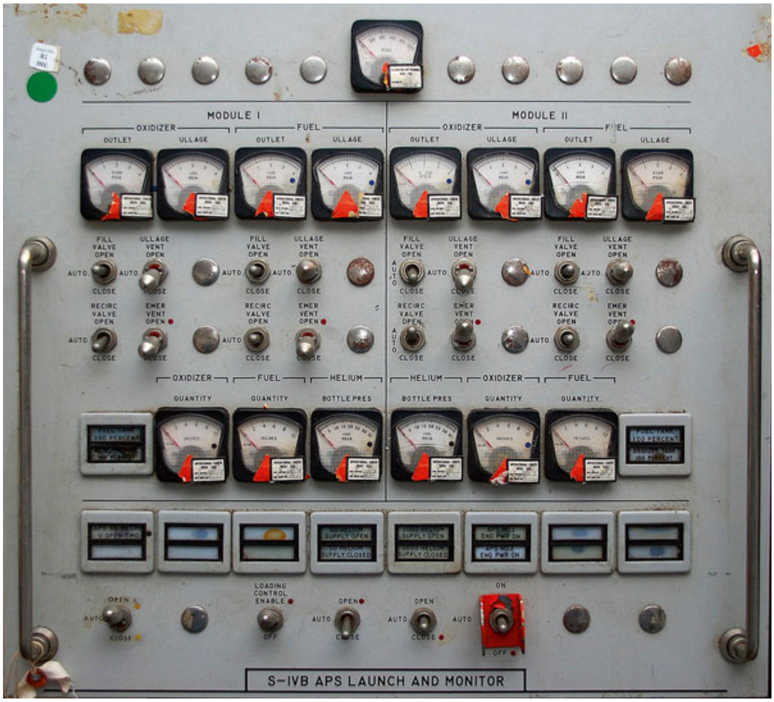
electrical support equipment, but this capability was only used one time in actual Saturn V launch countdowns. Otherwise, the Saturn ground computer complex had no part in the terminal phase of the countdown.

The Transfer-Logic-Distribution Complex

The transfer-logic-distribution complex took commands from the LCC consoles, computer, and test equipment in the LUT, and then activated systems on the LUT, pad, and launch vehicle. The logic in this immense distribution network was implemented entirely in relays and hardwire jumpers in distribution and relay racks in the firing room and the LUT—there was no computerization in the distribution system at all. A simplified version of just one portion of this vast electrical network is shown in Fig. 6.22.

The System in Operation

This section provides a sample of the range and scope of control of just two of the hundreds of panels in the firing room. One panel we will look at controlled functions on a stage and



6.23 The *S-IVB APS launch and monitor* control panel from area B, row B of the firing room. The McDonnell Douglas engineer at this panel tested and monitored the propellant system on the S-IVB's auxiliary engines. This particular panel was last used in firing room 3 for the *ASTP* test and launch (Author's collection). *Source*: Ward

its supporting equipment, and the other controlled some of the ground support equipment in the LUT that served the entire launch vehicle.

Our first example is the *S-IVB APS launch and monitor* panel. During the *ASTP* test and countdown, a McDonnell Douglas engineer, call sign C4AL, ran this control panel from his station in firing room 3, area B, row B, console 16. This panel controlled the vents and valves and monitored the pressures of the hypergolic propellant systems for the APS engines (referred to as APS modules) on the S-IVB. The two APS modules helped steer the S-IVB in flight and also performed ullage burns to settle the propellants in the S-IVB's main tanks before engine restart at trans-lunar injection. Helium bottles on the stage pressurized the APS propellant tanks (Fig. 6.23).

Let's look at the circuits controlled by four of the many switches on this panel. Just to the right of center in the upper half of the panel are 2 meters displaying pressures in two segments in module II's oxidizer system. Beneath these meters are two switches that controlled valves in the system and two switches that opened vents. The simplified circuit diagram shows the action of these four switches. Any test engineer would have to know many of these circuit diagrams intimately before being certified to operate a control panel (Figs. 6.24 and 6.25).

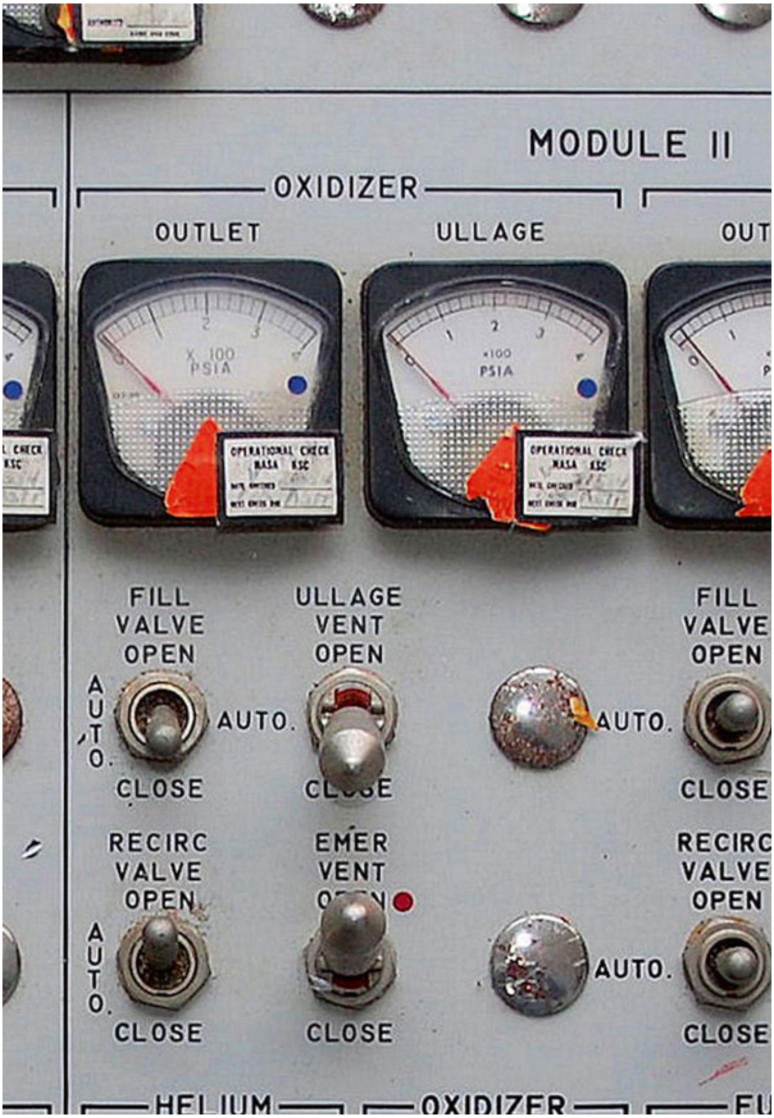
The leftmost part of the diagram shows the circuits controlled by the o*xidizer fill valve* switch. If the switch is placed in the *CLOSE* position, the RCA 110A computer is commanded to energize circuit D12321 in the ESE, which closes the valve. In the *OPEN* position, the computer energizes circuit D12320 and opens the valve. With the switch left in the *AUTO* position, the computer has discretion to command the ESE, via relays K800-2 and K952, to operate S-IVB oxidizer tank II's fill and drain valve as commanded by the computerized test program.

At the right of the circuit diagram is the *oxidizer ullage emergency vent valve* switch. As shown in the diagram, this switch has a hardwire connection that bypasses the RCA 110A computers in the firing room and the LUT. Throwing the switch directly energizes relay K960 in the ESE to open the emergency vent valve on the S-IVB. This action would only be taken if there were a loss of computer control over the tank pressure on the S-IVB prior to launch. As a safeguard, these hardwire switches have to be pulled back to unlock them before they can be flipped into another position (Figs. 6.24 and 6.25).

In our second example, we will look at the *pneumatic distribution system* console, which was located at position BC28 (area B, row C, position 28) in the firing room. The Boeing test engineer who manned this panel had the OIS call sign CPDC, pneumatic distribution complex control console. His control panel was divided into sections that monitored the gaseous helium distribution system, the gaseous nitrogen distribution system, the Q-ball removal system, the nitrogen-fed service module deluge purge system, and valve panels 11 and 12 on the LUT.

Analog meters, fed by the digital data acquisition system and converted to analog information for display, gave the CPDC test engineer real-time information on gas pressures in the various pad systems. *CLOSED-AUTO-OPEN* switches would normally be left in the *AUTO* position to allow the RCA 110A computer to run its test programs. However, he could override the program and manually command gas inlets and outlets to open or close if necessary. Indicator lights displayed the status of approximately 50 discretes associated with the systems (e.g., 6,000 psi GN_2 supply valve open, balance valve closed, etc.). Although he could not manually command any actions on valve panels 11 and 12, which were located in the high-pressure pneumatic center compartment 1B in the mobile launcher, he could monitor the overall status of the systems fed by the panels. He could also issue instructions over the OIS to other engineers who had direct control over the valve panels. The diagram illustrating the pneumatics control and distribution system shows the extent of the ESE and GSE operated and monitored by a single test engineer at a single control panel in the firing room (Figs. 6.26 and 6.27).

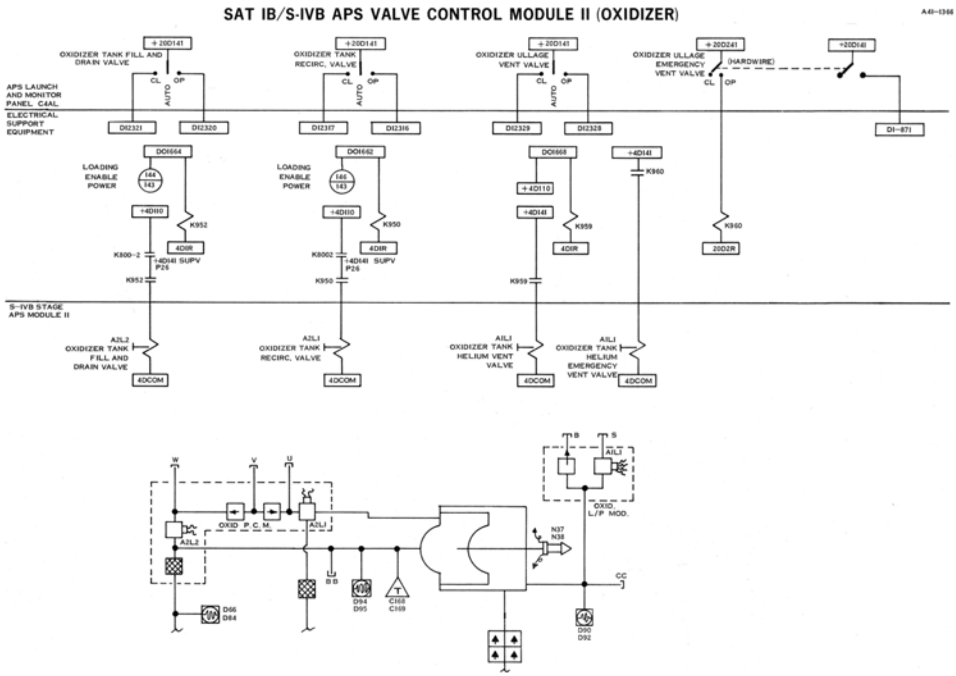
These were just two of about 100 test control panels in area B, each of which was dedicated to controlling, testing, and monitoring its own specific piece of the ESE, GSE, or launch vehicle systems. Using these panels, the computer consoles, and the OIS, test conductors and the engineers in the firing room were able to test and control all critical operations at the launch pads from a facility more than 3 miles away. Similar types of test consoles were also located in the VAB, LUT, propellants facilities, and other locations around LC-39.



6.24 An enlargement of a section of the *S-IVB APS launch and monitor* panel, showing the controls for the oxidizer system on APS engine (module) II. *Source*: Ward

ACTIVATING THE LCC

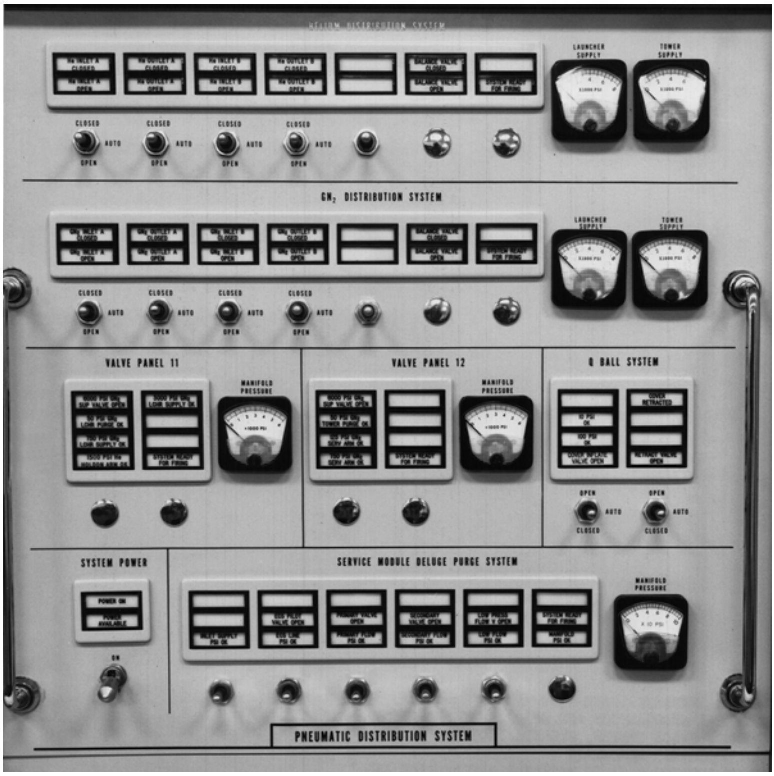
Simultaneously activating the equipment in both the firing room and the VAB during 1965 and 1966 was a laborious process. Rockwell engineer Rich Robitaille's experience was shared by hundreds of other workers getting LC-39 ready to support its first launch operations. He recalled:



6.25 A simplified circuit diagram showing how the switches shown in Fig. 6.24 panel commanded the S-IVB stage and the computer. The circuit at right shows a hardwire connection, which bypasses the computer when necessary to take emergency control over the stage. *Source*: NASA/Ward

I got to spend most of my time during that period helping guys from all the contractors install those panels and wire them. There were engineers, technicians, and quality control people. The QC guys and technicians were non-degreed, highly skilled technicians that did most of the grunt work. Our engineer always had to sign off on their work. Most of the technicians were five to ten years older than me. I helped them and worked with them and learned a lot. They really taught me what this stuff was all about, since I had no experience in wiring per se.

We had to go in and work with the 110A and learn about that computer and how it works. We all had to start running test procedures. We each had our subsystem and our panels to work with. If you had a software glitch in the computer, you might not have a connection between your switch and out to your panel and the vehicle. If your meter didn't go on, you spent maybe three days trying to troubleshoot why the meter didn't have an indication. And the first thing you blamed was the computer! They had some problems with the computer, but most of the problems were in all that wiring, wires after wires, that went from the computer to the stage. The mechanical guys worried about pipe after pipe, and they absolutely hated the computer. IBM knew

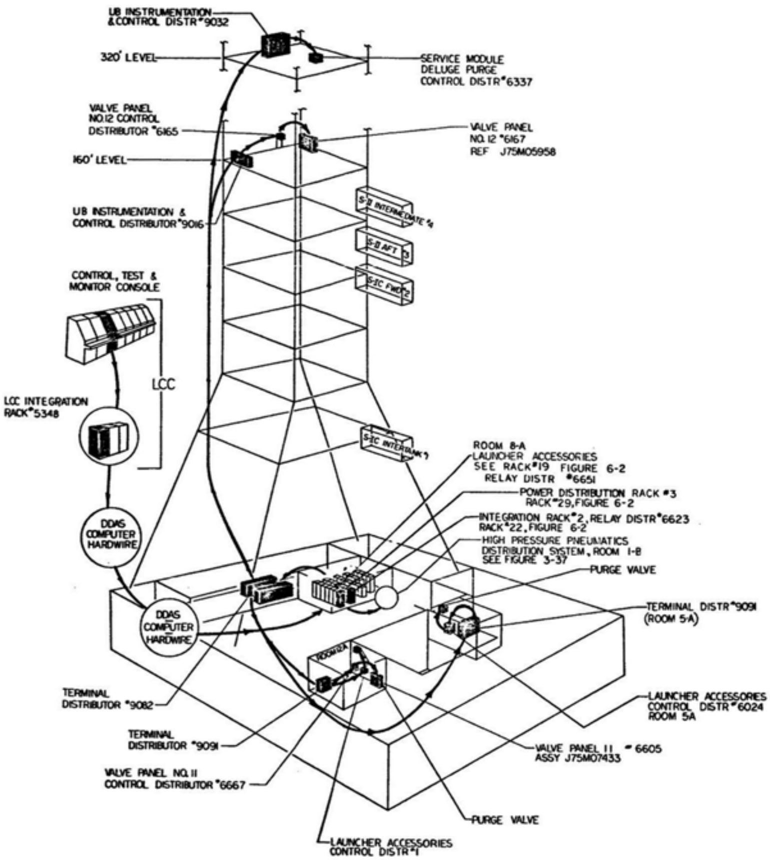


6.26 The *pneumatic distribution system* control panel from area B, row C, of firing room 1. *Source*: NASA/Ward

what they were doing, but every time something happened, people would say, "That computer screwed up again!"

Everybody was getting honed down to a fine team. Everybody was working together, your procedures are talking on the net, the troubleshooting procedures, everything was starting to become like test pilots – people that have been around for years. The activation was where all the bugs were worked out, because there was no vehicle out there. We spent probably a year just activating.

We activated the launch control center at the same time that we went out to the mobile launcher. When you had a problem, the mobile launcher was inside the high bay, so you just had to go up to the 16th floor, where our offices were. We could walk right out from our office into the high bay, and go work on the system. You've got one guy in the LCC and the other one in the high bay, working together on the intercom, trying to figure out "How come when I flip that switch I don't get a light?" and you have to start working backwards. All that wire mishmash in the panels – you might have a wire that was bad in the panel, and you had to pull the panel. And the technician would find out that a wire wasn't soldered properly. There was a lot of

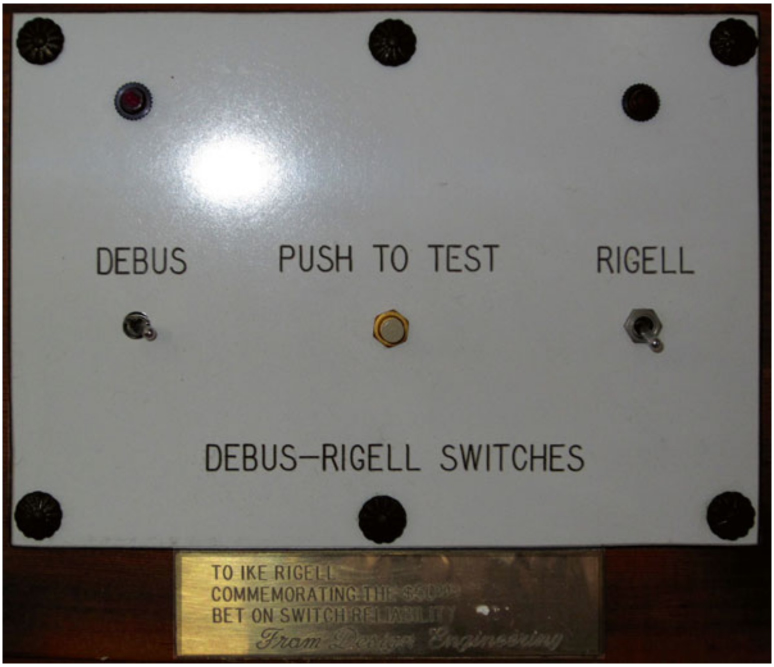


6.27 Schematic diagram of some of the LUT and pad systems controlled by the *pneumatic distribution system* panel shown in Fig. 6.26. *Source*: NASA/Ward

work to figure out just where the problems were. That's what a lot of our time was spent doing for most of a year.

Frank Bryan helped shake out the equipment:

When we first fired up the ground equipment out at LC-39, and all the stage contractors were trying to check out their equipment and make their panels talk to the relay racks on the LUT, I got some troubleshooting paper opened up. I went through and functionally operated these ON-OFF-AUTO switches in the firing room in every sequence you could think of, just to make sure what was going to happen. Every contractor in that firing room dialed in and listened and took notes. That was good, because it actually showed them. It's one thing to have the drawings say it's going to do this, and another thing to actually see it happen, particularly with the 110A – nobody trusted it.



6.28 The switch panel made by KSC design engineering to commemorate Dr. Debus' $50 bet to Ike Rigell on switch reliability in the firing room (Author's photo). *Source*: Ward

Ike Rigell, in his role as chief engineer for launch vehicle operations, was understandably conservative in his assessment of the readiness of the 110A system to support launch operations at LC-39. Kurt Debus sometimes chided him about being too cautious. During the activation of firing room 1, Rigell recalls, "I was hesitant to start one test because I wasn't sure the control room was ready. Dr. Debus said, 'Ike, take any switch here. I'll bet you $50 that if I go flip it, it will work.' I couldn't take that bet, because I figured he was right! It was his devil's advocate thing, to see if you really could support your position. One of the guys made that little panel as a result of our back-and-forth on the amount of testing." (Fig. 6.28).

Dave Moja recounted his impressions of some of the difficulties and pressure associated with activating the firing rooms:

> *Firing room 1 was activated for the first Saturn V launch. We were trying to get all the electrical equipment ready, and Randy Youmans was the guru of doing all that testing. Ike Rigell and Dr. Debus sometimes would come in. Of course we were always in a hurry to do everything. It took literally months.*
>
> *And then it became my task to lead the parade to activate firing room 2 for the second Saturn V launch. And all the emphasis was still on firing room 1. I often said, "If we had that problem in firing room 1, we'd be off in a room trying to explain it to*

> *100 people, all of us trying to figure it out." For firing room 2, a group of us called the* Flow Two *people were off by ourselves. We had just as many problems, but we were able to just work it out ourselves without the spotlight on us.*

ABOUT THAT *SPACECRAFT READY* LIGHT…

A lone test conductor from spaceflight operations/preflight operations branch in the firing room during a launch countdown. This was usually John Heard, although Charlie Stevenson and another test conductor also manned the station at times. While Heard was in the firing room at the Launch Control Center, his colleagues were all at their consoles in the ACE control room in the MSOB, nearly 5 miles (8 km) away.

When instructed by Skip Chauvin at about T minus 7 min, the spacecraft test conductor in the firing room flipped the *spacecraft ready* switch on his console. Bob Sieck said:

> *We spacecraft folks had two people in the Launch Control Center. One was our director of spacecraft operations, who was a member the mission management team on the top row. Then we had an engineer whose job it was to throw a switch that lit a light up on the big display board that showed either spacecraft as green or spacecraft as red (which would be* no go), *or the light was totally off. That was his only job. And he did that only at the direction of Skip Chauvin in the ACE control room in the MSOB. That engineer and the director were the only spacecraft people who were in the Launch Control Center, for all the tests and launches.*

Spacecraft ready for launch was one of the interlocks for the electrical support equipment logic. As originally designed and built, that interlock was energized when the switch on the *spacecraft operations* control panel was flipped. What the people from spacecraft operations may not have known was that during much of the Apollo program, their *spacecraft ready* switch did absolutely nothing other than light the green light on the big display board.

The story goes that there was a procedural near-miss during one countdown. All indications over the OIS showed that the Apollo spacecraft was clearly *go*. However, for one reason or another, the spacecraft test conductor in the firing room did not receive instructions from spacecraft operations to throw the switch at the appointed time. The *spacecraft ready for launch* interlock was not energized in the ESE logic chain, which would have halted the countdown at an upcoming decision point. Test operations director Paul Donnelly was informed of the situation, and he ran over to the spacecraft test engineer and demanded that he throw the switch. After an initial objection, he complied just in time to keep the countdown running. The incident provoked a heated discussion between members of the mission management team after the launch.

In the weeks following the launch, the *spacecraft ready* switch in the firing room was quietly patched out of the terminal count ESE. A technician installed a jumper in the LCC terminal room to bypass the output from the spacecraft panel to the ESE. The *spacecraft ready* switch continued to operate the lights on the critical events display, but it no longer had any effect on the countdown sequence. The official explanation given was that the switch in the firing room was redundant to the information coming directly from the ACE control room. The spacecraft test conductor in the firing room could call for cutoff if he needed to stop the countdown, but his one switch was rendered—without his knowledge—merely ceremonial.

7

Launch Pads 39A and 39B

INTRODUCTION

We've seen the facilities where the spacecraft and the launch vehicle were assembled, tested, and integrated into the space vehicle. Now, it's time to look at the place where the Apollo/Saturn V spent its final 2 months on Earth in the Florida sun: the launch pad. This section of the book will explore the LC-39 launch pads and their supporting facilities. We will also hear first-hand accounts of the challenges of working at the launch pads during the Apollo years.

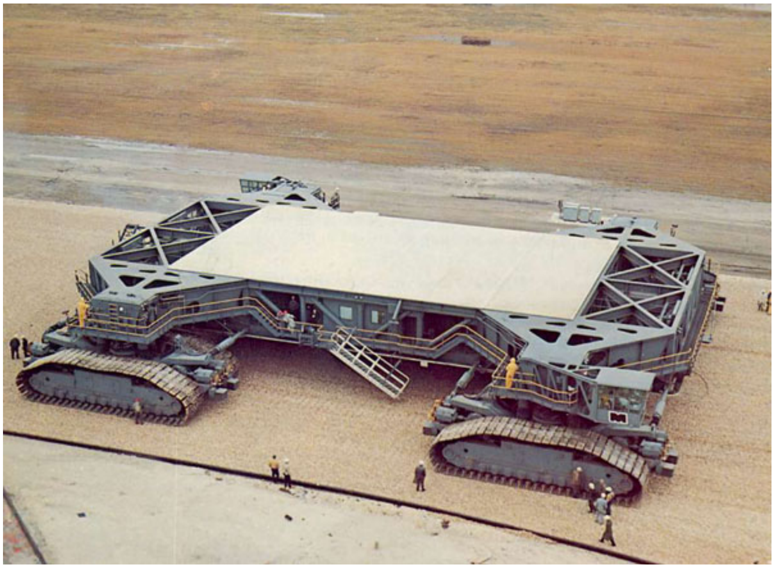
As with everything else in the Apollo/Saturn program, the scale of the launch facilities is difficult to fathom, even when seen first-hand. The construction of pads A and B and the facilities to access and service them at Launch Complex 39 was one of the largest civil engineering projects of the twentieth century. This "rocket ranch," crown jewel of American space superiority, was the home of the *pad rats*—men (and a few women) who spent months at these overwhelming facilities enduring heat, humidity, intense sun, insects, snakes, alligators, lightning, bone-chilling cold, and abundant manmade dangers.

You will read many first-hand accounts from Apollo/Saturn engineers and technicians in this section of the book. Aside from being interesting stories in their own right, these recollections are intended to demonstrate that the success of the Apollo program was due to a marriage of technology and human ingenuity and adaptability. The best-designed facilities of the 1960s could not operate themselves. The diligence and perseverance of the people on the ground ensured the Apollo program's success.

THE CRAWLER/TRANSPORTER AND CRAWLERWAY

The first piece of equipment we will look at was the crawler/transporter (usually referred to simply as *the crawler*). This mammoth vehicle carried the LUT and space vehicle from the VAB to the launch pad. Two crawlers were constructed for Apollo/Saturn operations at Launch Complex 39. With overhauls to support the Space Shuttle and now the Space Launch System, they are still in use today (Fig. 7.1).

J.H. Ward, *Rocket Ranch*, Springer Praxis Books, DOI 10.1007/978-3-319-17789-2_7



7.1 One of the crawler/transporters in 1966. *Source*: NASA

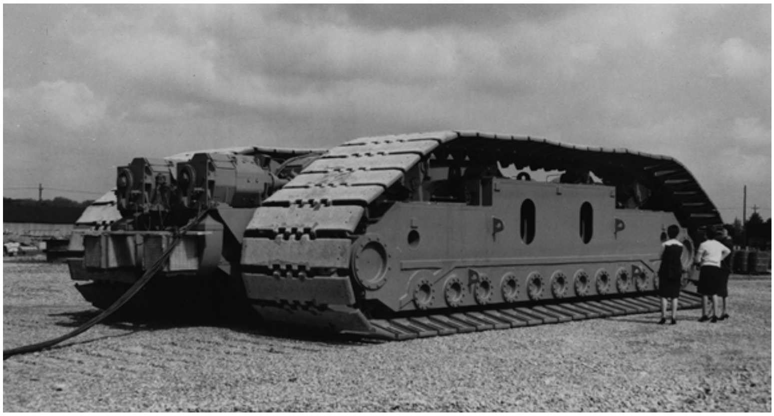
Design engineers explored a number of different options for transporting the LUT and space vehicle from the VAB to the pad. One option was towing the LUT on a barge. That idea was discarded after analysis showed there was no way to work around the combined system being top-heavy and prone to capsizing. A rail system was also considered but not pursued.

The design of the crawler was inspired by a 1962 visit of KSC leaders and engineers to a strip mine. Ike Rigell recalled, "I went up with Dr. Debus to a strip mine in Kentucky to look at this big shovel. That thing was humongous! It had huge cables power, because its generator wasn't on board. But out of that visit came the crawler." Renowned KSC engineer Donald "Buck" Buchanan also went along on that site visit, and it inspired his design of KSC's crawler system.

Each of KSC's crawlers weighs approximately 6,000,000 lb [2,700 t], and is 131 ft (40 m) long and 114 ft (35 m) wide. Its deck height is adjustable from 20 to 26 ft (6–8 m). The crawler deck rides on four double-tracked *trucks*, each 10 ft (3 m) high and 40 ft (12 m) long. There are 57 *shoes* (cleats) on each track, and each shoe weighs about 1 t (Fig. 7.2).

Two driver cabs jut out on diagonally opposite corners of the crawler. In the Apollo era, the driver's controls were relatively simple, including windshield wipers, an accelerator, brakes, two-way radio, and an adjustable seat.

The crawler's interior volume was almost completely taken up with engines and associated equipment. Two primary diesel engines provided 5,500 hp (4.1 MW) for the main drive. Two other diesel engines, producing 2,130 hp (1.6 MW), powered the systems to level and jack the crawler deck, steer the crawler, and provide ventilation. Auxiliary generators in the crawler supplied electrical power to the LUT during transportation. The engineer room inside the crawler contained the gauges and controls for these systems.



7.2 One of the four tractor sections of the crawler/transporter. *Source*: NASA/Jerome Bascom-Pipp

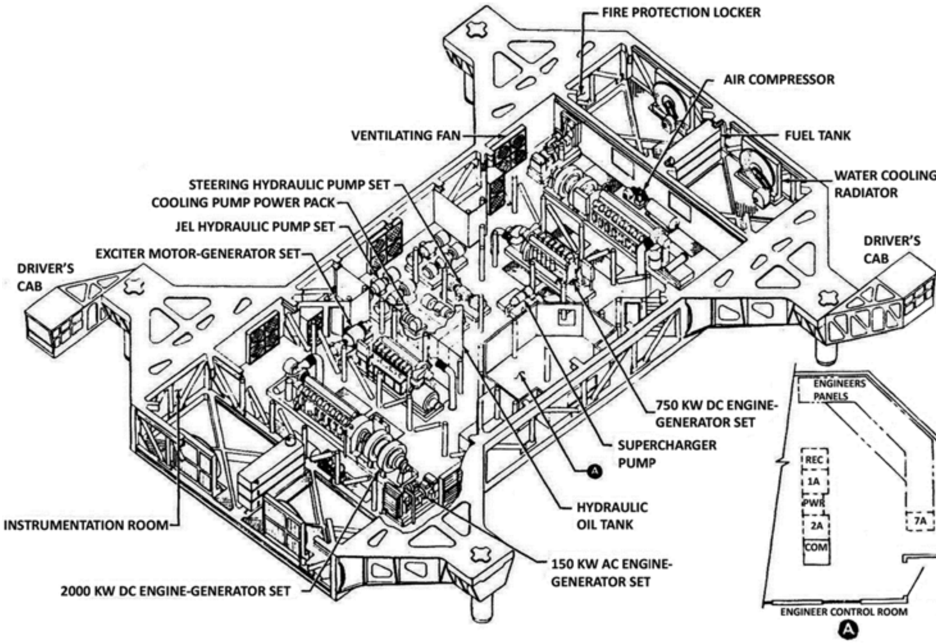
In the Apollo era, a crew of 14 manned the crawler when it was in operation. It took 90 min to warm up the engines and start up the various pneumatic and hydraulic systems before the crawler was ready to move (Fig. 7.3).

Firemen rode on the crawler and LUT on the trip out to the pad to monitor the fire protection systems. A dry powder extinguisher system protected the engine compartment. After an automatic system dumped 500 lb (227 kg) of powder into the engine while the crawler was moving in one early test, NASA switched to posting a fireman who could set off the system manually if necessary.

A fireman also rode on the umbilical tower during rollout, since there was no water while the crawler was in motion. Technicians maintained equipment at various levels of the tower, and the elevator was still active even while the crawler was moving. Lee Starrick said, "The crawler motion caused the tower to have some kind of a harmonic, and it would shake. You could be up there hanging onto the rail, and the whole thing would be shaking. It produced a tone the whole time they were moving." (Fig. 7.4)

Russ Lloyd explained the systems for keeping the crawler's load level during transport:

> *One system was very rudimentary. It was comprised of two great big mercury manometers, and they ran diagonally from corner to corner. Each was a Plexiglas tube and then a pipe that ran diagonally all the way across the crawler. The system was full of mercury, and it was very well sealed and all the piping was solid. Then, diagonally the other way, you had another mercury manometer.*
>
> *Our primary leveling system was jacking cylinders on the four corners. We kept it level by monitoring the pressure in the jacking cylinders. We had a very rudimentary control system, but it was sufficient to balance the pressures once we told it what pressures we wanted.*



7.3 Schematic drawing of major equipment inside the crawler/transporter. *Source*: NASA/Ward

7.4 *Apollo 14* CDR Alan Shepard in the engineer control room of a crawler during the rollout of *Apollo 14*, November 9, 1970. *Source*: NASA/Jerome Bascom-Pipp

NASA built a special road (the *crawlerway*) to accommodate the enormous combined weight of the crawler, LUT, and Saturn V, which was in excess of 16 million pounds [7,250 t] altogether. The crawlerway is two 40-ft-wide (12 m) lanes separated by a 50-ft (15 m) median strip. The overall width of the crawlerway is about that of an eight-lane highway. The roadbed is approximately 7 ft (2 m) deep. The crawlerway runs from the VAB to the present-day observation gantry (formerly the MSS park site), where the crawlerway splits into separate paths leading to pads A and B. The distance from the VAB to pad A along the crawlerway is about 3.5 miles (5.6 km). Moving at a top speed of about 1 mph [1.6 kph], the crawler took about 5 h to carry the LUT and Saturn V from the VAB to the launch pad.

Lloyd described one of the issues encountered while building of the crawlerway: “The crawlerway was a design challenge in itself, because of the immense weight of the crawler/transporter plus the launch vehicle and LUT, or with the mobile service structure. They had to excavate down, get rid of all the Florida muck, and then backfill it with good material. About a mile or a mile and a half out there along the crawlerway, there was a spot with underground water flow. In order to protect the sub-base and keep us from having a dip in the crawlerway, we had to put in sheet piles to stop the water flow across the material.”

Another challenge to the army corps of engineers in building the crawlerway was the top course of rock. The corps specified rounded glacier run rock, which would minimize friction on the crawler’s tread shoes, each of which weighed 1 t. Transporting glacier run rock from Montana or North Dakota to Florida was far too expensive. NASA settled for Alabama river rock, which shared most of the desired characteristics and worked well. The surface coat has been redone several times since Apollo, most recently in 2013 (Fig. 7.5).

When being transported by the crawler/transporter, the mobile launcher was supported by four interfaces on the lower deck. At the launch pad, the LUT rested on six mount mechanisms, which were located along the perimeter of the launcher on its underside. A tapered centering pin with a maximum diameter of 9 in. (23 cm) ensured that the launcher was properly aligned with the mounting mechanisms at the launch pad. Four of the mount mechanisms were on extensible columns that acted like hydraulic jacks and absorbed additional weights of fuel and changes in dynamic load as the vehicle was being fueled.

MOBILE SERVICE STRUCTURE

Another unique component of Launch Complex 39 in the Apollo/Saturn era was the ungainly mobile service structure (MSS, pronounced “miss”), which served several functions during space vehicle processing at the launch pad.

The LC-39 MSS was initially called the *arming tower*, because its original intended purpose was to support installation of the explosive ordnance that would destroy the Saturn V in the event of an in-flight abort. The MSS’s role broadened as the designs for LC-39 and Saturn V evolved. Its most important role became to provide access to the parts of the exterior of the spacecraft for testing and servicing at the launch pad, and also to protect the spacecraft from the elements. Bob Sieck said of the MSS, “We knew early on we were going to need something like that to work on the spacecraft at the pad. It wasn’t the kind

7.5 As *Apollo 14* rolls out to pad A, it passes the intersection of the crawlerway paths leading to pad B (*left*) and the MSS park site (*bottom right*). *Source*: NASA/Kipp Teague

of thing we could do with just some scaffolding from the LUT from the swing-arms. We were going to need room for a LOT of equipment."

The MSS was huge and massive. It was 402 ft (123 m) tall and weighed 12 million lbs. (5,443 t). The base of the MSS was 135 ft (41 m) square. It weighed more than the LUT and unfueled Saturn V combined.

NASA's launch facilities at LC-34 and LC-37B both had service structures that were mounted on wheels and could be rolled into place around the launch vehicle or back out of the way during launch. The LC-39 MSS too large to wheel into position on its own; it had to be moved by the crawler. The MSS sat at a park site near the intersection of the crawlerways leading to pads A and B when it was not needed at the launch pad.

Within 24 hours after the space vehicle and LUT arrived at the pad from the VAB, the crawler transported the MSS to the launch pad and parked it there on support posts south of the LUT. The MSS stayed in place until the countdown demonstration test, when it was moved to the foot of the launch pad. The crawler put the MSS back into place on the pad after the CDDT, and the MSS remained on the pad until the final hours before launch.

When parked on the pad, the MSS was hooked up to power, data, communications, water, and hypergolic fuel lines. An ACE facility in the base of the MSS communicated with the ACE rooms in the MSOB during spacecraft tests.

Three elevators ran up the outside of the MSS. Their open-cage, high-rise cabs accommodated both equipment and passengers. Many people were nervous about riding in them. Russell Lloyd said, "We had a stabilizer bar on the counterweights for the elevators, because the cabs could start moving around if the wind was blowing. About halfway up, you'd hear this *clang*! as the counterweights either picked up or dropped off the stabilizer bar. We facilities guys got used to it, because we rode it all the time. Other people had a problem with it."

John Tribe recalled that the MSS elevators were prone to stopping on random occasions, the doors suddenly opening out to nothingness. Tribe said, "You quickly learned not to lean against those doors!" Sieck added: "We spent a lot of time going up and down the elevators on the service structure. They weren't that reliable. One time, the elevator that I was in with two other guys suddenly stopped between the stages, and the doors opened on both sides. Beautiful view, but you know we're up there 200-something feet up, with nothing to hold onto. We were crawling on our hands and knees! The breeze is blowing. You're thinking, 'Don't look up! Don't look down! Sooner or later, somebody will rescue us.'"

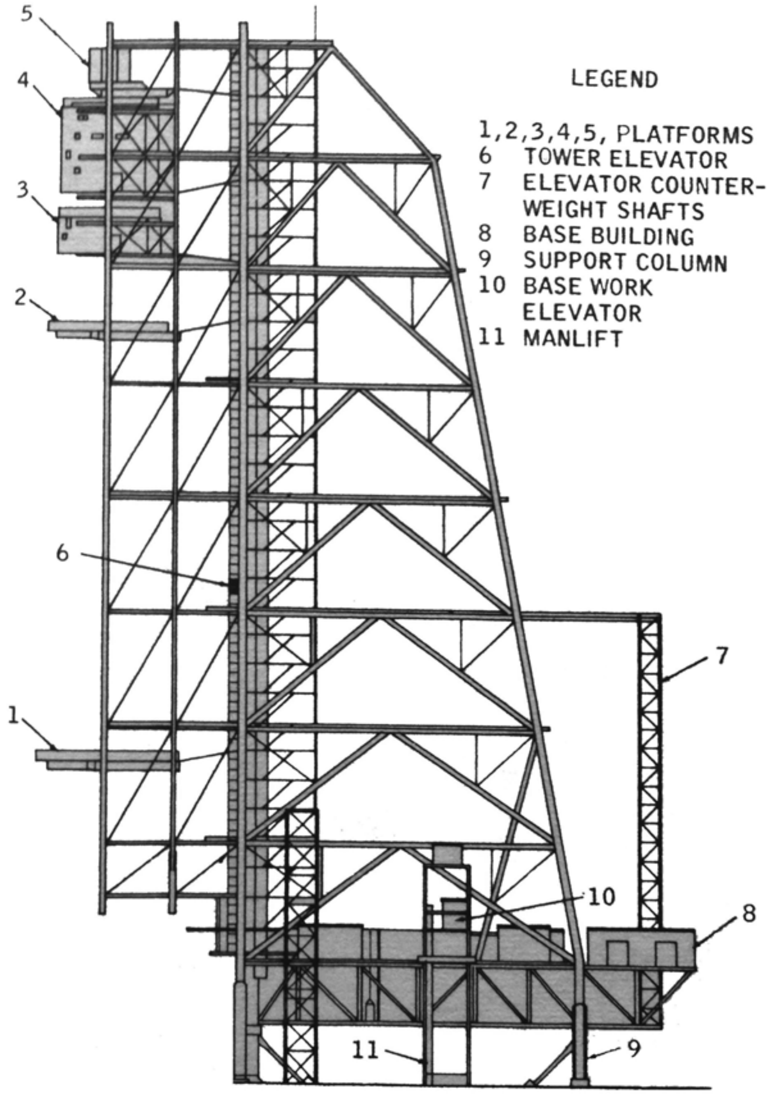
An endless belt man-lift system, designed to take people from the launch pad level to the first level of the MSS, was also considered extremely unreliable and hazardous. At times, people stepped onto the man-lift, expecting to go up, only to be dropped into a fenced-in enclosure at the bottom of the structure.

Five work platforms on the MSS provided access to the space vehicle. The outboard sections of the platforms were open as the MSS was moved into place, and the platforms closed to encircle the vehicle once the MSS was parked (Figs. 7.6 and 7.7).

The lower two platforms could be adjusted up and down on hydraulic cylinders to service different stages of the Saturn V. These lower platforms were open to the elements and bounded by chain link fences. The two lower work platforms were used for installing Primacord and linear shaped charges in the propellant dispersion systems on the S-IC, S-II, and S-IVB stages of the launch vehicle.

The upper three platforms were clamshells that completely surrounded the spacecraft with environmentally controlled work areas. The lowest of these three spacecraft platforms serviced the SLA and the lunar module. The next platform up consisted of two floors of compartments that provided access to the command and service modules. Getting from one level of this platform to the other involved stepping outside and climbing or descending a ladder, if a worker did not wish to wait for the MSS elevator. The uppermost MSS work platform surrounded the launch escape system tower. A gangway on top of this platform gave access to the Q-ball, mounted at the tip of the LES.

Tribe said that the deck atop the uppermost platform could be a scary place for people who were afraid of heights: "I sent one of my guys up on the MSS. Right at the very back



7.6 A simplified schematic of the MSS showing the work platforms. Platforms 1 and 2 could be moved vertically. *Source*: Author's adaptation of NASA diagram

on the top level were valve boxes that interfaced with the S-IVB APS system, and he had to go up there and maintain those boxes. We had to go get him and bring him down. He was frozen in place, absolutely couldn't move."

The upper work platforms afforded the primary means for the spacecraft contractors to access the CSM and LM for servicing equipment and loading propellants. One could access the command module's crew compartment by walking across swing arm 9 from the LUT to the White Room, or by entering the White Room from a door leading from a work

7.7 The MSS and crawler on the launch pad ramp. *Source*: NASA/Ward

platform on the MSS. The lower part of the SLA could be entered from swing arm 7 via the instrument unit. Access to any part of the CSM other than the crew compartment or the SPS engine bell was only possible from the MSS work platforms.

Hypergolic fuels were supplied to the spacecraft and to the auxiliary propulsion system on the S-IVB via a propellant loading system on the MSS. Dick Lyon recalls that the systems originally designed by Houston for servicing the spacecraft propellants and cryogens did not work:

> *There were valve boxes and control boxes and so forth attached to piping running all up the structure, and servicing equipment sitting down on the bottom. We kept saying, "This is not going to work!" We couldn't get anybody's attention, so we built it the way we were told to do it. When they first tried to service the spacecraft propellants,*

> *they got nothing but little fumes coming up to the spacecraft. There was no fluid. They were trying to pump it 400 feet (122 m) through a 1/2″ (1 cm) tubing coming up through the MSS. It just would not pump more than 20 feet (6 m).*
>
> *We stepped in at the very last minute, and in a very short time, to redesign everything. We took out all the piping and structure we'd put in. We put in mid-station pumps and much larger lines. All this servicing gear was mounted on the very lowest level of the MSS. The original thought was putting the servicing gear on an elevator and taking it up there and servicing it up there. But you really didn't want to be hauling several hundred pounds of hypergols around! So we KSC guys got very entwined in designing interfaces between Houston's ground hardware and Houston's spacecraft, which created a lot of mods to both.*

The servicing systems at the spacecraft platforms were a jumble of equipment and flex hoses for loading propellants into the CSM and LM. Although Rockwell tried to have as much hardline piping as possible, flexible hoses had to be used to accommodate the breakpoints in the MSS clamshell.

Photographs of the interior of the MSS are difficult to find. Most of the best photographs available today were taken from the top of the LUT as the MSS was rolled back. The photos in this section provide a glimpse of the interior of the spacecraft servicing platforms. Some of the equipment and hoses can be seen in the shadows (Fig. 7.8).

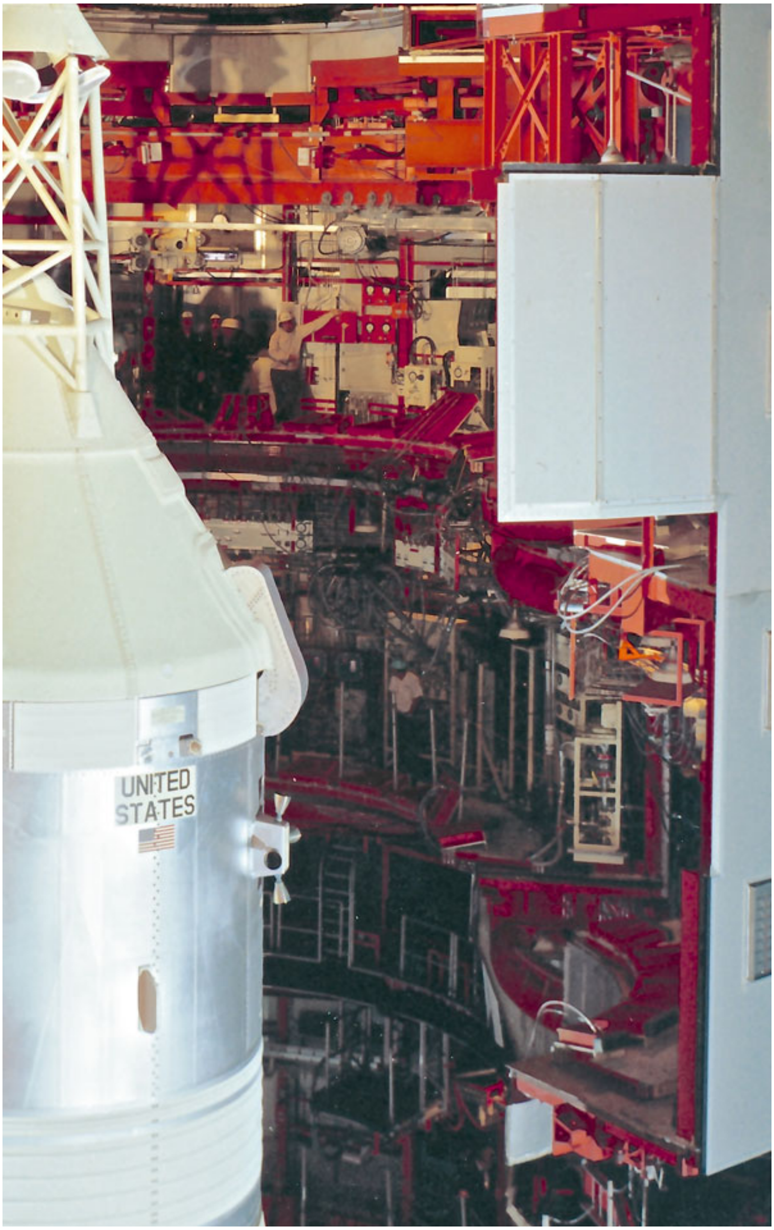
The heavy servicing platforms and equipment made the MSS ungainly, and it had a huge counterweight at the bottom of its south end to keep it from tipping forward. As the spacecraft servicing systems at the top of the MSS grew in complexity over the course of the program, additional counterweights had to be added to the back of the MSS to keep the structure in balance.

The MSS was further modified for the Skylab program. In 1977, 2 years after the Apollo-Soyuz Test Project, the MSS was scrapped. Its counterpart in the Space Shuttle program was the rotating service structure (RSS), which was permanently installed on the launch pad.

LAUNCH PADS 39A AND 39B

NASA built two launch pads in the "launch area" at Launch Complex 39 to support the Apollo lunar missions. These are pad LC-39A (or more simply, *39A* or *pad A*, located at the southern end of the launch area) and its identical twin pad B to the north. They are about 3.5 miles (6 km) from the "assembly area" of LC-39—that is, the VAB.

Original plans for LC-39 included one or two other pads to the north of pad B. NASA's initial projections were that launches might have to be as frequent as once per week to ensure a manned Moon landing by 1970. The Apollo/Saturn system design and flight strategy matured, and engineers realized that these pads would not be needed. As it was, many people felt that pad B was superfluous. There was even a plan for another launch site much farther north along the coast to accommodate a proposed nuclear-powered launch vehicle, which was never built.



7.8 View of the spacecraft servicing areas of the MSS, as seen during the MSS rollback prior to *Apollo 8*'*s* launch. Part of the morass of flex lines used for hypergolic fueling is visible near the center of the photo. *Source*: NASA

7.9 A mound of dredged material piled atop the pad A site, October 1964. The weight of this pile of material compacted the soil on which the launch pad would be constructed (Photo courtesy Frank Penovich). *Source*: Penovich

Pads A and B were essentially identical. Each pad was an eight-sided polygon approximately 3,000 ft (914 m) across, with an area of about 30 acres (12 ha). A perimeter road circled each pad. The primary entrance to the pad area was a gate at the south end, where the crawlerway entered the pad. The space vehicle in launch position sat at the center of the pad area. Since the layout and configuration of the two pads were the same, our discussions in this section of the book will just refer to the features of both as "the pad," unless there is a specific need to refer to a particular launch pad. Most of the pad-related incidents described in this book happened at pad A, since pad B was only used for *Apollo 10*, *Skylab* manned launches, and *ASTP*.

When the pads were constructed, dredged material was piled up 80 ft (24 m) high where the launch pads were to be located. The weight of this surcharge material compacted the marshy soil, and the material was removed once the soil under the launch pad site was at the required density. Rooms that would be enclosed within the launch pad were then constructed (see below). Then, the pad *hard stand* was built, a reinforced concrete and fill structure rising 48 ft (15 m) above sea level. The long axis of the pad hard stand is oriented north-south. It served as a stable foundation for the LUT, and also as an interface between the LUT and the servicing systems for power, fuel, oxygen, hydraulics, and pneumatics. When the LUT was sitting on the pad, the umbilical tower was at the far north end of the pad hard stand (Figs. 7.9 and 7.10).

A prominent feature of the pad is the flame trench, which bisects the hard stand on the north-south axis. Some workers at KSC referred to it as the *flame bucket*, a carry-over term from Atlas and earlier launch facilities. It provided an exit path for flames, exhaust, and acoustical energy as the Saturn V's engines built to full thrust prior to liftoff. A wedge-shaped steel flame diverter, mounted on wheels, was rolled along rails into the

7.10 Overview of pad A, with the crawlerway leading off in the distance to the VAB. The Atlantic Ocean shoreline is at the *bottom* of the frame. *Source*: NASA/Ward

flame trench for countdown and launch. The flame trench is 450 ft (137 m) long and 58 ft (18 m) wide. There is no significant physical connection across the flame trench between the two sides of the launch pad hard stand.

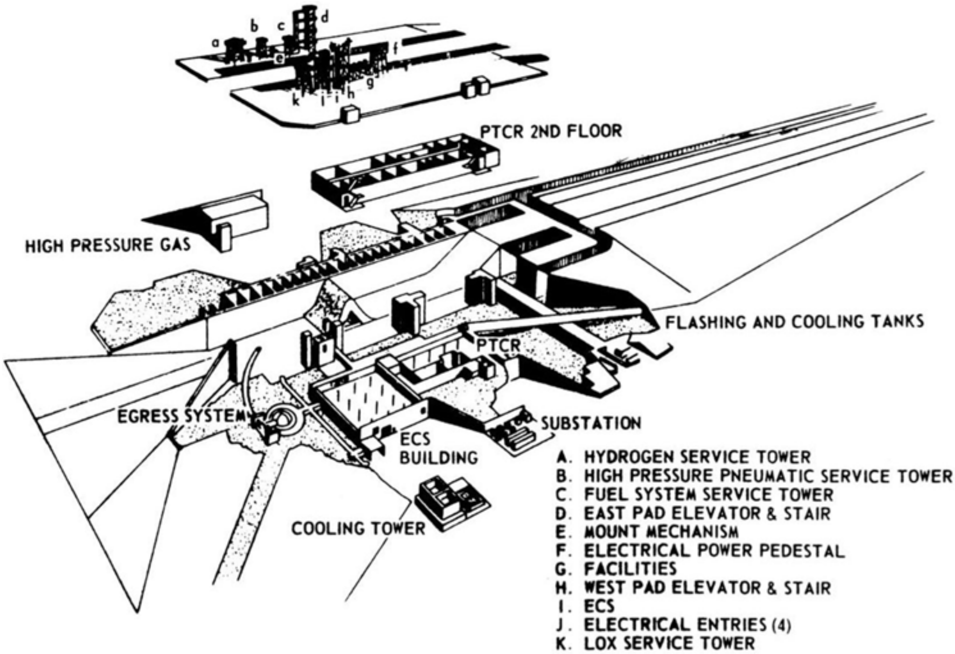
In the sections below, we will explore some of the rooms and facilities located within the pad hard stand (Fig. 7.11).

Pad Terminal Connection Room (PTCR)

The pad terminal connection room housed the equipment for communications and data links between the LUT, mobile service structure, and the firing room. Test equipment in the PTCR could simulate vehicle and LUT functions, which enabled the firing room to check out the pad facilities and functionality when the LUT was not present. Critical equipment in the PTCR was shock-mounted to protect it from the forces of the Saturn V launch, since the PTCR was immediately to the west of the flame diverter at launch.

The PTCR was a two-story building, 136 ft (41 m) long, built above ground. Fill dirt was compacted over top of it and around it, and then it was covered with the concrete of the pad structure. Despite the singular “room” in its name, it held a conference room, equipment rooms, and offices used by workers during pre-launch checkout activities. The air conditioning system in the PTCR kept the electronic equipment cool, and could be operated remotely from the complex control center in the LCC when the pad was evacuated for launch.

Computer and hardline connections ran out to the pad from the LCC in conduits under the crawlerway. The wiring came into the PTCR under raised flooring, connected to terminal equipment in the PTCR, and was routed from there to the LUT (Fig. 7.12).



7.11 Exploded diagram of major structures in the launch pad. *Source*: NASA/Ward

Environmental Control System (ECS) Room

The environmental control system room was located on the ground level at the west side of the launch pad, north of the PTCR. This huge room housed the equipment to furnish air and nitrogen for space vehicle cooling at the pad. ECS room mechanical equipment included air compressors, chillers, a water/glycol storage tank, cooling coil units, air re-heat units, blowers, and air conditioning equipment for room and equipment cooling (Fig. 7.13).

Three large air handling circuits serviced the stages of the Saturn V, and later the Shuttle. In the event of a hydrogen or oxygen leak inside the launch vehicle, the air handlers could be flooded with nitrogen to force out the explosive gases. A smaller separate air handling circuit serviced the spacecraft area. The spacecraft circuit was completely isolated from the nitrogen systems to preclude any chance of accidentally flooding the crew area with nitrogen.[1]

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[1] The service module deluge purge system (SMDPS) was a nitrogen purge system that could be activated by a spacecraft operations engineer stationed in the firing room. During hazardous operations at the launch pad, the system was armed such that one push of a button flooded the exterior of the spacecraft and the interior of the service module, SLA, and IU with gaseous nitrogen to quickly deprive a fire of oxygen. A pure nitrogen atmosphere was hazardous to any humans in the vicinity, so the SMDPS was only set to one-button mode when hazardous operations were underway and pad personnel were already wearing SCAPE suits.

7.12 The pad A PTCR second floor hallway, looking south. In August 2013, it looked much as it did in the Apollo era (Photo by the author). *Source*: Ward

Rubber Room and Blast Room

Two rooms north of the ECS room inside the launch pad fill served as part of an emergency escape system for astronauts and pad crew. The entire system was officially called the *Apollo emergency ingress/egress and escape system*.[2] Pad workers referred to the rooms within the launch pad as the *rubber room* and the *blast room*. The function of these rooms is covered in detail in the next chapter.

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[2] The other parts of the emergency escape system included the command module access arm (swing arm 9), a transition platform, two high-speed elevators on the LUT, pad elevator no. 2, armored personnel carriers, the escape tube, and a slide wire system.

7.13 Pad A ECS room in August 2013. Much of major mechanical equipment installed for Apollo/Saturn was used throughout the Space Shuttle era (Author's photo). *Source*: Ward

High-Pressure Gas Storage Facility

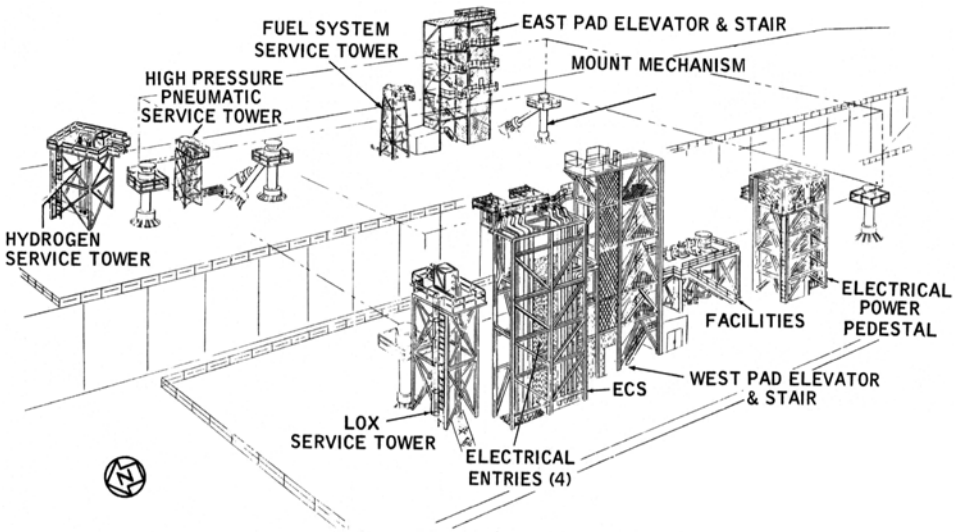
Built into the east side of the launch pad, on the opposite side of the flame trench from the PTCR, was the high-pressure gas storage facility, a storage battery of pressurized tanks filled with gaseous nitrogen and helium. These gases were piped to the launch vehicle for purging and pressurizing the propulsion and propellant systems. The facility and distribution system could be operated remotely from the firing room.

Pad Interface for LUT and MSS

The upper surface of the hard stand was the docking area for the mobile launcher and the mobile service structure. Six steel pedestals supported the LUT, and the MSS rested on four pedestals. Once the LUT and MSS were in place on the support pedestals, workers connected the various pad facilities to the LUT and MSS via *interface structures*, towers built into the pad surface that carried cables and pipework that then connected to the LUT and MSS. Technicians spent about a day connecting the pad systems to the LUT after it arrived from the VAB (Fig. 7.14).

The connections from the pad systems to the LUT included:

- Liquid hydrogen
- Gaseous hydrogen
- High-pressure pneumatics (helium and nitrogen)
- RP-1
- Liquid oxygen



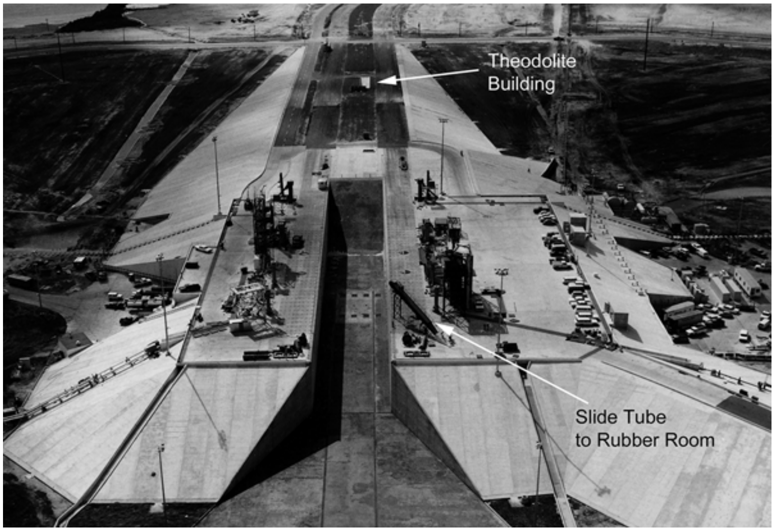
7.14 Launch pad interface towers for services to the LUT. *Source*: NASA/Ward

- Electrical power
- Environmental control
- Electrical communications, control circuits, computer data lines, and instrumentation
- Slide chute to rubber room/blast room

Azimuth Alignment Building

Located on the approach ramp to the pad, about 700 ft (213 m) from the LUT support pedestals, was a short, squat facility called the azimuth alignment building. It housed the theodolite that was used to control the orientation of the Saturn V's ST-124M gyroscopic guidance platform and set the vehicle's internal navigation reference system. The theodolite instrument sat on a short pedestal, whose footing was isolated from the rest of the building structure. The distance from the center of the theodolite to the center of the space vehicle was precisely established at 765 ft, 7-1/6 in. (233.354 m), with an elevation angle of 25° to a sighting window on the Saturn V's instrument unit (Fig. 7.15).

The theodolite system generated a beam of infrared light that was aimed at a small window in the side of the instrument unit. Prisms inside the IU, two of which were mounted on the ST-124M guidance platform, reflected three different wavelengths of infrared light. The theodolite control system sent commands to motors that moved the ST-124M so as to align the beams of infrared light and reflect them back to the theodolite. A computer feedback loop enabled the theodolite to command the ST-124M to hold this axis fixed as a frame of reference for the vehicle's guidance system. At T-17 s, the theodolite released control of the platform, and the public affairs officer announced, "Guidance is internal."



7.15 View of pad A showing the theodolite building and the slide tube to the rubber room/ blast room. *Source*: NASA/Ward

The azimuth alignment building and theodolite system were the purview of Milt Chambers, chief of the launch vehicle gyro and stabilizer systems branch. David Buchine was IBM's ST-124M guru and manned the ST-124M control console in the instrument unit section of the firing room. Chambers said that the system worked pretty well, "except for the time LOX vapors kept blocking the light beam."

S-IC Engine Servicing Equipment

The F-1 engines at the base of the Saturn V were the only main engines that could be replaced at the launch pad if they failed during testing. Since they hung down into the flame compartment of the LUT, they were not accessible from the LUT deck or via the swing arms. A bright yellow-painted engine servicing platform, similar to the one in the VAB, was employed at the pad for working on the engines.

A platform transporter cart was parked on the launch pad ramp near the azimuth alignment building. It was pulled on rails by two motor winches at the north and south ends of its travel. The transporter straddled the flame trench and carried the engine servicing platform into position under the LUT. Once the servicing platform was underneath the engine compartment, workers attached cables to the four corners of the platform, and four winches on the LUT deck hoisted the platform into position to give access to the engines (Fig. 7.16).

Launch Pad Cameras

The operational television system relied on cameras situated throughout the launch pad area to monitor activities during tests and launch countdown. All of the cameras in the pad area could be remotely panned and pointed from the complex control center in the LCC.

7.16 The engine servicing platform sits on its carrier at the top of the launch pad ramp prior to being winched to its stowage location. *Source*: NASA/Kipp Teague

On launch day, high-speed film cameras in heavily shielded enclosures at various levels on the LUT provided engineering footage of umbilical ejection and swing arm retraction as the Saturn V lifted off. These films have become some of the most iconic records of the Apollo era.

Six other camera sites were located within the launch pad perimeter. Each site had an access road and five elevated concrete camera pads for four engineering sequential cameras and one fixed high-speed metric camera (a CZR-1 ribbon frame tracking camera).

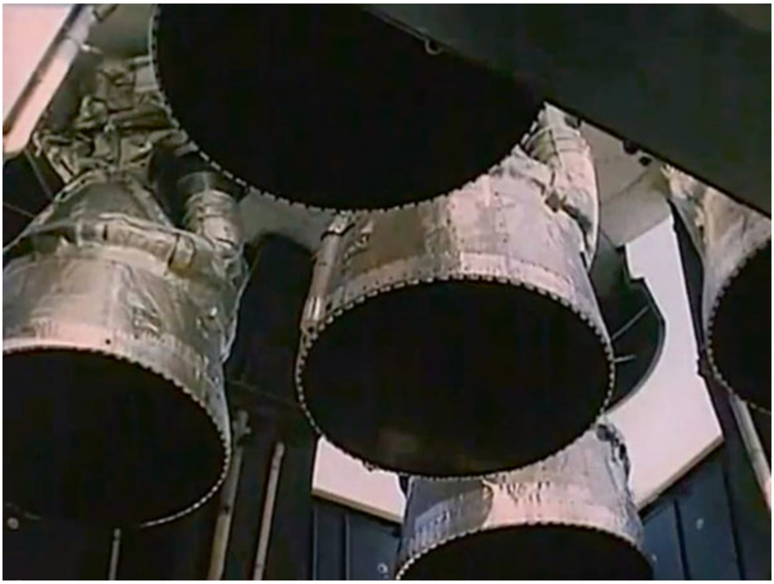
Footage from these cameras enabled engineers to measure and evaluate the performance of critical systems during launch, such as the motion of the vehicle as it cleared the launch tower.

Unfortunately, much of the high-speed and high-resolution camera footage was irreparably damaged in the years after Apollo/Saturn. The film was stored in the LC-34 blockhouse without proper environmental safeguards, and was ruined by heat and humidity.

Sidebar: Cameras in the Flame Trench

As the Apollo/Saturn V program progressed, engineers requested that a set of cameras be installed in the walls of the flame trench underneath the S-IC's engines to check for oxygen leaks. Tip Talone was charged with overseeing the installation and testing for these cameras. His account illustrates some of the challenges associated with both setting up this system and convincing management that it was safe. It also provides an insight into the personality and management practices of Rocco Petrone (Fig. 7.17):

> *We were having problems with leaking LOX seals on the F-1 engines. Oxygen would leak down into the bells of the engine. That would become a hazardous situation real quickly if you had a very oxygen-rich atmosphere and you tried to start the engines.*



7.17 View of *Apollo 11's* F-1 engines from cameras in the flame trench. *Source*: Author's adaptation of frame from NASA movie

There wasn't any way to instrument it. I don't know how they discovered the problem, but we were told we had to figure this damn thing out.

The solution was to hollow out a place on both sides of the flame trench and put in TV cameras that were sunk back into the flame trench wall and angled up to look into the engine bells. You could see LOX vapors during propellant loading if you were getting leaking down there, and then the engineers could then estimate what the volume was and decide whether or not it was a real problem.

As a junior officer, I got tasked with making sure the system was installed. I worked with the OTV guys that had to go out there and install the cameras. They chiseled out the enclosures in the flame brick wall, and ran some cable back underground, making a tunnel in there. It was a hell of a job. I think we had four cameras, two on each side, looking into the engine bells at an angle. They had to have lights, because you had to be able to see up into the engines. So there was a spotlight alongside of them in the cavity. There was a blast-proof glass panel over the front. The cavity was sealed, and it was purged with nitrogen. You had to keep the avionics purged so you didn't get any explosive gases in there.

Now, regarding Rocco Petrone: Rocco knew where every grate was over every flame trench on every pad, because he was Death *on loose grates over flame trenches. He could just picture in his mind all this flying debris at ignition. He knew where every cable tray cover was. He would do his own walkdowns of the launch pad. He would come back in with a checklist. He'd say, "There's a garbage can on level 240 that nobody secured."*

We'd been having a problem with those lights in the camera cavities in the flame trench. They'd turn the lights and cameras on and check them out, and the heat would build up inside the cavity, and the glass would crack, so that we would no longer had a purgeable area, and gases could leak in there. Rocco knew about that. We'd reported that to him earlier in a briefing when we were checking things out, and we told him we could get it fixed. I forgot what the fix was, but we did something that they promised me would ensure that the glass wouldn't crack.

Getting ready for the review meeting with Rocco before propellant loading, I wanted to do a walkdown, and one thing I wanted to concentrate on to make sure everything was right was those lights. Before I left to go out to the pad for the walk-down, I told the OTV guys, "Turn on the lights. Let heat build up. By the time I get out there, I'll check them out." I took a couple OTV guys with me.

To see the camera enclosures, you had to look across at the other side of the flame trench, and then walk around the other side and look back the other way. If you lay flat on your stomach in the flame trench and reached all the way down, you could just barely touch the face of that glass panel. I lay there on the trench, which had been swept clean for launch. I reached down, and I felt around to see if I could feel the heat on those things. The glass was a little bit warm, but it wasn't hot. I couldn't feel anything wrong with it. I checked both of them. I said to myself, "I think we've got this one whipped."

So maybe two hours later, we're in the pre-loading briefing in firing room 4. I'm sitting down at the table. I've got the spacecraft guy on one side of the test supervisor and me on the other side. Spacecraft gave their briefing. Then we started into our briefing, and I'm giving the launch vehicle report about all the ground systems and the vehicle itself. I give all the procedures status, all the IDRs, the constraints, the certification of the team members, the turnaround plans, how long the loading window was, how many times could we turn around, how much LOX did we have available, all the stuff that Rocco wants to know. As we go through the briefing, Rocco's looking at me, and I'm not getting a good feeling from this, because he's not smiling. If he thought you were doing a good job, he was the first one to tell you. But this time, he ain't smiling. In fact, he's boring a hole through me with his eyes.

I get done and I ask if there are any questions. Rocco says, "Yeah. How about those lights and cameras out there looking at the LOX seals?" I said, "Rocco, I checked them out myself. We fixed that problem. The lights work; the glass is intact. Cameras have been checked out; they're looking in the right place. I think we're go *with that one." Rocco held his finger up, and he had this damn Band-Aid on his finger. He said, "Then how come I cut myself on the glass when I was out there an hour ago?" Oh Jesus. I couldn't have gotten any smaller. And then he went off. When Rocco goes off, he goes off! It was like, "You guys don't take this seriously! I can't trust you for anything! You come in and you make up these goddamn stories!" He turns to Dr. [Hans] Gruene and the other guys and says, "I don't understand why you can't get this fixed right!" I'm sitting down there, and there's no blood left in my face. I'm drained. I wonder, "Can I just get under the table and die?" Everybody's staring down there at me, thinking I'm a complete idiot. Rocco gets up, storms around, and walks out.*

Dr. Gruene and the guys say, "Let's talk about this. How did this happen?" I told them my story. I said, "I was out there two hours ago. I leaned over. I ran my hands over it. I had two guys with me. We all verified it. There was nothing wrong with those things two hours ago!"

We went back out to the pad, and sure enough, the damn glass was cracked. Evidently, the heat had just kept building up until it actually cracked again. We had to get it fixed. I personally had to go up to Rocco's office, with the guys that did it, saying, "Here's what we did to fix it. Here's why it shouldn't be a problem. Please go back out there and check. We're very sorry. I promise you…" He said something like, "Well, you've got to try harder."

Pad Water Systems

Water system facilities furnished water to the launch pads for fire protection, cooling, and quenching. The water supply was from three wells and was stored in a one million gallon (3.8 million l) ground reservoir.

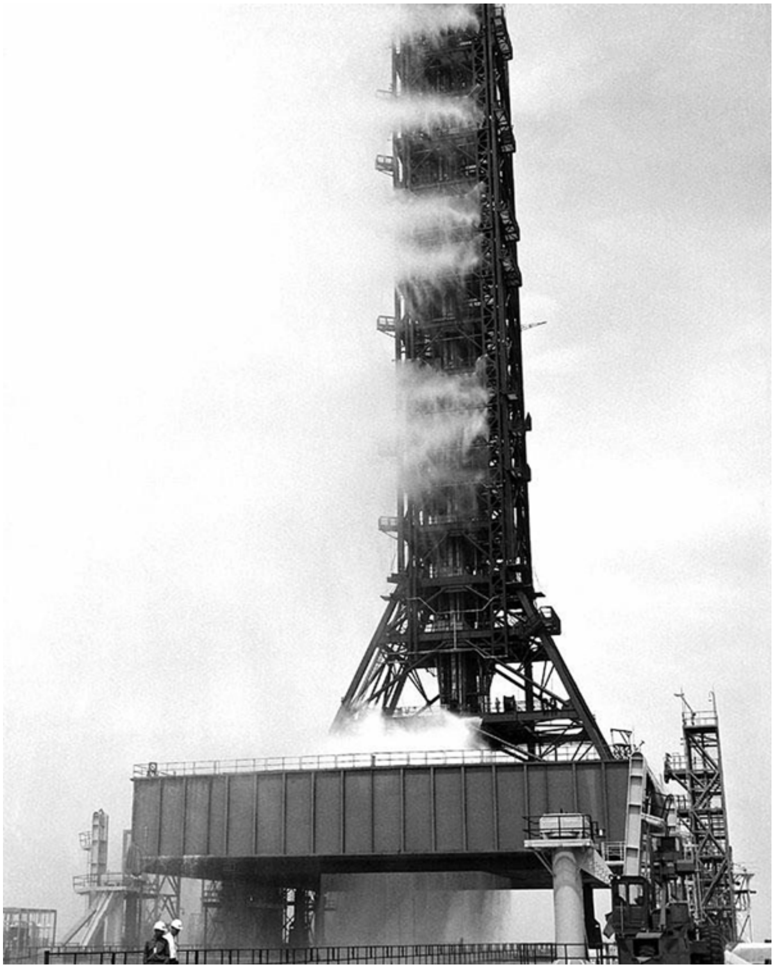
The flame trench and pad flushing system supplied water to flush out the pad and flame trench in case of a propellant spill. Water and fuel drained into two RP-1 holding ponds north of the pad hard stand.

Water systems cooled and quenched the flame deflector and LUT from the heat generated during launch. Electrical support equipment, triggered by the terminal count sequencer, controlled the system. A 14,000 gal (53,000 l) storage tank in the pad's valve pit fed the system that cooled the flame deflector. Another system fed water from a 30,000 gal (113,560 l) tank and the reservoir into 44 quench nozzles and perforated pipes that sprayed water on the LUT deck. Finally, a fogging system cooled the LUT tower and service arms from nozzles at the four corners of the tower on levels 30, 120, 160, and 200. All of these systems could be monitored and controlled from the complex control center in the LCC (Fig. 7.18).

The quench and fire suppression systems were nitrogen-pressurized to put a <u>lot</u> of water onto the pad in a very short period of time. Because of the high pressures involved, the water systems were hazardous in their own right. Steve Coester recalled several situations where people at the pad failed to take proper precautions in dealing with the pressurized systems:

Water for fire suppression and exhaust cooling was supplied to the pad through giant 36-in. (91 cm) pipes, and at high pressure, to reach all the way to the top of the Saturn rocket. One day I was performing a test on the LH_2 disconnect tower and noticed technicians configuring the water system. They connected a reducer to the 36-in. flange, bringing it down to 12 in. (30 cm). Then ran a pipe about 40 ft. (12 m) from there over to the flame trench, with an elbow pointing down into the trench. Obviously they were going to do some kind of flow test of the water system.

They cleared the immediate area and hit the button to start the water flow. The tremendous pressure hit that 12-in. pipe like a rocket engine and ripped the whole 40 ft. of big pipe off of the 36-in. flange. Two things happened at once. First, we now had a 36-in. column of water shooting hundreds of feet straight up. Second, and



7.18 Test of the LUT fogging system, probably 1966. The swing arms have not yet been installed on the LUT. *Source*: NASA/Jerome Bascom-Pipp

more important to me, standing just across the flame trench, was 40 ft. of pipe launching up a couple of hundred feet and slowly tumbling as it decided where to land. We had nowhere to go, since we were 30 ft. (9 m) up on our little tower, so we just watched. Thankfully, the pipe fell into the flame trench, missing us and our tower.

Another time during the Apollo program, a technician began unbolting a 12-in. flange from the water system, not knowing the system was pressurized. The flange broke the last few bolts, hit the man in the chest, and killed him instantly.

PAD SUPPORT AREA

Located around the perimeter of the launch pad area were various support facilities for launch operations. These included the fuel system facilities, the LOX system facility, the gaseous hydrogen facility, pad water systems facilities, photography systems, and other utilities. Trailers for contractor and NASA offices were also sited at various locations around the pad area.

FUEL SYSTEMS FACILITIES

The liquid hydrogen (LH_2), gaseous hydrogen (GH_2), and RP-1 fuel facilities were in the northeast quadrant of the pad area. RP-1 was a highly-refined form of kerosene used for the S-IC stage of the Saturn V. LH_2 was the fuel for the S-II and S-IVB stages.

Boeing's fuels group operated the propellant facilities serving the Saturn V. Steve Coester said, "We had offices in the VAB, but spent all our time in trailers on 39A and B under the LH_2 sphere. In a bunker adjacent to the LH_2 tank was the RP-1 storage for the Saturn V first stage. Most of us specialized in RP-1 or LH_2, but a couple of us could operate both. A sister LOX group, also run by Boeing, was on the other side of the pad under the LOX tank."

The LH_2 facility's most prominent feature was an 850,000 gal (3.2 million l) spherical storage tank. Tanker trucks delivered LH_2 to the storage tank, and more than 80 truckloads were needed to fill the sphere. Transporting and unloading the LH_2 was a dangerous process. Lee Starrick recalled:

> *They would drive tanker trucks all the way from the hydrogen facility in New Orleans. Only one of them had a wreck. It ran off of Interstate 10 into a ditch. They wanted us to send one of our big crash trucks up there to stand by, but we didn't think our trucks could make it that far. We got on the radio and told those guys at the accident site what to do and what to be careful of.*
>
> *Those trucks had a vent stack in the back. When they came in here, if it was summertime and there were thunderstorms in the area and static electricity was bad, those vent tubes were always on fire, always burning. They finally put a cylinder on there with helium in it. They'd open the valve and pump helium up there, and it would put the fire out.*

A vaporizer in an electrical building near the tank converted some of the LH_2 to gaseous hydrogen. No fuel pumps were used in the LH_2 fueling system, because liquid hydrogen was so light that it could be moved through the pipeline just by pressurizing the LH_2 tank with gaseous hydrogen from the vaporizer. LH_2 was transferred to the pad at up to 10,000 gal per minute (37,850 l per minute) via a 10-in. (25 cm) diameter vacuum-jacketed line. Dozens of smaller valves were used for helium purging. There was instrumentation all over the system, valve position indicators, and hazardous gas detection at all possible leak locations.

7.19 Pad A hydrogen storage tank before and after repainting. *Source*: Author's adaptation of NASA photos

Coester related the following story about an incident involving the LH_2 tanks (Fig. 7.19):

When Launch Complex 39 was built, the LH_2 tank was painted per Government spec with white on top and tan on the bottom. The tank was simply labeled, "Liquid Hydrogen, No Smoking".

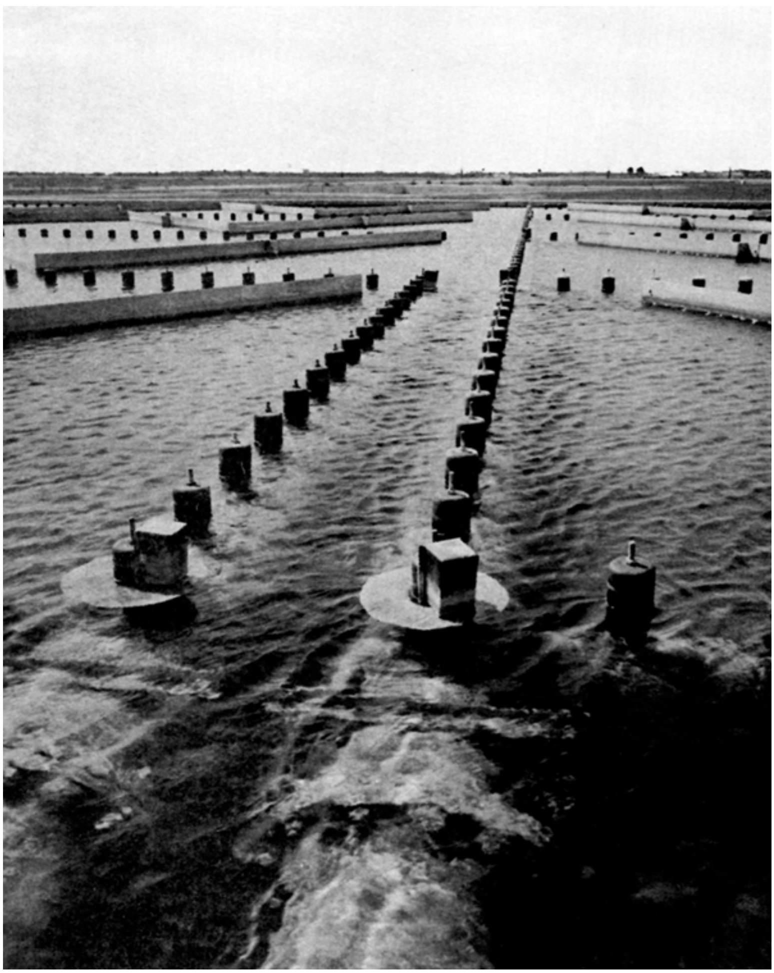
One day, we received a directive that our one-of-a-kind hydrogen tank was not in compliance with OSHA regulations. According to OSHA, the proper color was all white, and the terminology had to be "liquified hydrogen, flammable gas." I questioned the spelling of "liquified," since the preferred spelling is "liquefied," but OSHA prevailed.

We were told we had to re-paint the tank to comply with the new regulations. We thought this was pretty ridiculous, as the tank is 80 ft. (24 m) in diameter. You can imagine how much paint would be involved. We hemmed and hawed and delayed but were finally threatened with fines. I put in a work order to have the tank painted per the new design. Obviously this was a massive job, with painters in protective breathing gear and big spray guns, and it took several weeks.

The RP-1 facility had three cylindrical storage tanks with a combined capacity of 258,000 gal (976,636 l). An 8-in. (20 cm) line transferred RP-1 from the facility to the pad RP-1 at a rate of 2,000 gal (7,570 l) per minute. Railroad tanker cars delivered RP-1 to the site, requiring about 27 tanker cars to fill the RP-1 storage tanks.

Two holding ponds captured RP-1 runoff from fueling operations. One was due north of the launch pad, and the other was northwest of the pad. The holding ponds measured 250 ft by 150 ft (76 m by 46 m) and were filled with water to a depth of 2 ft (61 cm). RP-1 that spilled or overflowed in the launch pad went into the flame trench. The RP-1 was flushed out with water and ran down concrete culverts into the holding ponds. There, a trap retained the RP-1 (which floated on the surface) and discharged the excess water into drainage ditches.

A 100 by 100 ft (30 by 30 m) *burn pond* was located between the LH_2 tank and the launch pad. Hydrogen gas continuously boiled off from the Saturn V's liquid hydrogen tanks while the vehicle was fueled. This gas was captured and was routed by return lines from the LUT umbilicals through a pipeline to the burn pond. A piping system bubbled the waste hydrogen up through bubble caps in the pond, and a hot wire ignition system burned off the excess gas. It was a challenge to manage the 1,500 individually-adjusted caps to maintain the proper vent pressures (Fig. 7.20).



7.20 Bubblers in the hydrogen burn pond. *Source*: NASA/Ward

LOX SYSTEM FACILITY

The LOX system facility stored liquid oxygen and pumped it to the launch pad. The LOX facility was located northwest of the launch pad, near the perimeter road.

The LOX facilities included a spherical 900,000 gal (3.4 million l) storage tank, an electrical building, a vaporizer, pumps, and two cross-country vacuum-jacketed transfer lines. The system transferred LOX to the pad at up to 10,000 gal (37,850 l) per minute.

About 89 trailer-truckloads of LOX were needed to fill the storage tank. LOX came from the Big Three Industries plant in east Mims, just north of KSC. Tankers came to the site in waves of five trucks at a time. The LOX tank was kept as close to full as possible to avoid contamination by outside air.

In early tests at LC-39, the LOX system and transfer lines up the LUT were not chilled down before LOX loading began on the S-II stage. If LOX sat in the pipes for a short period of time, the LOX warmed up enough that gaseous oxygen (GOX) would form when the pressure was suddenly relieved by opening a valve. This sudden release of pressure was a phenomenon known as *geysering*, analogous to what happens when a radiator cap is removed from an overheated radiator. Geysering in the LOX system shot a LOX/GOX mixture into the S-II LOX tank with enough force to damage the tank's internal fuel level probes and anti-slosh baffles.

KSC needed to redesign the LOX loading system to prevent similar accidents in future missions. Irby Moore said, "We had to give a presentation to von Braun about what had happened. To assure that this didn't occur again, we had a recirculation line installed where we dumped the warm LOX for a period after any stop-flow to make sure that only 'cold' LOX reached the S-II."

Bill Heink recalls:

> *The design engineering guys – and Irby was part of that group – came up with a whole new technique to chill it down. They built a new line. The skid with the valves controlling the liquid going into the S-II was on the 120-ft. level of the LUT. They put in a bypass, so that when you were chilling down the system, the LOX would go up to the 140-ft. level, and then it went into the drain system and came back down the LUT. All the liquid and gas that came off the tower went down into a tank that was at ground level northwest of the pad slope. It was probably about 15 ft. (5 m) square and 6 ft. (2 m) high, with an earth revetment around it. The idea was you would put the waste LOX in there, and it would boil off, and you wouldn't have any trouble. Once the lines up the LUT were properly chilled down, then we could close the bypass valves and start loading the S-II LOX tank.*
>
> *The vent line was an 8-in. (20 cm) line that came over the edge of this metal LOX holding tank, did a 90° turn, and went straight down into it. We're running the system at 5,000 gal. (18,900 l) per minute. The line across country is a 14-in. (36 cm), uninsulated line. You have to get a lot of LOX through it before you get it chilled down to the point that you're not going to create more gas.*

The test of the new system was controlled from the firing room. Heink was stationed in the LOX storage area, about 1,000 ft (305 m) from the new holding tank. As expected, the first LOX coming through the drain line into the tank was a combination of liquid and gas. Heink said, "It would fill that tank up with beautiful, light blue liquid oxygen. Then a big burst of gas would come through the pipe, and it would blow every bit of liquid out of that tank. It looked like a blue tornado going up in the air. As it came down to the ground, it would change from a light blue to white and just be GOX. And the booms! Every time one of those gas pockets would come through, there would be this horrendous *KA-BOOM*! I thought I could feel the ground shaking underneath. It was really pounding."

The new system worked. S-II LOX tanks were never again damaged during propellant loading.

PUTTING IT ALL TOGETHER: THE AS-500F FACILITIES INTEGRATION VEHICLE

One other piece of hardware was crucial to successfully activating Launch Complex 39. This was the *facilities integration vehicle*, designated AS-500F. AS-500F was also called the *facility vehicle*, *test vehicle*, *SA-500F*, or usually just *500F*. It was a full-size mockup of the Saturn V that was used to test the fit and function of all of the LC-39 infrastructure while the Saturn V flight hardware was still in production. The AS-500F vehicle matched critical design dimensions of the flightworthy Saturn V vehicles. It had propellant tanks and connection plates for the umbilicals, so that the pad's propellant loading systems and processes could be tested. The CSM was a boilerplate spacecraft, and there was no LM. The engines on the stages were replaced by non-functional dummies.

The facility vehicle was easy to distinguish from other Saturn V space vehicles in photographs from the era. AS-500F was the only Saturn V that had horizontal stripes painted around the circumference of the first stage, at the aft end of the S-IVB, and around the base of the service module. The paint pattern was also different at the forward end of the S-IVB stage that in subsequent Saturn Vs (Fig. 7.21).

AS-500F's purpose was to enable the launch teams to demonstrate all aspects of space vehicle checkout, stacking, and pad operations. KSC's launch pad facilities were being designed and built at the same time as the MSFC-designed Saturn V and its ground support equipment, and at the same time as the MSC-designed Apollo spacecraft and its GSE. Engineers expected that some issues would crop up with fit and interface between the systems and the vehicles, and that was indeed the case. For example, the MSS clamshells interfered with the damper arm and upper swing arms from the LUT, which led to some "tense moments" between Rocco Petrone and KSC facilities designer Buck Buchanan.

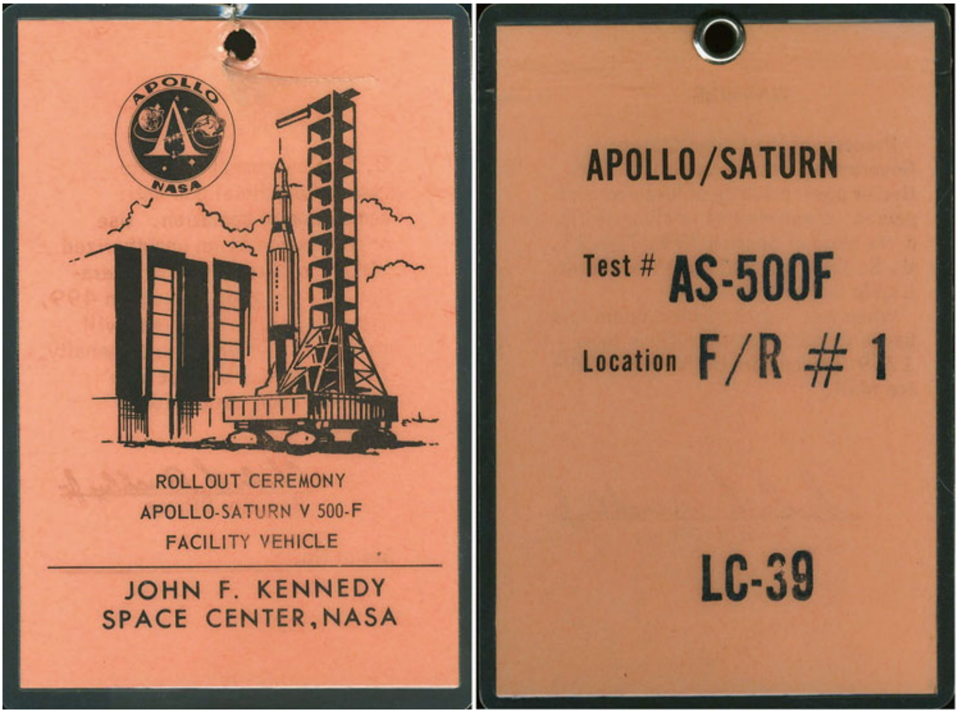
AS-500F rolled out from the VAB to the launch pad for the first time on May 25, 1966, which was 5 years to the day after President Kennedy issued his challenge to land an American on the Moon. It is incredible nowadays to consider the magnitude of the accomplishment involved in getting even this far. It would be almost impossible in our era just to acquire the land and perform the design work for LC-39 within the span of 5 years (Figs. 7.22 and 7.23).

7.21 Comparison of the AS-500F vehicle (*left*) with *Apollo 14*. Differences are apparent in paint patterns on the S-IC stage, the S-IVB stage, and the instrument Unit. *Source*: Author's adaptation of NASA photos

Hurricane Alma threatened the Cape in early June 1966. AS-500F was rolled back to the safety of the VAB on June 8, proving the wisdom of Kurt Debus' vision of a launch system that could enable a vehicle to be temporarily moved to shelter. The stack rolled back to the launch pad on June 10.

One of the most important facilities tests with AS-500F was a *wet test*, to check out all of the operations and systems associated with loading propellants into the vehicle, and the operation of myriad components such as storage tanks, pipelines, valves, sensors, relays, pressure switches, circuit breakers, pumps, motors, fans, vaporizers, vents, and the hydrogen burn pond. No one had prior experience with systems on the scale of LC-39. Engineers hoped to uncover and correct design and process flaws before actual missions were in flow. And indeed, during the wet test for AS-500F, a major system failure occurred that came close to endangering the Apollo/Saturn program timeline.

Regarding the LOX storage sphere, Bill Heink said (Fig. 7.24):



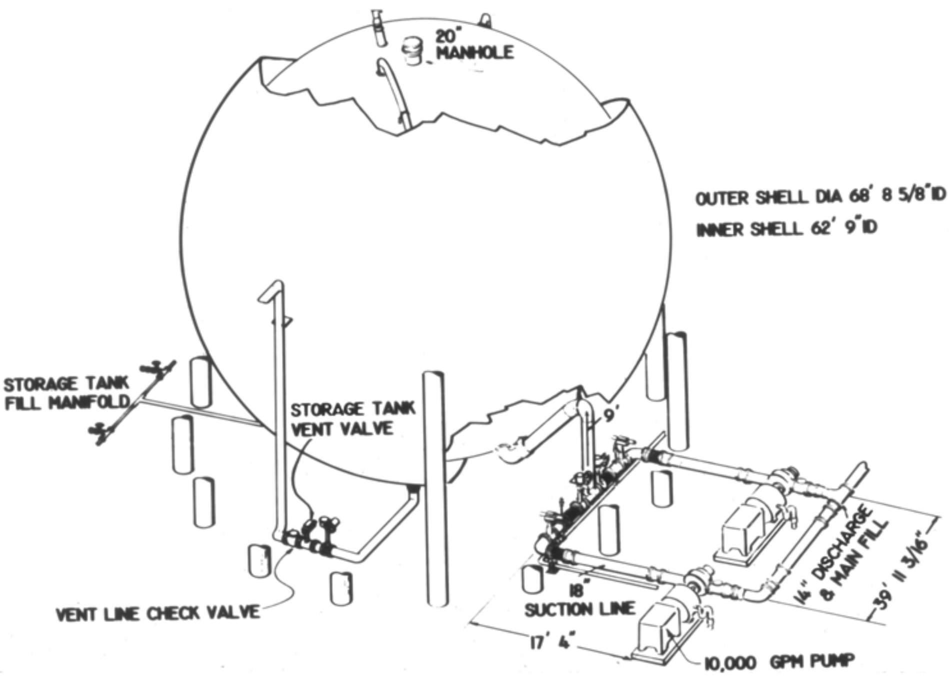
7.22 Badges from the AS-500F rollout and from firing room 1 during AS-500F testing (Author's collection). *Source*: Ward

We had a distinct problem with that double-walled tank. The liquid was inside the inner tank, and that annular space in the center was probably 3 ft. (1 m) wide and was filled with a powdery insulation called Perlite. The main lines to the pumps came down, and there was a gooseneck in there like underneath your sink. After you flowed liquid through there and you shut it down, the liquid that was still in the pipe would vaporize, due to the ambient heat. It would press that gooseneck up into that annular space. But you'd have no cold pipes outside the tank.

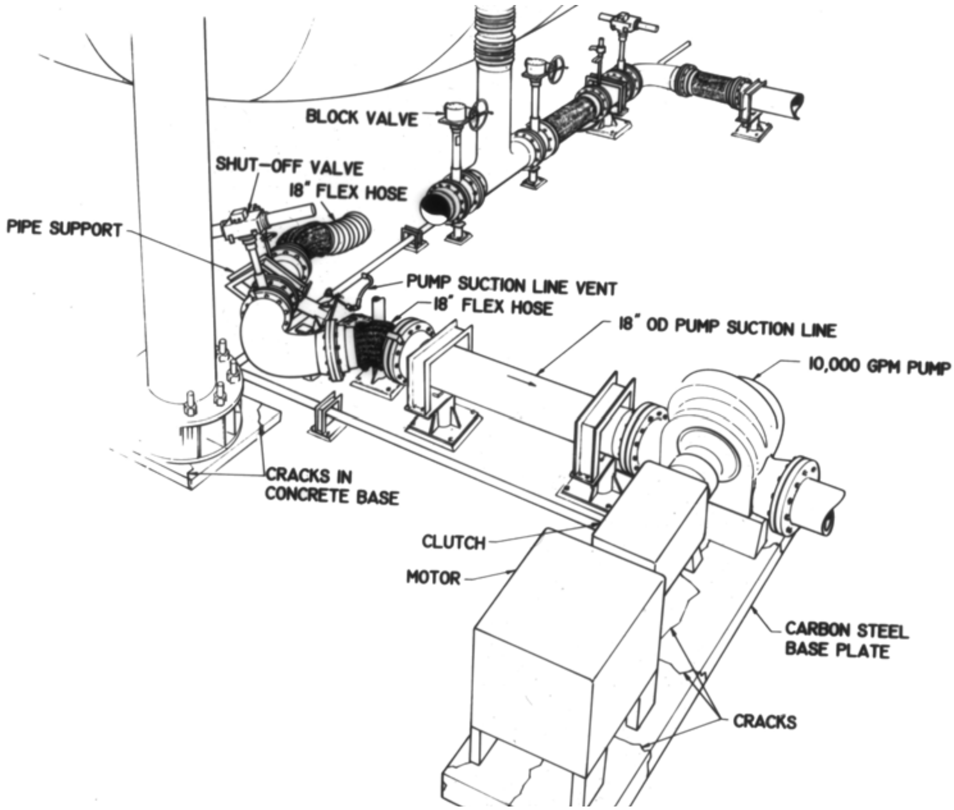
In the early days, we had not done anything specific to do a chill-down on those goosenecks when we were going to flow out of the tank. You would open the big valve, and this column of liquid would come whoooomp! *It made a horrendous noise, like a cannon going off. You even got a big bang out of our small 1,500 gpm pumps.*

The day before the failure, I remember thinking at the time, because I had been out there for a lot of tests, "Boy, that's the biggest bang we ever got on this thing." I don't know if that somehow contributed to it.

7.23 Launch of Gemini XI from CCAFS LC-19, September 12, 1966. Visible in the distance is the AS-500F vehicle on LC-39 pad A. *Source*: NASA



7.24 Piping diagram of the LOX tank at pad A prior to the AS-500F LOX loading accident. *Source*: NASA/Ward

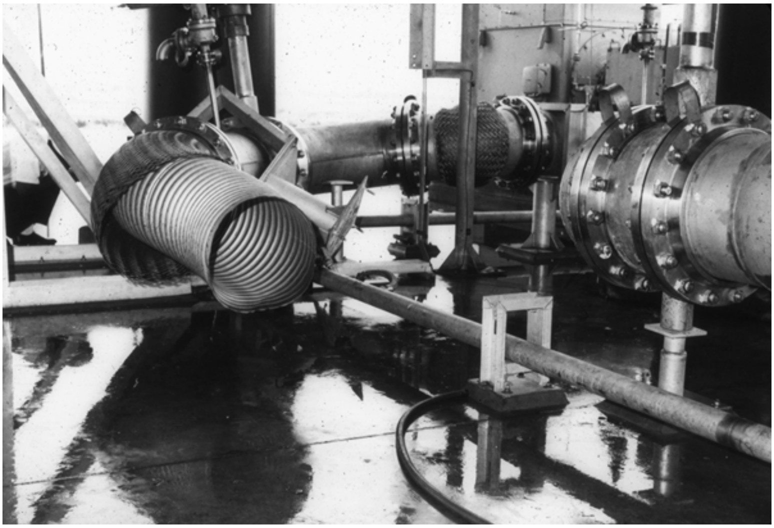


7.25 Diagram of the failed section of the LOX lines. *Source*: NASA/Ward

In August 1966, Boeing's propellants team made its first attempt to deliver LOX to the various stages on the AS-500F vehicle to verify that the system worked. Heink was on console in the firing room as the test got underway, and he recalls:

> *The day of the S-IC loading test* [*August 19*], *luckily we had just a small crew out there. The engineer in charge was a guy named Al Thomas. Al was on the headset, and he had the long cord plugged in at our little concrete electrical house out there. They opened the valve remotely from the firing room, and the gaseous oxygen came shooting down through the line, and when it got outside the tank, it ruptured the line. We were watching on TV. Al yelled out on the net, "Rupture!" All you could see was this belch of GOX, and then you couldn't see a thing. There were a couple of technicians with Al, and we heard nothing for probably 90 seconds. We didn't know if the guys were lying out there dead in a pool of liquid oxygen, or what was going on.*

Thomas ran around to the shop building on the east side of the LOX area, and he found a place to plug in his headset. He said that the main line had ruptured, and that LOX was pouring out. The team in the firing room discussed its options. There was a manual shutoff valve on the pipe, but the rupture was actually upstream of the valve, so the valve would not have done anything (Figs. 7.25 and 7.26).



7.26 Photograph of the ruptured section of the LOX line. *Source*: NASA/Irby Moore

The team watched helplessly on the OTV monitors. After about 3 hours, the tank had mostly drained itself. About 850,000 gal (3.2 million l) of LOX ran across the macadam road, which created a potential explosion hazard. Heink continued:

The one thing that really saved us was that we had a tremendous Firex water system. They turned the water on immediately, and it flooded the area. The water was running across the road, and the water kept the LOX from touching the road surface. They had a million-gallon water storage tank and pump station on the road to pad B, and I heard after the fact that it was almost dry by the time we finished draining the LOX tank.

Fire and safety went out there with their big airport-type crash trucks with the nozzles on the front. Within 15 minutes after we stopped flowing LOX, and all the GOX vapors had gone away and everything, the firemen drove the truck right past the tank on that asphalt road. Luckily, none of the liquid oxygen ever had a chance to get to the asphalt, because otherwise it would have blown those trucks to smithereens.

Had we not had the water flow, we all thought at the time that the liquid oxygen would have gotten up on the legs of that big LOX tank, which were carbon steel. The cold LOX would have crystallized the carbon steel, probably fractured it, and that huge LOX tank would have fallen over. That would have really set the Apollo program back, because there was no backup for that tank.

NASA engineer Irby Moore inspected the tank after the incident. He said (Fig. 7.27):

I had suspected the inner tank would be damaged due to a vacuum being created as the LOX drained. There was a head of about 60 ft. (18 m) of LOX in the tank and no way to ingest make-up air. We didn't want to use the vaporizer for safety reasons.

7.27 Photo taken inside the LOX sphere, showing the partially-collapsed tank. *Source*: NASA/Irby Moore

I knew there was a relief valve that came straight off the top of the inner sphere through the outer shell. The relief valve had an expansion bellows connected to the outer shell.

After the area was cleared, I ran up the stairway, hoping for the best, but when I got to the top of the tank, the bellows was collapsed downward, indicating my worst fear that the inner shell at the top had collapsed and pulled the relief valve piping downward with it. Later that day, I was rigged with a harness and Scott Air-Pak and lowered into the 3 ft. (1 m) annulus between the inner and outer spheres, which was full of Perlite insulation. Even though I couldn't see anything, I confirmed by feel that the tank had collapsed to some degree.

The tank had drained at up to 18,000 gal (68,100 l) per minute but still had some LOX left in it, so we opened a vent and drained the remainder. Then we blew warm air in to prepare for entry. That took about 24 hours.

We then removed the Perlite, filled the tank with water, hooked up a fire truck pumper, and popped the tank back out. The design engineering welding/materials engineer and I then paddled around in a rubber raft we had obtained from Patrick Air Force Base, inspecting the damage as the water was drained.

Design engineer Steve Harris led the recovery team. Boeing's staff and Catalytic Construction, who had built the tank, worked back-to-back 12-hour shifts for 3 weeks. Disaster averted, the LOX tank was back in service in less than a month.

In yet another facilities validation while AS-500F was at the launch pad, NASA conducted a power-out test to verify the ability of firing room personnel to maintain control of a fully-fueled Saturn V in the event of a power failure. If the firing room lost control of the propellant management process during a countdown demonstration test or a launch countdown, there was a very real explosion danger of the cryogenic propellants (LOX and LH_2). It was imperative that this emergency control capability be tested.

Rockwell's Fred Cordia described the electrical power system at LC-39:

Most vehicle and ground control used 28 volts DC (VDC) derived from 110 volts AC (VAC), using local DC power supplies throughout the facility. The 110 VAC power was provided by the local power company, Florida Power & Light Company (affectionately known to rocket folks at KSC as "Florida Flash & Flicker") and emergency back-up generators. Dedicated KSC emergency generators were also online during critical operations. These powered all of the control equipment at the launch complex under normal circumstances.

Emergency DC power was provided by a bank of 28 VDC batteries, located safely away from the launch pad in the LCC, in the event of a total power loss to provide control logic power to operate solenoids, valves, relays, etc., to safe the vehicle. This was a typical arrangement for rocket launch facilities everywhere. However, in the case of LC-39, it was necessary to connect two banks of 28 VDC batteries in series providing a 56 VDC potential for this contingency, as the distance from the LCC to the pad was over 3 mi. (5 km). Voltage loss over this distance required an additional 28 VDC to assure there was sufficient voltage available at the end of the three-plus miles of cables at the pad to operate appropriate devices. The power-out test was to ensure that the facility could fulfill its role to safely return the vehicle to a benign configuration should a major unplanned event occur.

Bill Heink recalls that this important test was almost sidetracked because of one minor oversight, which required quick thinking and a somewhat unorthodox fix:

A couple of days before that test, Bill Wheeler of NASA's electrical branch and I were in the firing room, and we both suddenly had the same revelation: "Holy Christ! We've got platforms all around this firing room with places for emergency lighting, and we don't have a single emergency light in the firing room. Nothing." He looked at me and said, "I know where we can get some. Give me about 10 minutes. Go get your pickup truck and meet me in front of the LCC." So I got the truck and met him in front. He in the meantime had written a note that said, "This emergency lighting removed for the power outage test at complex 39. Will be returned after completion of the test." And he signed it, "Bill Wheeler" and added his phone number. He made a bunch of copies of that note.

We had decided that we needed ten of those lighting units. Bill had commandeered a wheeled cart from somewhere, and we tossed it in the back of the pickup. We went down to the KSC headquarters building and parked in front. We proceeded to walk down the hall and steal the emergency lighting. We unplugged it, took it off the shelves, and he left a note on each shelf. We carried them up into the LCC. We couldn't get them up on the shelves – they were up real high – so we just set up the lights around the floor. So we had light when the power went out. And it did go out, and everything worked like it was supposed to.

Fred Cordia was also in the firing room for the test:

> *It was a surreal experience. The vehicle was loaded with propellants using normal operations and lighting. Once loaded, the direction was given to cut the power. Pretty soon, there was no light other than that provided by the building emergency lighting system. Lighting from the indicators on the control consoles was also seen but was very dim. All necessary stage consoles were manned and monitored until the vehicle was drained and safed. The 56 VDC battery system performed its job and enabled the safing of the vehicle without incident.*
>
> *Having been a test conductor on the Atlas ICBM and involved in several emergency situations, I can understand what this did to a test conductor. It was "pucker time"! The test structure worked as planned, and all test participants were professional and performed their tasks to safe the vehicle, especially the Boeing propellant folks who loaded (and drained) propellants on the entire vehicle. I'm sure there were some high heart rates among the stage and NASA vehicle test conductors!*

Having fulfilled its role in verifying the design and operation of LC-39 facilities, AS-500F was rolled back to the VAB for the last time on October 14, 1966 and de-stacked on October 21. AS-500F and the shakedown facilities tests over the summer of 1966 prepared KSC for launch operations from LC-39 beginning the following year.

8

Life at the Launch Pad

LC-39 represented the pinnacle of American technological prowess in the space race. State-of-the-art computers, remotely controlled equipment handling millions of gallons of cryogenic propellants, and facilities and vehicles of unimaginable scale and complexity came into being at KSC in just a few short years. The American public, with their new color televisions, watched the Saturn V gleam in the spotlights before a launch, and they saw it blast off into the blue Florida sky with three heroic astronauts on an epic mission.

Forgotten in the adrenaline rush of launch day—usually the only time most members of the public ever saw KSC on television—was what went on behind the scenes at KSC to make the launch possible. This was not just the work performed by the hundreds of men (and a few women) in lab coats, dress shirts, and ties in the firing room. Throughout much of the Saturn V's last 2 months on Earth, people braved extreme hazards and miserable working conditions to tend to the rocket.

This chapter will help the reader understand what work was like at the launch pad. Much of the story here is told directly in the colorful words of men and women who worked there, for whom the term *pad rat* was a badge of honor.

SECURITY

Security was a constant concern at KSC. On one hand, it was important to keep people out of dangerous areas for their own protection. Overly enthusiastic VIPs, tourists, and even workers from other areas at KSC wanted to get as close to the Saturn V on the launch pad as they possibly could. In their excitement, they may have failed to consider how dangerous the launch facilities could be. Security helped keep people safe.

The civil turmoil of the late 1960s occasionally came to KSC's doorstep. JoAnn Morgan recalls one time when there were people picketing south KSC gate, chanting, "We don't need Moon rocks, we need more food!" Jack King remembered a situation where a civil rights group was protesting outside the gates just prior to a launch. King recalled, "They brought a wagon pulled by oxen up to the gate, protesting that NASA was spending all this money.

J.H. Ward, *Rocket Ranch*, Springer Praxis Books, DOI 10.1007/978-3-319-17789-2_8

Our administrator was here for the launch, and he went out to the gate to talk with them. He said, 'If there was anything I could do, in any manner, to help you on this, I'll stop the launch.' He listened to them and made his point to them, and they accepted it."

Badges

Everyone at Kennedy Space Center usually wore at least one badge while on duty. All personnel had a NASA-issued photo identification badge. There were myriad other badges that personnel had to wear in order to gain access to restricted areas. These access badges did not have photos, but were frequently issued in different colors for different missions. Sometimes the badges had numbers or letters on them denoting the specific parts of the pad, mobile launcher, vehicle, or spacecraft that a person could access. Colored stripes on the badges were sometimes used to distinguish what the bearer could access.

8.1 Some of the various types of badges in use around KSC during preparations for the *Apollo 15* mission (Author's collection). *Source*: Ward

Badges were also issued for special events, such as vehicle rollout ceremonies, visits by dignitaries, review meetings, and launches (Fig. 8.1).

The KSC security office, headed by Charlie Buckley, controlled the badging process. In some cases, a block of badges was issued to an organization to be distributed to the appropriate staff. For example, the test supervisor's office maintained the list of personnel authorized to be in the firing room for a given mission. The badges were all keyed to the list by serial number. With his characteristic sense of humor, Buckley always reserved the badges numbered *007* for his own use.

Badge exchange stations were set up outside the launch pad area during hazardous tests. When reporting for a hazardous operation, the worker left his badge at the badge station and exchanged it for a special badge for the work area. This way, if there were a calamity at the launch pad, security knew who was in the area and, as Ernie Reyes said, "the investigators might be able to tell which grease spot you were."

The Soviet Threat

It is helpful to remember that KSC was at the front lines in the Cold War. Sabotage was a very real threat. It would have been far cheaper for the USSR to hinder the Americans from getting to the Moon than it would be for the USSR to pursue a lunar program of its own. The Soviet space program was so secretive that the United States had to assume that the USSR would use any means at its disposal to keep America from being first to the Moon.

One of the hallmarks of the American space program was that so much of it was performed in clear view of the media and the public. Contrary to what some launch vehicle workers experienced when they were with the Army Ballistic Missile Agency (before it became part of NASA), little of the Apollo/Saturn V program was secret. The few classified components included such items as the range safety code plugs, which decoded the radio signals to blow up a Saturn V in flight, and the workings of the ST-124M guidance platform, which used technology evolved from the Pershing guided missile program.

The price of the openness was that the Soviets were never far away. Ken Oyer of McDonnell Douglas was assigned to the air defense command during the Apollo years. He flew on modified *Super Constellation* airplanes, looking for Soviet interlopers. He said, "The Russians were curious about what we were doing at the Cape. They would fly aircraft over international waters with the intent of trying to eavesdrop and see what they could find through telemetry. We would pick those up, and at times would scramble fighters to chase them away. Using our lower radar scan, we picked up one of the Russian submarines that had surfaced. It had a problem, and it couldn't go down to depth. We were able to get some very good pictures of it and learn a lot about their technology at the time."

This last incident may or may not be related to an event that occurred when JoAnn Morgan was on a deep-sea fishing trip with her husband off the coast of Cape Canaveral in the late 1960s: "A submarine popped up real near our boat! We always had been told that they were somewhere out there, but to see one—that was quite rare for them to surface. I was half asleep, and all of a sudden, I saw this thing, and I said, 'Larry! What is that? Is it a Texaco ship?' He looked at it and said, 'Honey, it's a submarine! Let's take a picture.' He got out his camera, and then these people came out onto deck, and they had guns, and they were shouting, 'Nyet! Nyet!' They didn't want us taking pictures. We cranked up the boat and got out of there!"

APIP

The Apollo personnel investigation program (APIP) was unlike other government security clearance programs in that it was not necessarily about protecting access to confidential information. Rather, it was aimed at screening personnel who had hands-on access to the launch vehicle or spacecraft and could possibly sabotage it. Ike Rigell said that the most critical people were the technicians doing closeout on the vehicle prior to launch. Rigell said: "There were two things they would investigate. The main thing was if you were heavy-heels in debt, or if you only make so much money and you've got a 100-ft yacht tied up down there. Where'd that money come from? The other thing, and this is to tell you what the culture was back in the 1960s, was if you were homosexual. It was not based on a religious or moral judgment. It was the stigma that society had on it at the time, where someone could blackmail you. 'I'm gonna expose you if you don't go snip that little wire on the vehicle…'" (Fig. 8.2).

A KSC management panel reviewed the results of APIP investigations. Rigell said, "If there was a problem, you wouldn't necessarily be fired, but you might be taken out of a sensitive role temporarily or permanently. We learned one fellow was a cross-dresser. They transferred him to another center."

At particularly critical times in the processing flow, there were restrictions on individuals having access to the spacecraft or other systems. Schedules would indicate: *APIP in effect. Buddy system required*. At such times, people had to work in pairs on spacecraft or launch vehicle closeout crews.

There were also random threats to contend with. During the *Apollo 14* flight readiness test, an anonymous call came in to KSC, threatening to blow up the launch control center. Rigell said, "We did some secret looking around for bombs under the false floor in the firing room. They kept it quiet, but they had pull up some panels because somebody indicated there was a bomb under there."

WORKING IN THE PTCR

Personnel from the spacecraft, launch vehicle, and support operations organizations shared tight office space in the PTCR. Boeing's ECS staff sat in room 216. Bill Heink and the propellant electrical crew had an office in room 215 of the PTCR for about 10 years, across from the propellant electrical equipment in room 210.

Heink described one pastime of the workers at the pad: "In the Apollo days, the ceiling was covered with heavily sprayed-on insulation. We used to take a rubber band and shoot pencils into the ceiling, and they would stick. We would do that before a launch. Everybody was interested in finding out: Does the facility vibrate enough during launch to knock the pencils off? But none of them ever fell. I was back out there again in Shuttle days to visit our old rooms. All of that sprayed-on stuff was gone. I talked to a facilities friend, who said, 'That was all asbestos you guys were playing with.'" An extensive asbestos abatement program continues at KSC even today.

Although there was a cigarette machine near the entrance to the PTCR, there were no food facilities at the launch pad in the early days. Workers either carried their lunches or

8.2 Area permit showing that the bearer was cleared under the APIP program (Author's collection). *Source*: Ward

went back to the main part of KSC at lunchtime. Ernie Reyes recalled that the first food vending machines were installed in the PTCR during the processing of *Apollo 9*, and were the only official "dining facility" at the launch pad through the end of the Apollo era. Reyes said that the lack of a good meal was particularly felt on one Thanksgiving when crews were working at the pad: "It was lunchtime, and some guys and I went to look in the sandwich machine. There was only one sandwich in there. And there was a long line of ants going from the floor, up the machine, into the mechanism, and into the sandwich. That was really bad. You're out there for 12 hours, you're thinking about everybody at home having turkey, and you're there with one sandwich in the machine, and you probably don't have the right change. But it doesn't matter, because it belongs to the ants, anyway!"

WOMEN AT THE LAUNCH PAD

The men's restroom on the second floor of the PTCR was the only restroom in the launch pad area. When nature called, men usually relieved themselves off the side of the LUT or the pad structure. There was no women's restroom in the vicinity of the launch pad during the Apollo era. Women were just not expected (or even permitted, according to some people) to be at the pad, so no accommodations had been made for them. An unused battery lab in the PTCR was eventually converted to a women's restroom in the 1970s.

Ann Montgomery, who reported to Reyes, was one of the few women whose job regularly took her to the LC-39 launch pads. She was the flight crew equipment engineer responsible for all items stowed in the Apollo spacecraft. She assembled and maintained the book that documented where all loose items and equipment were located inside the capsule. Reyes said:

> *There was an unwritten rule that said, "No ladies at the launch pad." The first time she went out, I got a call from the security guy at the gate who said, "I'm sorry. Mr. Reyes, but we don't allow ladies at the pad." I said, "Look at what's in front of you. Tennis shoes, Levis, loose sweatshirt, hard hat, and a badge. She's got a truck and three other guys helping her. She's not just some lady; she's a NASA engineer. Let her in." After that first time, nobody questioned anything.*
>
> *She had to change into a* bunny suit [*clean room garments*] *to get into the capsule. Thank goodness she was not a very modest person! We put up some sheets as her dressing room.*

TRAILERS

Temporary office trailers were part of the landscape at the Cape going back to the earliest launches. The Gemini astronauts suited up in a trailer parked at another pad near the launch site. However, many more workers were housed in pad trailers as the Apollo/Saturn program evolved than NASA may have anticipated.

One engineer speculated that NASA's plan to use just a few trailers at the launch site, rather than building more permanent office space, stemmed from flawed assumptions about Apollo/Saturn processing at Kennedy. Huntsville's original goal was to produce a *ship-and-shoot* booster, one that arrived at KSC in such good condition that it would require minimal launch site processing and be ready for launch in just a few weeks. There would be no need to build permanent offices for launch operations personnel at KSC, since the workers would come in from Huntsville for a few weeks at most, launch the rocket, and then go back home. Unfortunately, that ideal state was not even remotely achievable. Trailers proliferated, as an army of NASA and contractors required workspace close to the propellant farms and the launch pad.

The trailers served valuable roles as TAIR stations (where configuration management records were maintained), as well as staging and storage areas for logistics, spare parts, pad clothing, paper forms, tools, and other items needed in the pad area. Trailers also served as staging areas for people working in self-contained atmospheric protective ensemble (*SCAPE suits*) during hypergolic loading operations. SCAPE operations are covered in more detail later in this chapter.

While the trailers provided relatively inexpensive office facilities, they posed one significant logistical challenge: they had to be towed out of the launch pad area prior to every launch. Beginning shortly after the countdown demonstration test, the trailers were relocated near the MSS park site, about 1 mi. (1.6 km) from the launch pad. They were towed back to the pad area again after launch.

The combined effects of repeated hauling back and forth and the corrosive seaside environment were more than many trailers could stand. Connie Perez said that the frame of his office trailer became so badly bent that the doors and windows would not close completely. Every time it rained and the wind blew, rain gushed in around the doorframe, and the trailer occupants had to scramble to protect their paperwork and files.

The trailers were utilitarian at best, providing a bare minimum of shelter from the pad environment. John Tribe said, “In 1969, I sent one of my guys to be the lead engineer out at the pad and moved him into one of the trailers. I drew a Snoopy cartoon about it, because he was absolutely horrified. He went out there in a suit and tie, and there were roaches and awful stuff everywhere.” (Fig. 8.3).

Dick Koralewicz recalled the efforts of one enterprising worker to make trailer life a little more tolerable for the rest of the Grumman crew on site: “We had a guy who ran something like a little store out there all by himself. He used to buy stuff like soda and crackers for purchase by the pad crews out there. He didn’t take any profit for himself. When he got enough money, all of us who bought stuff from him in his little store would have a big steak dinner at the Merritt Island firehouse. The firehouse would buy steaks and a couple kegs of beer. It was really good for morale.”

INSIDE THE MOBILE LAUNCHER AT THE LAUNCH PAD

Fred Cordia remembers that on a typical day at the pad, there might be several dozen people working inside the base of the mobile launcher. The interior of the mobile launcher was positively pressurized relative to the external environment. A remote intake source supplied air that was free from potential contamination by fumes at the launch pad. This ensured that potentially hazardous gases and vapors did not accumulate within the launcher.

To maintain the positive pressure differential inside the LUT, the exit doors from the LUT were equipped with airlocks. Failure to follow proper procedures in the sequence of opening and closing the airlock doors could result in injury. Kelly Fiorentino recalled that one young technician lost a finger when a LUT airlock door was sucked closed on the worker’s hand.

8.3 Spacecraft operations schedule cartoon lampooning a CSM engineer who was unprepared for life as a *pad rat* (Courtesy of John Tribe). *Source*: Tribe

Even though the computer and electronics rooms in the LUT were climate controlled, that was not true of the rest of the LUT interior. Gene Spilger described working conditions in the mobile launcher: “When the vehicle moved out to the pad, each stage contractor was given a work area in the base of the LUT. Ours was room 6AB, and in the middle of the summer it would get to be about 120 °F (49 °C) in there. At the time, our boss insisted that we all wear shirts and ties. I’m sure all the other contractors had a similar problem. It was really miserable. The only good thing about it was that nobody wanted to stay down there! We were ready to get out.”

Spacecraft operations personnel did not normally enter the mobile launcher; it was the domain of launch vehicle operations. Reyes summed up his impressions of the interior of the launcher as a spacecraft engineer: “I went through the inside of the LUT several times, and each time, I said to myself, ‘Thank God I wasn’t born to work here!’ I couldn’t stand it. It was like you were loading ammo down there.”

CROSSING THE SWING ARMS

The umbilical tower structure needed to be as open as possible to allow rain and fire suppression liquids to pass through and fall to the ground. It also had to allow wind to blow through it to avoid excessive motion that might damage the Saturn V. So, as Fred Cordia described it: “Every inch of the LUT was nothing but a grate. If you were in the central part of it and you looked down, you’d see down to the next floor. You go down three or four steps, around a corner, down a couple more steps, and then you’re on the swing arm.

8.4 Nerves of steel: Boeing workers at the end of the viscous damper system, at the nose of the Skylab Orbital Workshop. They are about 400 ft (122 m) above the ground, without a safety net. *Source*: NASA/Ward

Once you leave the comfort of the envelope of the square box LUT and go out on the swing arm, it's all grating. If you were out on a swing arm and looked down, you basically looked straight to the ground. I couldn't wait to get inside the vehicle."

Walking across the swing arms while the vehicle was on the launch pad was a challenge for some people, especially their first time. John Conway vividly remembered his first visit to the vehicle on the launch pad (Fig. 8.4):

I had just started working for Dr. [Rudolf] Bruns in the CIF. He said to me one day, "We're going to the pad to see the Apollo. You haven't been out there, have you?" I said, "No, sir." He said, "Well, you're coming today!" I had no clue what I was in for.

We go out to the pad, and even just the base of that thing is about seven stories up. You drive up this big ramp at the pad to where the mobile launcher is. You're already up pretty high at that point. Then we get in this enclosed elevator cab, and we go up. I'm just as comfortable as I could be. I'm thinking, "There's nothing to this!"

When that door opened up, we were looking at the very tip of that escape rocket on top of that Apollo capsule. Everybody stepped out of that elevator onto this landing mat that was not welded down. It was just held in place by pegs. It moved when you stepped on it. Not much, but to a person that steps out at about 400 and some odd feet up in the air, and all that's between you and the ground is a little old two-inch pipe running across there – I tell you what: my knees started shaking. I was just *thinking, "Oh my God!" And I eeeeeeased over there and got a hold of the stair railing, where the stairwell went down, and I just sat down and held onto that rail, just in case. One of my colleagues said, "Boy, Conway really likes it up here! Hey, we're going to walk right on out on this little platform here and check some instruments. Why don't you come on out here with us?" They had this little platform that was about 18 inches wide and went right out to the rocket. I said, "Nooooooo, I think I'll just sit right here, thank you very much." They went on out and got their instrument data. They got a big kick out of my just sitting there.*

Chuck McEachern said that one challenge of crossing the swing arms was that the arms were unsteady: "They would actually move around in the wind. They pivoted from the tower, but the arms weren't fastened to the vehicle, other than the propellant lines and the electrical cables, so there was a lot of slack between the end of the swing arm and the vehicle. When the wind blew, the swing arm moved back and forth. The part you walked on was not solid, and some people would refuse to go out to the vehicle. They literally could not make themselves walk across there." (Fig. 8.5).

Even the astronauts, not normally known for being concerned about heights, had reservations about walking the 70 ft (21 m) across swing arm 9 to the White Room and command module. Neil Armstrong, when asked what he considered to be the most dangerous part of the *Apollo 11* mission, is sometimes quoted as saying it was, "the walk across the swing arm to the capsule." Dick Lyon took astronaut Pete Conrad out to visit the LUT on the pad during an early facilities checkout. He said: "Pete got out about halfway and he looked around, and he said, 'Does this have to be this way? Can't we opaque the sides and just build a tunnel? The guys aren't gonna like looking down there. That's scary-looking!' I said, 'This would be such a sail sitting up here in the wind that we can't put anything solid on it. We have to have something that the wind can pass through, or the wind would be constantly moving the spacecraft around.' Pete understood that, but he did not like there not being any flooring—just the grating—and the sides wide open. It was very uncomfortable for him."

Russell Lloyd said that the most dramatic view of the pad was from the hammerhead crane on the LUT. He said, "It's the highest structure on the pad, and the floor is open grating. You look down right into the flame trench."

INSIDE THE SATURN V

Once across the swing arm, workers entered the Saturn V via access doors in the interstage areas or a hatch into the IU. The interstage areas provided access for servicing avionics control boxes and containers, and the engines and the associated plumbing. The S-II had two levels of work platforms inside the aft interstage and one in the forward interstage. Portable lighting fixtures, strung up around the interior, provided illumination of work areas. John Plowden said:

I worked in there quite a bit, in the aft of the S-II between the S-IC and the S-II stage. There was a lot of hardware in that interstage area. There were five J-2 engines, and then all of the associated systems. We put platforms in there, and you could walk around all five of the engines. And then there were platforms that we called "diving

8.5 The *Apollo 17* crew poses on swing arm 9 a few days before their mission. *Source*: NASA/J. L. Pickering

boards" *between the outboard engines to get to the center engine. Each one of the engine systems had the hydraulic flight control system that drove the thrust vector control on the engines. The accumulators and all that were mounted up on the bulkhead of the bottom of the stage*, *where the engines attached. You had so many people trying to get into that area to work at the same time – the engine guys*, *the hydraulics*, *the propulsion*, *and the propellants. There was a lot of activity that went on in there after the vehicle was stacked.*

8.6 *Apollo 17* CMP Ron Evans (*left*) talks with McDonnell Douglas workers Len Blaskowski and Joe Hill. They are inside the S-II/S-IVB interstage of the Saturn V, with the S-IVB's J-2 engine at right. The platforms on which they are crouching will be removed during the launch countdown

Chuck McEachern recalls that the interstage between the S-II and S-IVB was not a bad place to work. "The S-IVB only had the one large engine, and it did not take up all the room in there. So to check the engines out, it was actually a very pleasant working area, especially with the ECS cooling on. In the summertime it was cool, and the wintertime it was pleasant. It certainly wasn't pleasant outside, but it was nice inside." Bill Heink said he had even seen workers playing Hearts on a small table inside the S-IVB aft interstage during their lunch break (Fig. 8.6).

At the forward end of the S-IVB, things started becoming more crowded. There, the instrument unit equipment was distributed around the inner hull of the IU, and the LM was directly overhead. McDonnell Douglas, IBM, and Grumman personnel all came into that area by crossing swing arm 7 to a hatch on the IU. MDAC's Gene Spilger said: "The LM was situated right above us. The footpads were folded up, and that whole center portion was just packed. We and the IBM guys had to be careful. We weren't supposed to touch that sucker because it was so delicate."

The top of the S-IVB interstage and the IU were where the launch vehicle ended and the spacecraft began, and it was here that tensions between the two teams occasionally rose. Launch vehicle test conductor Gene Sestile said, "The spacecraft guys were always dropping stuff into our 'crotch,' where the S-IVB tank came together with the skin of the vehicle. We always had to clean stuff out of our crotch. The LM guys couldn't understand why we had all these restrictions about what they could take inside the vehicle." Grumman's Walt Dermody recalled that someone standing on one of the lower LM platforms accidentally dropped pocket change into the forward end of the S-IVB, which obviously raised concerns and was a hassle to find and remove.

As the SLA narrowed at the top to the width of the service module, access became extremely cramped. Dermody recalled, "You could maybe fit eight or nine people inside the SLA on different platform levels if you were lucky." Above the SLA, all access to the spacecraft was only from the exterior, except for the White Room interface with the crew cabin.

LAUNCH PAD SAFETY

The launch pad was an extremely dangerous place to work, even when the Saturn V was not being fueled. Hardhats were mandatory at all times. One can easily imagine the damage potential of something falling off of a work platform 40 stories overhead.

Workers had to be certified in pad safety procedures before they were permitted to work at the launch pad. Some of the classes included location and use of safety showers/eye washes, Scott Air-Pak breathing, safety harnesses, dealing with hazardous gases, pad egress, and firefighting, among others.

Even after taking safety classes, expediency overcame better judgment at times. Steve Coester said, "Often I would climb outside of the handrails on the 240-ft level of the tower and shinny out on the vent line to inspect a pipe or expansion joint. I never gave a thought to a safety belt!"

WEATHER

Weather was frequently a concern at KSC. Hurricanes were a threat that needed to be planned for, but they were relatively infrequent. The AS-500F vehicle was rolled back to the VAB in June 1966 because of Hurricane Alma. In October 1968, Hurricane Gladys had a chance of hitting the Cape while *Apollo 8* was on the pad. Astronaut Vance Brand recalled attending a meeting in which launch director Rocco Petrone made "a real gutsy call" to trust the forecasters and leave the stack on the pad rather than rolling back to the VAB.

Wind and rain were nuisances, but could be mitigated. If the wind exceeded certain limits, workers were required to vacate the MSS and LUT. The viscous damper system that extended from the LUT to the Saturn V kept the vehicle from swaying too dramatically. Dick Lyon recalled: "Houston and Huntsville had given us requirements that we had to prepare for anywhere from a 24 to 48 in. (61–122 cm) excursion that swing arm 9 had to be able to track if wind moved the spacecraft and the stack. It didn't turn out to be nearly that bad; it was a whole lot stiffer than any of them had predicted. We had to build lots of things that stood well away from the spacecraft, and then we had these fold-down platforms. If we had high winds, you flipped everything up to give the vehicle room to move."

Lightning was a constant threat at KSC. Central Florida ("Lightning Alley") is renowned for having the highest frequency of lightning strikes in the United States. With miles of flat, featureless land around them, the raised pads and giant metal towers of LC-39 were obvious targets for lightning. On August 3, 1965, Albert J. Treib was working on construction of pad B and was struck by a lightning strike.

Two days after the AS-500F was rolled out to pad in May 1966, the LUT was hit by lightning. The hook on the LUT's hammerhead crane dropped in free fall and hit the side of the S-II. Analysis showed that the electrical current from the strike had welded open the crane's brake drum solenoids.

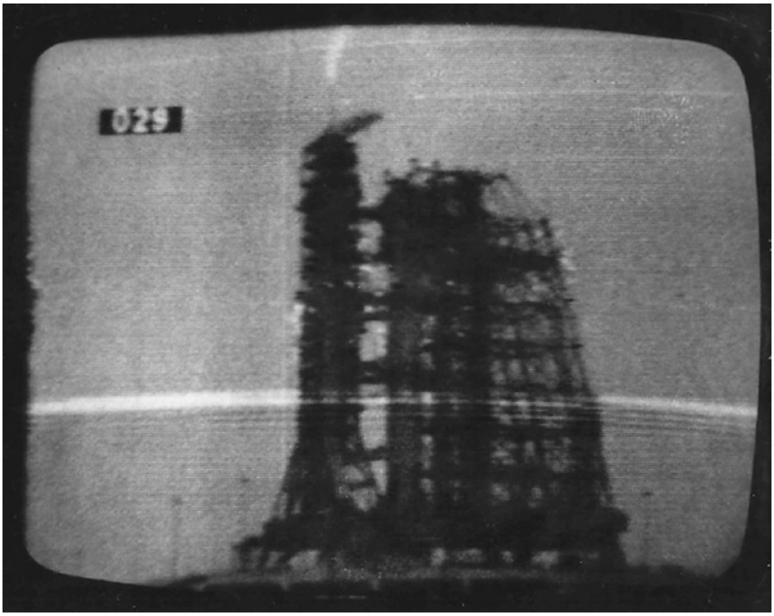
Subsequently, the launchers sported a folding lightning mast attached to the top of the LUT. The lighting mast—as tall as a Redstone rocket—was raised to a vertical position after the LUT rolled out of the VAB. Once at the pad, jumpers on the six support pedestals and a network of buried copper cables electrically grounded the LUT. The lightning mast and the ground lines established a 45° cone of protection that included the Saturn V and the LUT. Theoretically, lightning could not hit the Saturn V directly. Cable tray covers over the long cable runs up and down the umbilical tower shielded the ESE and GSE on the tower.

Frank Bryan said that, "Despite being plagued by thunderstorms and lightning strikes, the Saturn V launch vehicle never sustained damage from a strike. However, the possibility of damaging induced voltages from the strikes caused enough concern that that we developed a lightning retest procedure for the Saturn V stack. We instituted the rule: If you take a lightning strike on the umbilical tower, you retest everything in the Saturn—everything. After each strike to the LUT, we called in the crews from Boeing, Rockwell, McDonnell, and IBM, and we'd have a lightning retest."

JoAnn Morgan added, "If we got hit by lightning, we had to know what had been damaged, and what had to be repaired or replaced, components, and how much has to be re-tested. That could take days sometimes."

Even though there were five Saturn Vs at the launch pads at one time or another during the course of 1969, none of them were hit by lightning while on the pad. Bryan noted that things seemed to change after *Apollo 12* was struck by lightning after launch: "*Apollo 12* seemed to herald the start a series of lightning storms in the following months. Every launch we got into, during the countdown, during the preparation, during the testing, a month before launch and 2 weeks before launch, we'd get these damn lightning storms. As the afternoon and evening storms drifted over Merritt Island, lightning strikes in the launch area increased. I was in the firing room several evenings when we watched a storm approach and lightning strike the tower. TV cameras plus instrumentation on the lightning mast confirmed the strikes." (Fig. 8.7).

Magnetic slugs (also called *mag links*, which recorded the peak current of lightning strikes) were added to the LUT instrumentation starting with *Apollo 8*. Bryan described the mag links system: "It was a magnetic material that sat inside the coil, and the coil carried the lightning from the mast down to the ground. When lightning hit the mast, it went



8.7 Photograph from an OTV monitor, showing a strike on the LUT's lightning mast. *Source*: NASA/Frank Bryan

through this coil and magnetized that stamped metal slug. You could take that slug back to the lab and calculate how many amperes were in the strike. They measured it in kiloamps–thousands of amps. A lot of the strikes were 5 or 10 kA, just weak strikes. We had a big one at 150 kA! The electrical effect you got from the strike depended on the magnitude of the strike."

Slugs were also mounted on several lightning rods that protected the MSS vent stacks. However, these locations on the MSS were considered to be almost inaccessible. The slugs were not examined for years because of the potential danger to personnel just trying to get to them.

Lightning hit the launch complex on six different days when *Apollo 15* was at the pad in 1971. The first strike, recorded as 98 kA, vaporized the top 3 ft (1 m) of the LUT lightning rod. Roy Tharpe recalled a situation in the week leading up to *Apollo 15's* launch, where lightning strikes in the pad area nearly jeopardized the mission's ability to make the launch window:

We had a strike during countdown, and we had to get that toroidal coil off and get the mag links to the CIF. We needed Bendix to go out to lower the mast, and we needed Federal Electric technicians to go and remove the toroidal coil off of the lightning mast. We had lightning and thunder and everything, and the guys in the firing room said, "If we don't get that coil, we're not going to make the launch."

I called Ernie Amon in the weather office, and I said, "Ernie, I'm going to send people out in harm's way, and I need a 30-minute window that you guarantee me that they're not going to get hit by lightning." He called me back, and said, "Here's *your window." I directed the Bendix guys, and they went up and lowered the mast. Then I've got the Federal Electric guys who have all these instruments telling them, "Man, this atmosphere is charged! If we go out there, we could be hit by lightning!" I said, "Look, you've got to go out there and get that mag link. We've got to have that analyzed." I had to call their boss at home and have him tell them to go out there, because this schedule was just that critical.*

They went out and got the mag links, and we took them to the CIF under a police escort. The CIF was standing by to do the evaluation. We gave the data to the test team in the firing room. They determined everything was okay, and we launched on time.

Several powerful lightning strikes hit the LUT when the *Skylab 3* and *4* space vehicles were at the pad. Even though the vehicles were not directly hit, induced currents damaged some of the sensitive signal conditioning equipment just inside the skin of the vehicles. This equipment was repaired in time to avoid delaying the launches.

Whether or not the vehicle or service structures were at risk from lightning, workers at the pad needed to clear out as soon as thunderstorms threatened the area. The PA system announced the approach of storms. Fred Cordia said:

We had a thunderstorm it seemed like every afternoon in Florida. You could set your watch by it. They had a weather facility that monitored for lightning in the area. Once that weather detection operation detects lightning within 5 mi. (8 km), a warning goes out on the PA. If you're on the vehicle, you stay there; if you're on the LUT, take cover and stay there. You were never to go across from the LUT to the vehicle or from the vehicle to the LUT if there was lightning in the area. If there should be a lightning strike when you're stepping from the LUT to the vehicle, you're gonna get zapped, because the potential between the vehicle and the LUT is going to be monstrous.

I have talked to guys who got stuck and had to stay in the S-II aft interstage during a thunderstorm. You know damn well you're in the tallest thing anywhere around. If anything's going to get struck, you're going to get struck. You'd be protected as long as you stayed in there, but it would definitely be a thrill.

FIRE SAFETY

Fire safety was a concern at launch pads long before the *Apollo 1* accident. Wackenhut was the firefighting contractor during the activation and early years at LC-39, with subsequent contracts going to TWA and then to Boeing by the end of the Apollo program. Many of the firefighters transferred from one employer to the next as the contracts changed (Fig. 8.8).

Some workers received intensive training in firefighting as part of their pad safety certification. The basic rule was, "fight the fire to get yourself out." There was little chance of one person, or even a small team of people, being able to put out a major fire at the pad by himself. Escape was considered the only realistic option.

8.8 KSC firemen in their "silvers." The *ASTP* space vehicle is on pad B in the background.
Source: NASA/Jerome Bascom-Pipp

J. I. Daniel described training he attended for escaping fires: "It was an eight or ten day accelerated course for the close-out people, taught by navy firefighters. They were showing us how to use CO_2 on a gasoline fire. They had us walk through a fire pit. Some of us had fire bottles that weren't charged. They told us that if our bottle wasn't working, we should walk real close behind somebody whose bottle was working. If you put it between your legs and turned it on, you could walk through the pit."

Hydrogen fires posed an unusual challenge in that there was no visible flame or smoke in daylight. Fireman Lee Starrick related a low-tech way of detecting a hydrogen fire: "They said if there's a possibility of a hydrogen fire, you have to hold a broom out in front of you, because you can't see the flame. Believe me, you don't need to worry about using a broom to tell if there is a hydrogen fire, because there is so much heat. Hydrogen gives off an unbelievable amount of heat, and you can see the heat waves, day or night. There are enough particles in the vapors at night time that you can see the sparkles, and you know it's a fire."

Steve Coester remembered one run-in with hydrogen at the pad:

> *Once we had a leak on the 12-in. (30 cm) vent valve from the storage tank. At that time, helium for inerting was a rare and expensive commodity, and it was going to take months for the tank to warm up enough to inert it with nitrogen. So, we decided to remove the vent valve with a partially full tank. We all had on anti-static clothes and leg stats, and we had fans to blow the hydrogen away. As soon as the flange was loosened, we were enveloped in a cloud of hydrogen vapor. I was sure an explosion would ensue, but we had little choice but to complete the job. Somehow we survived.*

LOX also posed a fire and explosion hazard. Daniel recalled, "You could step on liquid oxygen and make it pop, but if you weren't careful you could hurt yourself. There was one guy at Wallops Island who blew his toe off stepping on LOX." Bill Heink recalled one situation involving Bob Bucina, Boeing's lead mechanical engineer for the LOX system: "Bucina had nerves of steel. I was out with him one time when we blew a relief valve on the LOX system. You are totally, immediately engulfed in a cloud of fog, and you can't see the ground, you can't see anything. Your immediate reaction is to run to get away. I remember Bob screaming, 'Hold your place! Stay where you are! Watch where you step!' The last thing you want to do is step in LOX. If there's any dirt or anything that can mix with it to make it a gel, it's going to blow your foot off."

Norm Carlson said: "LOX vapors would settle in your clothes. At the test stand in Huntsville, you wore white smocks. I saw a guy light up a cigarette after being near LOX. His shirt flashed with a *whoosh*! and his coat glowed blue for a second."

WORKING AROUND HYPERGOLIC PROPELLANTS

Hypergolic propellants (*hypers*, as they are known amongst rocketeers) consist of a fuel and an oxidizer which, when brought into contact with each other, immediately and violently combust. The Apollo spacecraft used nitrogen tetroxide (N_2O_4) as the oxidizer, and the hypergolic fuels included monomethylhydrazine (MMH), unsymmetrical dimethylhydrazine (UDMH), or a modified variant such as Aerozine 50 (A50).

Hypergols were extremely corrosive and toxic, and they caused any number of problems if one were exposed to them in even minute quantities. The oxidizer becomes concentrated nitric acid when it comes in contact with moisture, which can cause pneumonia and edema if inhaled. UDMH is carcinogenic and can be absorbed through the skin.

Starrick was uneasy about working around hypers, but his role as a firefighter required him to gain firsthand experience in dealing with them:

> *Nitrogen tetroxide was good in one regard, because when it vented, you could see the orange cloud, so at least you knew it was there. But hydrazine was a clear vapor, and you couldn't see it too well. The problem was that if you smelled it, it was supposedly already well past the threshold where it was toxic. So once you smelled it, it was too late!*

We trained with hypergols when we were preparing for Apollo 16. *I've got a movie of one of our training officers from that course, an Englishman named Roy Terry. We had a pit where they would mix the hypergols and burn them. Roy emptied a 20-pound dry chemical extinguisher in there, and it blew up. It could be heard in Titusville. He was standing there with that extinguisher spraying it, and when it blew, it backed him up and there was a huge fireball. He didn't get hurt, luckily.*

Later on in that same training, we were trying a new Nomex coating material that DuPont was developing to put in the threads on a firefighter coat. They sent us one to test. Roy actually literally backed into the fire. He was standing on the edge of the pit, and he had no air on at all. And he was standing in there, and it was popping and cracking. Hypergols spontaneously ignite when you mix the fuel and the oxidizer together, and the popping was basically small explosions.

Starrick remarked that in the 1990s, Roy Terry developed cancer that spread throughout his body. Terry blamed it on not having been more careful around hypergols in his career.

SCAPE SUITS

When the hypergolic propellants were being loaded into the spacecraft and S-IVB, the launch pad had to be cleared of all personnel who were not involved in the weeklong hyper loading process. Everyone whose job required them to be in the vicinity of the vehicle during hyper loading had to wear *self-contained atmospheric protective ensemble*, better known as *SCAPE suits*. As the formal name implies, SCAPE suits were completely sealed to protect the wearer against any inadvertent contact with liquids or vapors (Fig. 8.9).

John Tribe, who supervised the hypergolic propulsion systems for Rockwell, spent many hours during the Apollo era in a SCAPE suit. He provided the following vivid description of SCAPE operations in servicing the Apollo spacecraft before a mission (Fig. 8.10):

During the early years of the Apollo program, servicing operations were around-the-clock exercises, usually two 12-hour shifts. SCAPE tasks depended on the amount of air available and the endurance level of the worker in the suit. The duration of SCAPE tasks for each person was therefore limited to one hour in the suit, followed by one-hour rest, then back into the suit, and so on throughout the 12-hour shift. All of us healthy engineers had our turns in SCAPE on station, and we learned to appreciate what the technicians and quality control guys had to suffer through.

Trailers were set up at the pads to support SCAPE ops. In one trailer, personnel would strip and then put on yellow cotton long johns and tops, taping the wrists and ankles with duct tape to hold them secure such that they would not roll up when the SCAPE suits were donned.

Dressed in their long johns, personnel would then move on to the second trailer, where SCAPE technicians would help them into the legs of the one-piece rubberized suit, followed by the heavy rubber boots, locking the boots to the suit. With the wearer sitting on the upper half of the suit, technicians would help him shoulder the compressed air pack onto his back. The air pack supplied breathing air as well as

8.9 SCAPE suit for hypergolic loading operations, 1967 (Courtesy of John Tribe). *Source*: Tribe

cold air to the suit extremities through distribution hoses. The suit was then pulled up into place over the air pack. Helmets were part of the suits, with large hyper-resistant faceplates. They were not donned at this point. Personnel would then be in the standby mode awaiting the call to station.

When the word was received, the SCAPE technicians would turn on the air, verify adequate flow, and then assist the wearer in pulling the helmet up over the air pack and his head. Once secure and relatively comfortable, the suit was zipped up and the gloves attached and locked. The interior headset was plugged in and tested. The wearer was now self-contained and ready.

8.10 Donning the air pack as part of SCAPE suit-up (Courtesy of John Tribe). *Source*: Tribe

Transport to the work areas was by special truck to limit walking. Physical activities in the suit were very tiring; mobility was restricted and bending or stretching difficult. Some of the less physically fit personnel were often breathing very hard and suffering at the end of their duty.

Each shift was an exhausting 12 hours, and the suits became increasingly uncomfortable as the shift progressed – pinching at the joints, abrasion in the gloves, fogged face-plates, and never a comfortable temperature, either too hot or too cold. On one occasion, one of the engineers, Joel Robinson, had a malfunction in his air pack, and liquid air *was dumped into the cooling distribution lines. This made the lines brittle, and they broke. This burned his back and caused him to leave the operation to make an emergency egress from the suit.*

The rest periods meant that we would sit in the trailer with the upper part of the suit and helmet pulled back. The air-pack was removed and re-filled while we sat in the lower half of the suit with our boots on and gloves off. It was not too comfortable, but still better than being in the complete suit. The end of the shift was always welcome.

My old friend Guenter Wendt, who had been exposed to a hydrazine spill during the Shuttle program, suffered from peroneal neuropathy (loss of control in his feet) in his later years, which he always said had been caused by that spill. At the time of his death, the doctors were still out on that possibility.

HYPERGOLIC SPILLS AT THE LAUNCH PAD

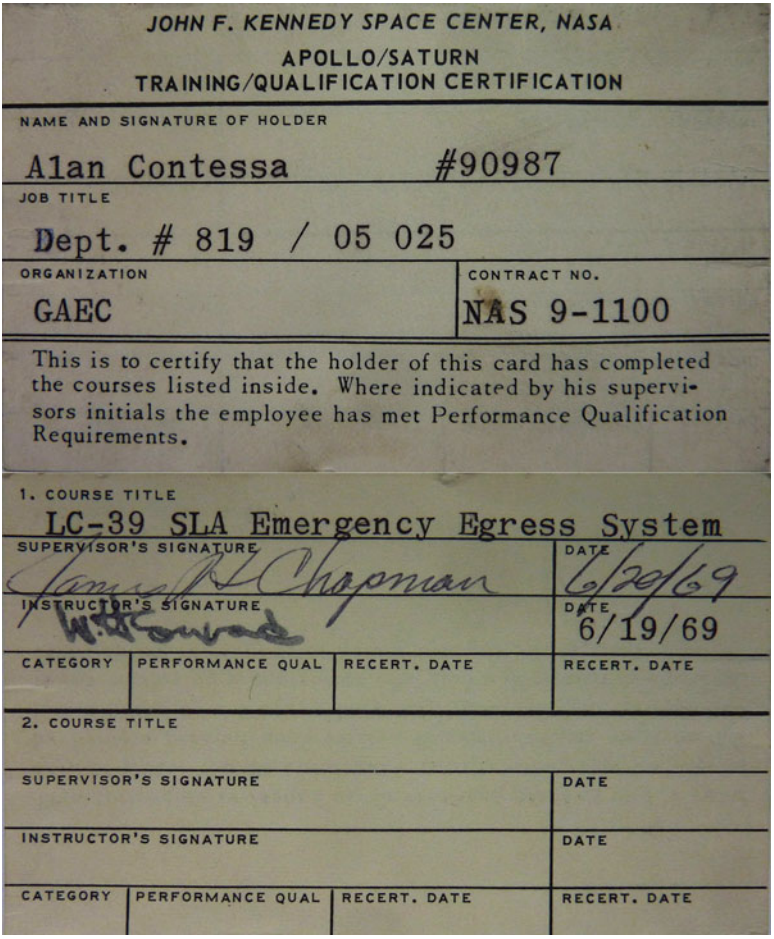
NASA needed to protect workers inside the SLA in case of a leak during the hyper servicing process. Dick Lyon described the thoughts behind the initial design: "What if we have a leak? What if one of these connectors breaks loose? You've got people trapped in there with free-flowing hydrazine. We came up with a system that flushed water in and around the S-IVB stage and then sprayed up inside the SLA. Then we decided against the sprays, because the LM was so fragile. We ended up with this deluge that would dump gross amounts of water to swirl around the dome of the S-IVB and wash it out and down the side of the rocket. We needed copious amounts of water so we could dilute it way down."

NASA also designed *cookie cutters* that punched holes in the sides of the SLA so that pad workers could quickly escape in the event of an emergency. Dick Lyon described the system: "The cookie cutters were near the walkways inside the SLA. If workers had an issue or there was a fuel spill, the firing room could call for them to activate the cookie cutters. They were activated by explosive bolts, and they cut right through the SLA—just opened up a big circular hole. The cutout fell out onto the deck of the launch structure, so a servicing technician that was in there could escape quickly."

Alan Contessa recalled the warnings he received about the cookie cutters: "We had to go to 'SLA school.' They trained us in emergency procedures before you could go into the SLA. In case of emergency, they said, 'Before you push that button, you had better make sure that your life is on the line!' If those buttons were pushed, they would have to unstack the vehicle and put a new SLA on. So they didn't want us touching those buttons. We were young, and I guess they thought we might do something reckless." (Fig. 8.11).

There was never a hyper spill of consequence inside the SLA during Apollo. However, an accident with serious consequences to the Saturn IB launch vehicle destined for the *Apollo 7* mission occurred during a hyper loading test at the CSM level of the stack at LC-34. John Tribe, Ted Sasseen, Horace Lamberth, Frank Bryan, Tip Talone, Gene Sestile, and Ike Rigell contributed to the following account of this incident.

On Sunday morning, April 21, 1968, a boilerplate spacecraft was sitting on the launch vehicle, since the *Apollo 7* CSM and SLA had not yet been delivered to the pad. Propellant servicing for this hyper loading test was supposed to be exactly like the process to be used later with the flight vehicle, but test tanks were used instead. Service module tanks were oriented vertically, and could be filled by overflow. Command module tanks were horizontally oriented and required a vacuum, collapsing the internal fuel bladders around the standpipe before filling them.


JOHN F. KENNEDY SPACE CENTER, NASA
APOLLO/SATURN
TRAINING/QUALIFICATION CERTIFICATION

NAME AND SIGNATURE OF HOLDER
Alan Contessa #90987

JOB TITLE
Dept. # 819 / 05 025

ORGANIZATION	CONTRACT NO.
GAEC	NAS 9-1100

This is to certify that the holder of this card has completed the courses listed inside. Where indicated by his supervisors initials the employee has met Performance Qualification Requirements.

1. COURSE TITLE
LC-39 SLA Emergency Egress System

SUPERVISOR'S SIGNATURE			DATE
			6/20/69
INSTRUCTOR'S SIGNATURE			DATE
			6/19/69
CATEGORY	PERFORMANCE QUAL	RECERT. DATE	RECERT. DATE

2. COURSE TITLE

SUPERVISOR'S SIGNATURE			DATE
INSTRUCTOR'S SIGNATURE			DATE
CATEGORY	PERFORMANCE QUAL	RECERT. DATE	RECERT. DATE

8.11 SLA emergency egress training certification card. Workers carried these cards as proof that they were trained in use of the cookie cutter system. This cleared them to work inside the SLA after the LM was fueled with hypergols (Courtesy of Alan Contessa). *Source*: Contessa

Test operations were being run from the ACE control room in the MSOB. The system engineer in the ACE room could operate each valve, and he could control the thermal and pumping units. The process of actually servicing the propellant tanks was completely manual. Two technicians in SCAPE suits were stationed at each area on the servicing platforms.

SM tank loading was complete, and the crew was getting ready to fill a CM tank. The CM test tanks had been emptied after the initial load, or so the Rockwell engineers thought. However, because of an undetected blockage in the quick-disconnects, one horizontal tank was still partially filled with nitrogen tetroxide. As the preparations for reload continued, evacuation of this supposedly empty tank commenced. Almost immediately, the vacuum pump sucked in the fluid remaining in the tank, and the oil sump vent spewed a stream of nitrogen tetroxide several feet into the air.

The SCAPE technicians reported the spill, and found they could stop flow just by placing a gloved thumb over the hole. As engineers tried to understand what was happening, the oxidizer flow continued. The techs addressed the growing puddle on the deck with the standard, approved procedure, which was to dilute the spill with copious amounts of water.

Oxidizer flow was quickly terminated. The techs completed their cleanup with a fire hose, washing what was now dilute nitric acid from the upper levels of the servicing structure. This run-off was later estimated to be some 400 gal (1,500 l). The dilute acid, mixed with pump-oil, flowed through numerous openings in the decks, down the side of the service module and empty SLA. The acid found its way into hatches and panels and numerous small holes. It flowed down to the instrument unit, S-IVB, and S-IB stages, spreading into joint interfaces and finally down to the launch platform.

Tip Talone recalled: “They started hosing everything down. So here you’ve got an instrument unit that’s all powered up, all the computers and all the avionics and electronics for the whole launch vehicle. They’ve got the fire hose on it. It diluted the leak into where it was still acid, but it was then running out the scuppers of the instrument unit, down the side of the S-IVB, and stripping the paint off as it ran down the side.”

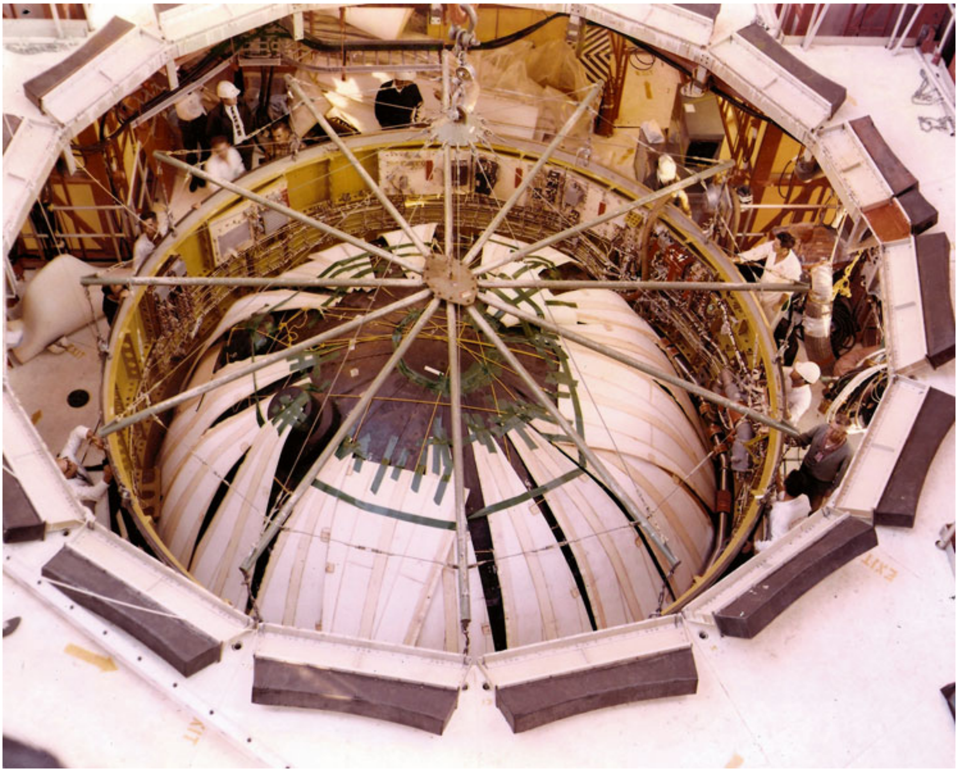
The S-IVB stage personnel showed up in the next few hours. Everything seemed wet. Clean up and mopping began immediately with a 1 % sodium bicarbonate solution. Bosun’s chairs were used to wipe the outside of the vehicle (Fig. 8.12).

The Monday morning after the incident, a meeting was held for the unpleasant task of informing launch director Rocco Petrone about the accident. John Tribe described the scene: “Everybody involved was there, from the base managers on down—IBM, Douglas, Chrysler, and, of course, North American—all with their NASA counterparts. Rocco was a big man, dominating the room. He spent the entire morning ‘chewing.’ I sat in the spotlight. It was my first experience being chewed out by Rocco. I learned to listen. We could only plead *nolo contendere*. We hadn’t been very smart. It damn well wasn’t going to happen again.”

A lot of fluid had made its way inside the IU. The IU was taken to its hangar. McDonnell Douglas had to remove the S-IVB forward interstage and the top of the tank, and the interstage went to the VAB. The other interfaces were de-mated and carefully cleaned. The lab analyzed many hundreds of sample wipes taken outside and inside the vehicle. The process took several weeks.

Frank Bryan recalls: “I was assigned the job of tracking wherever the spill went inside the instrument unit. I had chemists out there with litmus paper going over every part of the IU. We made a big map of the IU and plotted wherever they found traces of the spill, so Huntsville could figure out which parts to replace. It looked like it had just splashed around in there. Those guys had taken a 4-in. fire hose and hit that little puddle of oxidizer full force. That blew it everywhere.”

MSFC’s major worry was long-term corrosion. They started tests to evaluate the condition of the vehicle and its components. Most of the IU cabling came out and was wiped down. Four cables were replaced, and five connectors re-terminated. All the electronics boxes appeared to be okay. Three outside antennas were changed. The S-IVB only required

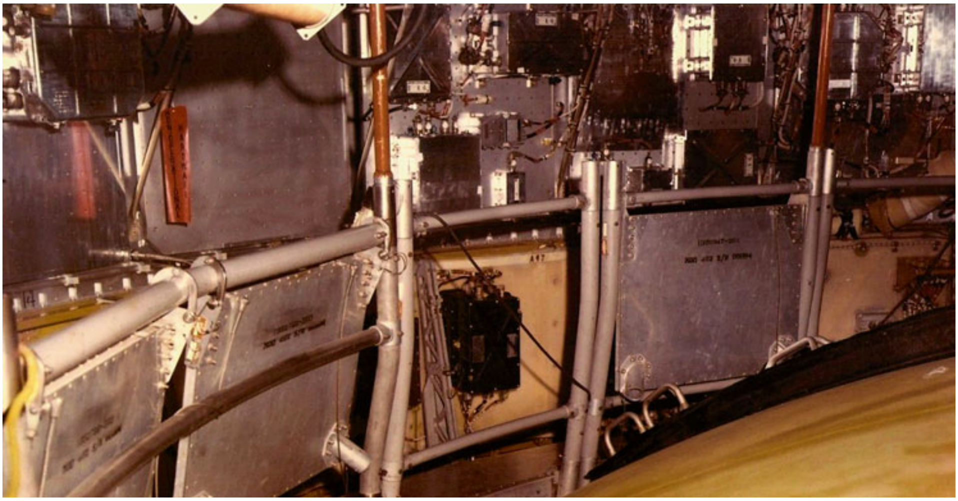


8.12 Looking down into the S-IVB forward section after the AS-205 hypergol spill. Frank Bryan is in suit and tie at *upper left. Source*: NASA/Frank Bryan

extensive cleaning. On the S-IB, fin #4 and the door to LOX bay 3 were replaced due to staining. Everything else was cleaned (Fig. 8.13).

Tribe said, "While this regrettable incident caused a significant amount of cleanup, it did establish a much better appreciation and heightened sensitivity for working with hypergolic propellants, both by the spacecraft and launch vehicle teams." Rockwell rewrote the hyper servicing procedures after the accident. All work except the incident report was complete by May 10, 1968. Writing the incident report took until mid-June, and the report was 1.5 in. (4 cm) thick.

Rockwell materials engineers developed a special *Velostat* cloth, which was graphite-impregnated, Teflon-coated, and totally inert. Rockwell used Velostat to make an enclosed tub of each deck on the servicing structure, and scuppers under every joint. Rockwell also developed an aspirator (which Tribe described as "a miniature venturi in a pot") that ran on pressurized nitrogen and could suck up any fluid spills. The hyper loading crews could now contain small spills without the need to use a fire hose, and in major spills, everything could be washed down without anything leaking down the vehicle.



8.13 Some of the IU components that had to be removed and examined after the hypergol spill. *Source*: NASA/Frank Bryan

Another procedural change was that each quick-disconnect would be disassembled and cleaned, and the seals replaced, after each use. Finally, the crew would use non-hazardous test fluids such as Freon and alcohol in future tests of the hypergolic servicing equipment.

The launch vehicle people were equally determined to protect themselves from hyper spills. They fabricated special curtains and wrote procedures to tape all interface joints and all other invasive leak paths. These would be put in place before hyper loading operations and removed before flight. Contingency procedures were also developed.

Perhaps as a fitting bookend to the program, another minor hyper spill occurred during the processing of the Apollo-Soyuz Test Project mission, the final flight of Apollo/Saturn hardware. Ernie Reyes said: “We had a little spill at the pad one day. A crew mopped it up and cleaned everything up. We talked about it and drew a cartoon on our processing schedule. John Tribe drew the cartoon. Snoopy is holding something the size of a huge bucket, but it looks like a thimble, because when John was asked to describe the spill, he said, ‘We only spilled a thimble full.’ Snoopy has a clothespin on his nose. If we had said we spilled two gallons, management would have said, ‘Cease and desist.’” (Fig. 8.14).

CREW EXTRACTION AND RESCUE

KSC firemen and the white room crews trained to rescue the Apollo crew from the command module in case of an emergency at the pad. The original procedures forbade anyone on the rescue team from completely entering the command module. While the astronaut in the center couch was relatively easy to extract while the rescuer leaned into the hatch, it was much more difficult to pull the other crewmen out of the vehicle. It could take the rescue team 3.5–5 min to extract an incapacitated crew and take them to across the swing arm to safety.

8.14 "Only a thimble full" of hypergolic propellant was spilled during *ASTP* processing at the pad (Courtesy of John Tribe). *Source*: Tribe

One of the rescue team members questioned the restriction on entering the vehicle. He proposed a process in which he would remove the center crewman, straddle the center couch from inside the cabin, and then pass the other astronauts over to the center to be pulled out. Lee Starrick described the astonishing performance improvement resulting from this proposal:

The rescue leader let us try that, and the very first time, we pulled the crew out in about a minute and twenty seconds. With practice, we got it down to less than a minute. We would go from the LUT end of the swing arm all the way to the White Room, pull the three astronauts out, put them in our chairs, and be back at the LUT end of the swing arm in less than a minute. It was amazing.

We had to get the procedure changed. Guenter Wendt, as pad leader, was one of the technicians who came to see what we were proposing. The first time he had seen a crew extraction, it took almost ten minutes to get the guys out. When we told Guenter we could do it in less than a minute, he said, "That's impossible. You cannot do it that fast."

He stood at the end of the swing arm and operated a stopwatch, and we did it in like 58 seconds. He said, "You obviously didn't have them hooked in there." We said, "Okay, come with us." We put him in the capsule standing behind the seats. We said, "You stand up here and you watch." We did it in 57 seconds. Guenter came out of there shaking his head. He said, "I don't believe I saw what I just saw. They were in there, connected."

We also practiced the procedure with our face masks blackened to simulate the capsule being full of smoke. We were the first rescue team to do that for Apollo.

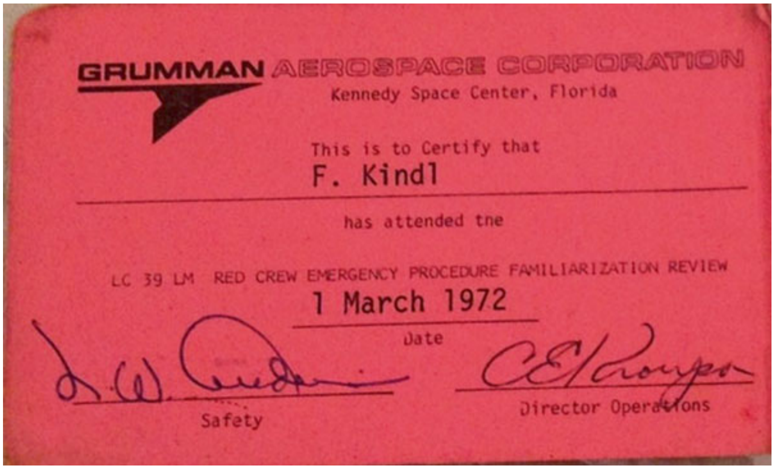
8.15 Vehicle pass for the fallback area near the VAB, which was the staging point for support personnel and red crews during launch countdown (Author's collection). *Source*: Ward

RED CREWS

Any test that involved hazardous operations during countdown required a *red crew* (also called a *red team*) to be assembled and posted at a staging (fallback) area. The red crew had to be ready to enter the hazardous area to resolve an anomaly that might crop up. The red crew had mechanical, propulsion, electrical, and instrumentation specialists from technician operations, quality control, and safety. Test engineers joined the red crew when required to assess an anomaly. Only those personnel deemed absolutely necessary to troubleshoot or investigate an anomaly were allowed to enter the hazardous area. The red crew was in constant communication with the stage test conductor and was monitored via the OTV system the entire time they were in the hazardous area (Figs. 8.15 and 8.16).

Russ Lloyd said:

> *We had a standby team, in trailers over by the press site near the VAB, with technicians and engineers from basically every discipline, both flight side and ground side. If an anomaly in flight or ground systems cropped up during countdown, we did what we could to analyze it by our telemetry systems and make any corrections that we could. But if necessary, we would send in a red crew. We would get the vehicle and everything in as safe a condition as we could from the firing room, and then we'd send the team in. The team would go in and do their troubleshooting and then exit and come back to the staging area. Hopefully the situation would not be serious enough to cause a launch scrub.*



8.16 Red crew emergency procedure familiarization certification card for Grumman's Fred Kindl (Author's collection). *Source*: Ward

Red crews rarely had to make trips to the launch pad, but when they did, it was a memorable experience. Bill Heink said:

As someone who made a total of three Apollo red crew pad entries with fully loaded Saturn V vehicles, I can attest to the strange and unearthly noises that damned rocket could make: creaking, groaning, an occasional loud ssssssss! *and sometimes sounding like a group of screaming banshees. The best comparison was to a steamed-up railroad locomotive, ready to go and sitting on a siding waiting for a green board. It really seemed like a kind of living, breathing beast.*

One of those pad entries was to fix a badly leaking LOX valve on the 120 ft. level. Our fix involved wrapping the leaking area with wet baby diapers until they froze and the leak went away, or at least was reduced to an acceptable level. Hey! It worked!

I must say I don't remember ever being scared while out there, but perhaps I was too young and dumb to experience that. Surely at that time of life, we all thought we were immortal! I do know that we were sure prepared for whatever might occur and tried to "what-if" everything before heading out.

A fully-fueled Saturn V was a truly impressive thing. There's no way to describe what you felt walking out to that damn vehicle and suddenly realizing what was there, and knowing what was going to happen – that in a matter of hours, that whole huge thing was going to fly away into space.

Apollo 4/*AS-501 Relay Failure*

William E. "Bill" Moore was on the red crew during the *Apollo 4* (AS-501) countdown when an electrical systems test uncovered a circuitry problem. Cryogenic propellants were already loaded on the vehicle. In a recollection he wrote after the incident, Moore said:

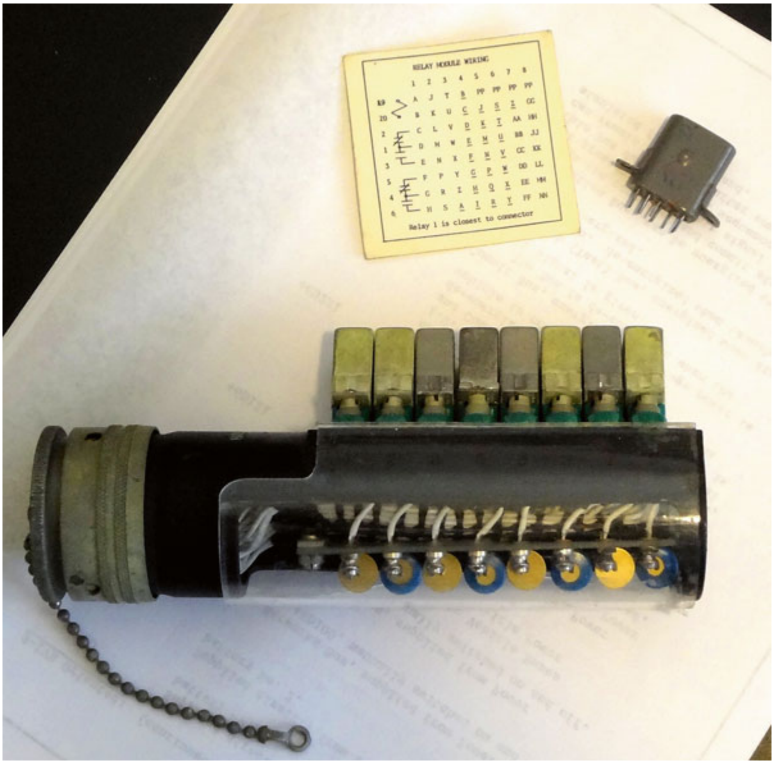
> *Five of us "rocket scientists" were lounging around the ready room, listening to the* Apollo 4 *countdown on loudspeakers and headsets. We were members of the red crew, and we were the electrical systems experts on all hardware interfaces between the firing room and the Saturn V three miles away. Our ears were now being drawn to a situation developing on the net. No response was received from an electrical circuit that controlled the separation of the S-II stage from the S-IC stage in flight.*
>
> *That circuit was controlled by a series of relays located almost directly beneath that beast that was spewing out all kinds of very cold gases. We took a look at our schematics and found the relay that must be the problem. We suggested a recycle in the countdown to a point where we could cycle the switch on the electrical networks console to see if the relay would pick up. That was a* no-go. *Now things got serious.*

The options ranged from scrubbing the launch to going to the pad to try to fix the problem. The red phone rang in the ready room. Rockwell's Albert C. "AC" Martin asked Moore how sure he was that the relay was the problem. Moore replied: "It's worth a shot. The signal is not reaching the vehicle, and that relay module is the only active component between the firing room console and the vehicle. You snap out the old relay module and snap in the new one, and we'll be able to tell if that was the problem a few seconds later."

Moore said that about half an hour later, he, Rockwell technician Bob Kelso, a Rockwell QC representative, a safety engineer, and the NASA pad leader were told to go to the pad with a replacement relay module. It was 11:30 p.m (Fig. 8.17).

The van stopped, and the team began walking up to level A of the launcher. Moore said:

> *At about this time, it came to my mind that during one of our training sessions, we were told that one of the fully-fueled prototype rocket stages had exploded out in the desert. The results showed that all buildings better be at least three miles from the launch pads, which they are. And we were now within 25 ft. (8 m) of this 363 ft. (111 m) tall bomb that sounded like its giant fuse had been lit, and we were soon going to get much closer.*
>
> *The Saturn V was more noisy and ghostly than I had ever expected, and it had grown much taller and certainly more threatening since last week. The venting fumes made loud hissing sounds when relief valves popped or opened up suddenly. It was very easy to let your imagination infect your brain. This is a very dangerous place, and everything seems to be moving in the heavy foggy mist. There was no way to talk to each other. Heck, we could barely see each other. We held onto each other's yellow protective clothing like kindergartners crossing the street. We all wore safety helmets, but they just did not make you feel like you were really safe.*
>
> *We climbed up the last step prior to opening the sealed submarine type entry door that led into the second level. We slowly opened the heavy steel hatch-type pressurized door. It was like stepping into the jaws of a huge steaming dragon. The*



8.17 A relay module, one of hundreds that were part of the electrical support equipment in the firing room and mobile launcher (Author's collection). *Source*: Ward

swirling mists outside and the dim red glow from the emergency lights of level A made it look like a Hollywood swamp scene. We started making our way through the 21 compartments to find our relay rack. The noise took on a more penetrating tone that seemed to bounce from wall to wall.

The smell became a mixture of kerosene with a mild touch of burnt paint and rubber. I was glad that the astronauts did not take this path to go aboard the Saturn V, because my goose bumps were changing to a weird color of purple. With the realization that this was a much worse place to be trapped in, the team moved more rapidly to the relay rack. We replaced the old relay module and then called back and had them cycle the switch on the firing room console. We checked that the relay kicked in and that the signal was picked up on the vehicle. We resealed the cabinet, signed off on all the paperwork, and got out of there without any more sightseeing.

The drive back to the ready room very was fast and uneventful. The five of us were like stone figures, thinking about where we had been and what we had just accomplished, what could have happened and didn't. And all of this was without ever realizing that this experience was as close to being in the shoes of a Saturn V astronaut as any of us would ever be again.

Another member of the team recalled: "I have a vivid recollection of the experience. Bill's description is very accurate, except he failed to mention the eerie sounds that we heard when something, probably ice, fell on the deck and sounded like a drum beating—except we were inside the drum. I got 'volunteered' because I was single and did not have a family to worry about if something happened. Like the 24+ hours I spent in the rubber room under the pad, it is a one-of-a-kind memory I'll have for the rest of my life. Those really were the 'good old days.'"

RUBBER ROOM AND BLAST ROOM

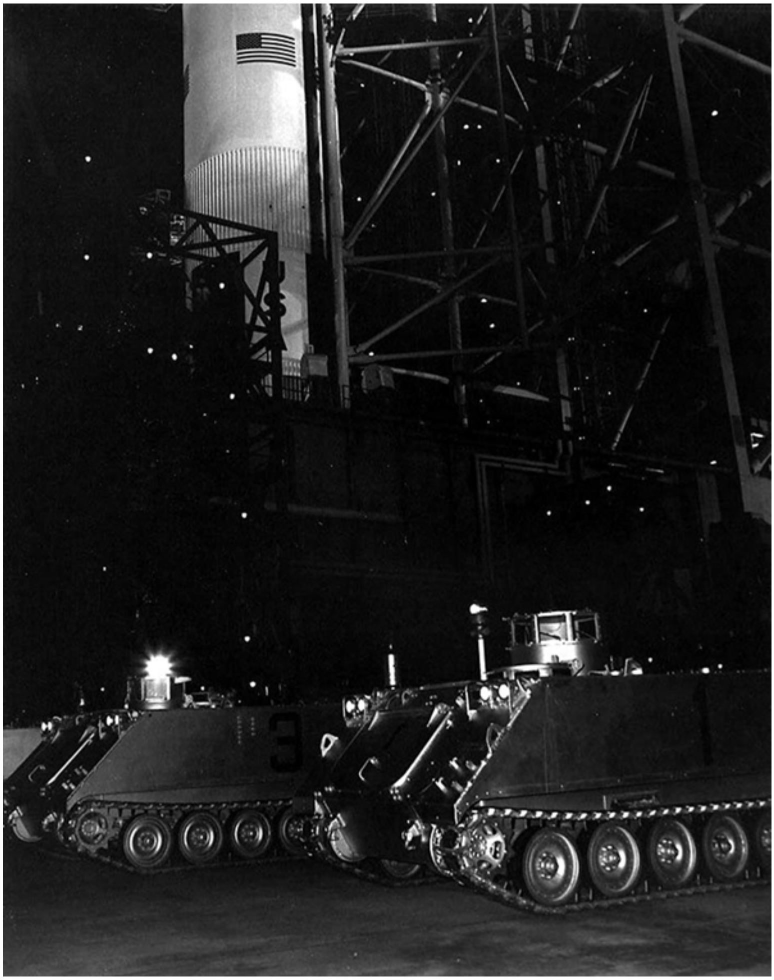
If the firing room lost control of the Saturn V while it was either partially or fully fueled, there was an immediate danger of fire or detonation from propellants that could leak, mix, ignite, or rupture tanks. Workers at the pad needed to get to safety as quickly as possible if the firing room lost control during propellant loading.

Personnel on the LUT, the MSS, and in the vehicle had two possible escape routes. The preferred method was to take the high-speed LUT elevators to level A inside the LUT, exit the LUT airlock, and then take pad elevator 2 to the base of the launch pad, where M-113 armored personnel carriers would transport the workers to safety (Fig. 8.18).

If there was not enough time to take this escape route, the alternative was to seek safety in the blast room under the launch pad. A slide tube led from the elevator vestibule on LUT level A, out through the north side of the LUT, and into a chute that continued down into the pad. The chute curved steeply around to the west. At the lower end of the chute was a room with a rubber-lined deceleration ramp that angled slightly upwards to permit "safe exit for the user," according to safety instructions. This *rubber room* was deep inside the launch pad, on the same level as the ECS room (Figs. 8.19 and 8.20).

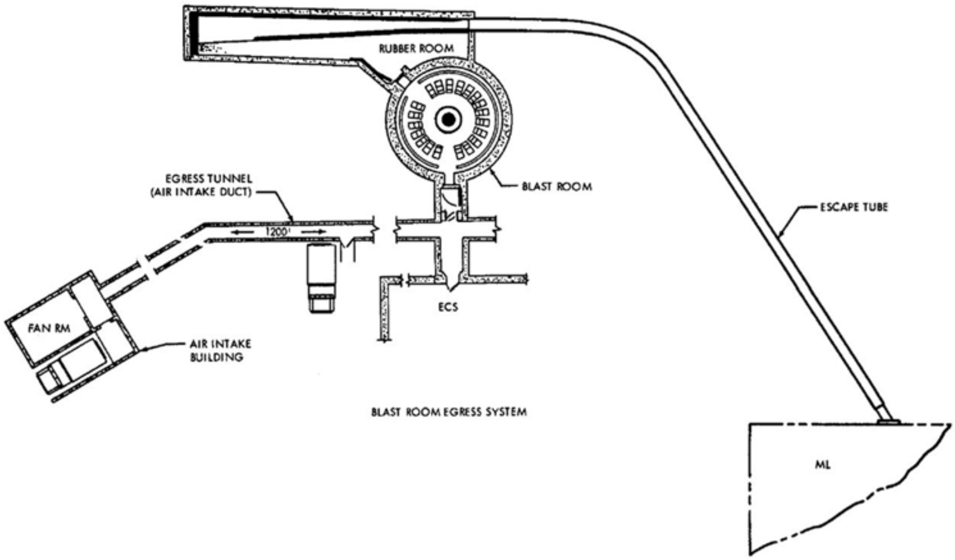
Safety chief Norris Gray tested several methods to maximize the speed at which crews could safely make their escape down the slide tube. First, the slide tube was waxed, and crews rode on burlap sacks to polish the wax. Later, NASA added a water deluge system to the escape tube. Lee Starrick described tests of the final emergency slide procedure (Figs. 8.21 and 8.22):

> *The high-speed elevator went into the A level of the mobile launcher. As soon as you got out of the elevator, the tube opening was right there, and you hit a bar that turned on the deluge system, which sprayed water into the tube. That was supposed to be protection in case there was a fire inside of the launcher.*
>
> *The first time I went down the tube, I was in a pair of coveralls. I had to push myself. It didn't go hardly at all. The second time I went down, I had my silvers* [*fire protective suit*] *on, and I went a little faster. The third time I went down, they turned the water system on. I was the front guy out of the first three, and we had a rope that we held onto with knots in it. And I was holding onto the rope, and the astronaut-suited subject got behind me, put his feet over in front of me, and then the third guy got in. They tapped my helmet, and I let go of the rope. It seemed like we hit the other end at the rubber room almost instantly. It was so fast that I don't even remember going down the tube. There were five recessed lights in the ceiling. The first time I went down, I could see each one of them. And the second time, I could count them. The third time, I didn't even see them. They were just a blur.*



8.18 Two M-113 armored personnel carriers, used as rescue vehicles, wait at the base of the launch pad during *Apollo 17* processing, October 1972. *Source*: NASA/Jerome Bascom-Pipp

We hit the wall at the other end, and luckily I had my feet up like they told us to do, to use for brakes. But we hit the wall hard. Then I was worried the next three were coming down behind us. We had to get off there and get out of the way so we wouldn't get run into. Where the tube came down to where the rubber room started, there was a dip area in the ramp, and they were supposed to have a janitor mopping the water to keep the water from building up in that dip. The janitor didn't show up that day. So the guy at the front of the next group hit that water and hydroplaned, and he hit the wall before they could get him off the ramp and on the ground. He had a pair of fire boots on, and it ripped the side of his boots. He broke nine bones in his foot.



8.19 Schematic showing the relationship of the slide chute, rubber room, blast room, and ECS room at the launch pad. These facilities were inside the northwest corner of the pad hardstand. *Source*: NASA/Ward

8.20 *Arrows* point to the exit port on the LUT and the top of the slide chute to the rubber room. These two will connect when the crawler finishes moving the *Apollo 15* stack into position on the launch pad. *Source*: Author's adaptation of NASA photo

8.21 The exit from the escape chute that came down through the pad structure into the rubber room. The outer wall of the blast room is at *right* (Photo by the author, August 2013). *Source*: Ward

8.22 The deceleration ramp in the rubber room. A slight upward slope was supposed to be sufficient to slow people down, but it was still dangerous (Photo by the author, August 2013). *Source*: Ward

After jumping off the ramp, the workers ran across the room and through a solid steel blast door (similar to those used in missile silos), and into a circular, concrete-domed room with 20 partially-reclined seats ringing the wall. The floor was mounted on springs to reduce any shock forces to 2–3 G, even if a fully fueled Saturn V blew up on the launch pad directly overhead. The seats provided enough room for the astronaut crew, the close-out crew, and the rescue crew. Oxygen candles produced breathable air, and food and supplies were stored in a cage in the center of the room. A radio provided communications with the outside world. Occupants could stay in the room for 24 hours if necessary.

Present-day pad operations manager Steve Bulloch said, "You would probably not hear anything from the pad above unless you had a really big blast. You'd have a big shake like an earthquake, and then you'd be fine. You waited in here until everything was okay. If for some reason, you couldn't wait any longer, and there's still a chance of a big fireball up there—maybe not a detonation, but a big fireball—you'd want to come through the blast room and go out via the escape tunnel. A rescue crew would meet you at the end of that tunnel." (Figs. 8.23, 8.24, and 8.25).

When it was safe to exit, workers could either leave through a door into the ECS room, or they could walk through a ventilation tunnel that led to an air intake building near the western perimeter of the pad area—a tunnel which Bulloch described as a favorite hiding place for snakes.

8.23 Door to the pad A blast room, similar to doors used in missile silos (Photo by the author, August 2013). *Source*: Ward

8.24 The interior of the pad A blast room. The cage in the center of the room held food and other supplies. The floor was mounted on springs to absorb shock from explosions on the pad (Photo by the author, August 2013). *Source*: Ward

Anybody whose job required them to be out at the launch pad during hazardous operations had to be *rubber room certified*. The certification process entailed taking at least one trip down the chute into the rubber room.

The rubber room and blast room remained active throughout the Apollo era as a safe haven for red crews and other pad workers who were working in hazardous conditions at the lower levels of the LUT. The blast rooms and slide chutes at the two pads were abandoned at the end of the Apollo era. The interface where the slide chute entered the pad structure was closed off with a bolted steel plate.

SLIDE WIRE SYSTEM

The *Apollo 1* fire occurred after the LC-39 rubber room and blast room had already been constructed. Review of safety procedures after the fire led to the conclusion that the rubber room system was not a practical means for astronaut escape. The high-speed elevator ride down the tower into the LUT to get to the rubber room slide would take astronauts through the most potentially hazardous area on the pad in the event of fire or propellant spills. As Bulloch put it, “Rockets tend to have fire at the bottom end. Why would you ride an elevator down into a fire?”

The astronauts and closeout crew needed an alternate emergency escape method from the vehicle and the pad, and NASA selected a slide wire system. This would be the fastest way of getting the astronauts off of the launch pad, short of their firing the launch escape system and blasting the spacecraft off the top of the Saturn V.

8.25 Ventilation tunnel leading from the blast room to an air intake building at the perimeter of the pad (Photo by the author, August 2013). *Source*: Ward

Boeing fuels engineer Steve Coester described an early version of slide wire system that was under consideration for Apollo but eventually rejected: “One of the early designs was to have the astronauts wear a harness that would clip onto the wire. One day I was walking in the pad surface near the LOX disconnect tower, and I heard a scream to take cover. They were testing the harness system with a life-sized dummy. It fell off the wire at 320 ft (98 m) above the pad surface. The dummy smashed into the LOX disconnect tower, bounced off, and landed near me.”

Bill Heink as in charge of the equipment that the dummy smashed into. He said, "We had an electrical cabinet that had all the controls to the disconnect system in it. That damn dummy bulls-eyed my box! Just destroyed it. And it was not very long before a vehicle [*Apollo 8*] was supposed to arrive out there at the pad. We were in Panicsville getting that thing fixed in time."

As a worker at the pad, Heink watched with deep personal interest the evolution of the slide wire system, as he would have to be certified in its use. Heink related his experience in being trained to use one of the early versions of the slide wire system:

> *Initially they had nine one-man trolleys to go down that wire. The big problem was how to slow them down when they got out to the far end, because the cable ended in a pylon. They were sending down dummies of different weights, because people are of different weights. When they sent a heavy one down, their braking system wouldn't slow it down enough, and the poor dummy would go* splat! *right into the pylon. Had it been a person, he would have been very, very dead. When they sent the light ones down, they stopped too fast. If you can picture this dummy, with its legs hanging down beneath it under the wire, when it came to a screeching halt, it flung the dummy up and slammed its crotch right into that wire. They finally decided that the single-man trolleys wouldn't work.*
>
> *Next they developed a 9-man trolley. It was a big I-beam with trolley wheels on both halves, and 9 hooks on it. Everybody that was up on the tower after we started propellant loading, including the astronauts and the close-out crew, had to wear a harness that had a big D-ring that you could latch onto the hook on the bottom of the rail.*
>
> *NASA safety was in a panic mode. They've got the system finished, and now they've got to certify everybody that might be on the red crew. So they're racing like crazy, and it's early December of 1968, just before Apollo 8. They were running classes all through the daylight hours.*
>
> *My turn came on a Sunday morning at 10:00. We had about 45 minutes of ground school down in the PTCR. Then they took this group of 9 people up the tower to the rail. There were two Bendix instructors, and they are talking all the way up, "You guys are so damn lucky! You're going to be the first people to ride this thing." We were nervous, to say the least.*
>
> *They had taken big chunks of sheet steel with the corrugated anti-slip stuff on it, welded them to the side of the tower, and on the outside edge, they had cables from above that supported it. They were in kind of a stair-step pattern, because the beam is sitting at an angle on that cable. Then on the outside of that, there was a welded latticework made up of probably ¾ in. (2 cm) rebar welded together in a 1 ft. (0.3 m) square pattern. You'd walk out on this platform, out over the edge of the tower – trying not to look down – and grab the latticework to climb up high enough to hook yourself up to the hook on the rail.*
>
> *You started at the bottom with the #1 position and worked your way up. Once #9 got hooked on, then #8 and #9 together pulled a pair of D-rings that released the rail, and away you went for the ride of your life. When you look at it from the side, it's pretty gentle slope, but when you're up on the top of that damn thing looking*

down, it looks like that cable goes right straight down to the ground. Nobody was real happy about it.

I was in the #3 position. Coming past me and going to #5 was a Rockwell technician. He got up there and hooked in. The other guys got hooked in. Now we've got everybody on, and the two instructors, who are over on the safety of the tower, say, "8 and 9! Pull your D-ring! You guys are going for a ride!" The guy in the #5 position says, "Please, mister, don't pull those D-rings!" Immediately following that, you hear click-click-click-click-click-click-click-click-click. All nine of us disconnected. We get back on the tower, and I see that there are two large shackles across this cable, right in front of the beam. Had it been cut loose, there was no way we could have gone down the wire, but we didn't know that!

The Gondola

The final iteration of the Apollo-era slide wire system employed a gondola that was parked on the LUT near the entrance to swing arm 9. A 1-1/8 in. (3 cm) diameter steel cable extended from the LUT to a tail tower approximately 2,200 ft (670 m) west of the LUT. There was enough room in the gondola for nine people—the three astronauts plus six White Room staff or other personnel working at the top of the LUT.

In an emergency, the astronauts and technicians evacuated the White Room, crossed the command module access arm, and followed a catwalk along the east and north sides of the LUT to the egress platform at the 320-ft (98 m) level of the tower. Here, they boarded the 9-man cab suspended from the cable. Levers inside the cab released it from the tower. It rode down the slide wire down to a landing area near the pad perimeter, where it was decelerated and stopped by an arresting gear assembly. A rescue crew awaited the evacuees at the landing area. Rescue test crews practiced evacuation from that spot both with armored personnel carriers and helicopter.

NASA tested the basket system one time, with astronaut Stu Roosa, Art Porcher from NASA design engineering, and Chuck Billings from NASA safety as the test subjects. They reported that it was a "terrible ride," as they were facing backward and could only see the cable going by them on their way down (Figs. 8.26, 8.27, and 8.28).

Lee Starrick was part of the rescue crew and ran innumerable drills to practice getting astronauts and closeout crew into the gondola. He said: "We would come out of the White Room with our chairs with the astronauts in them, go around the corner, and as we started up the ramp there, there were signs pointing to the slide wire or elevator. I absolutely hated when they put us in the basket in the simulation. You're looking out the side of the basket right down to the pad level, 480-some feet down below, and then you see this little tiny cable that's holding the basket up there. The more people got in the basket, the more it would sag. I thought, 'If that thing lets go, this is not gonna be a fun ride.'"

NASA also used a basket and slide wire system as the primary means of crew escape in the Space Shuttle program. NASA administrator and former astronaut Charlie Bolden was one of the test subjects for the Shuttle system. Although the end points of the two systems were approximately in the same place near the pad perimeter, it worth pondering that the starting point on the launch tower was nearly 130 ft (40 m) higher on Apollo's system than on the Shuttle's.

8.26 The only manned test run of the Apollo-era slide wire system, January 25, 1969. Safety engineer Chuck Billings, astronaut Stu Roosa, and design engineer Art Porcher were the three test subjects. *Source*: NASA/Kipp Teague

8.27 The gondola begins its descent on the slide wire system. *Source*: NASA/Ward

8.28 To slow the gondola at the end of the slide wire run, the support system leveled off the wires and then raised them slightly. In the Shuttle-era system, drag chains slowed the escape baskets, which then hit a net. *Source*: NASA/Ward

LAUNCH PAD EXPLOSIONS

A fully-fueled Saturn V was a potential bomb sitting on the launch pad. Bellcomm calculated that the maximum explosive force of a Saturn V detonating on the pad would be the equivalent of a 0.5 kt atomic bomb—smaller than the bomb that destroyed Hiroshima, but still a significant blast.

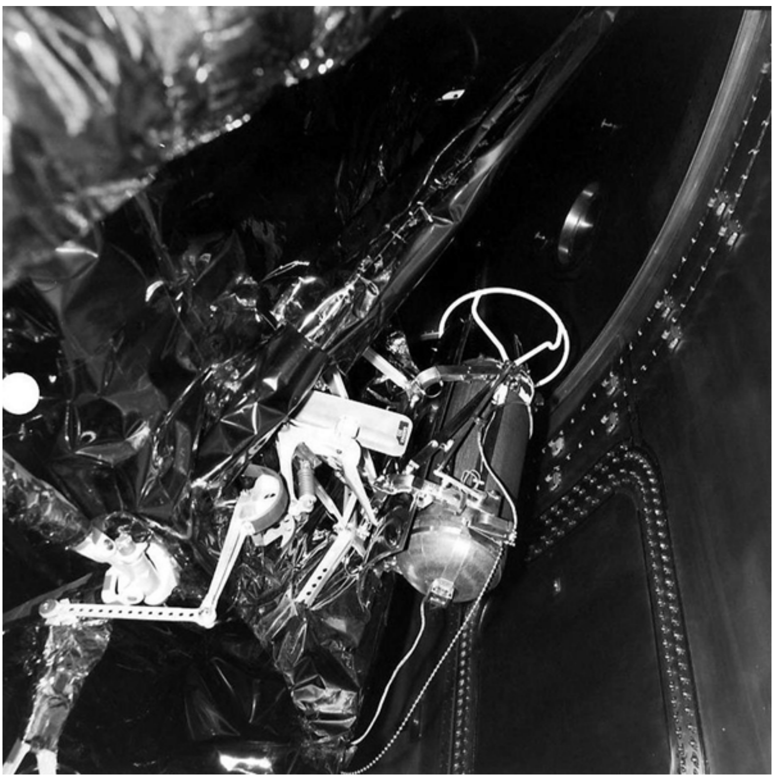
Bellcomm's study doubted that all of the propellants in the Saturn V would be consumed in a launch pad explosion. A large amount of the RP-1 fuel in the first stage would likely fall through the engine compartment and into the flame trench rather than exploding. The S-II stage, with its large liquid hydrogen and liquid oxygen tanks, actually represented the greatest potential explosive threat on the Saturn V. Even if only 60 % of the propellants in the Saturn V exploded, it would create an immense conflagration at the pad. The LUT would be completely destroyed, large parts of the launch pad would be damaged, and fires would spread for miles around. Assuming the crew in the command module had sufficient warning, they could fire the launch escape system rockets to whisk the command module far enough away that the overpressure from the blast would not endanger the spacecraft.

Three and one half miles (6 km) away, the windows in the firing room were hardened and protected by louvered shutters that could close over the window if there was an explosion. During launch, Rocco Petrone, watching from the firing room, could command the shutters to close immediately. However, Petrone was quoted as saying that he suspected he would just watch the catastrophe unfold if something had gone wrong.

PLUTONIUM AND CAR WASHES

The lunar landing missions from *Apollo 12* onward carried a cask of plutonium-238 pellets on the LM to fuel a radioisotopic thermal generator. The RTG powered the ALSEP experiment packages that were deployed on the Moon's surface. It does not take much imagination to visualize the danger scenarios that kept many people awake at night, worrying about a container full of plutonium sitting atop a 6.1 million lb (2.8 million kg) "bomb." (Fig. 8.29).

Dick Lyon was the Apollo lunar surface experiments manager after *Apollo 11*, and he was tasked with coordinating the plutonium safety program. He said, "The doomsday scenario was that there was supposed to be enough plutonium in this thing to poison every human being on Earth. If it exploded in the sky and vaporized all this plutonium, then it could circle the world in clouds and there would be this huge danger. You had to fight all of that kind of misinformation."



8.29 Plutonium cask (tank with *circular white ring*) mounted on the side of *Apollo 17's* LM. This photo was taken inside the SLA during closeout and preparations for launch. *Source*: NASA/J. L. Pickering

The plutonium was compressed into disk-shaped pellets and stored within a hardened canister. NASA tested the system by dropping the canister from heights of over 20,000 ft (6 km) and by "literally shooting the canister at solid rock," according to Lyon. The canister was never breached during a test, and NASA was convinced that it was safe. Even if the plutonium escaped, it represented a threat only if it was pulverized and inhaled.

A war of words ensued between scientists who believed that the plutonium was totally safe in the pelletized form that NASA would use, and scientists who were convinced that there was no safe way to launch plutonium into space. The US Atomic Energy Commission (AEC) fought NASA over safety provisions. At one point, the AEC demanded that NASA clear everyone except essential personnel within a 20-mi. (32 km) radius of the launch site. This was clearly an unrealistic demand, and Kurt Debus fought back, eventually winning the day.

As a compromise, NASA devised an interesting system for mitigating plutonium contamination. Lyon explained, "To be overly cautious, we had to assume that the vehicle would explode, and it would open up the canister and spray particles on the crowd of people. We built a whole series of car washes that would capture all the water so that it would be safe. People would be instructed to go to their cars if there was an accident, and wait in their cars for security to guide them to these car washes. We designed, built, and paid for all that stuff."

BRUTE FORCE SOMETIMES SAVED THE DAY

Managing the facilities and launch vehicle at the pad often involved delicate operations with tight tolerances. At other times, the mammoth scale of problems required a less subtle approach.

An example of the latter situation was dealing with an ice blockage in the huge LOX storage sphere. If the humid Florida air entered the storage tank, the moisture in the air froze, which could block relief standpipes. Boeing engineer Bill Heink recalled one ingenious approach for dealing with an ice blockage in the system. It was not elegant, and it certainly carried an element of risk:

A big 4-in. (10 cm) flange came to a manifold up on top of the storage tank, and there were dual relief valves. The guys had taken the relief valves to the lab to check the set points. While the valves were off, the tank breathed in some outside air. The moisture in the air froze, and that built up a huge block of ice in that standpipe that went down through the annulus on the tank.

We worked out a plan to break up the ice and get rid of the blockage. They built a large tee-handled, stainless steel 'icepick' out of 1-in. (2.5 cm) diameter steel. The tee handle at the top of this icepick was big enough that there was no way it could have fallen down into the tank. That would have been a real disaster, because you would have had to drain the tank and make a tank entry to retrieve it.

It was a Saturday, and we didn't have firing room control of the LOX facility that day. We had a checkout box in that little electrical equipment building near the tank. I got tasked with going inside the equipment house and operating the box to pressur-

ize the tank. We went to like 5 or 6 psi (34-41 kPa), and then I operated the vaporizer valve enough to maintain that pressure. It was not to the normal 10 psi. (69 kPa) pressure for LOX transfer, but just enough that any ice that they broke up with the icepick would blow out through the hole and shoot up over the top of the tank.

Dick Kitto, one of the mechanical engineers, drew the short straw and was the guy selected to do the dirty work. Dick's up there on this platform on top of the pressurized tank, plunging with that rod to chip the ice, and these big chunks of ice are blowing out right past him. If he'd gotten his head in the way, he would have been in deep yogurt. The wind that morning was out of the north-northwest. I'm over there in the concrete electrical building, listening to these huge chunks of ice hitting the roof. We got all the ice cleaned out. Everything was fine, and we were back in business.

REPLACING LAUNCH VEHICLE FINS ON THE LAUNCH PAD

NASA sometimes had to effect repairs on the spacecraft or launch vehicle while the Apollo/Saturn was at the pad. The scope and complexity of repairs varied widely, from replacing oxygen tanks on *Apollo 14's* service module to repairing the baffles inside AS-500F's S-II LOX tank. One of the most unusual fixes at the launch pad involved replacing all eight fins on the first stage of *Skylab 4's* Saturn IB the week before launch.

The Saturn IB rocket and its S-IB first stage flew without problems on seven previous missions. The Saturn IB for the final manned flight of the Skylab program, *Skylab 4*, rolled out to pad B on August 14, 1973, for a planned launch on November 16, 1973. The vehicle went through the usual tests at the pad without any major issues.

As the launch date approached, Marshall Space Flight Center engineers expressed concerns about potential stress corrosion cracks in the eight stabilizer fins on the S-IB stage. Stress corrosion occurs when certain metal alloys are exposed to a corrosive environment at the same time they are subjected to a continuously maintained, significant amount of tension. This S-IB stage was already 6 years old, and it had been in storage most of that time. After it was erected, it sat for several months on a launch pad less than a mile from the ocean. The fins were clamped to the holddown arms on the launch platform, and they supported the weight of the vehicle as it rested on the milkstool. Add in the humid, salty air, and you had prime conditions for stress corrosion to occur.

Inspection verified MSFC's fears: the fins were cracked. Failure of any of S-IB's fins during launch or in flight could result in loss of control of the rocket and an immediate mission abort. The question became how to replace the fins. Huntsville proposed a conservative approach in which the vehicle would be taken back to the VAB, de-stacked, and the fins changed out.

Engineers at KSC came up with another proposal that avoided the cost and time of rolling the vehicle back to the VAB. They wrote a procedure for replacing the fins at the launch pad. It was an operation that had never been envisioned, let alone attempted. In the meantime, the *Skylab 4* countdown demonstration test ran on November 2, 1973. The pressure was on to get the fin replacement procedure written and approved.

The changeout work was underway on November 9, 1 week before the scheduled launch date. The estimated time to perform the task was 3 days, and the crews worked around the clock. The procedure was declared to be a hazardous operation because personnel had to work high above the ground, there was little room on the milkstool platform around the large opening for the S-IB's engines, heavy equipment was involved, and crews needed to work around massive loads that were suspended by cranes.

The procedure called for boxed replacement fins to be delivered to the launch pad, where a mobile crane would pick them up and place them on the LUT 0 level platform. They would be unboxed and inspected for cracks using fluorescent dye. Meanwhile, on the milkstool platform 120 ft (37 m) above the launcher deck, technicians would retract the holddown arm from a fin, attach handling assemblies to the fin, and unbolt it from the vehicle. The LUT hammerhead crane would lower the fin to the level 0 platform. The hammerhead crane would then lift the replacement fin back to the top of the milkstool, where technicians would align it and secure it to the vehicle. The holddown arm for that fin would then be reloaded. The process was repeated for all eight fins, one at a time. Only one could be replaced at a time because the fins supported the weight of the launch vehicle.

The procedure called for an unusually large crew—20 mechanical technicians, 10 mechanical engineers, 6 firing accessory technicians, 6 firing accessory engineers, a team of representatives from the various launch vehicle operations branches, security, safety, crane crews, and trucks (Figs. 8.30 and 8.31).

Tip Talone found himself working yet another unusual job, supervising the *high crew* in the fin replacement operation. He recalled:

> *These heroes – these high crew guys – they were just wizards. They were like the ironworkers that you read about. They could climb anywhere, go anywhere, and handle anything, and rig anything such that it could be lifted, moved, and protected. They could do it just instinctively. Just watching these guys working – that was the fun part.*
>
> *We had one guy named "Tiny," who was anything but. He was a giant. He had huge arms, a big chest, and big legs. He was about 6′ 5″ (1.65 m) tall. He could literally manhandle half the stuff those other guys were having to use cranes to move around. They'd have a fin on a crane in that cold wind, and they would use him as the stabilizer. They'd have tag lines, but these other guys are trying to hang on these tag lines, and Tiny is just maneuvering it right into place with his hands, hanging out over that thrust hole in the milkstool. It was pretty spectacular.*

The work was accomplished on time, and *Skylab 4* launched on schedule. It was the last launch from LC-39 for more than 1-1/2 years.

Norm Carlson recalled that Talone always found a way to have fun with even the most difficult assignment: "Those fins were held on with something called *Rosan fittings*. I remember Tip got one and put it on the bulletin board, and wrote, 'Rosan's Fittings: Call 555-1234.' (*Laughs*) That was Tip for you."

Chuck McEachern found satisfaction in the challenge and accomplishment of such an unusual task: "It was an interesting experience working on those. One thing that made it more enjoyable was that the people from the design centers couldn't come tell you what to do, because they didn't know how to do it either. Those are the kind of missions that are fun to do. Sometimes the less help you have, the easier it is."

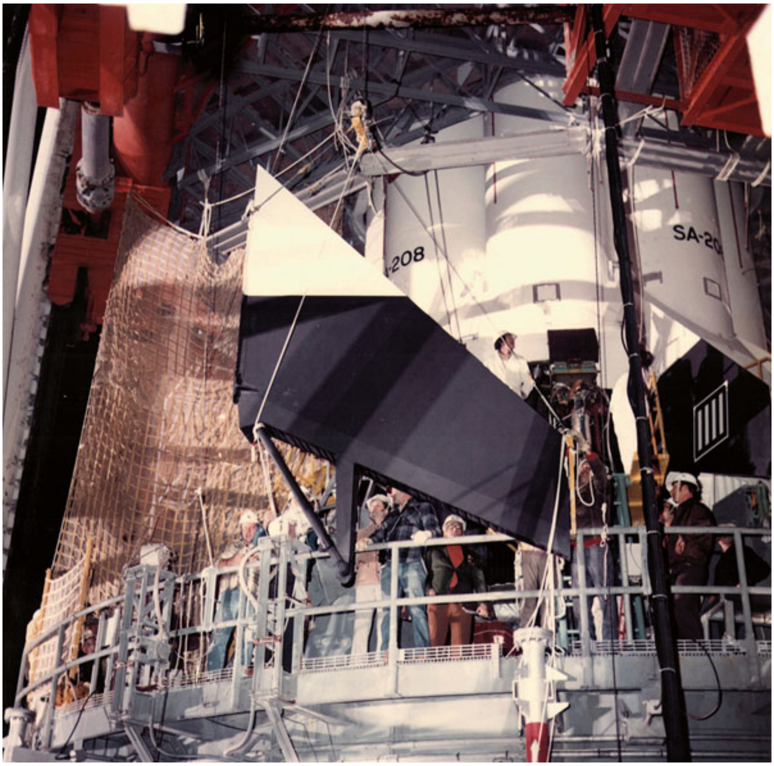
8.30 Working in extremely tight quarters on top of the milkstool, workers replace the fins on *Skylab 4*'s S-IB stage, November 9, 1973. *Source*: NASA/KSC

THOUGHTS ON WORKING AT THE LAUNCH PAD

Spacecraft operations and launch vehicle operations had teams at the pad preparing the Apollo spacecraft and the Saturn V launch vehicle for flight. Spacecraft tests were controlled from the ACE rooms and management information rooms in the MSO building. Overall space vehicle testing was controlled from the firing room in the Launch Control Center. Even though spacecraft and launch vehicle personnel were both at the pad, their paths did not often cross. Launch vehicle personnel used the LUT for most of their access to the vehicle, and spacecraft personnel used the MSS.

Connie Perez said that working at the launch pad was not always a very glamorous operation:

> *Working out on the pad often meant going to work in the rain. We'd park our cars outside what we referred to as the Butler building outside the gate. To get to where trailer 240 was, where we did all our engineering work, you had to walk a long way, and often at night when all those mosquitoes came out. I'd have to run to the car if*

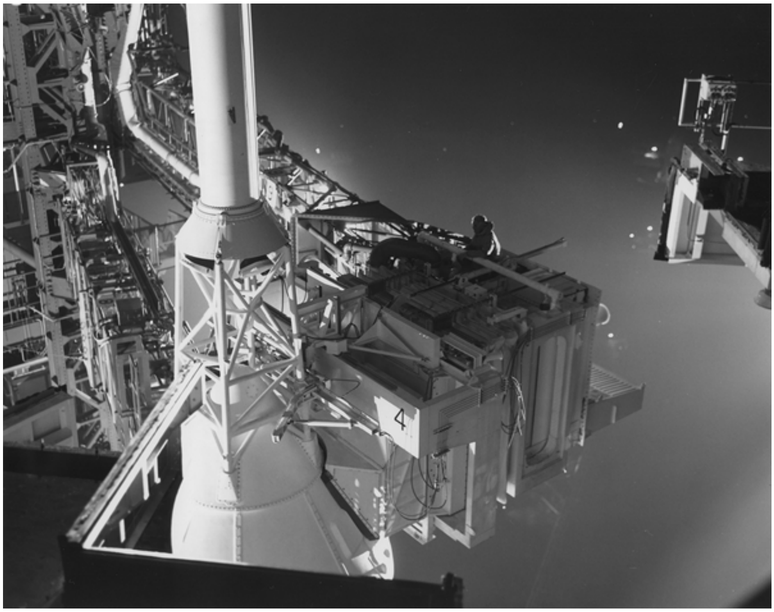


8.31 *Skylab 4* fin replacement underway, as old fin 6 is removed, November 10, 1973. *Source*: NASA/KSC

> *it was raining, and run back. We kept a logbook of all our activities. I had to take the logbook all the way to the MSO building, where the front offices were. I'd jump out of my car, leave my car at the MSOB parking lot, and then ride the van all the way back out to the pad. I'd go up the stack in the MSS elevator in the rain, and come back down. If the wind was blowing more than a certain amount, I'd have to tell people, "Get off the stack! Safety isn't allowing us to be up there!" That's the life of operations at the pad.*

Chuck McEachern remembered that it could get extremely cold on the LUT in the winter: "The coldest I have ever been since I left Germany was working out on the Saturn V in the wintertime, with the wind blowing off the ocean. It was unbelievably cold. The crew out there wore parkas all the time. You didn't want to go out there a lot in the wintertime, especially at night." (Fig. 8.32).

While working at the launch pad could be uncomfortable, challenging, and dangerous, there were sublime moments where the magnificence of the Apollo/Saturn project and its hardware captured people's imaginations. Jerry Trachtman said that even on the coldest nights, with the wind howling, he always thought, "I am the luckiest guy in the world!

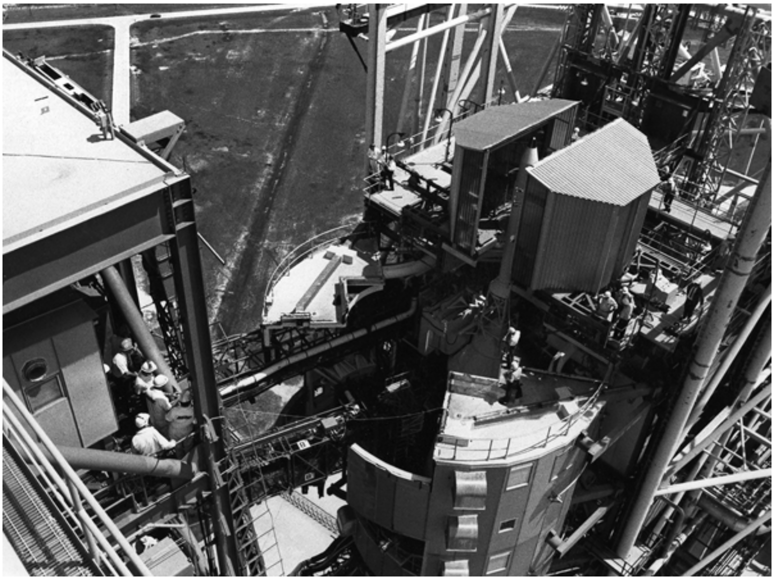


8.32 Worker atop the White Room on a cold winter's night. This photo was taken from the MSS during rollback in the *Apollo 14* launch countdown, January 30, 1971. *Source*: NASA/ Jerome Bascom-Pipp

I get to work on the Apollo spacecraft!" Workers from the Apollo era invariably cite the beauty of watching the sunrise over the ocean from their vantage point high above the launch pad, or the brilliantly illuminated Saturn V in the glare of floodlights late at night.

The ride up the elevator at the pad or in the VAB provided a time for reflection. Although pad workers usually got acclimated to working around the pad and the Saturn V, the immensity of the vehicle and the enormity of its mission always impressed them when they took the elevator. Trachtman said, "You're watching the booster stages going by you as you're going up the elevator, and it seems to go on forever. Whether it was in the VAB, which had the glass doors in the elevator, or the open-air elevator on the MSS, the size of the Saturn V is just indescribable. And to think this thing is going to lift off! And not only that, it's going to go into orbit, and then to the Moon! My jaw never ceased to drop every time I was at the spacecraft after it was stacked."

Gene Spilger added, "Our forward skirt was at the 230 ft level. You look down at that son-of-a-gun from that level, and you think, 'This sucker can't fly! It *cannot* fly!' Even though you knew about everything that was there, it always took me back." As a young man at the age of 22, Alan Contessa recalled the special feeling of excitement of working at the launch pad: "In that open-cage elevator, you started at the ground, where it's hot. It gets cooler as you go up. It was almost surreal, the bright white of the rocket as you're going up. And then the door opens, and you get up on these little catwalks and walk around. What a cool experience!" (Fig. 8.33).



8.33 View of the *Apollo 13* stack from the LUT hammerhead crane catwalk, with the spacecraft partially visible inside the MSS clamshell. *Source*: NASA/Jerome Bascom-Pipp

OBSERVING A LAUNCH

Kennedy Space Center workers were not just casual observers at a Saturn V launch, whether they were manning consoles in the firing room or witnessing the launch as spectators near the VAB. Even though they were intimately familiar with the Saturn V and the Apollo spacecraft and had seen countless launches during their careers, watching a launch was an emotional moment for even the most hardened engineer.

Apollo 4

The *Apollo 4* (AS-501) mission was the first flight of a Saturn V. No one knew exactly what to expect, and the element of shock and surprise made for vivid memories. Consequently, *Apollo 4* made even more of an impression on many Apollo/Saturn workers than did the launch of *Apollo 11*. Here is what some of them had to say about the AS-501 launch.

Rich Robitaille was in firing room 1 that first launch day:

> *For six or nine months, we were hearing that if that thing ever had a problem or exploded, we were all going to die. We were only four miles away. Nobody really knew for sure. Supposedly we were protected, but you heard rumors.*
>
> *On* 501, *when the S-IC engines fired up, I swear to God that it seemed like everyone in the firing room ran to the windows. They were trying to get everyone to shut up, because everyone wanted to go see. That thing just stood there for 10 seconds*

and didn't move, and people had their hands on the windows and the windows were visibly shaking. Incredible, incredible experience. We had all watched those early Saturn launches in the first couple of years from the Cape. But you get all these people in the firing room, and you've got the first launch of the biggest rocket ship in the world ever…

The mathematical geniuses and the people that modeled it and the people that do mission analysis, they knew it was going to work. But the damn thing lifted off, and we all had tears in our eyes. You never forget that for the rest of your life.

Jack King and Norm Carlson were in area A of the firing room:

King: *In November of '67, we had* Apollo 4, *first launch of Saturn V. I'm always asked about* Apollo 11, *but* Apollo 4 *is high on my list of memories of launches.*

We issued earplugs to the press at the press site, which was nearby. We'd done all kinds of acoustic testing. I think they expected the sound to be like in the first row of a hard-rock concert. They did all kinds of tests, and that sort of established the 3-1/2 mile limit and blast effects and acoustic effects.

So the thing I always remember, on top of everything else, is listening to Norm and Skip Chauvin on Apollo 4. *We get down in the count at 3 minutes and 10 seconds, and then down to 10, 9, ignition sequence start. And then it counted down and lifted off. Then that sound hit us, and the windows started to rattle right behind me. They were shaking. The Launch Control Center was a brand new building. All of the construction dust started to come down from the ceiling. I thought the whole roof was going to fall in on us, Norm.*

Carlson: *Yeah, I know. Those windows, I could have sworn the first time that they were coming down. There was visible movement in that 2-in. thick glass.*

Joe Williams observed the launch from outside of the LCC:

It's scary, absolutely scary. I watched the first one. I was outside on the stairway on the southeast side that goes up to the different levels of the LCC. There must have been 500 people standing on that staircase. When that shockwave hit, it was like a staccato effect. It scared the living hell out of me. I nearly panicked. I wanted to get off that staircase as fast as I could, because I was sure it was going to collapse, there was that much sound pressure coming onto it. If that thing had collapsed, there would have been a lot of dead folk.

Dick Lyon saw the liftoff from a spot near the VAB, and recalled, "The first one was the most memorable for me. Seeing the panels on the VAB just going through these horrible vibrations—just to see the building panels just rolling back and forth."

Ernie Reyes was also near the VAB with spacecraft engineer John Heard:

I remember the very first one that took off. Some of the guys that worked on it were crying, big tears on their faces. John Heard was one of our guys. When he was 19 years old, he was flying bomber missions over Germany in WWII as a B-17 pilot. Now he was the spacecraft manager working for me. He said, "Ernie, I don't think there will be a bigger thrill in my life than working on this thing."

> *You feel it rumble, and you feel the change in your pockets jingling when you're in front of the VAB, then you feel the pressure on your chest, and then you see the whole thing going. Wowee-wow!*
>
> *It was unbelievable to see something that big flying, something that took us that long to get up past on the elevator to go up to the work levels. As you were going up and down that elevator, you saw "U…S…A". And then you get up to the very top, and you're looking out at whales and the surf, and you look all the way out to Orlando on a clear day. And you look down, and you say, "This thing is filled up, all at once…how many millions of gallons?" It's impossible. From a simple little dinky V-2 that we tested in the desert, to something that big. If you never saw one launched, you missed one of the grand sights of your life.*

Lee Solid was the site manager at KSC for Rocketdyne, which built and serviced all of the engines on the Saturn V. Solid watched countdowns and launches from firing room 4, which was set aside for contractor executives on launch day. As the man ultimately responsible for the five F-1 engines on first stage of the Saturn V, his thoughts at liftoff went in a slightly different direction than others: "There was nothing like watching a Sat V lift off. I could only imagine what would have happened if one of those engines had let go, what it would have done to that thing when it was sitting 200 ft off the ground. But I had to think that way."

John Tribe was inside the CSM ACE room in the MSOB, about 7 miles (11 km) from the launch pad:

> *We watched on our black and white TV monitors as the five giant F-1 engines lit in sequence. Flame swept across the launcher like a fiery waterfall, beating into the flame pit and sending showers of concrete particles two miles across the flat Florida landscape onto the fallback personnel located as close as safely possible in case of emergencies. The monster vehicle, weighing 3,000 tons and longer than a destroyer, slowly lifted on an incredible tail of fire that smashed metal railings, winches, and elevator doors off the launcher and blew them to the pad perimeter. The shock wave reached the press site, nearly demolishing TV trailers and beating reporters with pulsing waves that hammered and shook at them. The noise actually reached us deep inside the MSOB as we held our breath and watched our TV monitors.*

In summary, Bill Heink said that perhaps one of the biggest surprises about AS-501 was that it got off the ground at all. After the 17-day "CDDT from Hell," almost no one believed that the Saturn V would actually launch on its first attempt. He said that the launch parties began just a few hours later, and that Florida's entire Space Coast partied late into the night in celebration. Thousands of spectators, still in the area after the launch, joined in the celebrations.

Apollo 11

Bob Sieck worked launches in the ACE control room on alternating missions. He was able to watch the *Apollo 11* launch as a spectator in Titusville. His experience mirrored many of the nearly one million visitors who came to the Cape area to witness the *Apollo 11* launch:

> Apollo 11 *was the only launch I got to watch with my family, and it was because they told us if we weren't on the prime launch team, don't come out to KSC because it's going to be gridlocked with traffic. You got administrative leave for the day. I lived in Titusville at that time and I thought, "Well, fine. My one-year-old daughter and my wife and I will go down the river, which is only a couple of miles from where we live, and watch the launch."*
>
> *Well, we started driving down toward the river. We only get halfway there, and we've got to park the car, because there's just no traffic moving anywhere in Titusville. We put the kid in the stroller, and by the time we got to the river, it was T minus so many minutes and counting.*
>
> *There was gridlock traffic. It was four-lane road, with a median. The cars and trucks weren't even trying to move. They were just parked with people sitting on the hood or on the back. You could look right across the river, and there was the Saturn V sitting up like that, perfect view. It was just a mass of humanity.*
>
> *A woman was standing close to where we were, and she pulled up a plug of grass from the median strip and put it in a plastic bag. We asked her what the heck she was doing. She said, "All the trinket and memorabilia vendors have sold out of everything. There's no buttons, patches, T-shirts, hats, or anything available, and I've got to have a souvenir!"*
>
> *I got to thinking, "You dummy engineer! Out on your desk is 5,000 pages of* Apollo 11 *spacecraft launch countdown procedures." If I was thinking differently than a nerdy engineer, I would have brought that procedure home and worked this crowd. I could have sold it one page at a time and earned enough money to send my kid to college! But no; tomorrow I'm going to go back to work and throw that procedure in the barrel like I have all the previous ones, because we have to start working on the next one. So it goes.*

Other Missions

Frank Penovich recalled the only launch he was able to see from outside the firing room:

> *Apollo 15 was the only one I got to see. I was so impressed with that! I was standing in front of the VAB when that thing launched. Two things: first, I couldn't believe the color of the flame! It was the most beautiful baby blue color I've ever seen. And also, the roar of the engines wasn't just a roar, it was like a bunch of small explosions. I thought, "Holy cow! What have I been missing?" We had an 8″ black and white monitor in the control room to see launch. I would wait until I got home before I*

could see the color TV of the launch. But it sure didn't show the color that I saw with my own eyes, or the noise. And the reverberations in my chest, wow, you could really feel it!

When asked if he ever got to witness a Saturn V launch, CSM test conductor Skip Chauvin laughed, and said, "No, I only ever saw them on a black and white monitor in the ACE room. I never saw an Apollo liftoff."

BACK TO WORK

Whether they were on duty on launch day or taking the time to enjoy the launch as a spectator, every one of the 24,000 men and women at KSC took personal pride in knowing that they had contributed to one of the most remarkable achievements in history. In the missions up through *Apollo 11*, most workers at KSC had no time to savor the accomplishment. Most personnel would be back at work the next day, either cleaning up after the launch or focusing on the next mission in flow, doing everything in their power to ensure that the US achieved the goal of landing a man on the Moon before the end of the decade.

9

Epilogue

THE END OF AN ERA

The success of the *Apollo 11* mission was a bittersweet occasion for many contractors at Kennedy Space Center. With President Kennedy's challenge met, there was no longer any need to work three shifts per day, 7 days per week to meet a grueling launch schedule. KSC's budget was cut by more than 10 %, and the workforce needed to be reduced by 20 %. Some of the reductions came through attrition, some through layoffs. The Apollo KSC/CCAFS workforce was at 16,235 people by the middle of 1970, down from a peak of 26,000 during the *Apollo 7* mission.

Apollo/Saturn missions achieved even more incredible technical and scientific results during the remaining years of the program. Walt Kapryan (who replaced Rocco Petrone as launch director after *Apollo 11*) and the astronauts did everything they could to keep morale high at KSC despite the layoffs and uncertain future.

Many NASA employees at KSC began to transition to Space Shuttle planning and implementation after *Apollo 17* returned to Earth in December 1972. There were still four Skylab launches to support in 1973, which kept processing flows going in the MSOB and the VAB.

After Skylab, there was a hiatus of more than a year before the Apollo-Soyuz Test Project, the last flight of Apollo/Saturn hardware, in July 1975. A relatively small team processed the *ASTP* spacecraft through its flow. John Tribe recalls that *ASTP* processing as a particularly satisfying time for him:

> *In 1975 when the Apollo skills were getting very thin, I was called back to work* ASTP. *By that time RCS was down to two engineers (including me) and SPS was down to three – all of us working for a general group manager for all mechanical and fluid systems. We two engineers accomplished all the RCS functions on that flow. We had a one-shift operation, which made all the difference. In a three-shift operation, you lost a lot of time on shift changeovers, just trying to catch up and figure out what they did on the other two shifts. On a one-shift operation, you know exactly where you're going to pick up the next day, because that's where you left it.*

J.H. Ward, *Rocket Ranch*, Springer Praxis Books, DOI 10.1007/978-3-319-17789-2_9

9.1 Launch vehicle operations held a thank-you party for contractors after the *ASTP* launch, July 1975. This photo is of the McDonnell Douglas S-IVB team. *Source*: NASA/Frank Bryan

The beauty of ASTP *was that the procedures were clean, standardized, and all the bugs had been worked out of them. The technicians were very experienced. We were down to a hard core of the best people. We had tremendous morale. Don Hendricks and I were the two engineers, and we spent most of our time out with the techs at the pad. We had competitions out there to see how far you could leap onto a table from a standing position! Warren Lackie was the champion. We had ditch-jumping competitions. It was a great time, and we were working at peak performance.* ASTP *was one of the most enjoyable flows of all Apollo flights for me. And at the end of that, we just shut it all down.*

Bill Heink said, "I rode Apollo to the bitter end. The Boeing Company had 5,000 employees at KSC when we went to the Moon for the first time. When we got to *ASTP*, Boeing had 125 people, and I was one of those 125. At the end of that launch, we knew it was the end of the world." (Fig. 9.1).

Apollo-era equipment was modified or scrapped. LC-34 and LC-37B had already been mothballed after *Apollo 7*. After a few years being open to public tours, the LC-34 blockhouse became a warehouse for Apollo/Saturn documentation. Tip Talone oversaw the conversion of LC-39 pad A from Apollo/Saturn to Shuttle. The umbilical tower from LUT 1 was cut into sections and saved for possible preservation due to its historical significance. However, time, lack of money, and the elements conspired to make it impracticable to preserve the massive amount of ironwork rusting in the Florida salt air. The tower was scrapped in KSC's Ransom Road salvage yard.

9.2 Conversion of pad A from Saturn to Shuttle. The top of the umbilical tower has been removed from LUT 3 and placed on the pad at left. LUT 2 is still on the pad, and its tower will also be removed. Both towers will be transformed into the rotating service structure (RSS) and fixed service structure (FSS) for Shuttle. The mobile launcher base will be converted into a mobile launch platform (MLP). *Source*: NASA

The umbilical towers from LUTs 2 and 3 were removed from the launcher platforms, shortened, and converted into the Shuttle-era fixed service structures (FSS) mounted on pads A and B. All three mobile launchers were modified to become the Shuttle's mobile launch platforms (MLPs) (Figs. 9.2 and 9.3).

The Apollo MSS was scrapped. Dave Mohr, hired by Rockwell just after *ASTP*, recalled being on the roof of the VAB when salvage operations began on the MSS: "I could see off in the distance that there was somebody hanging in a strap off the MSS. I asked my friend,

9.3 Pad A structures and an MLP after the end of the Shuttle program, August 2013 (Photo by the author). *Source*: Ward

'What's he doing up there?' He said, 'I hate to tell you this, but they're starting to cut it down.' I watched the guy cut the first member off with a torch, and it fell 400 ft to the ground and went *WHOMP*! It was really sad. I didn't want them to change anything."

After the launch of *Apollo 17*, NASA began updating firing room 1 for Space Shuttle operations. All of the control panels and consoles were scrapped. John Conway, who worked on designing and implementing the launch processing system for Shuttle, said many of the Apollo-era equipment consoles were purchased back from a salvage dealer and repurposed for Shuttle. Engineers turned the consoles upside-down and inserted computer monitors or control panels into what had been the legs of the consoles. Firing room 1 supported the first Shuttle launch in 1981, and NASA named it the *Young-Crippen Firing Room* in 2008 (Figs. 9.4 and 9.5).

Firing room 2 was gutted after Skylab. Firing room 3 was the last firing room used for Apollo/Saturn launches, supporting the Skylab manned missions and ASTP. Firing room 3 served briefly as a KSC tourist stop during Bicentennial celebrations. From the observation room off to the side of area A, visitors could watch replays of the *Apollo 11* countdown and launch on the overhead screens. The room was eventually stripped bare and refitted to support Shuttle. Many of the Apollo-era control panels that made their way into the hands of private collectors appear to be from firing rooms 2 and 3.

All four firing rooms served as the primary firing room at one time or another during the Space Shuttle era. Firing room 4, which was never outfitted as an active firing room during Apollo, launched the final 21 Space Shuttle missions (Figs. 9.6 and 9.7).

The MSOB became known as the Operations and Checkout (O&C) Building toward the end of the Apollo era. After Apollo, the O&C was substantially reconfigured to support the Space Shuttle program. Although the astronaut offices and suit-up room on the third floor remained intact, the assembly and checkout area was completely stripped of all of its original fixtures except the two large altitude chambers (Figs. 9.8 and 9.9).

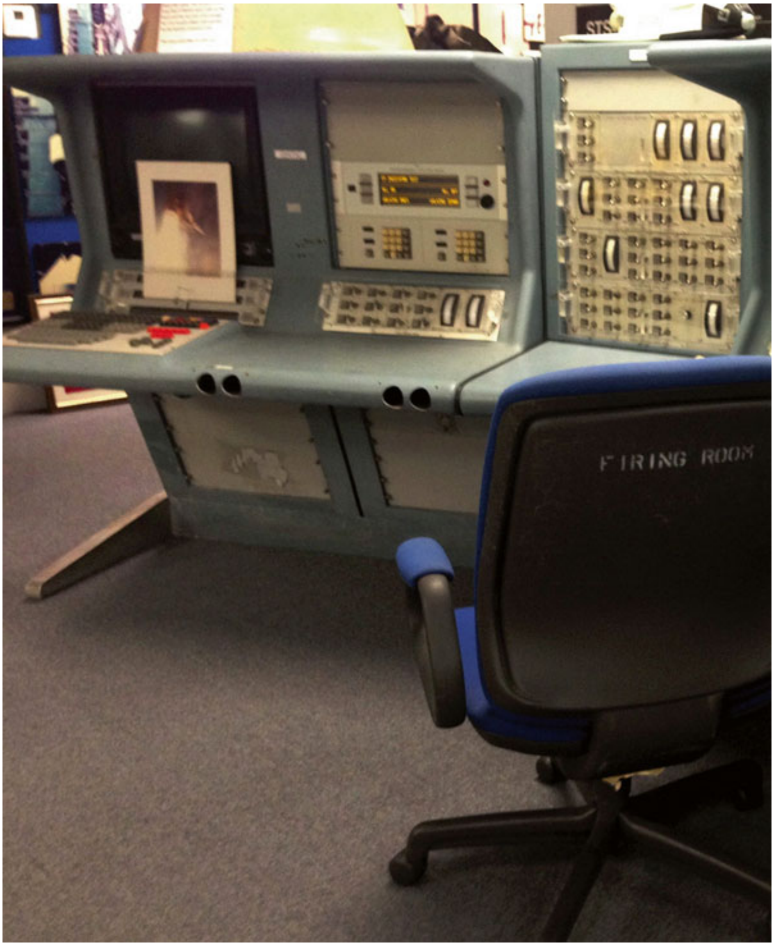
9.4 Firing room 1 during the early Shuttle program. Consoles are arrayed in arcs facing the window. *Source*: NASA

As of 2013, the low and high bays were leased to Lockheed Martin Company for fabrication of the Orion spacecraft. Rather than building the Orion at an offsite plant and shipping it to KSC for testing, Lockheed Martin assembles the Orion completely at KSC.

On July 21, 2014, the building was officially renamed *The Neil Armstrong Operations and Checkout Building* during the commemoration of the 45th anniversary of the *Apollo 11* landing (Fig. 9.10).

The Space Shuttle program brought tremendous changes to the makeup of the KSC workforce. Huntsville managed the solid rocket boosters, engines, and external tank. Houston took the lead role in the program and controlled the Shuttle orbiter. A cadre of 60 NASA staff from KSC, including Norm Carlson, Bob Sieck, Charlie Mars, and Roy Tharpe, went to California for 2 years for the flights of the *Enterprise* in the approach and landing test (ALT) program. John Conway helped design the ground launch sequencing computer system for Shuttle operations. George Page, formerly the head of spacecraft operations, became launch director for the first three Shuttle missions. Many of the former launch operations division and information systems personnel (among them Ike Rigell, Frank Bryan, JoAnn Morgan, and Gary Powers) were working on payloads, such as the Spacelab module, with Skip Chauvin and Ernie Reyes. To some people, it seemed like a confusing flip-flop in roles and specialties.

Some contractor personnel stayed in the KSC area to ride out the hiatus between Apollo and Shuttle; others took assignments across the country and hoped to be called back eventually. Work for the contractors at KSC began picking back up again at the end of the



9.5 Early Shuttle firing room consoles on display in the Space Walk of Fame Museum. Their heritage is apparent in this view: they are Apollo-era consoles turned upside-down (Photo by the author). *Source*: Ward

1970s, but it was nothing like the heyday of the Apollo era. Rockwell was back in force with the orbiter, but Grumman was for all practical purposes no longer a major player at KSC.

REFLECTIONS ON THE EXPERIENCE

Many of the people interviewed for this book worked both on Apollo/Saturn and Space Shuttle missions. A few had careers that spanned the entire duration of both programs. Surprisingly, even though their Apollo/Saturn experiences stretched back 35 years earlier,

9.6 Firing room 4 during activation of LC-39, late 1966. On the other side of the wall is a room full of Boeing schedulers and site activation PERT charts at the next level of detail. *Source*: NASA/Ward

many workers said that they actually remembered their Apollo days more vividly than Shuttle.

Most of the veterans of both programs who were interviewed for this book said that Apollo/Saturn was by far their best work experience. These included people who started their careers as junior engineers in Apollo/Saturn and went on to become some of the most senior people at KSC during the Shuttle era.

What made Apollo/Saturn such a satisfying program at KSC? What made it a success? The themes most often repeated during the interviews were:

- Dedication to an important, compelling, and shared vision
- Teamwork without personal "agendas"
- Communications
- Telling the truth in difficult situations
- Work ethic and willingness to make personal sacrifices
- The challenge of solving complex problems

9.7 Firing room 4 in 2012, after the conclusion of the Shuttle program. The final 21 Shuttle launches were controlled here (Photo by the author). *Source*: Ward

- Discipline and rigorous testing
- Designing for reliability and fail-safe operations

One of the remarkable accomplishments of the Apollo/Saturn program was that every launch vehicle got its payload into space. There were no launch pad explosions, aborts, or range safety terminations of launches. Of course, there was the loss of the crew in the *Apollo 1* fire during testing, and several missions were near misses. However, the achievement still stands that every Saturn that went into countdown took off from the launch pad and accomplished its primary mission. The Apollo crews that flew into space all came home alive, when many astronauts felt they had maybe a 33 % chance of perishing during a mission. The program's success rate was unprecedented in the 1960s, and it remains an enviable achievement today.

This book's purpose is not to justify the importance of the Apollo program to the nation or the world. Rather, it is an opportunity to gain some insight on what it meant to be among the thousands of "nobodies" at KSC who worked countless hours without public recognition to accomplish their tasks in the program. We will close out this book by having some

9.8 Spacecraft test conductor Clarence "Skip" Chauvin briefs the Apollo-Soyuz Test Project crews about spacecraft testing in ACE control room 1, February 10, 1975. *Source*: NASA/ Jerome Bascom-Pipp

of the contributors share their reflections on the meaning of the Apollo/Saturn experience in their lives.

John Conway:

You realize that this is bigger than you. You've got this little piece of it, and you're terrified that you're going to screw it up, that you're going to let this whole team down, people that are better and smarter and more capable than you. You work hours upon hours upon hours to make absolutely certain nothing will go wrong with your piece, so that you aren't going to be the one that screws up.

The person that you respect the most is the person who speaks up, saying, "I have a potential problem," or "I have a potential schedule risk," long before it's a problem. The person that sits on something that could become a problem, because he thinks he can solve it and not tell anybody about it, is the most dangerous person on the team.

It makes you redouble your effort to not let them down. In those days, everybody was expected to speak out with any concern, with any potential issue, anything you thought might be a problem. As far as the NASA and contractor relationship, when we had a team working on something, whoever was the smartest on the situation was the one at the blackboard with the chalk. The rest of us were supporting. It didn't

9.9 One of the former ACE rooms in August 2013. The pedestal and glassed-in management room are all that remain of the original facility (Photo by the author). *Source*: Ward

matter who you were or where you came from. Nothing mattered except that you might be able to help solve this problem. It was a great experience.

Norm Carlson:

One thing I've tried to do my whole life, maybe I've failed on occasion, but my mother told me, "Never tell a lie. If you tell a lie, you'll have to remember exactly what you said yesterday. If you don't lie, you can tell 100 different people the same story and it'll always be the same. You'll never get yourself in the situation of someone saying, 'Well, that's not what he told me.'" When you're dealing with a lot of people like we were in Apollo, that's a must. You can't have the people who work

9.10 *Apollo 11* CMP Michael Collins, backup CDR James Lovell, and LMP Buzz Aldrin in the high bay of the newly-dedicated Neil Armstrong Operations and Checkout Building, July 21, 2014. An Orion capsule is behind them. *Source*: NASA

> *for you or the people who work indirectly for you not respecting you. I think that advice that my mother gave me is just good advice for everybody.*
>
> *I always felt that if you get into trouble with your boss, just tell him the truth. "I made a mistake. I threw the wrong switch. I'm sorry, and it will never happen again." What can he say? What comeback does he have? He can't get his whip and whip you, because you admitted you were wrong.*

Lee Solid: "It was an interesting environment to work in, not because of the pressure it put you under—and yes, there was a lot of pressure on us—but just the challenge. The human spirit needs to be challenged. And in my lifetime, that whole experience was the ultimate in challenging you as to what you could do."

JoAnn Morgan:

> *I always felt at the time that I was moving warp speed at so many different levels and in such a high-pressure environment, that I could not stop to think about the historical aspects of it or what it meant in the big picture of technology. We were inventing so many things for the first time, and using computers in so many ways for the first time, and building computers, because we didn't have ones that met our needs, and software to go with them. And we were trying to make all that mesh together into this mission. It takes you years to reflect on what that meant. Now, I look back and I think, "My God! How in the world did we do that?"*
>
> *It's the ability to work together as a team and make things happen. I think that one of our great strengths was that everybody that came to work there really wanted*

> *to work there. Everybody was focused the end mission, and you just did not let anything get in the way.*

Jackie Smith: "I don't have a secret for success for anyone except hard work. I learned early on that you don't have to be the smartest person in the world, but you can out-work most people. The trick was: all the smart people in the class, the really intelligent ones, they became sort of complacent, like they didn't have to do much. But over the long haul, they were going to lose, and the hard worker was going to win. If you have at least a fairly good level of intelligence, you can beat a smart person just by pure hard work."

Roy Tharpe:

> *I was having dinner the other night with someone, and they said, "How in the world did you do it?" I said, "We never even thought about how we did it." The only thing we knew we had to do was to come into work every day, and I mean* every *day. Twelve hours at Kennedy Space Center was what you committed to every day. When you left, you got home, and you called back to the console and said, "I know we rushed through transition as to what went on during my 12 hours. Do you have any questions about what's coming up in your next 12 hours?"*
>
> *One of my buddies said the other day, "You know, for a year and a half, I never missed a day's work, working 12 hours a day. And the guy who relieved me, I learned to love him, because I knew that when he came in to relieve me on console, I could leave!"*
>
> *We manifested a group of people who understood how critical it was that we were in a Cold War and that our president had committed us to do something that was just unbelievable. And still to this day, I think back to what all it took, and the human power to muscle through, every day, all of those systems and all of the equipment that it took to operate it. And the commanding few – and it was just a few because it was not that big a test team – we had a core of folks who understood, "I have to go to work no matter what I have going on. My work is more important than anything else."*

Gary Powers: "I've heard a lot of comments about government employees sitting with their feet up on their desks. I never saw that anywhere during Apollo. I don't think I've ever been associated with a group of such dedicated people as I have working with Norm [Carlson] in the LCC and our guys. We were in a race for space. Everybody picked up the spirit and ran with it—everybody, right down to the secretaries. We were going to beat the Russians. It inspired us. Man for man, it was a dedicated group."

Dick Lyon:

> *My career was a fairy-tale career. I can't think of anything I rather would have done. It was something you could commit yourself to, something you were proud of doing, something you could go home and tell your wife and children, "Guess what I'm a part of! Guess what we're doing!" I could get the people that worked for me pumped up and say, "You're the only person that knows this stuff. You're it, Bud! You're important! You're making a contribution." If people can feel like they're making a contribution to society, even if they make mistakes, they can feel good about what they're doing. They're going to give you everything they've got.*

Chuck McEachern: "The one thing about the Apollo program that I thought was much more significant that Shuttle, was that people were dedicated to what they were doing. Our goal was to go to the Moon. We worked a lot of hours we weren't supposed to. After the fire that killed the crew on 34, they said, 'You guys can't work all these extra hours.' So what happened is, people worked almost as much, but never put it on their time cards. It was unbelievable. I had a whole bunch of 60–80 hour weeks that I never reported."

Jack King: "I sure was honored to be a part of it, I tell you. Best people I've ever known. You know what the funny thing was? I don't think anybody got enjoyment in any kind of employment any more than we did. I mean, we worked our asses off. But you always felt good about it. Sometimes you just didn't want to leave. The enthusiasm, that wonderful word *dedication*, you've never seen anything like it."

CONCLUSION

We dub people 'workaholics' if they put in countless hours at their jobs. When people say they work 60 or 80 hours a week, one gets the feeling that they are looking for a combination of admiration and pity. The long hours become a matter of routine, a means for workers to justify their importance. The irony, of course, is that many workaholics ultimately have nothing of lasting value to show for their time spent on the job.

In the hundreds of hours of interviews for this book, I never heard any of the Apollo/Saturn people from KSC describe themselves or any of their colleagues as workaholics. All talked about the stress of working long hours, but they saw their time as a commitment to something they knew was important, something that was bigger than them, and something that they did without expectation of recognition. They truly saw their long hours as a necessary sacrifice of service to their nation.

I deeply admire the people at Downey, Bethpage, and at KSC who worked with the flight hardware. Heartfelt pride still rings clearly in the voices of those who built or touched something that sent Apollo to the Moon.

Their reward was the towering achievement of building nearly-perfect rockets and spacecraft that took Man on his first journeys away from his home planet. That is their lasting legacy (Fig. 9.11).

9.11 Milestones of the Apollo/Saturn program. From *left*: launch of the first Saturn (*SA-1*, September 1961); launch of the first Saturn V (*AS-501*, November 1967); and the final flight of Apollo/Saturn technology (*ASTP*, July 1975). *Source*: NASA/Ward

Appendix A

Acronyms and Abbreviations

Acronym	*Meaning*
A&E	Architecture and engineering (organization or function)
A&E	Administrative and engineering (area in MSO Building)
A&T	Assembly and test
A50	Aerozine 50
ABMA	Army Ballistic Missile Agency
ACE	Acceptance checkout equipment—spacecraft
AEC	Atomic Energy Commission
AGCS	Automatic ground control system facility
ALSEP	Apollo lunar surface experiments package
ALT	Approach and landing test (Shuttle)
APIP	Apollo Personnel Investigation Program
APS	Auxiliary propulsion system
ARFM	Airframe
ASI	Augmented spark igniter
ASTP	Apollo-Soyuz Test Project
ATM	Apollo telescope mount
ATOLL	Acceptance Test Or Launch Language
AUX	Auxiliary
Boeing-TIE	Boeing Technical Integration and Evaluation contract
BPC	Boost protective cover
C^2F^2	Crew compartment fit and function test
CALIPS	Calibratable pressure switch
CAPCOM	Capsule communicator
CCAFS	Cape Canaveral Air Force Station
CD	Countdown
CDDT	Countdown demonstration test
CDF	Confined detonating fuse
CDR	Commander
CG	Center of gravity

(continued)

J.H. Ward, *Rocket Ranch*, Springer Praxis Books, DOI 10.1007/978-3-319-17789-2

cont.

Acronym	*Meaning*
CIL	Configuration inspection log
CKAFS	Cape Kennedy Air Force Station
CLTC	NASA launch vehicle test conductor
CM	Command module
CMP	Command module pilot
COAS	Crewman optical alignment sight
CSM	Command/service module
CVTS	NASA test supervisor
DDAS	Digital data acquisition system
DE	Design engineering
DLO	Director of launch operations
DM	Docking module
DOD	Department of Defense
DTS	Data transmission system
EASEP	Early Apollo scientific experiments package
EBW	Exploding bridge wire
ECS	Environment control system
ECU	Environmental control unit
EDS	Emergency detection system
EDT	Eastern (US) Daylight Time
EMI	Electromagnetic interference
EO	Engineering order
EOR	Earth-orbit rendezvous
ESE	Electrical support equipment
EST	Eastern (US) Standard Time
ETR	Eastern Test Range
EVA	Extra-vehicular activity
FCC	Flight control computer
FCDR	Flight crew directorate representative
FCE	Flight crew equipment
FCTB	Flight Crew Training Building
FM	Frequency modulation
FRR	Flight readiness review
FRT	Flight readiness test
FRU	Field replaceable unit
FSRT	Flight systems redundancy test
FWDT	Flight worthiness demonstration test
GE	General Electric
GETS	Ground equipment test set
GH_2	Gaseous hydrogen
GN_2	Gaseous nitrogen
GOX	Gaseous oxygen
GSCU	Ground support cooling unit
GSE	Ground support equipment

(continued)

cont.

Acronym	*Meaning*
HDA	Holddown arm
HGA	High gain antenna
HOSC	Huntsville Operations Support Center
IBM	International Business Machines
IDR	Interim discrepancy report
IMU	Inertial measurement unit
ITP	Integrated test procedure
IU	Instrument unit
KSC	Kennedy Space Center
L/V	Launch vehicle
LC	Launch Complex
LCC	Launch Control Center
LCD	Launch countdown
LCRU	Lunar communications relay unit
LEM	Lunar excursion module, early name for LM
LES	Launch escape system
LH_2	Liquid hydrogen
LM	Lunar module
LMRD	Launch mission rules document
LMP	Lunar module pilot
LMR	Launch mission rule
LO_2	Liquid oxygen
LOC	Launch Operations Center
LOD	Launch operations directorate
LOR	Lunar-orbit rendezvous
LOS	Loss of signal
LOX	Liquid oxygen
LRR	Launch readiness review
LRV	Lunar roving vehicle
LSC	Linear shaped charge
LSE	Launch support equipment
LUT	Launcher/umbilical tower
LVDA	Launch vehicle data adapter
LVDC	Launch vehicle digital computer
LVO	Launch vehicle operations directorate (KSC organization)
MAF	Michoud Assembly Facility
Max Q	Maximum dynamic pressure
MCC	Mission Control Center (Houston)
MCR	Master change record
MDAC	McDonnell Douglas Aircraft Company
MESA	Modularized equipment stowage assembly
MIC	Management information and control (room)
MILA	Merritt Island Launch Annex
MIP	Mandatory inspection point
ML	Mobile launcher

(continued)

cont.

Acronym	*Meaning*
MMH	Monomethylhydrazine
MOCR	Mission operations control room (Houston)
MR	Material review
MSC	Manned Spacecraft Center
MSC-FO	Manned Spacecraft Center-Florida Operations
MSFC	Marshall Space Flight Center
MSOB	Manned Spacecraft Operations Building
MSS	Mobile service structure
MTF	Mississippi Test Facility
NAA	North American Aviation
NAR	North American Rockwell
NASA	National Aeronautics and Space Administration
NOAA	National Oceanic and Atmospheric Administration
NPDS	Nuclear particle detection system
O_2UU	Oxygen umbilical unit
OAT	Overall test
OIS	Operational intercom system
OMR	Operations management room
OMRSD	Operations and maintenance requirements and specification document
OTV	Operational television system
PA	Public address
PAO	Public affairs officer
PCM	Pulse code modulation
PD	Propellant dispersion
PE	Project engineer
PERT	Program evaluation and review technique
PET	Polyethylene terephthalate
PIB	Pyrotechnic installation building
PLT	Pilot
PTCR	Pad terminal connection room
PTCS	Propellant tanking computer system
PU	Propellant utilization
QC	Quality control
QD	Quick disconnect
QLDS	Quick look data station
RASPO	Resident Apollo spacecraft program office
RCA	Radio Corporation of America
RCS	Reaction control system
RF	Radio frequency
RP-1	Rocket propellant-1
RSCR	Range safety command receiver
RSO	Range safety officer
RSS	Rotating service structure
RTG	Radioisotopic thermal generator
S/C	Spacecraft

(continued)

cont.

Acronym	*Meaning*
S&A	Safe and arm
SACTO	Sacramento Test Operations
SCAPE	Self-contained atmospheric protective ensemble
SCE	Signal conditioning equipment
SCO	Spacecraft operations directorate
SEQ	Scientific equipment
SHe	Supercritical helium
SIM	Scientific instrument module
SIP	Surveillance inspection point
SLA	Spacecraft/lunar module adapter or spacecraft/launch vehicle adapter
SM	Service module
SMDPS	Service module deluge purge system
SPLT	Science pilot
SPS	Service propulsion system
START	Selections to activate random testing (ACE system test module)
STDN	Spaceflight tracking and data network
STG	Space Task Group
STM	Spacecraft test manager (Grumman)
SV or S/V	Space vehicle
TAIR	Test and inspection record
TC	Test conductor
TCP	Test and checkout procedure
TCS	Terminal countdown sequencer
TLI	Trans-lunar injection
TPS	Test preparation sheet
TRD	Test requirements document
TRS	Troubleshooting record sheet
TSM	Tail service mast
UDMH	Unsymmetrical dimethylhydrazine
USAF	US air force
USCG	US coast guard
USN	US navy
USNS	United States naval ship
UTC	Coordinated Universal Time, also known as Greenwich Mean Time or *Zulu*
VAB	Vertical Assembly Building, name later changed to Vehicle Assembly Building
VHF	Very high frequency
VJ	Vacuum-jacketed

Appendix B

Missions with Apollo and Saturn Flight Hardware

1. SATURN LAUNCH VEHICLE AND APOLLO SPACECRAFT DEVELOPMENT FLIGHTS (CAPE CANAVERAL AIR FORCE STATION, FLORIDA)

Mission	SA-1
Launch vehicle	SA-1 (Saturn I Block I)
Payload	Nose cone from Jupiter missile, dummy second stage
Launch pad	LC-34
Launch time	1961-Oct-27 15:00:06 UTC
Comments	First launch from LC-34. First flight of Saturn launch vehicle. Dummy second stage. Vehicle reached an altitude of 84.6 miles

Mission	SA-2
Launch vehicle	SA-2 (Saturn I Block I)
Payload	Jupiter nose cone, dummy second stage filled with water
Launch pad	LC-34
Launch time	1962-Apr-25 14:00:34 UTC
Comments	Project High Water I—22,900 gal of water released at altitude of 90 miles

Mission	SA-3
Launch vehicle	SA-3 (Saturn I Block I)
Payload	Jupiter nose cone, dummy second stage filled with water
Launch pad	LC-34
Launch time	1962-Nov-16 17:45:02 UTC
Comments	Project High Water II—22,900 gal of water released at altitude of 103.7 miles

J.H. Ward, *Rocket Ranch*, Springer Praxis Books, DOI 10.1007/978-3-319-17789-2

Mission	SA-4
Launch vehicle	SA-4 (Saturn I Block I)
Payload	Jupiter nose cone, dummy second stage
Launch pad	LC-34
Launch time	1963-Mar-28 20:11:55 UTC
Comments	Programmed premature cutoff of one engine to prove vehicle could perform mission with one engine out.

Mission	SA-5
Launch vehicle	SA-5 (Saturn I Block II)
Payload	Jupiter nose cone filled with sand as ballast
Launch pad	LC-37B
Launch time	1964-Jan-29 16:25:01 UTC
Comments	First launch from LC-37B. First flight of live S-IV upper stage and of instrument unit with guidance platform. First Saturn to place a payload in orbit.

Mission	A-101
Launch vehicle	SA-6 (Saturn I Block II)
Payload	Boilerplate Apollo CSM BP-13
Launch pad	LC-37B
Launch time	1964-May-28 17:07:00 UTC
Comments	S-IV, IU, and spacecraft were inserted into orbit as a single unit.

Mission	A-102
Launch vehicle	SA-7 (Saturn I Block II)
Payload	Boilerplate Apollo CSM BP-15
Launch pad	LC-37B
Launch time	1964-Sep-18 16:22:43 UTC
Comments	Repeat of AS-101 mission. First flight of guidance computer that could be programmed in flight.

Mission	A-103
Launch vehicle	SA-9 (Saturn I Block II)
Payload	Boilerplate CSM BP-16, Pegasus A satellite
Launch pad	LC-37B
Launch time	1965-Feb-16 14:37:03 UTC
Comments	Satellite carried inside modified dummy service module, and remained attached to spent S-IV after CM was jettisoned in orbit.

Mission	A-104
Launch vehicle	SA-8 (Saturn I Block II)
Payload	Boilerplate CSM BP-26, Pegasus B satellite
Launch pad	LC-37B
Launch time	1965-May-25 07:35:01 UTC
Comments	First night launch of a Saturn. Mission similar to A-103.

Mission	A-105
Launch vehicle	SA-10 (Saturn I Block II)
Payload	Boilerplate CSM BP-9A, Pegasus C satellite
Launch pad	LC-37B
Launch time	1965-Jul-30 13:00:00 UTC
Comments	Mission similar to A-103 and A-104. Last flight of Saturn I Block I launch vehicle.

2. APOLLO SPACECRAFT ABORT TESTS (WHITE SANDS MISSILE RANGE, NEW MEXICO)

Mission	Pad Abort Test 1
Launch vehicle	Launch escape system
Payload	Boilerplate CM BP-6
Launch time	1963-Nov-07 16:00:01 UTC
Comments	First flight of Apollo boilerplate CM.

Mission	A-001
Launch vehicle	Little Joe II
Payload	Boilerplate CSM BP-12
Launch time	1964-May-13 12:59:59.7 UTC
Comments	First flight of boilerplate CSM.

Mission	A-002
Launch vehicle	Little Joe II
Payload	Boilerplate CM BP-23
Launch time	1964-Dec-08 15:00:00 UTC
Comments	Boost protective cover and modified dual-drogue parachutes used.

Mission	A-003
Launch vehicle	Little Joe II
Payload	Boilerplate CM BP-22
Launch time	1965-May-19 13:01:04 UTC
Comments	Launch vehicle malfunction resulted in LV breakup before second stage ignition, causing low altitude abort. LES pulled CSM free successfully.

Mission	Pad Abort Test 2
Launch vehicle	LES
Payload	Boilerplate CM BP-23A
Launch time	1965-Jun-29 13:00:01 UTC
Comments	Successful test of LES abort initiated at launch pad.

Mission	A-004
Launch vehicle	Little Joe II
Payload	Airframe 002 (modified Block I CSM)
Launch time	1966-Jan-20 15:17:01 UTC
Comments	Successful test of LES ability to stabilize a tumbling spacecraft.

3. APOLLO/SATURN MISSIONS (CCAFS LC-34/37B AND KSC LC-39)

Mission	AS-201
Launch vehicle	SA-201 (Saturn IB)
CSM	CSM-009 (Block I CSM)
Launch pad	LC-34
Launch time	1966-Feb-26 16:12:01 UTC
Test Supervisor	Paul Donnelly
Comments	Unmanned suborbital flight. First flight of Saturn IB launch vehicle and Apollo service module.

Mission	AS-203
Launch vehicle	SA-203 (Saturn IB)
Launch pad	LC-37B
Launch time	1966-Jul-5 14:53:13 UTC
Test Supervisor	Paul Donnelly
Comments	Unmanned orbital test of S-IVB restart capability; no Apollo spacecraft.

Mission	AS-202
Launch vehicle	SA-202 (Saturn IB)
CSM	CSM-011 (Block I)
Launch pad	LC-34
Launch time	1966-Aug-25 17:15:32 UTC
Test Supervisor	Don Phillips
Comments	Unmanned test of service propulsion system and of heat shield's ability to withstand high-velocity re-entry.

Mission	AS-204/Apollo 204/Apollo 1
Launch vehicle	SA-204 (Saturn IB)
CSM	CSM-012 (Block I)
Launch pad	LC-34
Launch time	Not flown; planned launch date 1967-Feb-21
Crew	Virgil Grissom (command pilot), Edward White II (senior pilot); Roger Chaffee (pilot)
Test Supervisor	George Page
Comments	Spacecraft destroyed and crew killed in fire during space vehicle plugs-out overall test on 1967-Jan-27.

Mission	Apollo 4/AS-501
Launch vehicle	SA-501 (Saturn V)
CSM	CSM-017 (Block I)
LM	LTA-10R (dummy vehicle carried as ballast)
VAB High Bay	1
LUT	1
Firing Room	1
Launch pad	LC-39A
Launch time	1967-Nov-9 20:37:00 UTC
Test Supervisor	Chuck Henschel
Comments	Unmanned. First flight of Saturn V; 3 Earth orbits.

Mission	Apollo 5/AS-204
Launch vehicle	SA-204 (Saturn IB)
LM	LM-1
Launch pad	LC-37B
Launch time	1968-Jan-22 22:48:09 UTC
Test Supervisor	Don Phillips
Comments	Unmanned. First flight of LM; no CSM. SA-204 booster originally intended for Apollo 1 mission; de-stacked from LC-34 and erected at LC-37B. Last launch from LC-37B. Pad deactivated in 1972; rebuilt and re-opened in 2001 for Delta IV launches.

Mission	Apollo 6/AS-502
Launch vehicle	SA-502 (Saturn V)
CSM	CSM-020 (Block I)
LM	LTA-2R (dummy vehicle carried as ballast)
VAB High Bay	3
LUT	2
Firing Room	2
Launch pad	LC-39A
Launch time	1968-Apr-04 12:00:01 UTC
Test Supervisor	Jim Harrington
Comments	Unmanned test flight of Saturn V. Early shutdown of two engines on S-II stage and failure of S-IVB to restart due to damage caused by pogo oscillations during S-IC boost phase. Last flight of Block I CSM.

Mission	Apollo 7/AS-205
Launch vehicle	SA-205 (Saturn IB)
CSM	CSM-101 (Block II)
LM	Docking target
Launch pad	LC-34
Launch time	1968-Oct-11 15:02:45 UTC
Crew	Walter Schirra (CDR), Donn Eisele (CMP), Walter Cunningham (LMP)
Test Supervisor	Don Phillips
Comments	First manned Apollo launch. First flight of Block II spacecraft. Docking target carried in SLA. Last launch from LC-34.

Mission	Apollo 8/AS-503
Launch vehicle	SA-503 (Saturn V)
CSM	CSM-103
LM	LTA-B (ballast)
VAB High Bay	1
LUT	1
Firing Room	1
Launch pad	LC-39A
Launch time	1968-Dec-21 12:51:00 UTC
Crew	Frank Borman (CDR), James Lovell (CMP), William Anders (LMP)
Test Supervisor	Bill Schick
Comments	First manned flight of Saturn V. First manned spacecraft to orbit the Moon. S-IVB stage placed in solar orbit.

Mission	Apollo 9/AS-504
Launch vehicle	SA-504 (Saturn V)
CSM	CSM-104 "Gumdrop"
LM	LM-3 "Spider"
VAB High Bay	3
LUT	2
Firing Room	2
Launch pad	LC-39A
Launch time	1969-Mar-3 16:00:00 UTC
Crew	James McDivitt (CDR), David Scott (CMP), Rusty Schweickart (LMP)
Test Supervisor	Jim Harrington
Comments	Earth orbital mission; first manned flight of lunar module.

Mission	Apollo 10/AS-505
Launch vehicle	SA-505 (Saturn V)
CSM	CSM-106 "Charlie Brown"
LM	LM-4 "Snoopy"
VAB High Bay	2
LUT	3
Firing Room	3
Launch pad	LC-39B
Launch time	1969-May-18 16:49:00 UTC
Crew	Thomas Stafford (CDR), John Young (CMP), Eugene Cernan (LMP)
Test Supervisor	Don Phillips
Comments	First launch from LC-39B and only Saturn V launch from this pad. Test of LM in lunar orbit with simulation of landing mission up to the point of powered descent. S-IVB and LM ascent stage placed in solar orbit.

Mission	Apollo 11/AS-506
Launch vehicle	SA-506 (Saturn V)
CSM	CSM-107 "Columbia"
LM	LM-5 "Eagle"
VAB High Bay	1
LUT	1
Firing Room	1
Launch pad	LC-39A
Launch time	1969-Jul-16 12:32:00 UTC
Crew	Neil Armstrong (CDR), Michael Collins (CMP), Edwin "Buzz" Aldrin (LMP)
Test Supervisor	Bill Schick
Comments	First lunar landing, in Mare Tranquillitatis. First humans to set foot on another celestial body. President Kennedy's challenge met. S-IVB placed in solar orbit. Last use of LUT 1 for Saturn V (later modified with milkstool platform for Skylab Saturn IB launches).

Mission	Apollo 12/AS-507
Launch vehicle	SA-507 (Saturn V)
CSM	CSM-108 "Yankee Clipper"
LM	LM-6 "Intrepid"
VAB High Bay	3
LUT	2
Firing Room	2
Launch pad	LC-39A
Launch time	1969-Nov-14 16:22:00 UTC
Crew	Charles Conrad (CDR), Richard Gordon (CMP), Alan Bean (LMP)
Test Supervisor	Jim Harrington
Comments	Vehicle struck by lightning during boost phase. First pinpoint landing on the Moon, in Oceanus Procellarum. Returned portions of Surveyor 3 lander to Earth for analysis. S-IVB in solar orbit.

Mission	Apollo 13/AS-508
Launch vehicle	SA-508 (Saturn V)
CSM	CSM-109 "Odyssey"
LM	LM-7 "Aquarius"
VAB High Bay	2, 1
LUT	3
Firing Room	1
Launch pad	LC-39A
Launch time	1970-Apr-11 19:13:00 UTC
Crew	James Lovell (CDR), Jack Swigert (CMP), Fred Haise (LMP)
Test Supervisor	Bert Grenville
Comments	LOX tank explosion crippled CSM and forced early mission termination. Swigert replaced original CMP T. K. Mattingly due to possible measles exposure. Launch vehicle stacked in High Bay 2 then rolled over to high bay 1 for spacecraft stacking.

Mission	Apollo 14/AS-509
Launch vehicle	SA-509 (Saturn V)
CSM	CSM-110 "Kitty Hawk"
LM	LM-8 "Antares"
VAB High Bay	3
LUT	2
Firing Room	2
Launch pad	LC-39A
Launch time	1971-Jan-31 21:03:02 UTC
Crew	Alan Shepard (CDR), Stuart Roosa (CMP), Edgar Mitchell (LMP)
Test Supervisor	Chuck Henschel
Comments	Launch delayed 40 min 2 s due to weather. CSM docking problems, faulty abort indication on LM, and problems with LM landing radar nearly caused cancellation of landing attempt. Lunar landing in Fra Maura region.

Mission	Apollo 15/AS-510
Launch vehicle	SA-510 (Saturn V)
CSM	CSM-112 "Endeavour"
LM	LM-10 "Falcon"
VAB High Bay	1, 3
LUT	3
Firing Room	1
Launch pad	LC-39A
Launch time	1971-Jul-26 13:34:00.6 UTC
Crew	David Scott (CDR), Alfred Worden (CMP), James Irwin (LMP)
Test Supervisor	Jim Harrington
Comments	First flight of J-series spacecraft, "extended mission" LM and CSM with SIM Bay experiments. First flight of lunar rover. First deployment of subsatellite in lunar orbit. Landing near Hadley Rille in Hadley/Apennine region. First EVA by CMP on return trip from Moon to recover film and SIM bay data. Launch vehicle stacked in high bay 1 then rolled over to high bay 3 for spacecraft stacking.

Mission	Apollo 16/AS-511
Launch vehicle	SA-511 (Saturn V)
CSM	CSM-113 "Casper"
LM	LM-11 "Orion"
VAB High Bay	3
LUT	3
Firing Room	1
Launch pad	LC-39A
Launch time	1972-Apr-16 17:54:00
Crew	John Young (CDR), T. K. Mattingly (CMP), Charles Duke (LMP)
Test Supervisor	Gordon Turner
Comments	Launch date delayed one lunar month due to roll-back and destacking of space vehicle to replace ruptured fuel bladder on CM. Lunar landing in Descartes region, only landing in lunar highlands.

Mission	Apollo 17/AS-512
Launch vehicle	SA-512 (Saturn V)
CSM	CSM-114 "America"
LM	LM-12 "Challenger"
VAB High Bay	3
LUT	3
Firing Room	1
Launch pad	LC-39A
Launch time	1972-Dec-7 05:33:00
Crew	Eugene Cernan (CDR), Ron Evans (CMP), Harrison Schmitt (LMP)
Test Supervisor	Bill Schick
Comments	Last Apollo Moon landing. Only Saturn V night launch, delayed 2 h 40 min due to failure in terminal count sequencer. LUT 3 deactivated after launch for conversion to mobile launch platform 1 for Space Shuttle program. Firing room 1 deactivated after launch for modification to support Space Shuttle. MSS reconfigured after launch to support Skylab launch vehicles.

Mission	Skylab Orbital Workshop (OWS)/SL-1
Launch vehicle	SA-513 (Saturn V)
CSM	-
VAB High Bay	2
LUT	2
Firing Room	2
Launch pad	LC-39A
Launch time	1973-May-14 17:30:00 UTC
Crew	-
Test Supervisor	Chuck Henschel
Comments	Last launch of Saturn V, with inert S-IVB-212 converted to Skylab orbital workshop. Pad LC-39A and LUT 2 deactivated after launch to modify them for Space Shuttle.

Mission	Skylab 2/SL-2/AS-206
Launch vehicle	SA-206 (Saturn IB)
CSM	CSM-116
VAB High Bay	1
LUT	1
Firing Room	3
Launch pad	LC-39B
Launch time	1973-May-25 13:00:00 UTC
Crew	Pete Conrad (CDR), Paul Weitz (PLT), Joseph Kerwin (SPLT)
Test Supervisor	Bill Schick
Comments	Launch delayed 10 days to design and carry emergency repair equipment to the OWS. SA-206 was originally stacked on LC-37B for the first LM test flight in 1967. After the Apollo 1 fire, SA-206 was de-erected and stored at Michoud Assembly Facility.

Mission	Skylab 3/SL-3/AS-207
Launch vehicle	SA-207 (Saturn IB)
CSM	CSM-117
VAB High Bay	1
LUT	1
Firing Room	3
Launch pad	LC-39B
Launch time	1973-Jul-28 11:10:50 UTC
Crew	Alan Bean (CDR), Jack Lousma (PLT), Owen Garriott (SPLT)
Test Supervisor	Chuck Henschel
Comments	Propellant leaks in RCS quads prompted preparation of Skylab Rescue mission (not flown). Flew with IU originally intended for SA-208.

Mission	Skylab 4/SL-4/AS-208
Launch vehicle	SA-208 (Saturn IB)
CSM	CSM-118
VAB High Bay	1
LUT	1
Firing Room	3
Launch pad	LC-39B
Launch time	1973-Nov-16 14:01:23 UTC
Crew	Gerald Carr (CDR), William Pogue (PLT), Edward Gibson (SPLT)
Test Supervisor	Bill Schick
Comments	Last Skylab mission. Flew with IU originally intended for SA-207.

Mission	Skylab Rescue Mission/SL-R
Launch vehicle	SA-208, SA-209 (Saturn IB)
CSM	CSM-119
VAB High Bay	1
LUT	1
Firing Room	3
Launch pad	LC-39B
Launch time	-
Crew	Vance Brand (CDR), Don Lind (PLT)
Comments	Not flown. Mission on standby and CSM modified to carry 5 crewmen for rescue of Skylab crews if necessary.

Mission	Apollo-Soyuz Test Project/ASTP/AS-210
Launch vehicle	SA-210
CSM	CSM-111
DM	Docking Module carried in SLA for docking with Soyuz 19
VAB High Bay	1
LUT	1
Firing Room	3
Launch pad	LC-39B
Launch time	1975-July-15 12:20:00 UTC
Crew	Thomas Stafford (CDR), Vance Brand (CMP), Donald Slayton (DMP)
Test Supervisor	Bill Schick
Comments	Last flight of Apollo/Saturn hardware. Pad 39B and other active Launch Complex 39 facilities converted for Space Shuttle or scrapped (e.g., MSS).

Appendix C

RCA 110A Features

Most test programs for the RCA 110A were written in ATOLL (*Acceptance Test or Launch Language*). It was supposedly user-friendly, but writing routines in ATOLL still required considerable programming competency. HILA was another language used for early Saturn launches, and was eventually phased out in favor of ATOLL.

Control logic was an important part of the system. Urgent tasks were kept in core memory. *Reactive* routines were triggered by a measurement going out of acceptable limits, and they demanded immediate action to put the vehicle in a safe configuration. *Prerequisite* routines filtered commands to insure that conditions were appropriate for issuing the command. For example, if a command was issued to open drain lines, the prerequisite routine would first check to see if the vents were open.

Some of the capabilities of the RCA 110A included:

- Capability to monitor 2,048 discrete inputs and outputs. A Brown Corp. triple modular redundant (TMR) discrete output system in the LUT could withstand failures and still output the correct data. It was also able to retain the output status in the event of a power loss in the LUT. The TMR system prevented failure modes like the "discrete output blast" in the early 110 computer.
- Data buffer channels that moved information about the status of discrete inputs directly into computer memory. Priority interrupt circuitry alerted the control program to the changed status of inputs. This freed up the control part of the system to work on a test program without having to continually scan the many discrete inputs.
- Maintaining a status table of all discretes with timing data.
- Access to all vehicle measurements being relayed by telemetry via the digital data acquisition system (DDAS).
- Automatic transfer of data to the display system in the firing room.
- Automatic data link between the 110A computer in the firing room and the one in the mobile launcher. Each 'word' transmitted over the link was encoded so that it could be reconstructed at the other end of the line even if there were multiple bit failures. Losing communication between the firing room computer and the launcher computer was considered a major anomaly, so redundant data links between the two systems were implemented.

J.H. Ward, *Rocket Ranch*, Springer Praxis Books, DOI 10.1007/978-3-319-17789-2

- Output of test data to magnetic tape, with automatic switching between two tape stations as tapes filled up.
- Magnetic drum memory of 32,768 words for storage of data and programs to transfer to the CPU.
- Peripheral data transfer to line printers, card readers/punchers, paper tape readers/punchers, and electric typewriters.
- Interface from the 110A in the LUT to the flight computer (LVDC) in the Saturn V's instrument unit. This interface allowed the 110A to control the execution of programs in the LVDC and monitor the LVDC's status during tests.
- Interfaces with the countdown timing system. The 110A could start or stop the countdown clock or input a preset time into the clock.
- Register interface with the Acceptance Checkout Equipment-Spacecraft (ACE) system computers. Software was provided for this interface, but Penovich does not recall the capability ever being used.
- Control of the 110A in the LUT by a panel in the firing room. The LUT's computer system could be remotely controlled when the launcher was unmanned (for example, during hazardous tests such as launch countdowns). Bill Jafferis (KSC/Assistant Chief Engineer for Guidance and Control) conceived of this capability. The idea was considered such an important breakthrough that Jafferis received a $10,000 incentive award.

A Computer Control Company (CCC) DDP-224 computer was interfaced to the RCA 110A to output data to the 15 computer control consoles located throughout the firing room. Sanders Associates provided the display system, which had many advanced features for its time:

- "Stroke" graphics, in which the beam of the CRT was controlled to draw each character, rather than using dots to form characters.
- Slide/data mix, in which real-time data could be displayed beside slide information. For example, a propellants system engineer could draw a picture of the vehicle showing the propellant tanks and valves. He would leave blank areas where he wanted data to be displayed. The drawing was scanned into the system, and then during the test, real-time data was formatted to appear in the windows in the drawing.
- Video distribution, in which any display console could have information from any of the other 14 consoles routed to the screen. This was valuable in troubleshooting system problems.
- Data limit checking, in which the display computer could alert the engineer if data exceeded predetermined bounds.
- Frame freeze, enabling the engineer to take a snapshot of the data on the screen for later analysis.

Appendix D

Mobile Launcher Layout

This Appendix describes the basic layout of and equipment in the launcher/umbilical tower (LUT) (Fig. D.1).

MOBILE LAUNCHER

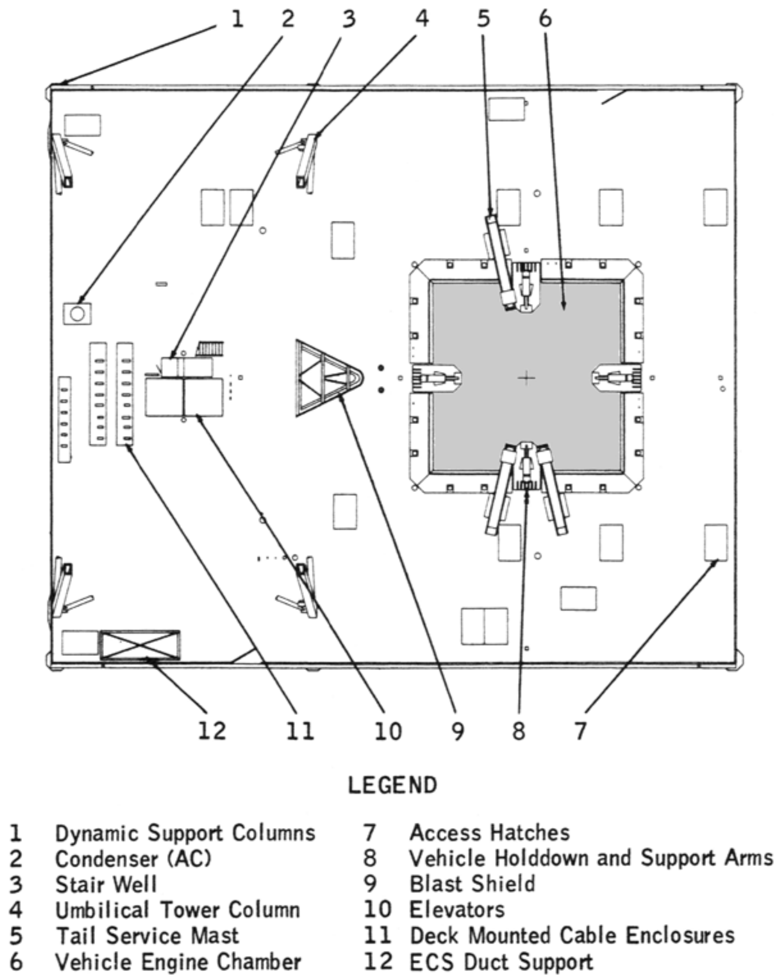
Level 0

Level 0 was the upper deck of the launcher—the platform on which the umbilical tower and the Saturn V itself were mounted. It was referred to as Level 0 because it was the reference level from which the heights of the LUT platforms were measured. The sides of the launcher were designated as sides 1 (at the south end of the launcher), 2 (west), 3 (north), and 4 (east).

The primary pieces of launch support equipment on Level 0 were:

- Four holddown arms, which secured the vehicle to the launcher deck for transport to the pad and held the Saturn V in place while its engines built up thrust prior to liftoff.
- Three tail service masts (TSMs).
- Four service platform winch motors, two each on the east and west sides of the deck about midway between the square opening for the engine compartment and the edges of the launcher deck. The winches raised or lowered the F-1 engine servicing platform, which came up from below the mobile launcher to level 0.
- Other pieces of portable support equipment, which were located on level 0 when the vehicle was at the pad, but were removed before launch to prevent damage. These included items such as servicing platforms, test equipment carts, and handrails around the launcher deck.

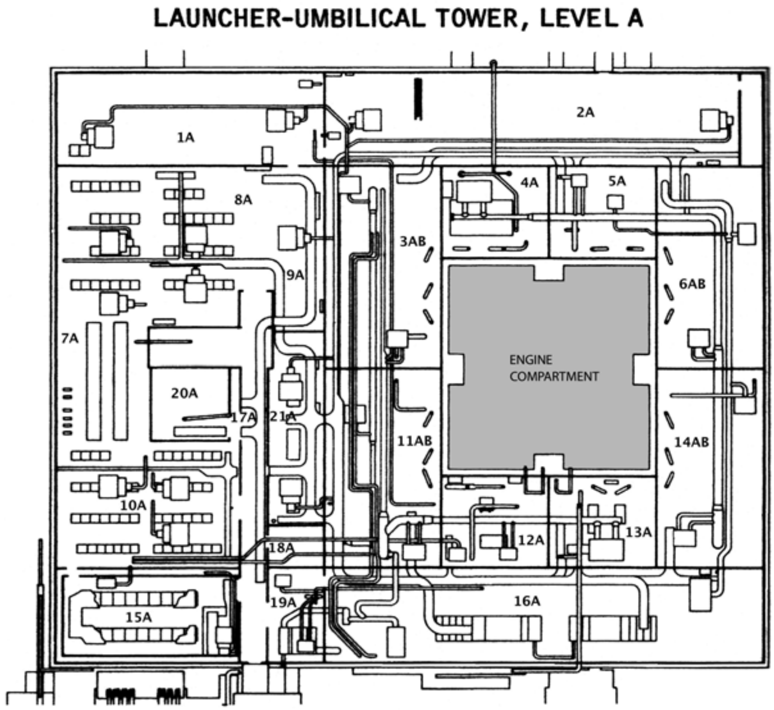
J.H. Ward, *Rocket Ranch*, Springer Praxis Books, DOI 10.1007/978-3-319-17789-2



D.1 Layout of the mobile launcher deck, LUT level 0. *Source*: Author's adaptation of NASA diagram

Level A

Level A, immediately below the launcher deck, was partitioned into compartments of support equipment for the launch vehicle. The primary access to level A was via the passenger elevator. Here also was the entrance to the emergency escape chute that led to the blast room at the base of the launch pad (Fig. D.2).



D.2 Layout of level A inside the mobile launcher. *Source*: Author's adaptation of NASA diagram

A partial listing of the equipment located in Level A is shown below.

- Room 1A—Service arms electrical equipment racks
- Room 2A—System checkout console; engine service platform relay distributor; engine gimbal motor control center; engine gimbal hydraulic checkout console; engine service platform relay distributor
- Room 3AB (open between the two interior levels of the ML)
- Room 4A—Fuel valve panel; RP-1 control distributor and RP-1 system; hydraulic skid; S-IC hydraulic pumping and checkout unit for engine gimbaling
- Room 5A—Launcher accessories control distributor; motor control center; hydraulic skid; launcher accessories control distributor, instrumentation and control distributor, power distributor; system checkout console
- Room 6AB (open between the two interior levels of the ML)
- Room 7A—Electrical support equipment racks for S-IC, S-II, S-IVB, and instrument unit; digital data acquisition system (DDAS) electrical equipment and command racks; countdown clock; theodolite laying racks; electrical support equipment racks for propellants and gases systems

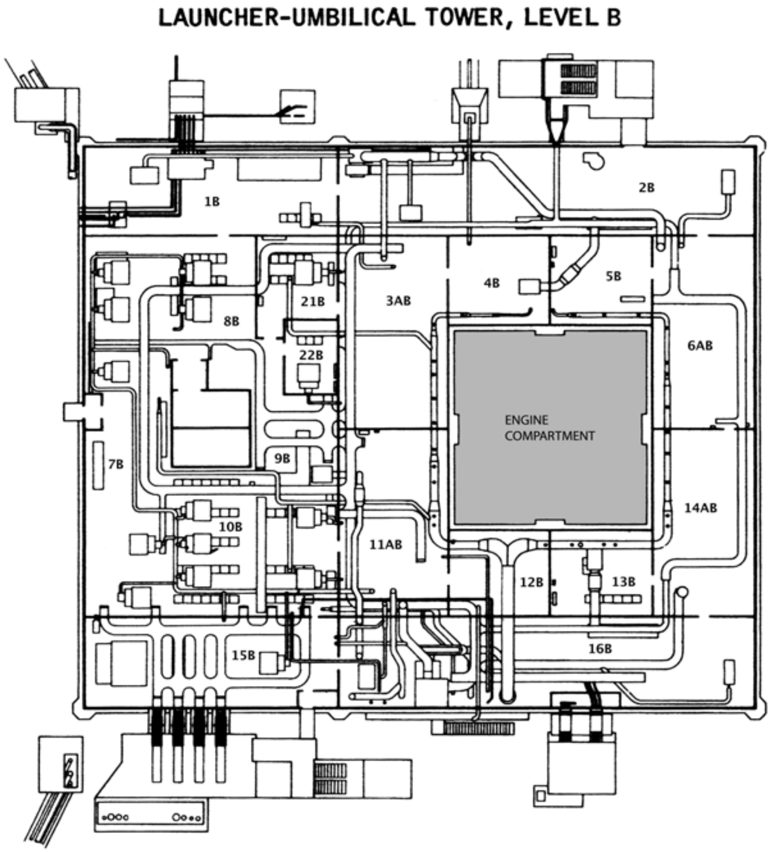
- Room 8A—Theodolite laying racks; IU platform racks; power and battery electrical equipment racks; service arm and launcher electrical equipment racks; mineral insulated (MI) cable tower firing distributor
- Room 9A—Propellant tanking computer system racks; communications distributors
- Room 10A—Countdown clock and timing racks; spacecraft simulator (for tests); electrical equipment racks for signal conditioning, systems integration, instrument unit, S-IVB, and S-II; ground measuring racks and DDAS racks; DEE-6C racks; water valve control distributor
- Room 11AB (open between the two interior levels of the ML)
- Room 12A—Deluge purge panel; launcher accessories/holddown arms control distributor; valve panel #11 and control distributor; operational intercom system (OIS) distributor
- Room 13A—Power distributor; instrumentation and control distributor; S-IC pneumatic console racks and valve panels
- Room 14AB (open between the two interior levels of the ML)
- Room 15A—RCA 110A computer room; card punch terminal; card reader; line printer; computer electrical equipment racks; discrete control racks
- Room 16A—Instrumentation unit substation (100 kVA); industrial load substation (2,500 kVA)
- Room 20A—High-speed elevator vestibule; entrance to emergency slide chute to blast room
- Room 21A
- Room 22A

Level B

Level B was the bottom level in the ML, and like level A, it was partitioned into rooms that housed support equipment for the launcher and launch vehicle (Fig. D.3).

A partial listing of the equipment located in Level B is shown below.

- Room 1B—GN_2 control panel; GN_2 accumulator; gas chromatography analyzer racks; high pressure control distributor; gaseous helium control panel, valve panel, and distribution manifold; hydraulic charging unit; safety switches
- Room 2B—Motor control center; S-IC inert pre-fill reservoir skid; S-IC inert pre-fill checkout console; inert pre-fill pump skid for hydraulic engine gimbal
- Room 3AB (open between the two interior levels of the ML)
- Room 4B—Engine gimbal hydraulic skid
- Room 5B—Operational intercom system (OIS) distributor
- Room 6AB (open between the two interior levels of the ML)
- Room 7B—Overall test equipment; stage and auxiliary power racks; telemetry sweep generator; safety switches; hydraulic charging unit; 28 VDC 400 Hz power distributor; miscellaneous electrical support equipment racks
- Room 8B—Stage and service arm power racks



D.3 Layout of Level B inside the Mobile Launcher. *Source*: Author's adaptation of NASA diagram

- Room 9B—Electrical equipment racks and terminal distributors for measuring; electrical equipment racks for NASA and base communications
- Room 10B—DDAS measuring racks; computer interface unit (CIU) DDAS data buffer
- Room 11AB (open between the two interior levels of the ML)
- Room 12B
- Room 13B—Ground measuring racks; S-IC pneumatic checkout racks
- Room 14AB (open between the two interior levels of the ML)
- Room 15B—Terminal room; air handling unit; DDAS racks; instrumentation and communications interface and control distributor
- Room 16B
- Room 21B—OIS and operational television (OTV) system racks
- Room 22B—Paging rack

SERVICE ARMS (SWING ARMS)

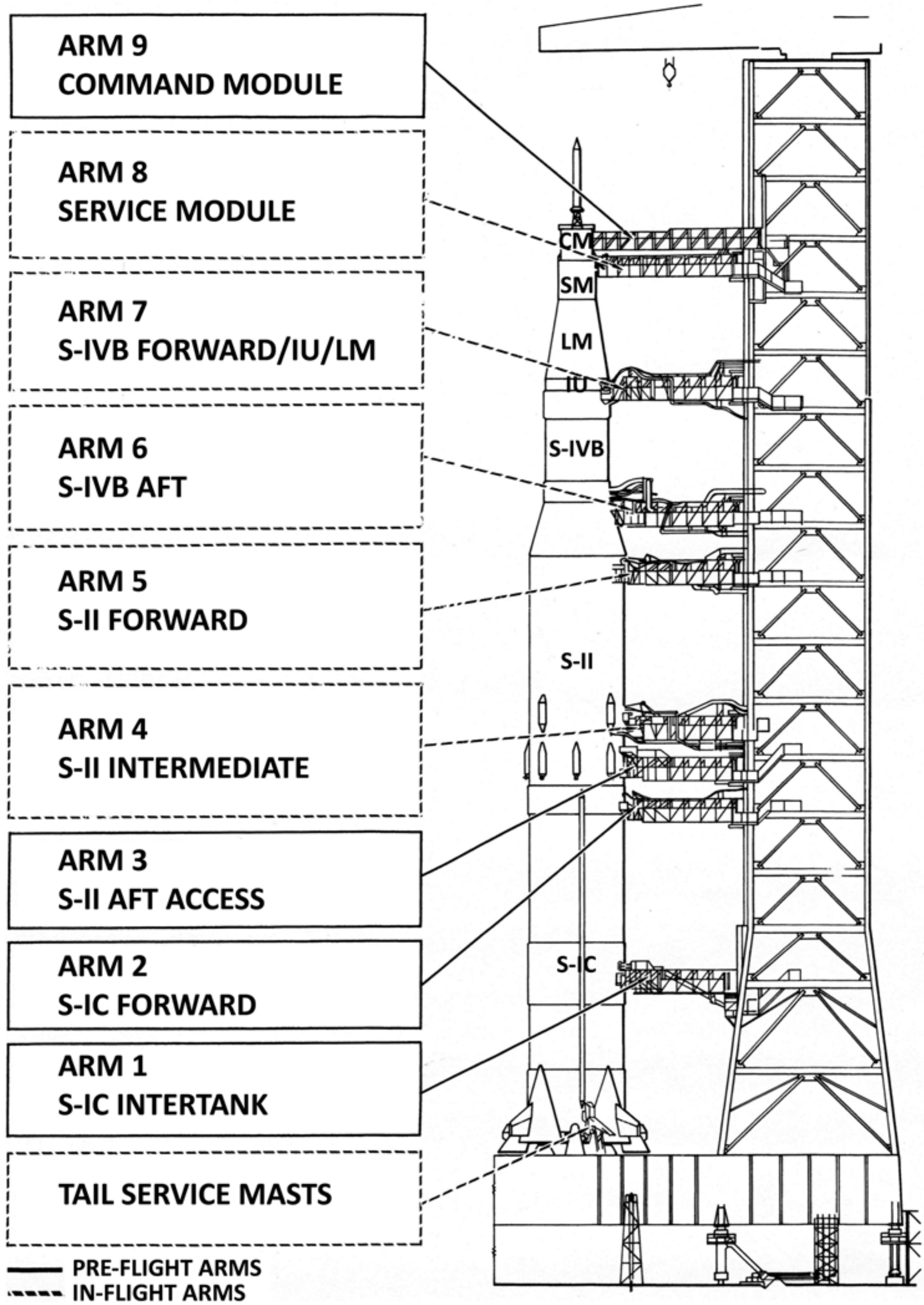
The primary functions of each service arm are listed below. Pre-flight arms were retracted before liftoff; in-flight arms retracted once vehicle motion began (Fig. D.4):

- Arm 1—S-IC intertank (pre-flight). Access from LUT level 60 to interior of S-IC intertank area. LOX fill and drain. Arm can be reconnected to vehicle from firing room. Retracted at T minus 25 s. Retract time: 8 s. Reconnect time: about 5 min.
- Arm 2—S-IC forward (pre-flight). Pneumatic, electrical, and air conditioning interfaces. Retracted at T minus 16.2 s. Retract time: 8 s.
- Arm 3—S-II Aft (pre-flight). Access from LUT level 140 to interior of S-IC/S-II interstage for servicing the S-II's J-2 engines. No umbilical connections. Retracted at T minus 12 h.
- Arm 4—S-II intermediate (in-flight). LH_2 and LOX transfer, vent line, pneumatic, instrument cooling, electrical, and air-conditioning interfaces. Retract time: 6.4 s.
- Arm 5—S-II forward (in-flight). Gaseous hydrogen vent, electrical, and pneumatic interfaces. Retract time: 7.4 s.
- Arm 6—S-IVB aft (in-flight). Access from LUT level 220 to interior of S-II/S-IVB interstage for servicing S-IVB's J-2 engine. LH_2 and LOX transfer; electrical, pneumatic, and air-conditioning interfaces. Retract time: 7.7 s.
- Arm 7—S-IVB forward (in-flight). Access from LUT level 260 to interior of S-IVB forward interstage area and instrument unit. Fuel tank vent; electrical, pneumatic, air-conditioning, and pre-flight conditioning interfaces. Retract time: 8.4 s.
- Arm 8—Service module (in-flight). Air-conditioning, vent line, coolant, electrical, and pneumatic interfaces. Retract time 9.0 s.
- Arm 9—Command module access arm (pre-flight). Access from LUT level 320 to the command module interior through the environmental chamber (White Room). Arm controlled by LCC. Retracted to 12° park position until T minus 4 min, then retracted fully.

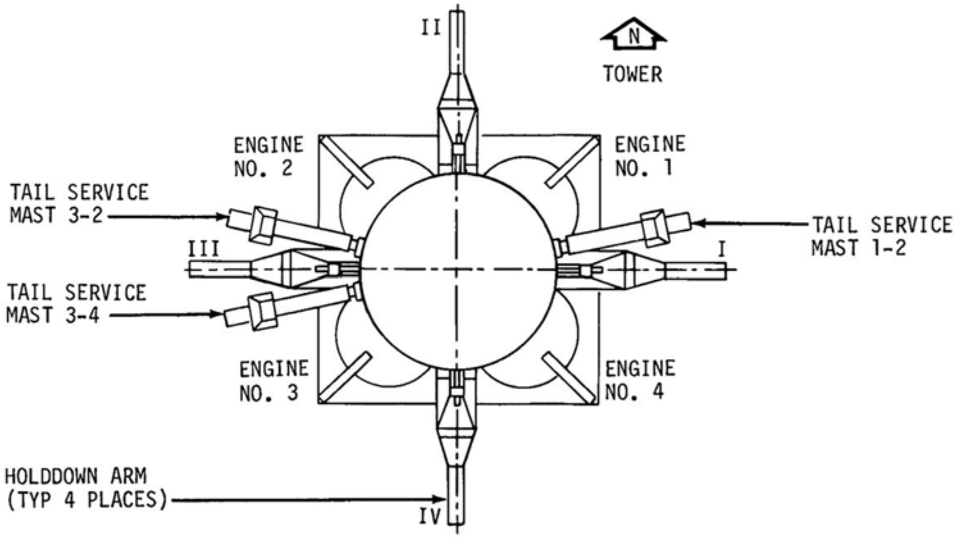
TAIL SERVICE MASTS (TSMS)

The vehicle services provided by the TSM connections were (Fig. D.5):

- TSM 1-2—RP-1 fill and drain; engine gimbal hydraulic fluid; gaseous helium to pressurize S-IC fuel tank; gaseous nitrogen (GN_2) for purges.
- TSM 3-2—GN_2 for valve control, purges, and fuel bubbling; gaseous helium for LOX bubbling.
- TSM 3-4—GN_2 for valve control and purges; gaseous helium for pre-pressurizing LOX tank; emergency LOX drain.



D.4 Location and function of swing arms. *Source*: Author's adaptation of NASA diagram



D.5 Location of tail service masts and holddown arms. *Source*: NASA/Ward

MODIFICATIONS FOR SATURN IB LAUNCHES

LUT 1 was modified to support the Skylab and *ASTP* Saturn IB launches from LC-39. Major modifications to the LUT included:

- Removal of swing arms 1, 2, 3, 4.
- Removal of the tail service masts.
- Removal of the holddown arms.
- Construction of the open-truss milkstool support pedestal.
- Construction of access bridge from utility tower to milkstool deck.
- Repurposing of swing arm 5 as new swing arm 1A to support the S-IB stage.
- Installation of launcher accessory equipment removed from LC-34/37B: holddown arms, boattail conditioning lines, and propellant fill masts.

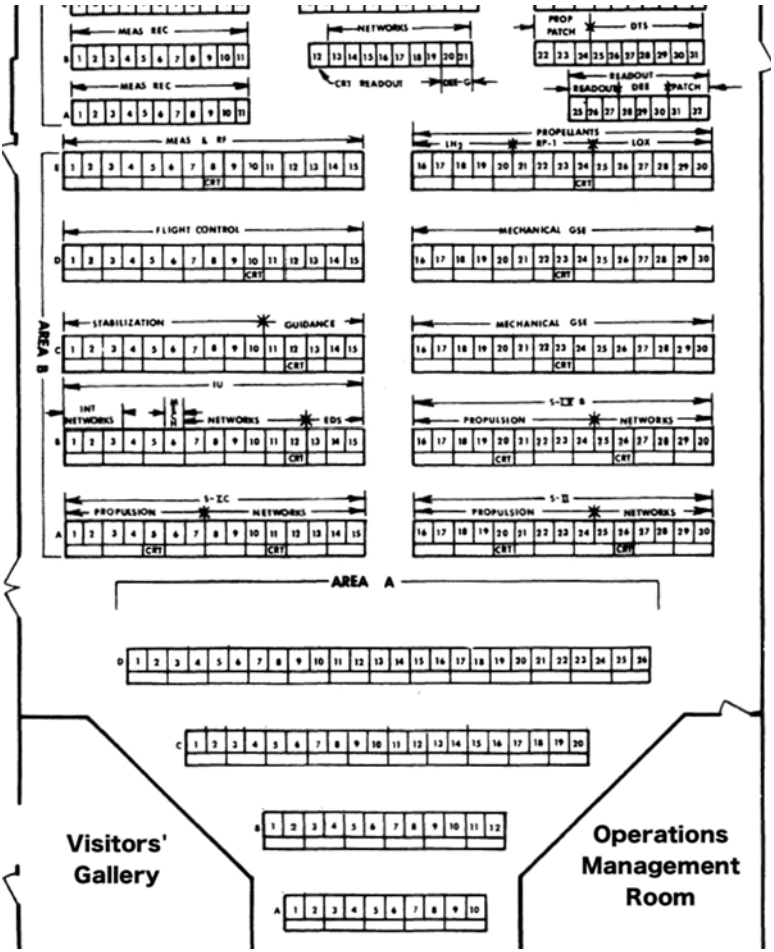
Appendix E

Firing Room Areas A and B Manager Positions and Test Engineer Consoles

This Appendix provides an overview of the functional responsibilities for personnel and workstations in areas A and B of the Apollo-era firing rooms.

The console or station numbers are read as area, row, and position. For example, console BC13 would be area B, row C, 13th console. The positions of consoles can be located on the diagram below. In the cases where a console number is listed twice in the tables, there were several control panels installed at that console or several people sitting at that station (Fig. E.1).

J.H. Ward, *Rocket Ranch*, Springer Praxis Books, DOI 10.1007/978-3-319-17789-2



E.1 Diagram of firing room areas A and B, with console numbers for locating positions of management and test personnel. *Source*: Author's adaptation of NASA diagram

AREA A

Area A seated the directors, managers, and chief test conductors for NASA and the major contractors. Personnel who filled some roles (such as launch vehicle test conductor or test supervisor) rotated between missions, so their names have not been assigned to a console location. In cases where management personnel were consistently in the firing rooms for many missions, their names are listed with their roles. Console locations varied sometimes between the three active firing rooms, so some people may be in slightly different locations in photos from the various missions. Names were taken from rosters of the *Apollo 12* and *Apollo 14* mission.

Console location	*Manager or function*
AA1	Isom A. “Ike” Rigell, chief engineer launch vehicle operations, later deputy director of launch vehicle operations (OIS call sign CIAR)
AA2	Dr. Hans F. Gruene, director, KSC launch vehicle operations
AA3	Richard G. “Dick” Smith, MSFC Saturn V program manager
AA4	Rocco A. Petrone, KSC director of launch operations
AA5	Walt “Kappy” Kapryan, KSC deputy director of launch operations
AA6	Dr. Kurt Debus, director, KSC
AA7	Dr. Robert “Bob” Gray, director, unmanned launch operations
AA8	John J. Williams, director, KSC spacecraft operations
AA9	Col. James McDivitt, MSC Apollo program manager
AA10	John W. “Jack” King, KSC public affairs officer
AB1	Chief launch vehicle test conductor (CLTC)
AB2	Launch vehicle test conductor
AB3	Launch vehicle test conductor
AB4	Space vehicle test supervisor
AB5	Lead space vehicle test supervisor (CVTS)
AB6	Paul Donnelly, launch operations manager
AB7	Robert Moser, director of launch operations test planning office
AB8	John Heard, CSM test conductor, KSC spacecraft operations
AB9	John Beeson, LM test conductor, KSC spacecraft operations
AB10	Rockwell CSM manager
AB11	Grumman LM manager
AB12	Boeing space vehicle test engineer
AC1	Boeing senior test conductor (C1TC)
AC2	Boeing test conductor
AC3	Boeing test conductor engineer
AC4	Boeing test conductor engineer
AC5	Rockwell S-II test conductor (C2TC)
AC6	Rockwell assistant test conductor
AC7	McDonnell Douglas S-IVB test conductor (C4TC)
AC8	McDonnell Douglas assistant test conductor
AC9	Edd Witt, IBM complex manager
AC10	IBM IU test conductor (CUTC)
AC11	IBM operations engineer
AC12	Spacecraft LC-39 operations branch engineer
AC13	Spacecraft ACE systems
AC14	Spacecraft ACE systems
AC15	Deke Slayton, director of flight crew operations
AC16	“Stoney” console (astronaut communicator)
AC17	KSC chief of medical services
AC18	MSC launch site medical operations
AC19	Dr. Charles Berry, MSC director of medical research and operations
AC20	
AD1	Kelly Fiorentino and John Conaway (instrumentation); David Moja and Nels Roseland (electrical networks)
AD2	Frank Bryan, engineering staff (CLES)

(continued)

cont.

Console location	*Manager or function*
AD3	Roy Lealman, electrical guidance and control systems (CLEG)
AD4	Lionel "Ed" Fannin, mechanical and propulsion systems
AD5	Marion Edwards, instrumentation
AD6	Donald Oswald, quality assurance (CLQS)
AD7	David Jaehne, technical assistant, QA
AD8	William Holmes, Boeing launch operations site manager
AD9	John Cully, Boeing Saturn V program manager
AD10	Albert Martin, NAR S-II operations manager
AD11	Harold Eaton, Jr., McDonnell Douglas Saturn/Apollo program director
AD12	George Smith, IBM test operations manager
AD13	Floyd Falkenberry, Bendix Systems safety
AD14	Arthur Williams, Bendix Systems safety
AD15	Sherman Evans, KSC security and safety
AD16	Steve Tatham, KSC security and safety
AD17	Robert Woods, KSC security and safety
AD18	Range safety officer, Air Force Eastern Test Range
AD19	Max Taylor, chief instrumentation controller, technical support division
AD20	Instrumentation controller
AD21	Joseph Barfus, chief test support controller
AD22	Richard Gramling, chief test support manager
AD23	Jansen Davenport, communications controller
AD24	Robert Young, display coordinator
AD25	Raymond Clark, director, technical support directorate
AD26	

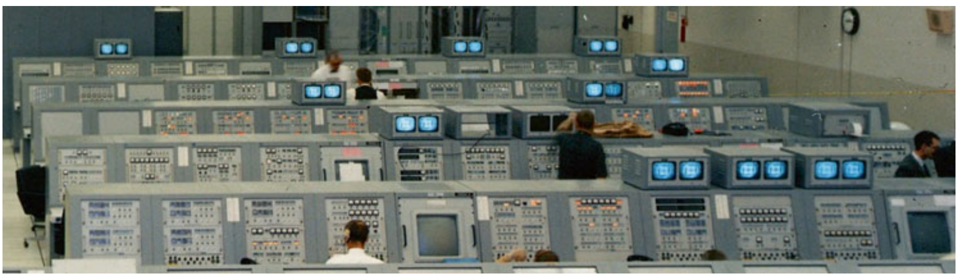
AREA B

Listed below are the consoles that were installed in area B of firing room 1 in 1967, about the time of the AS-501 (*Apollo 4*) mission. The author assembled this information by combining data from photographs of the individual firing room control consoles from 1966 with the launch vehicle OIS call signs in various launch vehicle countdown procedures.

Area B of the firing room had 150 console locations for testing stages, ground support equipment, electrical support equipment, and telemetry systems. Although a few control panels were moved during the course of the Apollo/Saturn program, the configuration of this area of the firing room remained relatively consistent throughout the program. Firing rooms 2 and 3 also followed this general layout. Some of the consoles did not have control panels installed in them, and so their position is blank in the table below.

A photograph of the firing room 1 taken while it was being activated in mid-1966 has perhaps the clearest photograph showing most of area B. It has been cropped into photo sections showing the left and right sides of the room. Consoles 1–15 were on the left side of each row; consoles 16–30 were on the right half (Figs. E.2 and E.3).

E.2 Left side of firing room 1, area B, during activation for AS-501 (*Apollo 4*). This is probably the best available overall photo showing the Apollo-era consoles in area B. *Source*: NASA/Ward



E.3 Right side of firing room 1, area B. *Source*: NASA/Ward

Console location	*Panel designation*	*OIS call sign*	*Major function*
BA1	S-IC PREFILL SYSTEM	C1PU	S-IC prefill system engine jacket wet simulation; reservoir and filter status
BA1	S-IC HYDRAULICS	C1HP	Hydraulic pump and flow controls for S-IC
BA2	S-IC ENGINE	C1EN	Control of LOX and fuel prevalves and valves; status of engine hypergol cartridge and igniters; solenoid start commands; checkout valve stage/ground position
BA3	S-IC ENGINE HEATER	C1EH	Status and temperature of S-IC engine heaters; heater power enable

(continued)

cont.

Console location	*Panel designation*	*OIS call sign*	*Major function*
BA3	S-IC CONTROL AND PURGE	C1PC	Pressurization and status of GN_2 purges for S-IC engine, LOX dome, and injector; engine thermal purge
BA4	S-IC GROUND PNEUMATICS	C1GP	Gaseous helium and nitrogen supply control valves and pressures
BA5	S-IC PROPULSION KEYBOARD	C1PK	Computer test program input and monitoring for S-IC propulsion systems
BA6	S-IC FUEL SYSTEM	C1RP	Fuel level adjustment monitoring; helium flow control valves; helium bottles pressurization and temperature; calips test; fuel tank pre-pressurization controls; ullage pressure monitor
BA7	S-IC LOX SYSTEM	C1LO	S-IC LOX system pressurization; stage valves and vents control; LOX bubbling; propellant status
BA8	S-IC SEQUENCE	C1SP	Sequencer power; arm terminal countdown sequencer and ignition sequencer; cutoff reset
BA8	S-IC FIRING	C1FR	S-IC engine preparation; firing command; firing sequence status; emergency cutoff
BA9	EVENTS DISPLAY	C1EV	S-IC discrete events status
BA10	SDS RECORDER CONSOLE	C1DE	DEE printer
BA11	S-IC NETWORKS CONTROL STATION		Computer test program input and monitoring for S-IC stage networks
BA12	S-IC NETWORKS	C1NP	S-IC stage power bus supervision; power transfer; switch selector; networks test functions
BA13	D C POWER SUPPLIES	C1PS	Control of auxiliary power supplies for launch support activities
BA13	POWER SWITCHING	C1PS	S-IC power bus switching
BA14	S-IC CUTOFF SENSORS	C1CS	Engine combustion status; propellant sensors status; CALIPS enable; propellant depleted inboard/outboard engines

(continued)

cont.

Console location	*Panel designation*	*OIS call sign*	*Major function*
BA15	S-IC EBW and ORDNANCE	C1OP	Pulse sensor controls; charge voltage for firing units for S-IC stage separation and retrorockets
BA15	S-IC PROPELLANT DISPERSION	C1DP	Power source for range safety command receivers and exploding bridgewire systems; EBW charge voltage monitoring
BA16	S-II ENGINE NO. 201	C2EC	Spark system component test, solenoid control, engine ignition simulation; status of engine valves and pre-valves
BA16	S-II ENGINE NO. 202	C2EC	Spark system component test, solenoid control, engine ignition simulation; status of engine valves and pre-valves
BA17	S-II ENGINE NO. 203	C2EC	Spark system component test, solenoid control, engine ignition simulation; status of engine valves and pre-valves
BA17	S-II ENGINE NO. 204	C2EC	Spark system component test, solenoid control, engine ignition simulation; status of engine valves and pre-valves
BA18	S-II ENGINE NO. 205	C2EC	Spark system component test, solenoid control, engine ignition simulation; status of engine valves and pre-valves
BA18	S-II RECIRCULATION	C2RP	LH pumps status; receiver and regulator out pressures; pneumatics controls; recirculation control; LH purge; LOX and LH prevalves control; LOX and LH bleed valves control
BA19	S-II ALL ENGINE	C2AE	Helium bottles pressures; start tanks pressures; turbo-charger purges and chill-down controls; thrust chamber and start tank temperatures; components test; all engine start; all engine emergency cutoff; start phase limit cutoff
BA20	S-II PROPULSION KEYBOARD	C2PK	Computer test program input and monitoring for S-II propulsion systems

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Console location	*Panel designation*	*OIS call sign*	*Major function*
BA21	S-II GROUND PNEUMATICS	C2GP	Gas pressure supply valve control; LH heat exchanger; regulator dome venting; checkout valves and pressures; S7-41 internal venting
BA22	S-II PRESSURIZATION	C2SP	LOX and LH receiver temperatures and pressures and tank pressures; LOX and LH pneumatics, purges, and component tests; vent valves emergency open and close
BA23	S-II PROPELLANT MONITOR	C2PM	LOX and LH automatic and manual mass readout; inlet and vent valves pressures; slow and fast fill monitors; vent valves and drain valves controls
BA24	S-II LEAK DETECTION AND PURGE	C2LD	Inlet and outlet purge pressures
BA24	S-II CAMERA PNEUMATICS	C2CP	Helium purges for stage cameras
BA25	S-II PROPELLANT DEPLETION	C2PU	Simulation of LOX and LH propellant depletion to test cutoff sensors
BA25	S-II PROPELLANT UTILIZATION	C2PU	Propellant utilization valve positions; propellant mass test; valves test; LOX and LH_2 coarse and fine mass
BA26	S-II NETWORKS KEYBOARD	C2NK	Computer test program input and monitoring for S-II stage networks
BA27	EVENTS DISPLAY	C2EV	S-II discrete events status
BA28	S-II NETWORKS	C2NP	Stage bus supervision; stage power control; power transfer; switch selector; test functions
BA29	D C POWER SUPPLIES	C2PC	Control of auxiliary power supplies for launch support activities
BA29	D C POWER SUPPLIES	C2PC	Control of auxiliary power supplies for launch support activities
BA29	POWER SWITCHING	C2PC	S-II DC power commit

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Console location	*Panel designation*	*OIS call sign*	*Major function*
BA30	S-II EBW AND ORDNANCE	C2DP	Charging voltage of ullage, stage separation EBW, and retrorockets; pulse sensors test; separation system simulation; liftoff simulation
BA30	S-II PROPELLANT DISPERSION	C2DP	Power source for range safety command receivers and exploding bridgewire systems; EBW charge voltage monitoring
BB1	D C POWER SUPPLIES	CCPR	Control of auxiliary power supplies for launch support activities
BB1	D C POWER SUPPLIES	CCPR	Control of auxiliary power supplies for launch support activities
BB1	POWER SWITCHING	CCPR	Power switching for IU, theodolite, 400 Hz power systems
BB2	60 CYCLE GENERATORS	CCPM	LCC power generators
BB2	D C POWER SUPPLIES	CCPM	Control of auxiliary power supplies for launch support activities
BB2	400 CYCLE FREQUENCY CHANGERS	CCPM	20T100 and 20T300 power
BB2	400 CYCLE GENERATORS	CCPM	23T200 and 23T300 generators
BB3	POWER SWITCHING	CUMC	Mobile launcher power switching
BB4	DISCRETE OUPUT CONTROL	CVNP	Computer testing—address and data word command and response
BB4	VEHICLE NETWORKS	CLVN	Enable EDS destruct logic during countdown; simulated liftoff enable; ML computer inhibit; LCC computer inhibit
BB5	IU GROUND PNEUMATICS		System and stage inlet pressures, manifold pressure, supply and vent
BB6	SECONDARY GSCU CONTROL		Ground support cooling unit flow controls
BB6	IU COOLING/GN SYSTEM	CUCP	Pre-flight and flight coolant/GN system temperatures and flow rates
BB7	SDS RECORDER CONSOLE	CUDE	DEE computer printer

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Console location	*Panel designation*	*OIS call sign*	*Major function*
BB8	EVENTS DISPLAY	CUEV	IU networks discrete events
BB9	SWITCH SELECTOR	CUSW	Issue switch selector commands; provide switch selector checkout for all stages; verify switch selector operations. Panel is hardwired through the umbilical directly to the onboard IU switch selector
BB10	IU NETWORKS	CUNP	Power bus supervision; power transfer; switch selector monitoring; simulation settings
BB11	D C POWER SUPPLIES	CUPP	Control of IU auxiliary power supplies for launch support activities
BB11	POWER SWITCHING	CUPP	IU ground cooling power; IU 400 CPS power; IU power supplies
BB12	COMMAND FUNCTIONS CONSOLE		Computer test program input and monitoring for IU stage networks
BB13	EDS PREPARATION	CUES	Emergency detection system monitoring (engine thrust, engine deflection and rate detection, abort request status); simulated "thrust OK" inhibit; simulated liftoff enable; works with spacecraft substitute panel and EDS substitute panel in mobile launcher for testing
BB14	EDS FLIGHT MONITOR	CUEF	S-II and S-IVB LOX and fuel pressure monitor; engine thrust monitor; cutoff and abort monitors; excessive roll/pitch/yaw rate detection; Q-ball vector sum; works with spacecraft substitute panel and EDS substitute panel in mobile launcher for testing
BB15			
BB16	S-IVB BULKHEAD VACUUM MONITOR	C4VM	Bulkhead and console pressures; calibration control; vacuum pump control

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Console location	*Panel designation*	*OIS call sign*	*Major function*
BB16	S-IVB APS PNEUMATICS	C4VM	Facility lines purge; high pressure switch checkout; supply pressure; leak check supply and control; vent valves control; control supply; coarse feed control
BB17	S-IVB APS LAUNCH AND MONITOR	C4AL	Fuel and oxygen ullage control; oxidizer, fuel, and helium bottle pressures and vent controls for APS modules I and II; loading control enable
BB18	S-IVB GH/GN CONTROL	C4HN	Gaseous nitrogen purge valve control; heat exchanger; level sensors; cold and ambient temperature gaseous hydrogen control
BB19	S-IVB HELIUM CONTROL	C4HC	Dome supply valve control; purge supply controls; checkout supply valve controls for LOX and LH_2 systems
BB20	S-IVB PROPULSION KEYBOARD	C4PK	Computer test program input and monitoring for S-IVB propulsion systems
BB21	S-IVB PROPELLANT MONITOR	C4PR	LOX and LH_2 automatic and manual mass readout; inlet and vent valves pressures; slow and fast fill monitors; vent valves and drain valves controls
BB22	S-IVB STAGE PRESSURE	C4SP	LOX and LH_2 repressurization and control valves; cold and repressurization helium supplies monitor and control; ullage pressure monitor; simulated flight system test
BB23	S-IVB RECIRCULATION	C4EP	LOX pump cavity pressure; LOX and LH_2 flow rate; prevalve and chilldown valve controls
BB23	S-IVB ENGINE PREPARATION	C4EP	Control bottle and start tank temperatures and pressures; purge and chilldown pump purge pressure and jacket temperature

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Console location	*Panel designation*	*OIS call sign*	*Major function*
BB24	S-IVB ENGINE TEST	C4ET	Ignition system status; spark system tests; injector temperature monitor; separation simulation; simulated engine start; “mainstage OK” simulation; cutoff sensor simulation; liquid level sensor cutoff; component test lockout
BB25	S-IVB PROPELLANT UTILIZATION	C4PU	Inverter/converter monitor for power supplies; LOX and LH_2 coarse and fine mass loading measurement enable; automated loading cutoff test
BB26	COMMAND FUNCTIONS CONSOLE	C4NK	Computer test program input and monitoring for S-IVB stage networks
BB27	EVENTS DISPLAY	C4EV	S-IVB stage discrete events status
BB28	S-IVB NETWORKS	C4NP	Stage power networks; stage power control; power transfer; switch selector; test functions
BB29	D C POWER SUPPLIES	C4PP	Control of auxiliary power supplies for launch support activities
BB29	D C POWER SUPPLIES	C4PP	Control of auxiliary power supplies for launch support activities
BB29	POWER SWITCHING	C4PP	Stage power switching
BB30	S-IVB EBW and ORDNANCE	C4DP	Ullage rocket ignition; ullage rocket jettison; pulse sensors
BB30	S-IVB PROPELLANT DISPERSION	C4DP	Power source for range safety command receivers and exploding bridgewire systems; EBW charge voltage monitoring
BC1	THEODOLITE ERRORS		Deviation of theodolite beam for inertial and moving prism; OTV monitor of theodolite system and targets
BC1	THEODOLITE CONTROL		Theodolite power control; moving and inertial prism power; prism and theodolite movement

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Console location	*Panel designation*	*OIS call sign*	*Major function*
BC2	AZIMUTH REMOTE CONTROL		Input for vehicle launch azimuth
BC3	BRUSH RECORDER CONSOLE		X, Y, Z gyro monitoring
BC4	COMMAND FUNCTIONS CONSOLE		Computer test program input and monitoring for stabilization and control systems
BC5	INVERTERS		Power inverters
BC5	DYMEC INTEGRATING DIGITAL VOLTMETER		STABILIZATION
BC5	DYMEC INPUT SCANNER		STABILIZATION
BC6	CMR ENCODER READOUT		Command module receiver sampling rate; resolution control
BC6	CMR REMOTE CONTROL		Command module receiver remote input
BC7	INERTIAL DATA BOX CONTROL		Mode select; brakes; demod output zero controls
BC8	BRUSH RECORDER CONSOLE		STABILIZATION
BC9	ST-124M CONTROL	CUPC	Steering command (yaw, roll, pitch); IDB demod output; torquing gyro controls; platform servo controls
BC10	BRUSH RECORDER CONSOLE		STABILIZATION
BC11	GUIDANCE COMPUTER PANEL		Select range of input signals from DDAS; status of LVDC/LVDA (temperature, voltages), checkout lines
BC12	COMMAND FUNCTIONS CONSOLE		LVDC command functions; computer test program input and monitoring for launch vehicle guidance systems
BC13	BRUSH RECORDER MARK 200 CONSOLE		Record DDAS analog signals from LVDC
BC14	BRUSH RECORDER MARK 200 CONSOLE		Record DDAS analog signals from LVDC
BC15	ANALOG RECORDER CONTROL NO. 2		Record DDAS analog signals from LVDC; guidance computer system control, calibration, and range selection (steering commands)
BC16			

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Console location	*Panel designation*	*OIS call sign*	*Major function*
BC17			
BC18	S-IC INTERTANK ARM #1	CSA1	Swing arm 1 position, carrier retraction, arm extension
BC19	S-IC FORWARD ARM #2	CSA2	Swing arm 2 position and status, pneumatics
BC20	S-II AFT ARM #3	CSA3	Swing arm 3 position and status
BC21	S-II INTERMEDIATE ARM #4	CSA4	Swing arm 4 position, carrier retraction, arm extension, pneumatics
BC22	S-II FORWARD ARM #5	CSA5	Swing arm 5 position, carrier retraction, arm extension, pneumatics
BC23	CONTROL CONSOLE	CSAK	Computer test program input and monitoring for mechanical GSE systems
BC24	S-IVB AFT ARM #6	CSA6	Swing arm 6 position, carrier retraction, arm extension, pneumatics
BC25	S-IVB FORWARD ARM #7	CSA7	Swing arm 7 position, carrier retraction, arm extension, pneumatics
BC26	SERVICE MODULE ARM #8	CSA8	Swing arm 8 position, carrier retraction, arm extension
BC27	COMMAND MODULE ARM #9	CSA9	Swing arm 9 position, arm extension, White Room connection, escape tower connector attachment
BC28	PNEUMATIC DISTRIBUTION SYSTEM	CPDC	Helium distribution system; GN_2 distribution system; valve panels 11 and 12; Q-ball system; service module deluge purge system
BC29	HYDRAULIC CHARGING UNIT	CHCU	Units 1 and 2 power and hydraulic pressure
BC30			
BD1	BRUSH RECORDER MARK 200 CONSOLE		FLIGHT CONTROL
BD2	BRUSH RECORDER MARK 200 CONSOLE		FLIGHT CONTROL
BD3	ANALOG RECORDER CONTROL NO 1		FLIGHT CONTROL
BD4	BRUSH RECORDER MARK 200 CONSOLE		FLIGHT CONTROL
BD5	BRUSH RECORDER MARK 200 CONSOLE		FLIGHT CONTROL
BD6	CONTROL ACCELEROMETER		Control accelerometer for yaw and pitch

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Console location	*Panel designation*	*OIS call sign*	*Major function*
BD6	CONTROL RATE GYRO		Gyro torque monitoring
BD7	EDS/CONTROL RATE GYRO	CUGA	Torque current measurement; output of roll, pitch, and yaw commands in degrees/s.
BD8	CONTROL COMPUTER INPUT SUBSTITUTE	CUSP	Redundancy check; attitude control jets; burn tests and failure mode inputs for simulations in all stages
BD9	FLIGHT CONTROL COMPUTER		Flight control procedure integrator—control over all stage flight control and monitoring after flight control equipment is installed in IU. Attitude error measurement; attitude rate measurement; control attenuator timer
BD10	COMMAND FUNCTIONS CONSOLE		Computer test program input and monitoring for flight control systems
BD11	S-IC ENGINE DEFLECTION	C1FC	Servo valve current and engine deflection (yaw and pitch) for engines 1–4
BD12	S-II ENG DEFLECTION	C2FE	Servo valve current and engine deflection (yaw and pitch) for engines 1–4
BD13	S-II HYDRAULICS	C2FC	Hydraulic fluid temperature and accumulator pressure; controls for auxiliary pumps and accumulator
BD14	S-IVB HYDRAULIC	C4HY	Oil pressures and temperatures in system and reservoir; GN_2 accumulator pressure and temperature
BD15	APS CHAMBER PRESSURE		Chamber pressures in auxiliary propulsion system engines
BD15	S-IVB ENGINE DEFLECTION	C4FC	Servo valve current and engine deflection (yaw and pitch) for J-2 engine; APS engine activation; relay monitor; valve monitor
BD16	DIGITAL EVENTS READOUT		Discrete events display for mechanical GSE systems
BD17	ECS CONTROL AND MONITOR NO. 1	CECS	Blower controls; temperatures in north and south coils; GN_2 system pressures; valve and blower control

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Console location	*Panel designation*	*OIS call sign*	*Major function*
BD18	ECS CONTROL AND MONITOR NO. 2	CECS	Cooling tower water temperature; pump control; cooling system tank temperature; pump and GN_2 control
BD19	ECS VEHICLE CONTROL AND MONITOR NO. 1		Duct temperature, compartment temperature, reheat, and duct differential temperature measurement; flow rate and heater controls (S-I aft, S-I forward, S-II aft)
BD20	ECS VEHICLE CONTROL AND MONITOR NO. 2		Duct temperature, compartment temperature, reheat, and duct differential temperature measurement; flow rate and heater controls (S-II aft electrical, S-II forward, S-IVB aft)
BD21	ECS VEHICLE CONTROL AND MONITOR NO. 3		Duct temperature, compartment temperature, reheat, and duct differential temperature measurement; flow rate and heater controls (IU, service module, command module)
BD22	ECS VEHICLE CONTROL AND MONITOR NO. 4		Duct temperature, compartment temperature, reheat, and duct differential temperature measurement; flow rate and heater controls (S-I forward upper, two spare units)
BD23	COMMAND FUNCTIONS CONSOLE		Computer test program input and monitoring for environmental control systems
BD24	TAIL SERVICE MAST 1-2 FIRING MONITOR and TEST	CTS1	Firing monitor (mast position, valve control pressure, hydraulic return valve pressure, accumulator pressure, hood pressure, umbilical retract pressure); system preparation; extend monitor; retract test
BD25	TAIL SERVICE MAST 3-2 FIRING MONITOR and TEST	CTS2	Firing monitor (mast position, valve control pressure, hydraulic return valve pressure, accumulator pressure, hood pressure, umbilical retract pressure); system preparation; extend monitor; retract test

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Console location	*Panel designation*	*OIS call sign*	*Major function*
BD26	TAIL SERVICE MAST 3-4 FIRING MONITOR and TEST	CTS3	Firing monitor (mast position, valve control pressure, hydraulic return valve pressure, accumulator pressure, hood pressure, umbilical retract pressure); system preparation; extend monitor; retract test
BD27	HOLDDOWN ARMS and PURGE VALVES	CHDA	Holddown arms accumulator pressures; arm released indicators; purge valve control
BD27	SERVICE ARM CONTROL SWITCHES	CSAC	Battery 1 and 2 voltage and percent discharged; control switches, pressure test valve controls, accumulator pressure, control switches arming (holddown arms 2 and 4)
BD28	INDUSTRIAL WATER CONTROL SYSTEM	CWCP	Industrial water supply control power (console and PTCR, arming bus); main water pressure and flow rate; flame deflector tank valve control; cool and quench valve controls; mobile launcher deck and pad flush valve controls; mobile launcher valve controls (inlet, supply, fogging, deluge, arms quenching)
BD29	STATUS PANEL		Discrete events status of hydraulics and pneumatics for service arms and TSMs
BD30	POWER SWITCHING		Power bus switching for GSE
BD30	D C POWER SUPPLIES		DC power supplies for GSE
BE1	IU MEASURING and TRACKING		Power to RF, telemetry, and metering equipment in IU; RF silence; measuring voltage; telemeter calibration; controls for transmitters, telemeters, tracking, and tape recorders
BE2			
BE3	Q-ANGLE OF ATTACK	CQAA	Deflection in PSI differential; Q-ball A and B vector sums; Q-ball heater control; Q-ball cover controls
BE4			

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Console location	*Panel designation*	*OIS call sign*	*Major function*
BE5	S-IVB MEASURING and RF	C4IP	Measuring voltage; telemeter calibration; controls for tape recorder, telemeters, measurement transfer; telemeter mode select; DDAS mode select
BE6			
BE7			
BE8	COMMAND CONSOLE		Computer test program input and monitoring for measuring and RF systems
BE9			
BE10	S-II CAMERA CONTROL	C2CC	Lights (on/off and current); cameras on/off and frame rate
BE11	S-II MEASURING and RF	C2IP	Measuring voltage; telemeter calibration; controls for tape recorders, transmitters, and test functions; in-flight switching control
BE12			
BE13			
BE14			
BE15	S-IC MEASURING AND RF	C1IP	Measuring voltage; telemeter calibration; controls for power, telemeters, measurement racks, measurement transfer, tape recorders; transmit mode select
BE16	S-II LH2 TANKING COMPUTER	C2HU	Mass readout (automatic and manual mode); manual/auto mode select; discrete readouts of chilldown, fast/slow fill, replenish, flight mass; replenish valve override and manual control; simulate/operate control
BE17	AUXILIARY COMPONENTS	CPH3	Ignitors power-on; controls for chilldown, transfer, transfer line vent, precondition vent, and storage tank vent

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Console location	*Panel designation*	*OIS call sign*	*Major function*
BE17	S-IVB LH2 TANKING COMPUTER	C4HU	Mass readout (automatic and manual mode); manual/auto mode select; discrete readouts of chilldown, fast/slow fill, replenish, flight mass; replenish valve override and manual control; simulate/operate control
BE18	LH2 COMPONENTS	CPH2	Storage area tank level and pressure; LUT fill line pressures, vehicle vent pressures, filter differential pressures (S-II and S-IVB); tank pressures (S-II and S-IVB); storage area controls (vents, vaporizer, chilldown, transfer line valve, transfer line vent, preconditioning vent)
BE19	LH2 CONTROL	CCLH	Status indicators for LH_2 loading systems in S-II, S-IVB, and tower; fill and revert controls; drain status; igniters status; simulate/operate control; stage selector
BE20	LH2 COMPONENTS	CPH1	Vent and valve controls for LH_2 fill, drain, replenish, and heat exchanger operation (S-II and S-IVB)
BE21	S-IC RP-1 TANKING COMPUTER	C1RU	Mass readout (automatic and manual mode); 100 % reference indicator; adjust level drain valve control; simulate/operate control
BE22	AUXILIARY COMPONENTS	CCRP	Controls for fast fill, slow fill, and gravity drain
BE22	RP-1 CONTROL	CCRP	Fill command and discrete status; level adjust and line inerting control; mast purge; drain control; simulate/operate/manual control

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Console location	*Panel designation*	*OIS call sign*	*Major function*
BE23	RP-1 COMPONENTS	CPRP	Storage tank level and pressure; filters 1 and 2 differential pressures; S-IC vehicle tank status; launcher area sensors and vents status; storage area controls (fast/slow fill, pump motors, filter pump motors, gravity drain, power drain)
BE24	PROPELLANTS DISPLAY COMPUTER CONSOLE	CPRK	Computer test program input and monitoring for propellants systems
BE25	S-IC LOX TANKING COMPUTER	C1OU	Mass readout (automatic and manual mode); discrete status of fast/slow fill and replenish; 100 % reference indicator; replenish valve override; manual/auto mode control; simulate/operate control
BE26	S-II LOX TANKING COMPUTER	C2OU	Mass readout (automatic and manual mode); discrete status of fast/slow fill and replenish; replenish valve override; manual/auto mode control; simulate/operate control
BE27	AUXILIARY COMPONENTS	C4OU	Controls for storage tank vents, main line drain, main pump suction valve, chilldown valves, tank line vents, pump heaters
BE27	S-IVB LOX TANKING COMPUTER	C4OU	Mass readout (automatic and manual mode); discrete status of fast/slow fill and replenish; replenish valve override; manual/auto mode control; simulate/operate control
BE28	LOX COMPONENTS (Storage Area, Lines)	CPO1	Storage area LOX tank pressure and level; controls for vaporizer, tank vent, line drain, pumps, suction, bypass; main line flow rate control; replenish line flow and suction pressure; drain line flow; pump RPM

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Console location	*Panel designation*	*OIS call sign*	*Major function*
BE29	LOX CONTROL	CCLO	Status indicators for LOX loading systems in S-IC, S-II, S-IVB, and storage area; fill and revert controls; drain start/stop control and status; simulate/operate control; stage selector; manual arming
BE30	LOX COMPONENTS (Tower-Vehicle)	CPO2	Tank pressures and inlet pressures (all stages); status of liquid sensors; controls for all stages for main fill valves, debris valves, replenish throttle, tank vents, fill and drain valves, umbilical vents

Appendix F

Recommended Reading and References

RECOMMENDED READING

The following NASA History Series books can be accessed online via the NASA History Office website (http://history.nasa.gov/publications.html):

Benson, Charles D. and Faherty, William Barnaby. "Moonport: A History of Apollo Launch Facilities and Operations." The NASA History Series, NASA SP-4204. Washington, DC: 1978.

Bilstein, Roger E. "Stages to Saturn: A Technological History of the Apollo/Saturn Launch Vehicles." The NASA History Series, NASA SP-4206. Washington, DC: 1996.

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Swanson, Glen E., ed. "Before This Decade Is Out…Personal Reflections on the Apollo Program." The NASA History Series, NASA SP-4233. Washington, DC: 1999.

Other highly-recommended books:

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Appendix G

Interviewees

The following people worked at KSC at some point during the Apollo/Saturn era or worked with Apollo/Saturn hardware. They were most generous with their time and information. Where possible, my interviews with them were recorded and transcribed, and they served as the primary source materials for most of the first-person accounts in this book.

Interviewee	*Employer*	*Division/Resp*	*Role during Apollo/Saturn*
Brand, Vance	NASA	MSC	Astronaut, *ASTP*
Bryan, Frank	NASA	LVO	Electrical Networks
Bulloch, Steve	NASA	GSE	Pad director, LC-39 (current, post-Apollo)
Carlson, Norman "Norm"	NASA	LVO	Launch vehicle test conductor
Cernan, Eugene "Gene"	NASA	MSC	Astronaut, Apollo 10 and 17
Chambers, Milton "Milt"	NASA	LVO	Chief, gyro and stabilization systems branch
Chauvin, Clarence "Skip"	NASA	SCO	Spacecraft test conductor
Chow, Gilroy	Grumman	SCO	Assembly and test ops planning
Contessa, Alan	Grumman	SCO	Insulation and thermal systems technician
Conway, John	NASA	CIF	CIF integration manager
Cordia, Fred	NAR	LVO	S-II stage manager
Cunningham, Walter	NASA	MSC	Astronaut, *Apollo 7*
Daniel, J. I.	NASA	SCO	QC inspector
Dermody, Walter	Grumman	SCO	LM electrical technician
English, George	NASA	KSC Exec	Executive staff
Fannin, Lionel "Ed"	NASA	LVO	Director, mechanical and propulsion systems
Fiorentino, Kelly	NASA	LVO	Instrumentation
Fore, Ken	NASA	LVO	Pneumatics and umbilicals engineer
Fore, Lori	IBM	LVO	Administrative assistant

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cont.

Interviewee	*Employer*	*Division/Resp*	*Role during Apollo/Saturn*
Garcia, Jose	NASA	SCO	Telecommunications and experiments project engineer
Goodkind, Marcus	Grumman	SCO	LM-5 test manager
Gordon, Richard "Dick"	NASA	MSC	Astronaut, *Apollo 12*
Haise, Fred	NASA	MSC	Astronaut, *Apollo 13*
Heiner, Ed	Grumman	SCO	Contracts manager
Heink, William "Bill"	Boeing	GSE	LOX electrical systems engineer
King, John "Jack"	NASA	PAO	Public affairs officer
Koralewicz, Richard "Dick"	Grumman	LM	LM technician
Lloyd, Russell	NASA	GSE	Facilities manager, KSC industrial area and LC-39
Losee, Fred	Grumman	SCO	QC supervisor
Lousma, Jack	NASA	MSC	Astronaut, *Skylab 3*
Lyon, John R. "Dick"	NASA	LVO	Design engineering
Mars, Charles "Charlie"	NASA	SCO	LM project engineer
Matthews, Dennis	NASA	ULO	Spacecraft/launch vehicle interface engineer, KSC unmanned launch operations
McDivitt, James "Jim"	NASA	MSC	Astronaut, *Apollo 9*; Apollo lunar program director
McEachern, Charles "Chuck"	NASA	LVO	S-IVB mechanical engineer
Merrilees, Beverly	NASA	Manpower	Personnel officer
Merrilees, Robert	NASA	Budget	NASA budget analyst, US Coast Guard reservist
Moja, David "Dave"	NASA	LVO	Guidance and controls systems engineer
Morgan, JoAnn	NASA	LVO	Instrumentation engineer
Mullet, Rafael	Boeing	ECS	S-IC ECS mechanical and electrical systems engineer
Nawracki, Andrew	Grumman	SCO	Consultant
Ogle, George "Jim"	MDAC	LVO	S-IVB engineer
Oyer, Kenneth	MDAC		Engineer
Penovich, Frank	NASA	LVO	Manager, RCA 110A computer systems
Perez, Conrad "Connie"	Rockwell	SCO	Propulsion engineer—hypergols
Phillips, Donald "Don"	NASA	LVO	Lead test supervisor
Plowden, John	Boeing/ Rockwell	LVO SCO	Boeing-TIE/S-II/CSM engineer
Pound, Charles R. "Bob"	NASA	CIF	Ground instrumentation engineer
Powers, Gary	NASA	LVO	Assistant test manager
Presnell, John	NASA	SCO	LM flow manager

(continued)

cont.

Interviewee	*Employer*	*Division/Resp*	*Role during Apollo/Saturn*
Reyes, Ida	-	-	Wife of Ernie Reyes
Reyes, Raul "Ernie"	NASA	SCO	Chief, preflight operations branch
Rigell, Isom A. "Ike"	NASA	LVO	Chief engineer; Deputy director, launch vehicle operations directorate
Risler, Welby	NASA	SCO	Design engineering
Robitaille, Richard "Rich"	NAR	LVO	S-II propellants management engineer
Scott, David	NASA	MSC	Astronaut, *Apollo 9* and *15*
Sestile, Eugene "Gene"	NASA	LVO	Launch vehicle test conductor
Sieck, Robert "Bob"	NASA	SCO	Project engineer
Skurla, Marty	Grumman	SCO	Son of George Skurla (Grumman site manager)
Smith, George	IBM	LVO	IU stage manager; IBM site manager
Smith, Jackie	NASA	SCO	Project engineer
Solid, Lee	Rocketdyne	LVO	Site manager, Rocketdyne
Spilger, Gene	MDAC	LVO	Quality control
Starrick, Lee	Boeing	Safety	Fireman
Talone, John "Tip"	NASA	LVO	Assistant launch vehicle test conductor
Teague, Gerald "Taco"	MDAC	LVO	S-IVB GSE design engineer
Tharpe, Roy	NASA	CIF	Instrumentation engineer
Thurston, Gene	NASA	JSC/SCO	CSM payloads engineer
Trachtman, Jerry	Rockwell	SCO	Telemetry systems engineer; lead engineer, CSM experiments
Tribe, John	NAR	SCO	Lead CSM propulsion systems engineer
Williams, Joe	GE	MSFC	Project manager for launch support, Skylab Apollo telescope mount
Woods, Ron	ILC	SCO	Spacesuit technician

Several other former KSC workers contributed to this project via email correspondence. They included W. Irby Moore (NASA/Systems Engineering), Russel Rhodes (NASA/LVO Fuels), Steve Coester (Boeing/Fuels), Gerald Autry (Boeing-TIE), David Henson (NAR/S-II), and David Shomper (Boeing/GSE Pneumatics & Hydraulics).

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