ONR ASSESSMENT SERIES

2001 Assessment of the Office of Naval Research's Aircraft Technology Program

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2001 Assessment of the Office of Naval Research's Aircraft Technology Program

Committee for the Review of ONR's Aircraft Technology Program
Naval Studies Board
Division on Engineering and Physical Sciences
National Research Council

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Preface

The mission of the Office of Naval Research (ONR) is to maintain a close relationship with the research and development community to support long-range research, foster discovery, nurture future generations of researchers, produce new technologies that meet known naval requirements, and provide innovations in fields relevant to the future Navy and Marine Corps. Accordingly, ONR supports research activities across a broad range of scientific and engineering disciplines. As one means of ensuring that its investments appropriately address naval priorities and requirements and that its programs are of high scientific and technical quality, ONR requires that each of its departments undergo an annual review (with a detailed focus on about one-third of the reviewed department's programs). The Aircraft Technology Program reviewed in this report resides within the Strike Technology Division (Code 351) of the Naval Expeditionary Warfare Science and Technology Department (Code 35) of ONR.

At the request of ONR, the National Research Council (NRC) established the Committee for the Review of ONR's Aircraft Technology Program to review and evaluate ONR's Aircraft Technology Program components in the areas of integrated avionics, propulsion and power, air vehicle technology, unmanned aerial vehicles/unmanned combat air vehicles (UAVs/UCAVs), and survivability against criteria that the committee would select. In addition, the review would seek to identify promising basic (6.1), exploratory (6.2), and advanced (6.3) research topics that could be considered to support the Aircraft Technology Program. At the request of the head of ONR's Code 35, the committee also reviewed a special aviation projects thrust.

The committee met once, May 15 to 17, 2001, in Washington, D.C., to both gather information and prepare an initial draft report. The 3-day meeting was divided into two parts: the first comprised presentations by and interactions with project managers (and ONR-supported principal investigators) responsible for various program components, and the second was devoted to discussing the issues, developing consensus, and drafting the committee's findings and recommendations. (The committee received read-ahead material from the sponsor prior to the first meeting.) The committee's report represents its consensus views on the issues posed in the charge.

Acknowledgment of Reviewers

This report has been reviewed in draft form by individuals chosen for their diverse perspectives and technical expertise, in accordance with procedures approved by the NRC's Report Review Committee. The purpose of this independent review is to provide candid and critical comments that will assist the institution in making its published report as sound as possible and to ensure that the report meets institutional standards for objectivity, evidence, and responsiveness to the study charge. The review comments and draft manuscript remain confidential to protect the integrity of the deliberative process. We wish to thank the following individuals for their review of this report:

Harold Andrews, Arlington, Virginia,
Philip S. Anselmo, Northrop Grumman Corporation,
Roy L. Buehler, Mableton, Georgia,
Jose B. Cruz, Jr., Ohio State University,
Bernard H. Paiewonsky, Institute for Defense Analyses,
George S. Sebestyen, Systems Development, LLC, and
Robert F. Stengel, Princeton University.

Although the reviewers listed above have provided many constructive comments and suggestions, they were not asked to endorse the conclusions or recommendations, nor did they see the final draft of the report before its release. The review of this report was overseen by Lee M. Hunt, Alexandria, Virginia. Appointed by the National Research Council, he was responsible for making certain that an independent examination of this report was carried out in accordance with institutional procedures and that all review comments were carefully considered. Responsibility for the final content of this report rests entirely with the authoring committee and the institution.

Contents

APPENDIXES

Executive Summary

The Office of Naval Research (ONR) contracted with the Naval Studies Board (NSB) of the National Research Council (NRC) to establish a committee to review ONR's Aircraft Technology Program (ATP).[1] The committee convened on May 15 and 16, 2001, and reviewed some 28 science and technology (S&T) efforts that were presented as constituting the ATP. The committee met separately on May 17, 2001, to formulate its findings and recommendations.[2] This report represents the consensus opinion of the committee and is based on the information presented at the review.

The ONR ATP resides within the Strike Technology Division (Code 351) of the Naval Expeditionary Warfare Science and Technology Department (Code 35). In 2001 the ATP is funded at $55.0 million, which is approximately 60 percent of the Strike Technology Division budget. The ATP S&T 2001 budget is further divided into the following categories: (1) 6.1 basic research at $4.3 million, (2) 6.2 exploratory development at $18.1 million, and (3) 6.3 advanced development, including technology demonstrations, at $32.5 million. However, the ATP will be in major transition beginning in FY02. Starting in FY02, all of the 6.3 funding and one-half of the 6.2 funding at the ONR will be dedicated to 12 major program areas referred to as Future Naval Capabilities (FNCs). The purpose of the FNCs is to focus advanced technology development at ONR on naval force capabilities that have been identified as high priority for the future by a cross-functional group of naval operators, naval development and support organizations, and ONR program managers. Plans have been made to integrate several of the Code 351 programs reviewed into FNCs, as discussed in Chapter 2.

The ATP was presented to the committee in six thrust areas: integrated avionics, propulsion and power, air vehicle technology, unmanned aerial vehicles/unmanned combat air vehicles (UAVs/UCAVs), survivability, and special aviation projects. Several projects were presented within each thrust area. The committee organized this report in response to these thrust areas, and in several of these areas it also suggests new S&T topics for consideration for the future ATP.

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[1]Biographies of committee members are given in Appendix A.
[2]The agenda for the 3-day meeting is presented in Appendix B.

The committee reviewed only the elements of naval aviation S&T managed by the ATP in Code 351. The committee was told that all naval aviation S&T was conducted by ONR. Other significant contributing technologies, such as materials for aircraft that are developed in the ONR Engineering, Materials, and Physical Sciences S&T Department (Code 33) and sensors and information management that are developed in the ONR Information, Electronics, and Surveillance S&T Department (Code 31), were not reviewed at this time. Therefore, in some respects, the committee did not receive a complete picture of the state of naval aviation S&T.

Within the ATP as presented, the committee identified several excellent S&T projects that fully satisfied all of the evaluation criteria established. The criteria selected by the committee, based on its experience in conducting similar reviews, included the scientific and technical quality of the program and performing personnel, the appropriateness of the project or program as an S&T activity, the impact of the program on Navy and Marine Corps needs, the extent to which the program interacts with other Department of Defense and National Aeronautics and Space Administration programs performing similar work, and appropriateness and balance in the funding among basic research, exploratory development, and advanced development. These projects—helmet-mounted displays, real-time image indexing, Defense Advanced Research Projects Agency/Navy Unmanned Combat Air Vehicle-Navy (DARPA/UCAV-N) advanced technology demonstration (ATD), reconfigurable rotor blade, and flight controls and dynamics—were of high technical quality, appeared to be led by very competent personnel, had the potential for a major positive impact on future Navy and Marine Corps needs, and were adequately balanced and funded. The committee recommends that these excellent projects be continued and that sufficient funding, acknowledgment, and ongoing support be provided to ensure their successful transition into major programs.

Despite these few excellent but isolated programs, the committee was concerned that it could not identify any influence on the ATP of a long-range vision or strategic planning for the future of naval aircraft technology that involved the Office of the Chief of Naval Operations (OPNAV), Naval Air Systems Command (NAVAIR), ONR, and other Navy Department elements. As a result, the ATP appeared to be focused on the near term and to be tactical, opportunistic, and largely reactive. Some projects were marginal S&T activities and perhaps should have been funded as engineering fixes with major program funding. The lack of any significant 6.1 funding in the ATP aimed at discovery and invention (D&I) is additional evidence of this near-term focus. As part of the S&T planning process, there seems to be little or no systems analysis capability at ONR or NAVAIR. This seriously limits the assessment of potentially high-payoff, long-term S&T opportunities.

The committee therefore recommends that OPNAV, in cooperation with NAVAIR and ONR and the appropriate offices in the Marine Corps, develop a long-range naval aircraft strategic plan that includes a NAVAIR-led technology development plan. Such planning would provide (1) a framework for future ONR S&T investments, including significant emphasis on D&I, and (2) a vision for new capabilities, including advanced air vehicle concepts at affordable costs.[3] It is particularly important now with the advent of FNC thrusts and as ONR funding shifts from manned aircraft to UAVs and UCAVs. The committee believes that failure to establish such a balanced strategy will lead to a more near-term focus, with unacceptable consequences for naval aviation. ONR should develop or contract for a strong systems analysis capability to support long-range planning. Finally, as part of this strategic plan, the committee recommends that all projects relevant to an S&T aviation capability throughout

[3]The committee recognizes that this recommendation is broader than the charter of ONR, but ONR can serve as a catalyst in drawing together the various parts of the naval aviation community.

ONR (and the Department of the Navy) be collectively reviewed, even though they exist in several functional organizations.

The above findings and recommendations overarch all of the individual findings and recommendations that are provided in each thrust area in this report. Following the Introduction (Chapter 1) and General Observations (Chapter 2), the body of this report (Chapters 3 through 8) describes in detail the committee's findings and recommendations concerning the individual projects now being pursued by Code 351. The recommended actions, which include continuation, redirection, and termination, are summarized in Table ES.1. Appendix C lists the abbreviations and acronyms used throughout this report.

At the request of the ATP leadership, the committee also provides in Chapters 4, 5, and 6 some S&T topics for consideration in the future ATP activities. The committee believes that many of these topics are relevant to the FNC thrusts that will begin in FY02. The topics, which span the range from basic research to advanced technologies, are offered as suggestions but are not endorsed by the committee to the exclusion of other programs; they are summarized in Table ES.2.

TABLE ES.1 Summary of Recommendations for Code 351 ATP Projects

Thrust Area	Project	Recommendation
Integrated avionics	Smart skins	None. Effort is ending.
	Advanced common electronic modules	Monitor other DOD efforts (e.g., JSF) and coordinate opportunities to apply their results to naval aircraft since this program has been terminated for schedule and cost reasons.
	Fiber-optic roadmap	Track needs and available products and help coordinate customers with sources.
	Advanced avionics subsystems	If program ends in January 2002 and feasibility has been established, transition results to both Navy and Air Force strike platforms.
	Real-time image indexing	Maintain expertise in Code 31 and continue work on the overall "difficult targets" dilemma.
	Visually coupled displays	Maintain above-critical-mass funding and continue aggressive efforts aimed at demonstrating advanced HMD systems.
Propulsion and power	Propulsion	Devote more attention to STOVL and VTOL areas unique to the Navy. Revisit the distribution of investment between large and small engines.
		Initiate 6.1 D&I investment.
	Multifunction power controller	Assess potential benefits relative to other high-priority, underfunded needs.
		Terminate and reinvest in higher-priority aircraft technology needs unless a critical capability will not be achieved from investments by industry and other agencies.
	Smart wire	Leverage other relevant work and focus on naval aviation-unique problems.
		Transition technology to demonstration as rapidly as possible and transfer implementation to the PMAs in charge of impacted aircraft maintenance and upgrade.
Air vehicle technology	Structural life attainment and enhancement	Ensure that activities meet the criteria for S&T funding. In FACIA, continue with heavily loaded composite control surface work but leverage other external technology programs.
		In the MUST activity, clarify types of failure modes being evaluated and quantify how results will be applied.
	Condition-based maintenance	Maintain the activity but aggressively transition technology to naval aviation systems and to other programs such as JSF.
		Examine operability and reliability of wireless sensors in the dense electronic environment aboard aircraft.

continued

TABLE ES.1 Continued

Thrust Area	Project	Recommendation
	Reconfigurable rotor blade	Excellent program. Continue as planned.
	Flight controls and dynamics	Focus on naval-unique requirements and extend current work to include mission-critical functions of UAVs.
	Abrupt wing stall	Continue CFD efforts but include critical unsteady aerodynamic effects until a clear understanding is obtained of the physical mechanisms involved in the problem.
		Involve the academic community in the resolution of the problem. Ensure that specific F/A-18E/F solutions are funded by that program.
	Aerodynamics of advanced Navy air vehicles	Increase support to ensure capability to understand tightly coupled, nonlinear aero-structure-control interactions.
		Review current aviation platforms and operational programs of interest to the Navy (e.g., V-22, F-18E/F, JSF) with respect to the potential for these types of problems.
Unmanned aerial vehicles/unmanned combat air vehicles	Canard rotor wing	Support flight test program to completion but transition out of S&T at that point.
	UCAV-N ATD	Focus on integration into the existing naval C3 infrastructure.
		Do not get overly absorbed with development and demonstration of any single airplane.
		Continue to leverage UCAV-A efforts in order to avoid duplications.
	UAV autonomy	Dramatically narrow and focus effort in BAA and FNC.
		Focus on decision aids for C2 and rapid, adaptive mission planning and execution.
		Commission a thorough review of project goals and plans by an independent panel of outside experts.
Survivability	LO technology	Integrate signature reduction knowledge and awareness across all aircraft technology pursuits.
		Fund an integrated 6.3 LO technology development.
Special aviation projects	VECTOR	Convoke a comprehensive review of overall project by an independent panel of outside experts.
		Consider incorporating multiaxis thrust vectoring nozzle in ESTOL X-31.
	VTDP	Terminate.

Note: See Appendix C for definitions of acronyms used.

TABLE ES.2 Summary of New Topics Suggested for Consideration in Future ATP Activities

Thrust Area	New Topic
Propulsion and power	Exploring and developing as necessary under S&T funding those technologies that will enable the design of compact, fuel-efficient, ship-compatible UAV engines suitable for long-endurance flight at low and medium altitudes.
Air vehicle technology	Improving understanding of the vortex ring state and its impact on operations near the ground for the unique V22 configuration.
	Exploring active reduction of vertical tail buffet by wing aerodynamic sources rather than by structural modification alone.
	Exploring concepts for expanding the speed limitations on air vehicle performance envelopes in an affordable manner at both supersonic and hypersonic speeds and at low speeds for ESTOL and toward routine post-stall flight.
	Exploring concepts that exploit the absence of human-based constraints on maneuvering of UAVs and UCAVs to achieve high maneuverability and greatly improved survivability and lethality.
UAV/UCAVs	Exploring fault tolerance and fail-safe characteristics of all flight-safety-critical control technologies to ensure that vehicle mission-critical functions are performed as reliably as necessary.
	Addressing in a small, but focused, 6.1 effort the fundamental technology issues of autonomy, i.e., the identification, structuring, and documentation of the mathematical and engineering principles inherent in the concept of autonomous behavior of complex military systems.
	Developing, documenting, and publishing guidelines for the structured design of autonomous systems, to include such things as the fundamental concepts, proven system architectural options, and design practices, including the introduction of meaningful figures of merit for trading off such parameters as machine versus human functionality.

Note: See Appendix C for definitions of acronyms used.

1

Introduction

CONTEXT

The Office of Naval Research's (ONR) Aircraft Technology Program (ATP) resides within the Strike Technology Division (Code 351) of the Naval Expeditionary Warfare Science and Technology Department (Code 35). In 2001 the ATP is funded at $55.0 million, which is approximately 60 percent of the Strike Technology Division budget. The ATP science and technology (S&T) 2001 budget is further divided into the following categories: (1) 6.1 basic research at $4.3 million, (2) 6.2 exploratory development at $18.1 million, and (3) 6.3 advanced development, including technology demonstrations, at $32.5 million. The ATP program office provided current and projected budget figures through FY02 for each of these areas (Table 1.1). This information was provided at the end of the study, by which time all of the 6.3 and some of the specific 6.2 ATP topics reviewed would have been moved to FNCs. Referring to Table 1.1, it should be noted that (1) condition-based maintenance (CBM), which is reviewed in the study as part of the air vehicle technology thrust, is now a separate category and (2) an explicit provision appears for as-yet-undefined new starts in FY02.

The stated goal of the ATP is to enhance the mission effectiveness and affordability of naval aviation systems by conducting basic and applied research and advanced technology demonstrations (ATDs) in preparation for transitioning of high-priority/high-payoff technology options in six thrust areas: (1) integrated avionics, (2) propulsion and power, (3) air vehicle technology, (4) unmanned aerial vehicles/unmanned combat air vehicles (UAVs/UCAVs), (5) survivability, and (6) special aviation projects.

The stated S&T investment strategy is as follows:

- Develop a high-quality naval aircraft technology core program;
- Leverage common aircraft technology programs with the U.S. Air Force, U.S. Army, National Aeronautics and Space Administration (NASA), Defense Advanced Research Projects Agency (DARPA), industry, and other countries;
- Influence other S&T sponsors and performers to support naval aviation goals; and
- Position the program to take advantage of future opportunities.

TABLE 1.1 ONR 351 Aircraft Technology Program Budget Through FY02 (millions of dollars)

Area	FY99	FY00	FY01	FY02
Avionics				
6.3 Processing (ACEMs, AAS, smart skins)	8.3	3.6	3.2	0.0
6.2 Processing (ACEMs, real-time high-definition image processing)	6.0	0.4	0.0	0.0
6.2 Displays	2.0	1.0	0.8	0.9
6.2 Cockpit	0.5	0.0	0.0	0.0
Subtotal	16.7	4.9	4.0	0.9
Propulsion and power				
6.2 Propulsion	4.0	4.9	4.6	0.0
6.2 UAV Propulsion (AO FNC)	0.0	0.0	0.0	1.4
6.2 Turbine improvement/IHPTET (TOCR FNC)	0.0	0.0	0.0	0.0
6.3 IHPTET	6.9	7.2	7.8	0.0
6.3 UAV propulsion (AO FNC)	0.0	0.0	0.0	1.5
6.3 Turbine improvement/IHPTET (TOCR FNC)	0.0	0.0	0.0	9.6
6.2 Thermal management	0.2	0.0	0.0	0.0
6.2 Power	0.5	0.5	0.1	0.1
6.2 AC power (TOCR FNC)	0.0	0.0	0.0	0.0
6.3 AC power (TOCR FNC)	0.0	0.0	0.0	0.9
Subtotal	11.6	12.6	12.4	13.5
Air vehicle technology				
6.2 Structures	0.7	0.8	0.8	1.6
6.2 AC corrosion (TOCR FNC)	0.0	0.0	0.0	1.8
6.1 Aerodynamics	0.5	0.5	0.3	0.2
6.2 Aerodynamics	1.4	0.8	0.6	0.2
6.2 FC&D	0.7	0.8	0.6	0.6
6.2 TWV	0.1	0.2	1.1	0.1
6.2 Concepts	0.0	0.0	0.0	0.0
6.3 Reconfigurable rotor blade (TOCR FNC)	0.0	0.0	0.0	2.0
Subtotal	3.3	3.0	3.3	6.4
UAV/UCAV-N				
6.1 UAV research	2.4	4.3	4.0	4.0
6.2 UAV research (including CRW)	2.3	3.5	3.9	0.0
6.2 UAV autonomy (AOC FNC)	0.0	0.0	0.0	7.0
6.3 UAV autonomy	0.0	0.0	0.0	3.0
6.3 UCAV-N (TCS FNC)	0.0	0.0	0.0	15.0
Subtotal	4.6	7.8	7.9	29.0
Condition-based maintenance				
6.2 CBM	1.8	2.0	1.4	0.0
6.3 CBM (TOCR FNC)	0.0	0.0	0.0	8.6
Subtotal	1.8	2.0	1.4	8.6
Survivability				
6.2 LO	3.6	3.6	4.4	4.1
Subtotal	3.6	3.6	4.4	4.1

continued

TABLE 1.1 Continued

Area	FY99	FY00	FY01	FY02
Special aviation projects				
6.3 Special projects	8.1	20.0	21.5	5.1
6.2 Special projects	4.9	0.0	0.0	0.0
Subtotal	13.0	20.0	21.5	5.1
New start funds				
6.2 New start	0.0	0.0	0.0	1.1
D&I and FNC total	54.7	53.9	55.0	68.6
6.1 Total	2.8	4.7	4.3	4.2
6.2 Total	28.5	18.5	18.1	18.8
6.3 Total	23.3	30.7	32.5	45.7
Total 6.1, 6.2, and 6.3	54.7	53.9	55.0	68.6

Note: See Appendix C for definitions of acronyms used.

The committee was charged with evaluating the ATP as represented by some 28 individual efforts that were presented over 2 days, May 15 and May 16, 2001. The committee selected the following evaluation criteria in its deliberations on May 17, 2001:

- Scientific and technical quality of the program and performing personnel;
- Appropriateness as an S&T program;
- Impact on and relevance to Navy and Marine Corps needs;
- Effectiveness of interaction with other Navy/Marine Corps, U.S. Air Force, U.S. Army, DARPA, and other external programs;
- Appropriateness of the investment and investment level; and
- Balance of the funding between basic research, exploratory development, and advanced development.

The committee was also asked to recommend new technology topics that should be considered for inclusion in future ATP activities.

ORGANIZATION OF THIS REPORT

In Chapter 2, the committee provides some general observations on the future of naval aviation and on the ATP. Each of the six chapters (Chapters 3 through 8) that follow pertains to one of the six ONR ATP thrusts—namely, integrated avionics, propulsion and power, air vehicle technology, unmanned aerial vehicles/unmanned combat air vehicles, survivability, and special aviation projects. Each begins with an overview of the thrust and then presents the committee's findings and recommendations for each of the projects described to it at its May 2001 meeting. In Chapters 4, 5, and 6, the committee recommends new S&T topics for consideration for the future ATP and that are relevant to some of the FNC thrusts.

2

General Observations

Within the ATP as presented, the committee identified several excellent S&T projects that fully satisfied all of the criteria established. These projects—helmet-mounted displays, real-time image indexing, DARPA/Navy Unmanned Combat Air Vehicle-Navy (UCAV-N) ATD, reconfigurable rotor blade, and flight controls and dynamics—were of high technical quality, appeared to be led by very competent personnel, had the potential for a major positive impact on future Navy and Marine Corps needs, and were adequately balanced and funded. The committee recommends that these excellent projects be continued and that sufficient funding, acknowledgment, and ongoing support be provided to ensure their successful transition into major programs.

The committee had some general observations on the future of naval aviation that overarch the specific findings and recommendations to follow. The ATP will be undergoing extensive change beginning in FY02, when all of the 6.3 funding and half of the 6.2 funding at the ONR will be dedicated to the 12 major program areas referred to as Future Naval Capabilities (FNCs). The purpose of the FNCs is to focus advanced technology development at ONR on naval force capabilities that have been identified by a cross-functional group of naval operators, naval development, and support organizations and ONR personnel as having high priority for the future. The idea is for the FNC process to enhance and accelerate the transfer of new technology capabilities to the fleet by engaging all of the interested parties in the advanced technology development phases. Each of the FNCs will be managed by an integrated product team consisting of representatives from the interested parties, including operators, product developers, support organizations, and ONR. The FNCs will be funded at approximately $750 million, which is about one-half of the total ONR S&T budget in 2001. The remaining half of the ONR 2001 budget will be allocated to D&I programs that encompass the former 6.1 basic research efforts and the reduced 6.2 exploratory development efforts.

Since the ATP is composed primarily (92 percent) of 6.2 and 6.3 programs, a significant shift in emphasis and management of the programs will take place in 2002 and beyond. The three FNCs that are the logical heirs of the technologies developed in the current ATP program are (1) Time Critical Strike,[1]

[1]The objectives of the Time Critical Strike FNC are as follows: (1) to defeat expeditionary/urban warfare targets with naval

(2) Autonomous Operations,[2] and (3) Total Ownership Cost Reduction.[3] It is planned that some current technology programs and areas will be deemphasized or eliminated entirely while others will receive increased emphasis and funding because they are perceived to be important to future naval needs and capabilities. For example, the committee observed that the integrated avionics area will be essentially dropped from funding in 2002 and beyond, with the exception of an ongoing modest effort in integrated helmet display systems. There will also be a major shift in emphasis from traditional naval aircraft technologies in 2002 to the new UAV autonomy activity that will be part of the Autonomous Operations FNC and the UCAV activity that will be part of the Time Critical Strike FNC. Current activities in turbine engine improvement, condition-based maintenance, and power handling will be shifted to the Total Ownership Cost Reduction FNC. In this time of major change, the committee recommends that ONR ATP management reevaluate the entire S&T program from a strategic perspective that looks at the long-term vision and goals of naval aviation.

The committee was concerned that it could not identify any influence on the ATP of a long-range vision or any strategic planning for the future of naval aircraft technology that involved the Office of the Chief of Naval Operations (OPNAV), Naval Air Systems Command (NAVAIR), ONR, or other Navy Department elements. As a result, the ATP appeared to be focused on the near term and to be tactical and opportunistic. The lack of any significant basic research (6.1) in the ATP aimed at D&I is additional evidence of this near-term focus. The ATP at ONR is closely coupled to the primary customer in NAVAIR, with many of the ATP S&T programs being led by NAVAIR personnel. While this closeness is desirable from a technology transfer standpoint, the time horizon of system developers such as NAVAIR is much shorter than deemed healthy for a vigorous, innovative S&T program, and this jeopardizes the future supremacy of U.S. naval airpower. In at least a few cases, the presented programs were inappropriate for S&T funding; they resembled instead engineering solutions to current aircraft problems, which should have been funded by program funds associated with specific platforms.

In order to avoid duplication of effort, and to proceed efficiently toward optimum technical solutions, it is good practice to search the technical literature for previous work contributing to solution of a problem. However, the committee's impression was that efforts in the ATP were often undertaken without such a search having been made. Aided by new information technology that makes the procedure much easier and more productive, literature searches should be done whenever a new effort is started toward solving a technical problem.

There seems to be little or no systems analysis capability at ONR or NAVAIR. The committee was presented with no evidence that top-level system requirements for future needs had been established or that trade-off analyses had been conducted to select the best approach for naval aviation. Such systems analyses would have identified technology needs and led to a technology development plan that contained requirements and milestone performance and delivery schedules. A systems analysis and

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fire support; (2) to defeat relocatable targets at range; (3) to defeat short dwell mobile intermittently emitting targets at range; (4) to defeat moving targets at range; and (5) to defeat active hard and deeply buried targets at range. See ONR's description online at <http://www.onr.navy.mil>.

[2]The objectives of the Autonomous Operations FNC are as follows: (1) to provide all-condition access to the area of responsibility through organic unmanned systems to perform multiple missions; (2) to enable automated surveillance and reconnaissance in all environmental conditions; (3) to enable automated surveillance and reconnaissance data processing; (4) to enable secure, jam-resistant sensor to shooter to weapon connectivity; and (5) to minimize human intervention and enable manned/unmanned platform operations and interoperability. See ONR's description online at <http://www.onr.navy.mil>.

[3]The objectives of the Total Ownership Cost Reduction FNC are as follows: (1) to reduce maintenance; (2) to enhance materials, designs, and processes for cost reduction; and (3) to enhance cost estimating tools for total ownership costs. See ONR's description online at <http://www.onr.navy.mil>.

engineering approach has been used successfully for each generation of the Fleet Ballistic Missile program for more than 40 years and is currently being followed in the DD-21 program. The failure to follow this proven disciplined approach seriously limits the identification and development of potentially high-payoff, long-term S&T opportunities and leads to the short-term, reactive, opportunistic approach witnessed by the committee.

The committee recommends that OPNAV, in cooperation with NAVAIR and ONR and the appropriate offices in the Marine Corps, develop a long-range naval aircraft strategic plan that includes a NAVAIR-led technology development plan. Such planning would provide (1) a framework for future ONR S&T investments, including significant emphasis on D&I, and (2) a vision for new capabilities, including advanced air vehicle concepts at affordable costs.[4] It is particularly important now, with the advent of FNC thrusts and as ONR funding shifts emphasis from manned aircraft to UAVs and UCAVs. The committee believes that failure to establish such a balanced strategy will lead to a more near-term focus, with unacceptable consequences for naval aviation.

ONR should develop or contract for a strong systems analysis capability to support long-range planning. In developing a long-range technology plan, different approaches to satisfying systems requirements need to be analyzed and traded-off until an optimum technology approach is developed, given the constraints of time, schedule, budget, technology maturity, and other parameters. This well-proven approach requires personnel trained and experienced in the systems analysis discipline. The committee saw no evidence that this approach was being followed or that the presenters had any experience with it.

Finally, as part of this strategic plan, the committee recommends that all projects relevant to an S&T aviation capability throughout ONR (and the Department of the Navy) be collectively reviewed, even though the area and projects may exist in several functional organizations.

The committee observed that many of the shortcomings noted above were consistent with the findings of previous committees that reviewed programs in the Naval Expeditionary Warfare S&T Department, Code 35. In the *1999 Assessment of the Office of Naval Research's Air and Surface Weapons Technology Program,*[5] there was concern that project selection was methodological rather than strategic, that the S&T work was evolutionary in nature and focused on short-term needs, and that trade-off studies needed to be conducted to determine how to fit the 6.2 and 6.3 program components into the overall weapons system architecture. That assessment, in turn, cited similar findings of an earlier Board of Visitors review in 1996. The committee believes that to remedy these shortcomings, the Naval Expeditionary Warfare S&T Department should take advantage of the new FNC focus to develop strategic long-range technology plans for each FNC using the systems analysis approach. This approach will identify technology gaps or needs that can be filled with a balanced S&T investment portfolio that includes a vibrant D&I element.

[4]The committee recognizes that this recommendation is broader than the charter of ONR, but ONR can serve as a catalyst in drawing together the various parts of the naval aviation community.

[5]Naval Studies Board, National Research Council. 1999. *Assessment of the Office of Naval Research's Air and Surface Weapons Technology Program*, National Academy Press, Washington, D.C.

3

Integrated Avionics

OVERVIEW

The integrated avionics thrust is composed of a set of programs addressing various aspects of avionics technology and systems. The first observation is that the avionics thrust is being substantially descoped in the near term, so that most of the efforts presented are coming to an end, as indicated in the ONR budget projection shown in Table 3.1. The second is that important components of avionics, including sensors and information processing, communications/navigation/target identification, electronic warfare, and many aspects of pilot-aircraft interfaces, are not conducted by Code 35 and were not part of this review. The committee can therefore only offer limited constructive advice for the future of the thrust.

Several of the efforts that were presented are technically excellent and highly relevant, especially those on visually coupled displays and automatic target classification (image indexing). Others were less impressive, mainly because they lacked clear paths to transition or application or appeared to duplicate work done previously or work done by other organizations. Specific comments are offered in the next section. However, the committee formed several general impressions that are significant for any future ONR activity in integrated avionics:

- ONR is exiting the field of avionics technology development and integration, with the possible exception of integrated helmet display systems. The Navy may have to rely on the Air Force, the Army, or possibly others for future avionics technology.
- The efforts as presented showed little or no evidence of an underpinning of architectural principles that should provide a unifying theme and without which integrated avionics systems cannot succeed.
- The emphasis here, as in other parts of the ATP, has been on near-term fixes for legacy aircraft rather than on innovation to enable future advances.

As in several other thrusts that the committee reviewed, there is a risk that the Navy will lose the

TABLE 3.1 ONR 351 Aircraft Technology Program Budget for Avionics Through FY02 (millions of dollars)

		FY99	FY00	FY01	FY02
6.3	Processing (ACEMs, AAS, smart skins)	8.3	3.6	3.2	0.0
6.2	Processing (ACEMs, real-time high definition image processing)	6.0	0.4	0.0	0.0
6.2	Displays	2.0	1.0	0.8	0.9
6.2	Cockpit	0.5	0.0	0.0	0.0
	Total	16.7	4.9	4.0	0.9

Note: See Appendix C for definitions of acronyms used.

critical mass of current expertise needed to be a smart buyer and to ensure that naval-unique needs are identified and addressed. If an integrated avionics thrust is not continued, the committee recommends that ONR/NAVAIR maintain, perhaps in Code 31 if not in Code 35, a select, funded team of experts who can interact with the broader avionics community. It is anticipated that the Time Critical Strike FNC will focus on developments in strike missions in littoral warfare and support to Marine Corps forces ashore.

PROGRAMS REVIEWED

Integrated Sensors/Electronics

Smart Skins

Findings

The term "smart skins" was coined to describe a very ambitious concept in which much, or all, of the surface of an air vehicle would be electromagnetically active, allowing comprehensive, multispectral interaction with the environment. The Code 351 effort has concentrated on leading-edge flap antennas for the F/A-18 in which surface-mounted array elements replace the more conventional approach of arrays embedded in the dielectric structure of the flap. Work done to date has demonstrated antenna functionalities such as electronic support measures, data link, communications, and identification friend or foe (IFF), along with improvements in weight and durability. No data were presented on performance factors such as angle-of-arrival precision and signature impact. Even so, this is a promising result that could have broad applications.

Recommendation

None. The effort is ending with several prospective transitions to weapon systems.

Advanced Common Electronic Modules

Findings

Advanced common electronic modules (ACEMs) have been one of a number of efforts in the general area of modular, software-controlled, resource-sharing multifunction radios. This effort has been minimizing the number of distinct module types and evaluating the feasibility of implementing such systems with available components. Given the funding constraints, ONR is unlikely to influence the direction of this technology. Furthermore, the program was drastically redirected (it went from being an aviation application to a sonobuoy application) and was then terminated in response to cost and schedule concerns.

Recommendation

This avionics functionality is being aggressively developed in programs like Joint Strike Fighter (JSF) and the DARPA Airborne Communications Node. ONR should monitor these efforts, identify opportunities to apply their results to Navy aircraft, and coordinate follow-on efforts.

High-speed Interconnects

Fiber-optic Roadmap

Findings

As described, this is essentially a low-level effort to track and forecast both evolving system needs for optical interconnects and potentially matching developments in technologies and products. ONR needs awareness in this area and seems to recognize that developments in weapons systems like the JSF and in industry will be the source of future system high-performance interconnect solutions.

Recommendation

ONR could perform a useful coordinating function for naval aviation by keeping track of needs and available products and helping match customers with sources.

Information Management

Advanced Avionics Subsystems

Findings

The project that was briefed involves porting Cambridge Technologies' PowerScene terrain visualization system, which has gained considerable currency in the command, control, and communications (C3) and mission planning arenas, to the cockpit. Strictly speaking, this is a perspective visualization technique rather than a true three-dimensional visualization technique, but it has demonstrated high utility in mission preview, aircrew orientation, target location, and similar situational awareness functions. It will be important to ensure that all the data displayed conforms with the National Imagery and Mapping Agency (NIMA) and national standards such that the "view" of the target is in fact an accurate position on the ground. It is quite believable that such functionality could enhance the performance of strike aircraft crews and lighten their workload. The effort has centered on establishing feasibility and solving problems in porting PowerScene to avionics processing environments. Results to date look promising. It is important for the Navy to examine all commercially available display applications for use in aircraft.

Recommendations

If, when the present effort ends in January 2002, the feasibility and utility of the technique have been established, ONR should pursue transitioning of the results to both Navy and Air Force strike platforms. This would probably require funding and supporting additional flight demonstrations on various platforms. The technique could be especially useful on long-range systems like the B-2.

Real-time Image Indexing

Findings

This is a very interesting approach to automatic target classification (ATC), and perhaps eventually to automatic target recognition (ATR), that makes a pattern-matching paradigm computationally feasible by applying invariant theory to derive a robust minimum set of geometric features (e.g., six distinct lines in an object's electro-optical image). Preliminary results with limited test cases show promise for decoy rejection. The work is well coordinated with (and in some ways predated) similar efforts at the Air Force Research Laboratory/Sensors Directorate (AFRL/SN). It has been transitioned to a 6.3 project in ONR Code 31. This is impressive work and a significant contribution to an important, pervasive, and very difficult surveillance and targeting problem.

Recommendation

Although Code 35 is ending its effort, the expertise of this team should be maintained and applied to continue the development and application of this promising approach to the problems of decoys, deception, obscuration, and other aspects of the overall "difficult targets" dilemma.

Displays

Visually Coupled Displays

Findings

This is the crown jewel of the Code 351 avionics program and the only area that will continue at a significant level after FY01. (The roadmap for the visually coupled displays project shows transitions to the fleet and Army rotary- and fixed-wing systems and/or to EMD phase by FY04.) ONR has, over the years, made perhaps the most important contribution to demonstrating the power and feasibility of helmet-mounted displays (HMDs). In systems like JSF, the HMD is likely to replace the head-up display as the primary flight reference and to greatly improve situational awareness, time of response to targets and threats, and overall mission success and survivability. Highlights include the compound helmet for light weight and lower cost, realistic approaches to achieving pointing accuracies on the order of one mrad, and approaches that promise helmet weights well under 5 pounds.

Recommendations

ONR should maintain above-critical-mass funding for this area, continue aggressive efforts to demonstrate advanced HMD systems, coordinate transition plans with the platforms that will use the HMDs, and attack fundamental technology limitations, especially in helmet weight and pointing/attitude reference accuracy.

4

Propulsion and Power

OVERVIEW

Power and propulsion are a concatenation of two very different technical areas. Power relates to onboard auxiliary electrical power systems of aircraft, including storage and distribution. Propulsion in the context of the current ONR program applies to gas turbine engine technology for naval vehicle applications such as missiles and manned and unmanned rotary- and fixed-wing aircraft. The only technical connection between the two is that the propulsion engines mechanically drive the electrical generators in most air vehicles.

Table 4.1 shows the ONR budget projection for the ATP propulsion and power programs, including planned transition to FNCs.

TABLE 4.1 ONR 351 Aircraft Technology Program Budget for Propulsion and Power Through FY02 (millions of dollars)

		FY99	FY00	FY01	FY02
6.2	Propulsion	4.0	4.9	4.6	0.0
6.2	UAV propulsion (AO FNC)	0.0	0.0	0.0	1.4
6.2	Turbine improvement/IHPTET (TOCR FNC)	0.0	0.0	0.0	0.0
6.3	IHPTET	6.9	7.2	7.8	0.0
6.3	UAV propulsion (AO FNC)	0.0	0.0	0.0	1.5
6.3	Turbine improvement/IHPTET (TOCR FNC)	0.0	0.0	0.0	9.6
6.2	Thermal management	0.2	0.0	0.0	0.0
6.2	Power	0.5	0.5	0.1	0.1
6.2	AC power (TOCR FNC)	0.0	0.0	0.0	0.0
6.3	AC power (TOCR FNC)	0.0	0.0	0.0	0.9
	Total	11.6	12.6	12.4	13.5

Note: See Appendix C for definitions of acronyms used.

PROGRAMS REVIEWED

Propulsion

Findings

The ONR Code 351 propulsion program consists entirely of a Navy portion of the Integrated High Performance Turbine Engine Technology (IHPTET) program. This is a highly integrated, cross-Service 6.2-6.3 program very tightly coordinated from the Office of the Under Secretary of Defense (OUSD), with additional participation by NASA. IHPTET encompasses all of the Department of Defense's (DOD's) turbine engine research investment. The Navy is a junior partner in this endeavor, contributing about 10 percent of the funding. In business for more than a decade, the program has clear, ambitious, quantitative goals for improving overall gas turbine performance and life-cycle costs. Systems analysis is used to relate air vehicle goals to specific engine types and component technologies. The program is a mix of mid-term and long-term technologies and runs the gamut from materials, to mechanical components, to aerothermal designs, to controls and diagnostics. Much of the technology is generic in that it may be applicable to new centerline engines and as well as to major upgrades of legacy designs in a wide variety of engine sizes and applications. Industrial cost sharing is an important part of the program, so the military and industry work closely in setting the targets and selecting the technologies. Most of the IHPTET funding goes to industry, and it now accounts for the majority of the basic and applied research funding for gas turbine technology in the United States. Thus, industry is very interested in generic, multiple-use technologies applicable to a wide set of turbine engine applications, both military and civil.

Only the Navy funds the 6.2 technology projects, while the funding of the 6.3 demonstration cores and engines is shared with the other services. Nine 6.2-funded projects include advanced materials (ceramic matrix vanes, tiled turbine blades), combustors (active combustor control, integrated-shortened combustors), integrated prognostics and health management, improved bearings (rolling contact bearings, magnetic bearings), and improved mechanical analysis (blade vibration code verification, crack growth models). Insufficient information was presented to the committee to permit detailed assessment of each effort. Since these Navy projects represent only a small fraction of the overall IHPTET 6.2 funding, a review of them in isolation runs the risk of being out of context. Regardless, these are all mainline, long-term gas turbine research topics done by creditable organizations. These efforts represent a reasonable research investment for the Navy. However, they are in no way Navy-specific and most do not fall into the category of D&I. None represent new ideas, but rather are part of the stepwise, long-term progression needed to develop new technology to the point that it can be adopted by gas turbine engine development programs with acceptable levels of technical risk. (Magnetic bearings, for example, represent a concept that has existed for several decades and has been demonstrated in an engine core as part of the IHPTET program. However, there is still considerable 6.2- and 6.3-level research needed on magnetic bearings before they can be a viable design option for an engine development program.)

With one exception, there are no naval-unique basic gas turbine technologies. Specific naval applications may have unique requirements (e.g., those associated with carrier operations and the marine environment), but these are accommodated in engine development through design and validation testing. The exception is short takeoff and vertical landing (STOVL) and vertical takeoff and landing

(VTOL). The Air Force has no current interest in STOVL and VTOL technologies, while the Army's interest is confined to rotorcraft. While many STOVL technologies are often considered part of the airframe rather than the propulsion systems, there are some gas turbine technologies (vectoring nozzles, short-life lift engines, enhanced emergency power-boost, and so on) that are of interest only to the Navy.

Recommendations

Currently, the Navy 6.2 propulsion program is focused on technologies appropriate to large manned aircraft. The committee recommends that the propulsion program devote more attention to areas unique to the Navy and Marine Corps, such as short takeoff and vertical landing (STOVL) and vertical takeoff and landing (VTOL), even at the expense of the more generic gas turbine technologies currently being pursued. In addition, given the marked shift in emphasis to small UAVs/UCAVs and the need for extended-range munitions, the committee recommends that ONR consider reallocating the investment portfolio between large and small gas turbine engines.

There is no balance between 6.1, 6.2, and 6.3 in propulsion since both the IHPTET program and the Navy have no direct 6.1 funding supporting gas turbine technology development. ONR ceded responsibility for 6.1 basic research to the Air Force and the Army about a decade ago. The IHPTET program never had a 6.1 component, which is perhaps its major weakness given the ambition of its technical goals.

Power

This technical area focuses on onboard auxiliary power systems for aircraft, including generation, storage, and distribution. Technology and performance improvements in this area are important to all military and civil aircraft. The problems for naval aircraft seem to be like those for all aircraft and vehicle systems. The national investment in this area, as reported by the Code 351 briefing, is broadly distributed among industry and government agencies. There are no novel or unique approaches being pursued by the ONR Code 351 program that will pace or focus the larger national efforts.

Multifunction Power Controller

Findings

The objectives and approach for this program area are reasonable and straightforward. Innovation is low and not unique from an S&T perspective. The solutions being developed are not unique to Navy applications.

Recommendations

ONR should assess the potential benefits of this program in the light of other high-priority, underfunded needs. Unless a critical capability will not be achieved from investments by industry and other agencies, it should terminate the work and invest in more pressing aircraft technology needs.

Smart Wire

Findings

This technology has the potential for significant payoff for most aircraft applications. The Navy has unique and difficult maintenance, environmental, and operational conditions that demand enhanced diagnostics and detection of anomalies in onboard electrical systems. This area has received considerable attention because of the problem of aging civil aircraft.

Recommendations

ONR should ensure that the program takes full advantage of other relevant work and focuses on the problems unique to naval aviation. It should move the technology to demonstration as rapidly as possible and transfer implementation to the program managers (aviation) in charge of the impacted aircraft maintenance and upgrade.

Only two projects were briefed as part of the review. However, based on the information provided, the committee believes that the power program has marginal impact on high-priority and naval-unique aircraft technologies and recommends that it be critically assessed against other high-priority demands on resources. The quality of the work is satisfactory, but most of the gains for the Navy in this area will come from industry and other agency investments.

Suggested Topic in Propulsion and Power for the Future ATP

The committee recognizes that the Navy and Marine Corps may wish to employ small/medium size UAVs for long-endurance intelligence, surveillance, and reconnaissance missions at low and medium altitudes in operations from both ship and shore bases. To power such air vehicles, compact, fuel-efficient, ship-compatible engines would be required. Accordingly, the committee recommends that ONR explore and develop as necessary under S&T funding the technologies that will enable the design and manufacture under program funding of fuel-efficient UAV engines suitable for long-endurance flight at low and medium altitudes.

5

Air Vehicle Technology

OVERVIEW

The Navy's air vehicle technology thrust consists of programs in the following areas:

- Structural life attainment and enhancement,
- Condition-based maintenance,
- Reconfigurable rotor blade,
- Flight controls and dynamics,
- Abrupt wing stall, and
- Aerodynamics of advanced Navy air vehicles.

Table 5.1 shows the ONR budget projection for the ATP air vehicle technology area, including transitions to FNCs. Note that condition-based maintenance, which the committee considered as part of this thrust area, has been separated out in this budget listing. Also, the rotary-wing vehicle and concepts areas appearing in this budget listing were not briefed to the committee.

The air vehicle technology thrust includes the traditional areas of aerodynamics, air vehicle structures, flight control, flight mechanics, and the area of air vehicle system health monitoring and maintenance diagnostics. In recent years, funding in this area has been declining. The current work appears to have a strong promise of transitioning useful technology to users in the near to medium term, and it appears to be reasonably well balanced across the technical disciplines.

Some committee members are alarmed that funding is below the critical level needed to keep the Navy a smart buyer in this technical area. Most of the committee is concerned that not enough exploratory development is under way or planned to enable long-term advanced concepts and to prevent technology surprises. Some are concerned that certain programs are marginal S&T activities and should be considered as engineering fixes under the appropriate acquisition program funding.

Areas such as high-speed flight, maneuvering flight, and low-speed flight are not being addressed to the degree that would ensure future capability. The fact that no Navy vision could be articulated that

TABLE 5.1 ONR 351 Aircraft Technology Program Budget for Air Vehicles Through FY02 (millions of dollars)

	FY99	FY00	FY01	FY02
6.2 Structures	0.7	0.8	0.8	1.6
6.2 AC corrosion (TOCR FNC)	0.0	0.0	0.0	1.8
6.1 Aerodynamics	0.5	0.5	0.3	0.2
6.2 Aerodynamics	1.4	0.8	0.6	0.2
6.2 FC&D	0.7	0.8	0.6	0.6
6.2 RWV	0.1	0.2	1.1	0.1
6.2 Concepts	0.0	0.0	0.0	0.0
6.3 Reconfigurable rotor blade (TOCR FNC)	0.0	0.0	0.0	2.0
Total	3.3	3.0	3.3	6.4

Note: See Appendix C for definitions of acronyms used.

includes advanced air vehicles reflects a lack of vision for the potential of aeronautics. From a physics and technology perspective, however, there is no limit to the potential for air vehicle technologies to enable advanced vehicle concepts. What the committee sees missing from the Navy is a call for more performance at affordable costs. Instead the committee sees an assumption that most new vehicle performance technologies would be too costly.

Furthermore, there are continuing problem areas that will limit capability but that, if they are understood, can be exploited. One example involves the complex coupling of transonic aerodynamics with an elastic structure, moving control surfaces, and maneuvering flight, most recently found in F/A-18E/F flight tests. Such coupling exemplifies the limits of current technologies, which will continue to surprise us and limit air vehicle capability until they are better understood. Investments are needed to develop the needed understanding in this problem area. Other areas that limit air vehicle capability now—such as high-speed (transonic, supersonic, hypersonic) maneuvering and low-speed flight—require a vision, a plan, and a resource commitment that goes beyond the current one.

PROGRAMS REVIEWED

Structural Life Attainment and Enhancement

The structural life attainment and enhancement (SLAE) program has four components: (1) fatigue- and corrosion-insensitive aircraft (FACIA), (2) maximizing usable service time (MUST), (3) corrosion-assisted fatigue, and (4) bonded composite patches.

The FACIA goal is to eliminate corrosion maintenance, corrosion-assisted fatigue, and other fatigue mechanisms (e.g., buffet) associated with current metal control surfaces by developing the following:

- Analytical capabilities to quantitatively predict corrosion-assisted fatigue life,
- A three-dimensional architecture for all-composite control surfaces, and
- A three-dimensional woven composite control-surface hinge.

The MUST project aims to increase the life of rotorcraft dynamic components. Technologies being developed under this project are targeted at the H-60 but can be transitioned to other naval rotorcraft, including AH-1 and H-53. The goal of significantly longer service life of rotorcraft dynamic components will be achieved by the following means:

- Characterization and modeling of the mechanical behavior of highly loaded dynamic components,
- Analytical tools for predicting failure modes, and
- Design of engineered soft (i.e., noncatastrophic) slow-growth failure modes.

The accomplishment of this goal will be demonstrated through the fabrication and testing of composite dynamic components (bifilar and swashplate).

The corrosion-assisted fatigue project is motivated by the accelerated fatigue failures of metallic wing fold lugs and control surface hinges. The objective of this project is to develop strain versus life models that use measured corrosion to predict component structural life with 99 percent reliability and 95 percent confidence. This project will also determine procedures for quantifying corrosion rates.

The SLAE program has successfully transitioned the technology of bonded composite patches for repair of primary airframe structures. Demonstrated on the F-5 vertical stabilizer, use of bonded composite patches showed a 75:1 savings compared with full removal and replacement and a 20:1 savings compared with complete reskinning.

Findings

Bonded composite patches were originally intended for temporary repair but have now been certified for permanent use. This technology transition directly addresses warfighter needs for rapid turnaround of damaged assets, reduced cost of operations, and life extension of legacy aircraft systems. In the FACIA project, the heavily loaded composite control surface hinge and fittings appear to be a unique technology application that warrants continued pursuit. It was unclear what types of failure modes are being evaluated in the MUST project, whether micromechanical considerations are included, or how the life of the engineered failure mode will be quantified and used to derive field-level inspection strategies and metrics. The corrosion-assisted fatigue project directly addresses reduction of operational costs of legacy systems by managing corrosion. The resulting models will enable the definition of corrosion maintenance criteria, including metrics for corrosion with respect to structural integrity.

Recommendations

While the products of the FACIA and MUST projects are highly relevant and useful to the Navy, ONR should ensure that the activities truly meet the criteria for S&T funding as distinguished from engineering enhancements that should be funded by the appropriate acquisition program. The FACIA project can maximize the effectiveness of its fragile budget by leveraging technology developments from other composite control surface programs. It should continue to pursue the heavily loaded composite control surface hinge and fittings. Long-lasting S&T benefits can also be achieved by leveraging the more accurate analytical predictions of buffet loads that are being developed by other Navy groups and external groups. The MUST project should clarify which types of failure modes are being evaluated, whether micromechanical considerations are included, and how the life of the engineered failure mode will be quantified and used to derive field-level inspection strategies and metrics.

Condition-based Maintenance

The ONR condition-based maintenance (CBM) program began in FY96 as a 5-year accelerated capabilities initiative to speed delivery of CBM capabilities to the fleet. The CBM program is conducted with the following four thrusts:

- Corrosion detection sensors,
- Wireless microelectromechanical systems (MEMS)-based sensors for machinery diagnostics,
- In situ oil quality monitoring, and
- Human information/advanced training.

Findings

An important element of the performance, safety, supportability, and affordability of future weapon systems lies in greatly enhanced self-sufficiency through embedded diagnostics, proactive maintenance and failure avoidance, and rapid restoration of degraded systems. ONR Code 351 efforts under the CBM thrust are making important contributions to this goal. In particular, ONR has had significant inputs to the autonomic logistics area of the JSF program and to the overall emergence of prognostics and health management as a central theme in system development. Specific products like the Total Oil Monitoring System promise near-term payoffs in logistics costs and aircraft availability. Overall, this activity is an important contributor to an evolving concept of aeronautical systems that can sustain high operational tempos under austere operating conditions and with significantly reduced cost of ownership. Technologies from the CBM project have been applied to date only to nonaviation platforms, the advanced amphibious assault vehicle (AAAV), and the drive-up simulated testbed (DUST). The latter includes participation in IMATE DUST, a demonstration of wireless, smart MEMS sensors on an operating aircraft engine.

Recommendations

ONR should maintain the CBM thrust but should work aggressively to transition the technology to naval aviation systems and to the aviation systems of the other Services. In particular, close liaison with the JSF program is essential to minimize duplication and ensure opportunities to transition CBM results that are identified and realized. The CBM project should take care to address the operability and reliability of wireless sensors in an already electronically dense onboard aircraft environment.

Reconfigurable Rotor Blade

The goal of this project is to develop a rotor blade that can be optimized in flight for the hover and cruise flight conditions to meet operational improvement goals of aerodynamic cruise efficiency and maximum blade hover loadings. The technology is being specifically developed for application on the V-22 for prop-rotor efficiency. The configuration utilizes component technology that is suitable for the Navy's severe operating environment. The funding profile includes a mix of 6.2 and 6.3 funds, with DARPA funding to transition the technology to application.

Findings

This project is an elegant solution to a well-known problem of basic aerodynamics. The utilization of new materials technology in the torsional actuator to solve a Navy operational problem is an excellent example of S&T research. The researchers have blended the technology research with realistic operational requirements by setting the failure mode of the actuator to default for the original V-22 proprotor blade configuration. The mix of funds and leveraging of DARPA funds provides a cost-effective way to meet the Navy's needs.

Recommendations

The committee strongly endorses this project and recommends that it be continued as planned.

Flight Control and Dynamics

This program is focused on naval-unique issues such as control and handling quality in low-speed shipboard approach, automated landing on moving ships with turbulent air wakes, UAV reliability for shipboard operations, and hardware with diagnostics/prognostics for maintenance in a maritime environment.

Findings

This is an important, relevant, and technically excellent program that is well coordinated with the other Services and NASA. The work in efficient, reliable design ("provably stable"), efficient generation of code, verification and validation (V&V)/testing of nondeterministic software, and prognostics and health management integrated with damage adaptive control, is commendable; however, that work remains restricted in application potential by its focus on traditional flight control functions. The joint Navy/Air Force program in automated/assisted maneuvering is focused on UAVs but appears restricted to gently maneuvering flight. The absence of human-based constraints on maneuvering (instantaneous and steady-state G loading, angular rates and accelerations, and the handling qualities criterion, for example) is not being exploited or studied for potential payoff.

Recommendations

The program should be kept focused on naval-unique areas, although some consideration should be given to two new directions in order to enable advanced capability systems in the future. The first direction is extending the science and technology of flight control system design (by means of tools that enable flight safety and reliability) to mission-critical functions, such as those required by more autonomous air vehicles. That would address the very critical need for UAVs to have extremely high mission reliability. The second direction involves enabling aggressive maneuvering of UAVs (and some manned air vehicles) for survivability reasons, by seeking out new combinations of propulsion, aerodynamics, structure, and control that purposely exploit elastic structures interacting with thrust vectoring and unsteady flow fields. Such combinations can also yield very-low-speed, short-distance landings.

Abrupt Wing Stall

This project has the stated objective of developing methodology required to analyze, predict, detect, and prevent uncommanded transonic lateral motions, especially wing drop, for future high-performance aircraft. In particular, it is necessary to understand the aerodynamic phenomena, to develop and validate figures of merit, and to provide guidance on design procedures. The project was instigated by a wing drop problem encountered in the F/A-18E/F, but the knowledge acquired and modeling tools developed in this effort will benefit all future aircraft design. Personnel involved in joint wind tunnel tests with NASA-Langley Research Center and a consortium of computational researchers from government, industry, and academia would form the core team.

Findings

The committee finds that this is the type of problem and project an S&T group needs to be responsive to. Motivated by new aerodynamic phenomena observed on an existing operational aircraft, the project team has undertaken to understand, characterize, and model the phenomena so that the research results can be applied to future aircraft design. It is noted that this project represents an appropriate leveraging of funds across ONR and technological expertise from other government agencies, industry, and academia. What is more, the principal investigator had expertise in the area, a sign that the project was monitored at the appropriate technological level.

Recommendations

Steady-state computational fluid dynamics (CFD) results show some promise and should be continued, with the inclusion of critical unsteady aerodynamic effects. In addition, because of the research finding that root moment is important, aeroelastic evaluation of the configuration is recommended. This project is scheduled for completion in FY02. Research should continue until the physical mechanisms that cause abrupt wing stall—for both notched and unnotched wings—are clearly understood. In addition, the basic research premise of the effort could be justified by releasing the wind tunnel data to the U.S. academic community for more accurate turbulence modeling and unsteady aerodynamics algorithm development. ONR, with NASA cooperation, should also consider expanding the wind tunnel experiments to include parameter variations (e.g., dynamic control surface motion, chordwise fences, dynamic angle-of-attack and sideslip inputs and/or responses, and so on) that could lead to a better understanding of significant unsteady and/or nonlinear interactions. This information should include both steady and unsteady data that are suitable for the development and/or modification of theoretical models as well as for the validation of unsteady RANS, LES, and DNS numerical methods for future aircraft development. However, the specific solution of the abrupt wing stall problem on the F/A-18 E/F should be funded by that program office and not by S&T funds.

Aerodynamics of Advanced Navy Air Vehicles

This program consists of efforts in high-lift aerodynamics, empennage buffet loads prediction, ship-aircraft airwake analysis for enhanced dynamic interface, and VSTOL suckdown, thermal, and acoustic limiting. Although the program was not formally briefed to the committee, the findings and recommendations below are based on the written material that was made available and committee members' knowledge of the program.

Findings

This program appears to focus on important maritime-unique technologies that are required by current and future air vehicles. Low-speed, high-lift aerodynamics and other areas mentioned previously are critical to Navy operations. Furthermore, this program appears to have a good record in transitioning those technologies. Recent program transitions also include other areas, such as aero-propulsion integration technology (for the JSF), stores integration technology (for the F/A-18), and VSTOL ground effect technology (for the V-22). The sources of funding for this work have been largely non-ONR; however, only modest ONR 6.2 funding in FY02 and beyond is proposed.

Recommendations

ONR should ensure that important work in these areas is increased, since it appears to have fallen below a critical level. At a minimum, the Navy needs to recognize some continuing problems—one of which is the lack of robust buffet loads prediction—as well as the potential for future configurations to benefit from technologies that involve tightly coupled, nonlinear aero-structure-controls interactions. The Navy must be a smart buyer in these key areas, and that would require more work in all of them.

It is recommended that current aviation platforms and operational programs of interest to the Navy (V-22, F-18E/F, JSF) be reviewed to identify specific historic problems that would require basic S&T research for their solution and then to propose such research for future S&T funding. In particular the committee believes there is an opportunity to expand the performance envelope of advanced aircraft such as the V-22 through an improved understanding of the aerodynamic processes involved and the interactions that occur in operations near the ground for that unique configuration. Such research would have numerous naval-unique operational benefits. ONR should consider the development of better tools and modeling to help realize the full potential of this research.

Suggested Topics in Air Vehicle Technology for the Future ATP

In addition, the following topics should be considered for the future ATP in this area:

- Research and development should be conducted on the active reduction of vertical tail buffet by use of wing aerodynamic sources rather than on modification of the resulting structural response to the buffeting forces.
- Improvements in high-lift aerodynamics could greatly improve naval air operations, especially by reducing the risk and cost of launch and recovery at sea; furthermore, there is an opportunity now to integrate old concepts with new technology. ONR should take a fresh look at improving the performance of lifting airfoils and bodies when influenced by air flows with energy added. Some aircraft, namely the QSRA, YC-14, and AV-8B, have used air flows with energy added, with marked effect on takeoff and landing characteristics. Such technology development (involving basic research and exploratory and advanced development efforts) would be especially important for the design of extremely short takeoff and landing (ESTOL) vehicles, and the technology could be applied to shipboard tactical aircraft, UAVs, and future logistic vehicles. Innovative propulsion system concepts that integrate productively with these added-energy concepts should also be investigated.
- Since speed of engagement is a key factor in increasing the tempo of combat, and since such speed is limited by aircraft (as well as missile) speed and maneuver capabilities, concepts for

expanding aircraft high-speed capabilities in an affordable manner should be considered. Low-speed performance may be equally critical. ONR should consider extending high speeds to quiet, efficient supersonic cruise and hypersonic flight and low speeds to ESTOL and even routine post-stall flight.

- Maneuvering performance of aircraft and missiles has always been a key parameter in combat. Trade-offs based on human physiological limits have yielded the current concepts and configurations for air vehicle platforms. But now there is an opportunity to rethink and greatly improve aircraft maneuverablity. New aerodynamic and air vehicle concepts should be explored by ONR to exploit the absence of human-based constraints on maneuvering of UAVs and UCAVs to achieve high maneuverability and greatly improved survivability and lethality.

6

Unmanned Aerial Vehicles/ Unmanned Combat Air Vehicles

OVERVIEW

A number of recent studies have pointed out the importance of unmanned aerial vehicles (UAVs) to the future of the naval forces. A multiplicity of cooperating and largely autonomous UAV sensor/communication platforms are integral to the vision of network-centric operations, as was discussed in a recent Naval Studies Board report.[1] In several other recent NSB reports,[2,3] it was pointed out that the Navy currently lacks an adequate organic airborne sensor with the capabilities needed to target many of its long-range precision weapons or to supply defense against overland cruise missiles attacking forces ashore. The rapidly evolving UAV technology could supply these much needed sensor/vehicle capabilities in an effective and economic fashion. There is growing interest from the requirements side of the Navy in encouraging the exploitation of UAVs.

The Navy is pursuing uninhabited combat air vehicle (UCAV) technology in concert with the Defense Advanced Research Projects Agency (DARPA). DARPA approached the Chief of Naval Operations (CNO) directly and proposed a joint DARPA/Navy version of the ongoing DARPA/U.S. Air Force UCAV ATD. Approved by the CNO in 2000 and now called UCAV-N, this joint ATD has been generously funded and is by far the largest UAV technology effort currently under way within the Navy. The UCAV-N program is well focused, is at the forefront of the state of the art, and fully leverages the existing U.S. Air Force (USAF) UCAV experience.[4]

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[1]Naval Studies Board, National Research Council. 2000. *Network-Centric Naval Forces: A Transition Strategy for Enhancing Operational Capabilities,* National Academy Press, Washington, D.C.

[2]Naval Studies Board, National Research Council. 1999. *1999 Assessment of the Office of Naval Research's Air and Surface Weapons Technology Program,* National Academy Press, Washington, D.C.

[3]Naval Studies Board, National Research Council. 2001. *Naval Forces Capability for Theater Missile Defense,* National Academy Press, Washington, D.C.

[4]For further reading on the Department of Defense's history of UAV technologies, as well as a recent review of a Code 351 (6.2) S&T UAV/UCAV effort, see Naval Studies Board, National Researh Council. 2000. *Review of ONR's Uninhabited Combat Air Vehicles Program,* National Academy Press, Washington, D.C.

TABLE 6.1 ONR 351 Aircraft Technology Program Budget for UAV/UCAV-N Through FY02 (millions of dollars)

		FY99	FY00	FY01	FY02
6.1	UAV research	2.4	4.3	4.0	4.0
6.2	UAV research (including CRW)	2.3	3.5	3.9	0.0
6.2	UAV autonomy (AO FNC)	0.0	0.0	0.0	7.0
6.3	UAV autonomy	0.0	0.0	0.0	3.0
6.3	UCAV-N (TCS FNC)	0.0	0.0	0.0	15.0
	Total	4.6	7.8	7.9	29.0

Note: See Appendix C for definitions of acronyms used.

At least 5 of the 12 new FNCs mentioned earlier in this report address UAV missions and technology. The UCAV-N program has been incorporated into the Time Critical Strike FNC. Along with the Autonomous Operations FNC, ONR 35 has an enormous opportunity to rapidly advance UAV/UCAV technology, with early transition as a prime objective.

Three programs with different objectives were briefed to the committee. Each was of a different size and stage of maturity. The Canard Rotor Wing ATD program, begun in FY98, is terminating at the end of this calendar year. The UCAV-N ATD, begun last year, is well into Phase I and showing results, with Phase II to come. The Autonomous Operations FNC, on the other hand, is just moving out of the planning stage with initial funding and is expected to start up in FY02. At the end of this chapter, the committee suggests new topics for the future ATP in this area.

Table 6.1 shows the ONR budget projection for the UAV/UCAV area in the ATP including FNC transitions. Note that in this budget listing, the Canard Rotor Wing ATD is presumably included in the 6.2 UAV research line ending in FY01. Note also that UAV propulsion will be included in the ATP budget for propulsion and power after FY01 (see Table 4.1).

PROGRAMS REVIEWED

Canard Rotor Wing

This project represents the Navy's small contribution to a current DARPA/Boeing ATD program that aims to demonstrate a novel class of aircraft suitable for UAV applications. The canard rotor wing (CRW) concept is a turbofan-powered, reaction-drive (via rotary-wing-tip jets), high-performance VTOL aircraft that uses its jet-driven rotary wing for vertical flight and converts in flight to a fixed-wing mode for fast (400+ knots) forward flight.

The design offers a number of advantages for naval operations, in addition to ship-compatible VTOL capability, including the following:

- A projected flight envelope (altitude vs. airspeed) that exceeds that of the V-22 and helicopters in general,
- A turbofan that uses heavy fuels, which is compatible with ship operations,
- A transmissionless reaction-drive rotor system that offers low maintenance, and
- A potential for signature reduction.

Because of these attractive features, the Navy has been funding a small amount of complementary research and development (R&D) efforts since FY98 to evaluate the CRW concept's suitability for naval applications. The approach involves a comprehensive modeling program for validation and parametric characterization of the full vehicle based on first principles, with an emphasis on structural dynamics, i.e., rotor/fuselage structural interactions and aeroelastic effects. Existing commercial off-the-shelf (COTS) modeling tools (e.g., FlightLab and NASTRAN) are being used.

This ATD is scheduled to end this year, with flight tests to begin in August 2001. The two demonstration vehicles being built for the program will be available to the government for further testing and evaluation after the program ends in December 2001.

Findings

The committee considers that the CRW has several projected vehicle characteristics that will be attractive for naval application and appear to offer significant advantages over traditional VTOL implementations. This ATD seems to represent the first serious attempt to demonstrate the full concept in hardware.

Funding by ONR is quite small—$3.3 million compared with $31 million each for Boeing and DARPA—and limited to general program support (e.g., Navy experience, milestone reviews, risk-reduction experiments, and so on) and the modeling of the vehicle flight characteristics with COTS tools.

In spite of the meager funding, the modeling effort is ambitious, addressing all major components of the vehicle (e.g., rotor/wing, canard, tail, and fuselage) as well as rotor/airframe dynamic coupling and the mutual interference between all lifting surfaces using dynamic wake theory. The models run in non-real time and involve different degrees of fidelity, as appropriate—for example, rigid blade to finite element. Successful correlation of the resulting FlightLab model with experimental data from the DARPA/Boeing team wind tunnel tests was claimed.

While the quality of the modeling effort could not be easily judged from the results briefed and nothing seemed clearly inappropriate, the committee felt that there was nevertheless a certain amount of reinventing-of-the-wheel going on. Under questioning, the presenters acknowledged that they were unfamiliar with other directly relevant aeroelastic modeling efforts under way in industry and academia.

Because this ATD is in its final stages, the plan presented for completing the program seems unrealistically aggressive, with many critical milestones scheduled between now and the end of the calendar year. This is definitely a success-oriented plan and as such will probably not be completed this year. ONR has requested another $300,000 to perform post-ATD flight demonstrations in FY02.

Assuming success of the flight tests, the challenge remaining is to transition the CRW concept into future Navy UAV/UCAV designs or perhaps to position it as a candidate future upgrade for the Navy's helicopter-like vertical takeoff and landing tactical uninhabited aerial vehicle (VTUAV) (planned as the Pioneer replacement), currently under contract for engineering and manufacturing development. Few such near-term opportunities are evident.

Although nothing was said at the review, it appears that the CRW program at DARPA represents only half of a broader exploration of "innovative vertical takeoff and landing (VTOL) concepts" to support the Navy and Marine Corps need for "affordable, survivable, VTOL UAVs to support dispersed units in littoral and urban areas."[5] The overall program is known as the Advanced Air Vehicle (AAV) program and is said on the above-mentioned DARPA Web site to be a partnership between DARPA,

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[5]Defense Advanced Research Projects Agency. 2001. "Tactical Technology Office (TTO) Programs—Hummingbird Warrior," Arlington, Va., August 13. Available online at <http://www.darpa.mil/tto/programs/hum_war.html>.

ONR, and industry. The AAV program has two components. The first is the CRW ATD just discussed and targeted for completion by the end of FY01. The second is the Hummingbird A160, or Hummingbird Warrior, scheduled through FY04. The A160 exploits a hingeless, rigid rotor concept to produce a VTOL with efficient low-power loiter and long endurance capabilities. On its Web site, DARPA describes the CRW and the A160 as being explored for surveillance and targeting, communications and data relay, lethal and nonlethal weapons delivery, assured crew recovery, and special operations missions in support of Navy, Marine Corps, Army, and other agency needs.[6] In summary, the DARPA Hummingbird A160 effort, while not as advanced as the CRW effort, offers the potential of longer range and greater endurance than the CRW.

Recommendations

The committee recommends that the CRW flight test program be supported to completion in FY02 but should then be transitioned out of S&T. Additional funding for the program may be required in FY02 since the flight test program will probably last longer than currently planned. The committee recommends no further development dollars be spent beyond the completion of the currently planned flight test program. If the test is successful, any follow-on efforts should focus on identifying real transition opportunities. VTUAVs and multirole endurance (MRE) UAVs do not seem to be real near-term transition opportunities as MRE may never happen and VTUAV is already defined and contracted. For future Navy UAV/UCAV developments, however, the demonstrated CRW concept definitely should be considered.

As a partner in the A160 effort, ONR should pay a great deal of attention to the technologies and capabilities of the Hummingbird A160, incorporating its concepts into future Navy UAV/UCAV developments as soon as they have been successfully demonstrated by the AAV program.

Unmanned Combat Air Vehicle–Navy

The goal of the Unmanned Combat Air Vehicle-Navy (UCAV-N) ATD program is to demonstrate the technical ability of a UCAV system to effectively and affordably prosecute sea-based surveillance, suppression of enemy air defense (SEAD), and strike missions within the emerging global command and control architecture. The 6-year program is well funded at $156 million—split equally between DARPA and the Navy—and emphasizes factors that are unique to the Navy, e.g., the desirability of ship-based launch and recovery and general compatibility with existing Navy infrastructure and CONOPS.

The program was approved by the CNO in January 2000 and later incorporated into the Time Critical Strike FNC. Both Boeing (the Air Force prime contractor) and Northrop Grumman are under contract for Phase I, with a Phase II execution decision scheduled for early FY02. The current strategy is to retain both contractors for the full program, i.e., through Phase II, scheduled to end in FY04.

Findings

The committee was impressed by this program and by the enthusiastic technical support team leader, who seemed remarkably well informed on all technical aspects of the program. This is an excellent program that is well structured and aggressive, with realistic and meaningful goals. The

[6]Defense Advanced Research Projects Agency. 2001. "Tactical Technology Office (TTO) Programs—Advanced Air Vehicle (AAV)," Arlington, Va., August 13. Available online at <http://www.darpa.mil/tto/>.

UCAV-N effort consciously complements the Air Force's program. Naval-unique issues are of prime importance, particularly carrier deck operations and integration with the Navy command, control, communications, computing, and intelligence (C4I) infrastructure.

Phase IA of the two-phase program was devoted to a systematic progression from UCAV mission simulations to concepts of operations, conceptual design of operational vehicles and systems, trade-off studies of effectiveness and affordability, and the identification of critical technologies, processes, and system attributes. Phase I was completed on March 31, 2001, and the program is progressing steadily toward the final Phase II demonstrations of such things as air vehicles, a multiple-air-vehicles mission-control system for strike and SEAD, robust and secure C3, and related vehicle health and logistics support systems.

The two selected airframe contractors, Boeing and Northrop Grumman, are exceptionally well qualified. Boeing's role as the UCAV-A prime contractor and Northrop Grumman's as the Navy's VTUAV contractor assure the explicitly intended leveraging of the DARPA/USAF UCAV ATD and provide a good understanding of naval-unique UAV/UCAV issues.

The tough part of UCAV is not the airplane; it is the technologies that enable an unmanned system as part of an integrated military operation. The UCAV-A ATD has made excellent progress in defining a set of technologies required for achieving an operational UCAV capability, but it will go only a very short way toward developing and demonstrating those technologies, because it is rapidly becoming consumed with development and demonstration of the airplane.

Recommendations

The committee strongly endorses the UCAV-N program but recommends that it maintain a strong focus on the technologies that enable the UCAV to be part of a naval operation, namely, its ability to be integrated into the existing command, control, and communications (C3) infrastructure and carrier deck operations.

In general, the committee recommends that the UCAV-N program continue to pay close attention to what UCAV-A will not develop and focus its efforts and demonstrations in those areas.

Unmanned Aerial Vehicle Autonomy

Scheduled to begin in FY02, the Autonomous Operations FNC is planned to be adequately funded. It addresses four topics: UAV autonomy (total $10 million/yr), UAV propulsion ($1.5 million/yr), unmanned ground vehicle autonomy ($5 million/yr), and an unmanned underwater vehicle program ($15 million/yr). Only the UAV autonomy portion was presented to the committee.

The generic objective of the Autonomous Operations FNC is to develop technologies that will dramatically increase the performance and affordability of naval organic unmanned vehicle systems. The UAV autonomy program, in particular, seeks to produce an autonomous, intelligent, real-time surveillance and reconnaissance capability that will permit UAVs/UCAVs to perform various missions with effectiveness comparable to that of manned aircraft yet with a greatly reduced need for human intervention. Long-term goals look to the development of an autonomous vehicle control capability that not only flies the aircraft but is also capable of distributed, collaborative operations with other unmanned and manned aircraft, planning in the face of uncertainty, independent action/adaptation, and situation- and self-awareness—all with minimal human intervention.

To implement this ambitious UAV/UCAV vision, ONR plans a combination of support contractors, various workshops and working groups from industry, academia, and government, and a broad area announcement (BAA) that has just been issued. Included in the plans are in-depth assessments of current autonomy-related activities throughout the military and defense contractor community. Leveraging this base of existing knowledge, requirement definitions and system design concepts are to be established, leading to an intelligent autonomy systems architecture for UAVs/UCAVs. As currently envisioned, these efforts culminate in a series of time-phased demonstrations of risk reduction technology that sequentially address situational awareness, multivehicle collaboration, and intelligent autonomy. The term "intelligent autonomy" seems to encompass the complete range of autonomous man-machine combinations—from total operator control to fully autonomous, no-link operation, including all of the mission and task capabilities proven in the first two risk reduction demonstrations.

Findings

The committee found the Autonomous Operations FNC to be a program in its infancy. The program offers laudable, elevated goals described in such terms as autonomous, intelligent, real-time, distributed, collaborative, dynamic, unstructured, independent, self-aware, intelligent adversary, and capable of operating on their own in controlled airspace (civil and military). However, in spite of the substantial level of funding projected (~$14 million/yr of 6.1, 6.2, and 6.3 combined), no details of how these objectives are to be attained were provided to the committee.

It was pointed out to the committee that a BAA had been issued with a response date of August 10, 2001.[7] However, the descriptions of the areas of interest are so generic (i.e., "new and innovative research . . . which will advance UAV autonomy systems technology required by future UAV missions") that the BAA is basically a call for creative concepts. Apparently the Autonomous Operations FNC program is to be detailed after the BAA responses are received. While good ideas can be obtained by means of BAAs, there is considerable risk in not having a better definition of requirements at this stage of a major FNC.

The overall program is to be a sequence of three demonstrations, with increasing levels of integration. If well chosen, these demonstrations can provide the needed structure. However, these planned "technical capability/products" demonstrations seem to be somewhat misdirected. That is, the first two overemphasized various sensor (e.g., data processing, ATR, displays) and communication (e.g., data relays, networking) capabilities and issues that have little or nothing to do with whether manned or unmanned vehicles are involved. These two demonstrations, as presented, touch on autonomy only peripherally. There is an abrupt jump in the third demonstration into the ultimate state of intelligent autonomy, with fully developed dynamic, autonomous in-flight replanning and threat reaction without link operation. Clearly this conceptual structure for the UAV portion of the FNC needs to be rethought and oriented more closely to the real problems of autonomy.

Recommendations

Autonomous operation certainly merits an investment, but the current acquisition strategy in UAV autonomy has serious problems. The program has very limited resources for attacking what is a very broad and deep set of problems. For ONR to expect to have any impact at all, the committee recommends a dramatic narrowing of the UAV autonomy focus within the FNC.

[7]Mersten, Gerald, Office of Naval Research. 2001. "Research and Science & Technology (RS&T) in Unmanned Aerial Vehicle (UAV) Autonomy," *Commerce Business Daily*, Solicitation Number: BAA 01-017, May 15.

For example, hundreds of millions of dollars have been spent to date on the development of automatic target detection, recognition, and identification technologies and other automated exploitation technologies. These technologies apply to any surveillance and reconnaissance system, whether unmanned or manned. ONR's limited investment will not make a dent in this effort, nor is it a technical area uniquely required to enable unmanned capabilities. The committee recommends that ONR not fund such surveillance and reconnaissance efforts under UAV autonomy in the AO FNC.

Global Hawk, VTUAV, Time Critical Strike (TCS), Predator, the Army's TUAV, and the Air Force and Navy UCAV programs are developing myriad technologies for autonomous navigation, vehicle management, and sensor management. The committee also recommends that the work of the Air Force Studies Board summer study on automation in combat aircraft[8] be considered in the formation of the ONR program. The committee recommends that ONR exploit advances made by others in autonomous navigation, vehicle management, and sensor management and that it sharply curtail additional investments in these areas.

Investment is needed in such key areas as decision aids for command and control (C2) and rapid, adaptive mission planning and execution to respond to changing environments. The programs mentioned above have just scratched the surface in developing key technologies in these areas, yet these technologies will ultimately determine how effective UAVs become in future military operations. The committee therefore recommends that ONR concentrate its efforts in UAV autonomy on the challenging deficiencies in decision aids for C2 and rapid, adaptive mission planning and execution, reexamining the proposed sequence of demonstrations to achieve the proper focus. There are also significant doctrinal and policy issues that must be addressed for both strategic and tactical UAVs with attack capabilities. There is a tremendous amount to be learned from ongoing UAV developments that could help to sharpen the focus of the investment. The committee recommends that the key people in those programs be involved with prioritizing and selecting technology focus areas.

With respect to the BAA that has just been released, the committee recommends that there be a clear definition of the awardees' relationship with, and involvement in, the planned focused demonstrations for 2003 and beyond. The idea was to bring the successful developers together in three focused demonstration events to quantify the benefits of different technologies. Without a clear sense of what the individual awardees are to design to, it is hard to imagine how this can happen. An integrated demonstration, just like an integrated system, requires interfaces and specifications to be defined first, to avert chaos. Without clear upfront definition of what is expected, white papers and proposals will probably be meaningless. The committee recommends that ONR slow down the BAA process to allow defining the demonstration platforms and venue more precisely and redefining the demonstrations to sharpen the focus on critical autonomy issues.

Also, if the VTUAV is to be used as a demonstration platform, a firm relationship needs to be established with Northrop Grumman, builder of the VTUAV, to ensure a clear pathway for integration of the technology/system provided by an awardee. The committee recommends that the VTUAV platform builder have at least an associate contractor relationship with the developer; otherwise the government will be in the position of being the integrator—a task that government has proven time and again it is ill-equipped to perform.

Accordingly, the committee recommends that ONR not fund areas, such as automatic target recognition, that other agencies are addressing with far greater resources. Rather, it should address key areas

[8]Committee on Automation in Combat Aircraft, Air Force Studies Board, National Research Council. 1982. *Automation in Combat Aircraft,* National Academy Press, Washington, D.C.

such as decision aids for C2 and rapid, adaptive mission planning and execution. The committee further recommends that the demonstrations planned as part of a new BAA need to be far better planned and defined to focus on critical autonomy issues. The committee also believes that ONR would benefit substantially from a thorough review of projected goals, technology transition potential, and the associated technical, operational, and financial risk. This review should be conducted by an independent panel of highly qualified individuals and undertaken with consideration of inputs obtained from the BAAs.

Furthermore, in spite of the critical importance of reliable autonomous behavior for future manned and unmanned naval systems, autonomy, as a technological discipline, remains diffuse and immature. Recently, in the commercial world, flexible and autonomous software systems have begun to emerge for such applications as e-commerce, logistics, and manufacturing hosted in distributed computing environments. Many of these products may apply to naval needs, and while ONR would be wise to leverage and complement these development efforts for its own applications (rather than compete directly), the technology underlying autonomous systems appears to be relatively unstructured and undocumented.

The current state of the art seems to be little more than a collection of ad hoc techniques—e.g., software agents, data fusion, adaption and learning, image understanding, behavior-based intelligence metaheuristics, and so on.[9] These proposed components of autonomy technology show little obvious relationship to one another. The underlying mathematical and engineering principles that unify these topics are not at all evident. In addition, current practice for the design of autonomous systems appears to be based on heuristic rather than structured approaches and the underlying philosophy is rarely, if ever, adequately documented.

Without question, these are difficult issues—particularly the identification of fundamental unifying principles—and may not be easily resolved, but they would seem to be worthy of attack. While the commercial world will no doubt address some of these issues, it is not motivated to freely distribute the resulting information, for obvious reasons.

Suggested Topics in UAV/UCAV for the Future ATP

The committee also offers for consideration as part of the future ATP in this area three S&T topics:

- A small, but focused, 6.1 effort addressing the fundamental technology issues of autonomy—namely, the identification, structuring, and documentation of the mathematical and engineering principles that are inherent in the concept of autonomous behavior of complex military systems. This should not be thought of as an effort by a large team, because it is by no means a straightforward engineering task. Rather, the team can hope to succeed only if it is small and consists of the appropriate, knowledgeable contributors. This is definitely a long shot but worth the attempt, because someone should be thinking about fundamentals in this important arena.
- Another task of interest would be the development, documentation, and publication of guidelines for the structured design of autonomous systems. This would be extremely useful to the Navy and the whole autonomy community, even if the techniques employed remain largely heuristic. It should include such things as the fundamental concepts and proven system architectural options

[9]Naval Studies Board, National Research Council. 2000. *Review of ONR's Uninhabited Combat Air Vehicles Program,* National Academy Press, Washington, D.C., pp. 20-26.

and design practices, including the introduction of meaningful figures of merit for trading off such parameters as machine versus human functionality.

- Because of the need for mission performance to be highly reliable—perhaps as reliable as safe manned flight—the fault tolerance and fail-safe characteristics of all flight-safety-critical control technologies on UAVs and UCAVs should be extended, as required, to ensure that mission-critical functions are performed reliably.

7

Survivability

OVERVIEW

All new Navy platforms have signature reduction as a requirement. Many existing Navy platforms that were designed without signature control in mind can still have their signatures reduced. This is true for all five of the platform signatures—radio frequency, infrared and visible spectra, acoustic, visual and electromagnetic, and gaseous and particulate emissions. Low-observable (LO) technology refers to the science of signature reduction technology and its application to a platform. Much in this area has been highly classified, for obvious reasons. However, in the past few years, DOD has revised its classification guide and has allowed much more discussion at lower classification levels in many areas.

Table 7.1 gives the ONR's current budget and projection for the ATP survivability area.

PROGRAM REVIEWED

Low-Observable Technology Development

The ONR 6.2 program in LO technology development presented only a few efforts in the area of susceptibility. Survivability includes susceptibility (technologies and tactics to avoid being hit) and vulnerability (technologies and systems that allow survival after being hit). ONR did not present any

TABLE 7.1 ONR 351 Aircraft Technology Program Budget for Survivability Through FY02 (millions of dollars)

	FY99	FY00	FY01	FY02
6.2 LO	3.6	3.6	4.4	4.1

technology programs on vulnerability (the other component of survivability), nor did it present an overview of all susceptibility technologies. The ONR 6.2 program presented appeared to be one part of a very large technology area. The ONR 6.2 program in survivability was presented by PMR 351, which reports directly to the Chief of Naval Research, even though survivability is listed as a thrust area in ONR 351. The committee looked for but could not find any evidence that LO technology has migrated into the other technical areas under ONR 351 or into any of the other ONR divisions.

Findings

Based on what was presented, it does not appear that the Navy is proceeding along the path outlined in Joint Vision 2010 and in the Naval Studies Board report *Technology for the United States Navy and Marine Corps, 2000-2035*.[1] Both state quite clearly that signature reduction is a key enabler of combat leverage, because it collapses the decision and reaction time lines, and that it should be incorporated into all future systems. An integrated vehicle design that includes signature reduction demands engineering skill and technical expertise in vehicle shaping, vulnerability reduction (damage resistance, damage tolerance), propulsion components, air data systems, high-lift devices, materials, sensors, avionics, and tactics. There was no discussion of such considerations in any of ONR 351's presentations on its Aircraft Technology Program.

The committee did not review any Navy 6.3 LO technology development, although the ONR 6.2 program indicated that most efforts were linked to follow-on work. The committee did not review any LO technology development that is under way in other Services or agencies. It may be that these other efforts are very well coordinated from a technology discovery perspective. However, it was apparent to the committee that there was minimal awareness and knowledge of reduced signatures technologies in ONR. Keeping LO tightly classified when it no longer needs to be will have an impact on the effectiveness of FNC technology thrusts and put the Navy a step behind the Air Force in technology advances that improve susceptibility.

Even though the individual 6.2 LO technologies examined appear well conceived and appropriate, this committee found that the survivability technology program is not focused, nor is it a system-level R&D effort targeted at wideband integrated vehicle designs.

Recommendations

The committee recommends that ONR, through changes in organization, alignment, and the program development process, should integrate signature reduction knowledge and awareness across all relevant technology pursuits. Furthermore, ONR should initiate funding of advanced development efforts at the 6.3 level that would integrate the various survivability technologies into a system.

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[1]Naval Studies Board, National Research Council. 1997. *Technology for the United States Navy and Marine Corps, 2000-2035: Becoming a 21st-Century Force,* National Academy Press, Washington, D.C.

8

Special Aviation Projects

OVERVIEW

The special aviation projects thrust is essentially a management umbrella for coordination, administration, and technical review of system-level efforts involving substantial funding. Currently this thrust consists of two projects, the impetus for which came from outside the normal ONR program development process: (1) vectoring extremely short takeoff and landing control, tailless operational research (VECTOR) and (2) vectored thrust ducted propeller (VTDP) compound helicopter. Table 8.1 gives the ONR budget projection for the ATP special aviation projects area.

Funding required for special aviation projects is estimated to total $79 million from U.S. sources over 5 years and, as of June 2001, $57 million is needed to complete the planned work. Table 8.1 does not contain any provision for this shortfall in FY02. Importantly, funding for special aviation projects (see Tables 1.1 and 8.1) constitutes a large portion of the Aircraft Technology Program budget—39 percent in FY01, for example. The funds come principally from within the Navy, with ONR being the main contributor. Like all government programs, the VECTOR and the VTDP compound helicopter projects are subject to the vagaries of the annual budget process. And further, it is not clear whether all the objectives of the two projects can be fully achieved within the current funding plan.

TABLE 8.1 ONR 351 Aircraft Technology Program Budget for Special Aviation Projects Through FY02 (millions of dollars)

		FY99	FY00	FY01	FY02
6.3	Special projects	8.1	20.0	21.5	5.1
6.2	Special projects	4.9	0.0	0.0	0.0
	Total	13.0	20.0	21.5	5.1

PROGRAMS REVIEWED

Vectoring Extremely Short Takeoff and Landing Control, Tailless Operational Research

VECTOR is a technology development and demonstration program that will employ the X-31 flight test vehicle to achieve three loosely related goals:

- Demonstrate extremely short takeoff and landing (ESTOL),
- Flight test the German-designed advanced air data system (AADS), and
- Analyze, design, install, and flight test a reduced-tail or tailless X-31 configuration.

The project's X-31 aircraft was originally fabricated and used for the enhanced fighter maneuverability (EFM) program, a NASA/DOD cooperative effort with Germany that was completed in 1995. The earlier program focused on slow speed, high angle of attack, and maneuvering at altitude and demonstrated the tactical advantage of a fighter equipped with a vectoring nozzle for post-stall flight control.

Recognizing that naval aviation operates in a STOL environment characterized by catapults and arresting gear, VSTOL aircraft like the AV-8B, and extensive use of rotorcraft, the idea of employing the X-31 for an ESTOL evaluation was advanced. The hope was that data from such a demonstration would contribute significantly to the body of knowledge supporting development of STOL concepts. Candidate platforms for improved STOL performance include F/A-18E/F and JSF derivatives, any new manned aircraft design, and unmanned air vehicles such as UCAV-N and the MRE UAV.

Planning for VECTOR began in 1997, a cooperative agreement with Germany was signed, and project operations commenced in 1999. The test vehicle was brought out of storage, restored to operational condition, and underwent a non-ESTOL safety-of-flight test in February 2001.

ESTOL Goal

The ESTOL phase of the project has as its goal demonstrating one technique for reducing aircraft landing speed. Lower landing speeds would facilitate tactical air operations from smaller carriers and smaller airfields or, alternatively, permit takeoffs and landings from existing bases with increased gross weights. The ESTOL task involves employing the X-31, a test vehicle originally designed for slow-speed maneuvering flight at altitude, to evaluate a slow-speed, short landing and roll-out technique. The proposed landing procedure calls for transitioning from normal flight to a near-stall, very nose-high attitude and then executing a slow-speed, controlled rate of descent on a 3- to 5-degree glide slope. To permit the plane to land on its main landing gear and prevent the tail from striking the deck, the approach ends with a pitch down (de-rotation) at a precise moment just prior to touchdown. The desired result is reduction of the X-31's landing speed from its normal 170 knots to as low as 100 knots.

AADS Goal

The goal of the AADS portion of VECTOR is to design, develop, install, and flight test, in a modified X-31 nose cone, an advanced air data system that replaces the current probe employed on most aircraft. By positioning the sensor away from the influence of the vehicle's local flow field, the system will provide accurate air data during all types of aircraft maneuvers, including those in stalled, high-angle-of-attack flight, without degrading normal fighter operational capability.

Tailless Goal

This project goal calls for installation and flight test of a reduced tail or tailless design equipped with a multiaxis thrust vectoring nozzle in lieu of the paddles used for the original EFM program. As presently structured and funded, however, it appears this effort will be limited to analysis and wind tunnel testing of reduced-tail configurations working in concert with thrust vectoring to provide control and stabilization. Although the payoffs of a reduced tail or tailless design are well known (they include lower aircraft weight, drag, and radar cross section), to date there have been no flight tests of tailless manned tactical aircraft.

Funding

As presented to the committee, funding required for VECTOR by the United States and Germany totals $78.6 million, with the U.S. share being $47 million. This figure does not cover development, installation, and flight test of a reduced-tail design. A quarter of the U.S. funds will come from NATO R&D accounts (Nunn-Warner); the remainder will come from internal Navy dollars garnered from acquisition programs and the ONR S&T budget. To date some $17 million of U.S. funds have been spent, with an estimated $30 million required to complete the project by FY03. Table 8.1 does not contain any provision for the shortfall.

Findings

The committee believes VECTOR is an appropriate ATP endeavor and the kind of S&T project ONR should pursue. This view affirms a prior conclusion of the Naval Studies Board that identified STOL as a key enabling technology meriting increased attention by the Navy. In its 1997 report, the NSB observed that an affordable STOL capability will require substantially improved flight stability and control at slow speeds and urged a follow-on to the X-31 EFM effort to explore multiaxis thrust vectoring and integrated flight and propulsion controls.[1] Although the X-31 is not representative of an operational aircraft, a properly structured and executed VECTOR project could yield data that would benefit current aircraft and influence the design of future manned and unmanned systems.

It is clear to the committee that ESTOL is the key, pacing element of VECTOR. While the AADS and Tailless research tasks may be interesting and worthy subjects of inquiry, with the exception of multiaxis thrust vectoring they appear to be ancillary and secondary in importance to ESTOL and would not in themselves justify starting or continuing a VECTOR project as presently defined. AADS data could be collected using other platforms if necessary. And as for benefits of the Tailless task, considerable flight and simulation data from Navy and Air Force programs are already available, and more will be forthcoming in the future.

The ESTOL landing maneuver involves high technical and operational risk. The slow-speed, nose-high approach demands good flight control authority, particularly for directional stability under certain wind conditions and in turbulence near the ground, as well as a reliable, very precise aircraft-to-surface ranging device to facilitate the critical, final derotation at touchdown. This risk could be mitigated

[1]Naval Studies Board, National Research Council. 1997. *Technology for the United States Navy and Marine Corps, 2000-2035, Vol 6: Platforms*, National Academy Press, Washington, D.C., pp. 60-62.

somewhat by employing a multiaxis thrust vectoring nozzle, which the committee understands was originally planned, in lieu of the current EFM paddles. Further, the reward aspect of the risk/reward equation, which governs most R&D decision making, would be strengthened because ESTOL flight data garnered from an X-31 with a true multiaxis nozzle would be more akin to data from an operational aircraft design. The committee is mindful that such a change in project direction would induce delay and increase cost. However, there appears to be no urgent need for ESTOL data, and the data's utility would be significantly enhanced if generated by a test vehicle equipped with a proper thrust-vectoring nozzle. In sum, incorporating a multiaxis thrust-vectoring nozzle in the X-31 ESTOL configuration would reduce risk while increasing the project's reward potential.

The VECTOR project undergoes periodic internal reviews by teams made up of representatives from ONR and the Naval Air Systems Command but does not undergo reviews by external panels of highly qualified experts with no connection to the project team, NAVAIR, or ONR.

Recommendations

The committee recommends that ONR convoke a comprehensive review of VECTOR by an independent panel of outside experts for the purpose of evaluating project goals and technology transition potential, assessing technical, operational and financial risk and determining the need for restructuring where appropriate. Further, the committee believes serious consideration should be given to incorporating a multiaxis thrust vectoring nozzle in the ESTOL X-31 in order to reduce technical and operational risk and generate flight data more representative of an operational aircraft design.

Vectored Thrust Ducted Propeller Compound Helicopter

The stated objectives of the VTDP compound helicopter ATD are to assess the potential for a VTDP-equipped compound helicopter to improve the speed, range, and survivability of naval aviation rotorcraft while reducing ownership cost. And since the demonstration aircraft will be substantially modified, a key aspect of the ATD is to determine the impact of the wing and increased weight on hover performance.

The concept, to be demonstrated by the Piasecki Aircraft Corporation, is a refinement of an earlier one—the Pathfinder of 1962 to 1965—with the principal difference being the VTDP tail thruster, which is said to be a more efficient design. The ATD calls for substantial modifications to the YSH-60F test vehicle, including (1) installation of a wing for added lift in cruise flight and to reduce rotor loading, (2) the VTDP for directional control as well as added thrust in cruise flight, and (3) a third engine to compensate for additional aircraft weight (empty) induced by the required alterations and to generate more thrust for faster, higher-gross-weight flight.

Regarding ownership or life-cycle costs, Piasecki believes its VTDP compound design would result in cost reductions across all H-60 mission areas, attributing the lower cost to decreased vibration in all flight modes and better specific range in cruise flight. The reduction in vibration is said, in turn, to increase airframe and rotor life, while a partially unloaded rotor in cruise flight induces less wear on bearings and rotating mechanisms. Considerable disagreement exists between the government and the contractor over these claims of potential improvement. Hence, an important goal of the project is to determine the impact on life-cycle cost of the VTDP compound helicopter design. And here, costs are very much determined by the type of mission flown—a typical short-range "lifting" mission characteristic of Navy helicopter operations or long-range cruise flight typical of commercial operations and Marine Corps ship-to-objective inland penetration.

Compound Helicopter Concepts

The DOD and U.S. helicopter manufacturers extensively studied compound helicopter technology from the late 1940s to the mid-1980s, and several flight demonstrations were funded, principally by the Army. The results of such tests indicate that, if increased speed is a priority requirement, then compounding does offer an advantage over the conventional helicopter. This increase in speed does not come without penalty, however. If a compound helicopter must be used for short-range lifting missions, its efficiency is diminished and operating costs increase.

In the early 1990s the Army looked in detail at a Piasecki compound concept similar to that proposed for the current ONR project, committing $10.7 million to doing so. Engineering and mission studies, wind tunnel tests, and piloted simulations were conducted, with the AH-64 as a potential candidate platform. While concluding that the Piasecki design had some positive attributes, the negatives were said to outweigh the positives, and the Army was unable to envision a unique requirement that the concept might satisfy.

ATD Technical Approach and Status

The current ATD was preceded by earlier exploration of the concept by the Navy Department, with the Marine Corps AH-1W as the candidate platform. Beginning in FY92 and carrying on from previous work for the Army, Piasecki was given $10.2 million by the Navy to ground test a VTDP for the AH-1W. But after the Marines fixed on the AH-1Z as their future attack helicopter, Congress directed a shift in FY99 from AH-1W to H-60 as the VTDP candidate, and $6.6 million in bridging funds were allocated for risk reduction and fabrication of a flightworthy VTDP. In total, $16.8 million in Navy funds had been invested in the VTDP compound helicopter concept before initiation of the ATD in FY00.

The technical approach is to employ design, analysis, and simulation, leading to fabrication, component ground testing, and installation on the test aircraft of the VTDP assembly, lifting wing, added engine, modified drive train, and a new flight and propulsion control system. The YSH-60F will then be subjected to a series of ground tests to validate the proposed concept and its readiness for flight. Flight testing will be approached in two steps: (1) a VTDP-only test of the aircraft without the lifting wing installed and (2) if step 1 is successful, testing the aircraft equipped with both VTDP and lifting wing to validate contractor claims of enhanced performance and reduced ownership costs. The products or deliverables resulting from the ATD will be a Navy YSH-60F equipped with Piasecki VTDP compound helicopter components, flight testing, and the resultant flight test data.

The ATD commenced formally in FY00 and is scheduled for completion in FY05. Since the change, in FY99, to the H-60 as VTDP platform candidate, the following have been accomplished: (1) ground test of the VTDP, (2) ATD master plan, and (3) initiation of design and fabrication of certain system components. As briefed to the committee, the funds required over the life of the ATD total $31.8 million, with some $4 million expended as of June 2001 and an estimated $28 million needed to complete project work. Table 8.1 does not include funds for this shortfall.

The original rationale behind the Navy's commitment to the ATD was the hope that a VTDP compound variant of the H-60 Seahawk might be suitable as an airborne mine countermeasures (AMCM) platform in the event the standard H-60 was unable to perform the mission. However, that prospect for employment was dashed when, after flight tests in February 2001, the Navy concluded the standard Seahawk was capable of performing all aspects of the AMCM mission.

Findings

A compound design is inherently more complex, heavier, and more costly to acquire than a conventional helicopter with the same lift capability. Hence, the argument for compounding turns on the degree of increased speed sought and the mission range requirement. And because top priority to date has, in the main, been placed on lifting ability rather than speed and specific range, no compound scheme derived from a conventional helicopter design has been introduced into operational service in either the commercial or military world. The tilt-rotor and tilt-wing compound concepts do offer marked advantages over conventional helicopters in speed and in specific range for long-distance missions, to such a degree that the former is about to enter military and commercial service.

Under normal circumstances the committee believes there should be only moderate technical risk associated with the proposed Piasecki concept, because lifting wing concepts are not new to the rotorcraft world, a VTDP-like concept flew successfully in the 1960s, and the current VTDP has undergone wind tunnel testing. However, the YSH-60F test vehicle is to be modified not at Paisecki facilities but at the Naval Air Warfare Center, Patuxent River, Maryland, by non-Piasecki contract engineers and technicians. This raises the prospect of ambiguity in management responsibility, with an attendant increase in technical, financial, and programmatic risk associated with execution of the ATD as now planned. Further, it insinuates an unusually high degree of intervention and supervision by the government during the course of aircraft modification and flight test. Here, the degree of risk is contingent on the competence of the contracted engineers and technicians and on how ATD work is to be managed.

Finally, technology transition potential should be an important consideration for initiation and continuation of any S&T program or ATD. The committee is concerned that, even if the planned VTDP compound helicopter demonstration is successful, no candidate platform exists today or can be foreseen in the future that might benefit from incorporation of the technology. Navy H-60s rarely undertake missions involving long-range cruise, where the Piasecki concept might offer some advantage; rather, their modus operandi is characterized by fairly short runs and frequent takeoffs and landings, where a regular helicopter is more efficient. And for long-range missions, a tilt-rotor aircraft such as the V-22 can fly much faster than any lifting wing compound helicopter and has superior specific range as well. Hence, the committee cannot see the reward aspect of the risk/reward consideration mentioned earlier in this report. It therefore believes naval aviation and the government overall would be better served if the funds planned for this ATD were applied to satisfy other, more pressing needs in support of naval aircraft technology development.

Recommendations

Because of cost-benefit considerations, program risk, and most important, the lack of a foreseeable requirement in the Navy and Marine Corps for a VDTP compound helicopter, the committee believes the sizable funding now allocated for this project (roughly 20 percent of the ATP) could be more beneficially utilized in pursuing higher-priority technology development efforts. Accordingly, the committee recommends that the VTDP compound helicopter ATD be terminated and unexpended project funds applied elsewhere within the ATP.

Appendixes

A

Biographies of Committee Members and Staff

Joseph B. Reagan, *Chair,* an independent consultant, is retired vice president and general manager of research and development at Lockheed Martin Missile and Space and was a corporate officer of the Lockheed Martin Corporation. Dr. Reagan, a member of the NAE, has a strong background in defense technology development, particularly in optics, electro-optics, information software, guidance and control, electronics, cryogenics, and materials. As general manager of the R&D Division, he led over 750 scientists and engineers in the development of advanced technologies in these fields. Dr. Reagan is also a fellow of the American Institute of Aeronautics and Astronautics. Today, he is chairman of the board of Southwall Technologies, Inc., a high-technology company specializing in the manufacturing of thin-film coatings for high-performance residential, industrial, and automotive windows. He is also a director on the board of the Tech Museum of Innovation, where he is the chairman of the Exhibits Committee. He is involved in numerous activities that foster the improvement of science and mathematics education. Dr. Reagan is currently vice chair of the NSB.

John M. Borky is chief scientist at Tamarac Technologies, a consulting firm that provides technical services in electronic technology, system architecture, and strategic planning to both government agencies and industry. Dr. Borky's career spans a broad range of government and commercial service in areas relating to integrated avionics, electronics, and weapon system architecture for advanced military aircraft and sensors. During a 25-year U.S. Air Force career, he played a key role in the development and application of the advanced electronic technologies that enable next-generation systems such as the F-22 Raptor Advanced Tactical Fighter and RAH-66 Commanche helicopter. In addition, Dr. Borky served as commander of Rome Laboratory, the U.S. Air Force's "superlab" for command, control, and communications. Today, Dr. Borky serves on many government and scientific advisory boards, including the U.S. Air Force Scientific Advisory Board.

Carl S. Carter is senior manager of signature integration at Lockheed Martin Aeronautics Company, where he is responsible for general management of radio frequency, infrared, and visual low observable technologies across the company. (In 2000, the Lockheed Martin Aeronautics Company was formed by the merger of the Lockheed Martin Advanced Development Company [known as the Skunk Works], the Lockheed Martin Aeronautical Systems Company [in Marietta, Georgia], and the Lockheed

Martin Aircraft Tactical Systems Company [in Fort Worth, Texas].) Before joining Lockheed in 1979, Mr. Carter worked at Vitro Laboratories, where he helped design shipboard weapon systems for detecting, tracking, and engaging small targets in clutter (i.e., counter low observables). During his tenure at Lockheed, he has worked on numerous cutting-edge aircraft programs, including the A-12, AX, F-22, and F-117 (used in the Gulf War). Mr. Carter has served on numerous government and scientific advisory boards, including the B-2 Blue Ribbon Committee sponsored by the U.S. Air Force and Low Observable/Counter Low Observable Technology Working Group.

Robert W. Day is director of business development operations at the Raytheon Company. Mr. Day's background is in combat C4I systems. He joined Raytheon through its merger with the Hughes Aircraft Company, where he was deputy manager of defense systems. Prior to joining Raytheon, Mr. Day served in the U.S. Navy for 26 years, during which time he flew A-6 aircraft combat missions in both Vietnam and Libya. In Washington, Mr. Day served on the OPNAV staff as a requirements officer for air warfare and a division manager for technology requirements. His last duty assignment was director of stealth and counterstealth technology, where he was responsible for all technology developments, testing, technology transfer, security, export policy, and inter-Service contacts in the area of stealth and counterstealth.

Alan H. Epstein is R.C. Maclaurin Professor at the Massachusetts Institute of Technology and is a member of the NAE. His research interests include engine propulsion, particularly for smart engines and microengines. Much of Dr. Epstein's research effort has focused on the testing and modeling of turbomachinery fluid mechanics and heat transfer; however, his recent efforts include MEMS for turbine and rocket engines, manufactured with semiconductor industry fabrication technology from ceramic materials. Dr. Epstein is a member of the NRC Air Force Science and Technology Board and recently served on the Committee for Materials, Structures, and Aeronautics for Advanced Uninhabited Air Vehicles.

Robert H. Gormley, RADM, USN (Ret.), is president of the Oceanus Company, a technology advisory and business development firm serving clients in aerospace, defense, and electronics. He is also senior vice president of Projects International, Inc., a Washington-based company that assists U.S. and foreign clients in developing trade and investment opportunities. Earlier, as a career officer and naval aviator, he commanded the aircraft carrier *John F. Kennedy*, a combat stores ship, an air wing, and a fighter squadron during the Vietnam War. Admiral Gormley has an extensive background in the aviation technologies, with emphasis on unmanned aerial vehicle systems, aircraft survivability, and vertical/short takeoff and landing aircraft. He participates in national security studies undertaken by the National Research Council and has been a member of study panels of the Defense Science Board and the Naval Research Advisory Committee.

Charles E. Heber is vice president and general manager of the Washington Group at SRS Technologies, a private company providing information technology services to government and commercial entities. Prior to joining SRS in 1998, Mr. Heber served as director of the High Altitude Endurance Unmanned Air Vehicle Joint Program Office at the Defense Advanced Research Projects Agency (DARPA), where he led the development of two fully automated unmanned aircraft, a suite of integrated imagery sensors, and a common ground control station for high-altitude, unmanned airborne reconnaissance operations. Before that, he served as deputy director of DARPA's Tactical Technology Office and as deputy director of technology for ONR's Low Observables Technology Office.

Frank A. Horrigan retired from the technical development staff for sensors and electronic systems at Raytheon Systems Company. A theoretical physicist, Dr. Horrigan has more than 35 years' experience in advanced electronics, electro-optics, radar and sensor technologies, and advanced information systems. In addition, he has extensive experience in planning and managing IR&D investments and in projecting future technology growth directions. Dr. Horrigan once served as a NATO fellow at the Saclay Nuclear Research Center in France. He has served on numerous scientific boards and advisory committees, including as chair of the NRC's Panel on Sensors and Electronic Devices and the Review of ONR's Technical Vision for Uninhabited Combat Air Vehicles Program. Dr. Horrigan is a member of the NSB.

James D. Lang, an independent consultant, is retired director of technology development at the Boeing Company Phantom Works. Dr. Lang is an expert in research and development of air vehicles. His eleven years of service with Boeing (and McDonnell Douglas) followed twenty-four and a half years of service with the U.S. Air Force. His career involved engineering and R&D management, university teaching and research, flight test engineering, and flying duties as a command pilot and engineering test pilot. Dr. Lang's current activities include (1) membership on the DARPA/U.S. Air Force/Boeing National Technical Advisory Board for the UCAV program, (2) ad hoc membership on the U.S. Air Force Scientific Advisory Board, (3) membership on the NRC team for review of ONR's UCAV program, and (4) membership in the U.S. Air Force workshop to plan the Air Force Research Laboratory's air vehicle technology program. Dr. Lang has authored or coauthored 41 technical publications including the text *Aircraft Performance, Stability, and Control*. He is a fellow of the American Institute of Aeronautics and Astronautics and a fellow of the Royal Aeronautical Society.

Douglas P. Looze is associate professor of electrical and computer engineering at the University of Massachusetts (UMASS), where his research interests include flight control systems, multi-human decision making, restructurable control systems for advanced fighter aircraft, and the development of dynamic weapon allocation algorithms. Prior to joining UMASS, Dr. Looze served on the faculty at the University of Illinois. He is a member of the Institute of Electrical and Electronic Engineers (IEEE) Control Systems Society and the American Institute of Aeronautics and Astronautics and is currently chair of the Multivariable Linear Systems Working Group of the IEEE Control Systems Society.

F. Robert Naka is president and CEO of CERA, Inc. Dr. Naka, a member of the NAE, has a strong background in reconnaissance, surveillance, communication and control systems, sensor technologies (both active and passive), radar, visibility spectrum, and infrared optics. Throughout his professional career, Dr. Naka has held a number of senior industry and government positions, including vice president of engineering at GTE Government Systems and chief scientist for the U.S. Air Force. Dr. Naka is widely regarded as an expert in reconnaissance, surveillance communications, and command systems. He has served on numerous government advisory and scientific boards, including the NASA Space Program Advisory Council and the Air Force Scientific Advisory Board. He is a senior member of the Institute of Electrical and Electronics Engineers.

Philip D. Shutler, LtGen, USMC (Ret.), is a senior fellow at the Center for Naval Analyses and a lecturer on the history of joint military operations. While on active duty, General Shutler, a naval aviator, saw combat both on the ground and in the air. He also has an extensive background in aircraft development and served as director of operations (J-3), Joint Chiefs of Staff.

Marilyn J. Smith is assistant professor of aerospace engineering at the Georgia Institute of Technology (GIT). Dr. Smith has extensive experience with fixed-wing aeroelastic problems; her research interests include unsteady computational aerodynamics, computational aeroelasticity, and the integrated multidisciplinary areas of design of aeroelastic configurations and acoustic/fluid/structure interactions. She is a member of the American Helicopter Society and an associate fellow of the American Institute of Aeronautics and Astronautics. She served on the National Technical Committee on Fluid Dynamics/Aerodynamics for both organizations.

Robert E. Whitehead, an independent consultant, retired from federal service in 1997. He began his career in 1971 with the Navy, as a research engineer in the Aviation Department of the David Taylor

Naval Ship R&D Center at Carderock, Maryland. Dr. Whitehead transferred to the Office of Naval Research in 1976 and held a number of positions before becoming director of the Mechanics Division from 1986 until 1989. He then transferred to NASA Headquarters, eventually becoming the associate administrator for aeronautics and space transportation technology. In this position, he led a research and technology enterprise of over 6,000 civil servants and a similar number of contractors at four research centers with an annual budget of approximately $1.5 billion. During his federal service career, he was awarded both the Presidential Rank Meritorious Executive and Distinguished Executive awards, and at NASA, he was awarded the agency's Distinguished Service Medal. He is a fellow of the American Institute of Aeronautics and Astronautics.

Dianne S. Wiley recently joined the Boeing Company Phantom Works, where she is program manager for airframe risk reduction on the NASA Space Launch Initiative program. Previously, she was with Northrop Grumman, where she served as manager of airframe technology. In that position, Dr. Wiley was responsible for R&D and technology transition in structural design and analysis, materials and processes, and manufacturing technology. During her tenure at Northrop, she served as a senior technical specialist on the B-2 program, where she was responsible for developing and implementing innovative structural solutions to ensure the structural integrity of the B-2 aircraft. Dr. Wiley currently serves as a member of the NRC Aeronautics and Space Engineering Board and the NRC Committee on Breakthrough Technology for Commercial Supersonic Aircraft.

Staff

Charles F. Draper is a senior program officer at the National Research Council's (NRC's) Naval Studies Board. Prior to joining the NRC in 1997, Dr. Draper was the lead mechanical engineer at S.T. Research Corporation, where he provided technical and program management support for satellite earth station and small satellite design. He received his Ph.D. in mechanical engineering from Vanderbilt University in 1995; his doctoral research was conducted at the Naval Research Laboratory (NRL), where he used an atomic force microscope to measure the nano-mechanical properties of thin film materials. In parallel with his graduate student duties, Dr. Draper was a mechanical engineer with Geo-Centers, Inc., working onsite at NRL on the development of an underwater x-ray backscattering tomography system used for the nondestructive evaluation of U.S. Navy sonar domes on surface ships.

Ronald D. Taylor has been the director of the Naval Studies Board of the National Research Council since 1995. He joined the National Research Council in 1990 as a program officer with the Board on Physics and Astronomy and in 1994 became associate director of the Naval Studies Board. During his tenure at the National Research Council, Dr. Taylor has overseen the initiation and production of more than 40 studies focused on the application of science and technology to problems of national interest. Many of these studies address national security and national defense issues. From 1984 to 1990 Dr. Taylor was a research staff scientist with Berkeley Research Associates, working onsite at the Naval Research Laboratory on projects related to the development and application of charged particle beams. Prior to 1984 Dr. Taylor held both teaching and research positions in several academic institutions, including assistant professor of physics at Villanova University, research associate in chemistry at the University of Toronto, and instructor of physics at Embry-Riddle Aeronautical University. Dr. Taylor holds a Ph.D. and an M.S. in physics from the College of William and Mary and a B.A. in physics from Johns Hopkins University. In addition to science policy, Dr. Taylor's scientific and technical expertise is in the areas of atomic and molecular collision theory, chemical dynamics, and atomic processes in plasmas. He has authored or coauthored nearly 30 professional scientific papers or technical reports and given more than two dozen contributed or invited papers at scientific meetings.

B

Agenda for the Meeting of the Committee for the Review of ONR's Aircraft Technology Program

MAY 15-17, 2001
NATIONAL RESEARCH COUNCIL, WASHINGTON, D.C.

Tuesday, May 15

Closed Session: Committee Members and NRC Staff Only

0800 CONVENE—Welcome, Composition and Balance Discussion
Dr. Joseph Reagan, Committee Chair
Dr. Ronald Taylor, Director, Naval Studies Board

Data-gathering Meeting Not Open to the Public: Classified Discussion

0915 NAVAL EXPEDITIONARY WARFARE S&T DEPARTMENT OVERVIEW
Dr. Eli Zimet, Head, Naval Expeditionary Warfare S&T Department, ONR

0940 STRIKE DIVISION OVERVIEW
Mr. Michael B. Deitchman, Director, Strike Technology Division, Naval Expeditionary Warfare S&T Department, ONR

1000 AIRCRAFT TECHNOLOGY PROGRAM OVERVIEW
Mr. John Kinzer, Program Manager, ONR

1100 THRUST 1: INTEGRATED AVIONICS—Overview, Smart Skins Aircraft, Real Time Imaging Indexing and Advanced Technology Cockpit
Mr. Larry Ott, Thrust Leader, ONR

1130 (CONTINUED) THRUST 1: INTEGRATED AVIONICS—Advanced Avionics Subsystems
Ms. Regina L. Gannaway, NAWCAD

1230 (CONTINUED) THRUST 1: INTEGRATED AVIONICS—Advanced Common Electronic Modules
Mr. Gerard Walles, NAWCAD

1300 (CONTINUED) THRUST 1: INTEGRATED AVIONICS—Visually Coupled and 3-D Volumetric Displays
Mr. John Parker and Mr. Jim Brindle, ONR
1345 THRUST 2: PROPULSION AND POWER
Mr. Thaler, ONR
1600 (CONTINUED) THRUST 2: PROPULSION AND POWER
Mr. Thaler, ONR

Closed Session: Committee Members and NRC Staff Only

1715 COMMITTEE DISCUSSION
Moderator: Dr. Joseph Reagan, Committee Chair
1900 END SESSION

Wednesday, May 16

Closed Session: Committee Members and NRC Staff Only

0800 CONVENE—Welcome, Opening Remarks, Report Discussion
Dr. Joseph Reagan, Committee Chair
Dr. Charles Draper, NSB Senior Program Officer

Data-gathering Meeting Not Open to the Public: Classified Discussion

0815 THRUST 3: AIR VEHICLE TECHNOLOGY
Mr. Michael Harris, Thrust Leader, ONR
1100 THRUST 4: UNMANNED COMBAT AIR VEHICLES/UNMANNED AIR VEHICLES
Mr. John Kinzer, Thrust Leader, ONR
1230 LUNCH. SELECTED MEMBERS WILL DEPART FROM 1230 TO 1530 FOR SPECIAL ACCESS BRIEFINGS ON THRUST 5: SURVIVABILITY
1330 THRUST 6: SPECIAL AVIATION PROJECTS—Vectored Thrust Ducted Propeller
CDR David B. Spracklen, USCG, PEO/AAASMP
1530 AIRCRAFT TECHNOLOGY PROGRAM SUMMARY
Mr. John Kinzer, Program Manager, ONR

Closed Session: Committee Members and NRC Staff Only

1600 COMMITTEE DISCUSSION
Moderator: Dr. Joseph Reagan, Committee Chair
1700 END SESSION

Thursday, May 17

Closed Session: Committee Members and NRC Staff Only

0830 CONVENE—Welcome, Opening Remarks, Report Discussion
Dr. Joseph Reagan, Committee Chair
Dr. Charles Draper, NSB Senior Program Officer
0845 COMMITTEE REPORT WRITING—Prepare Draft Report
Moderator: Dr. Joseph Reagan, Committee Chair
1300 (CONTINUED) COMMITTEE REPORT WRITING—Prepare Draft Report
1700 ADJOURN

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Acronyms and Abbreviations

AAAV	advanced amphibious assault vehicle
AADS	advanced air data system
AAS	advanced avionics subsystem
AAV	Advanced Air Vehicle (program)
AC	alternating current
ACEM	advanced common electronic module
AFRL/SN	Air Force Research Laboratory/Sensors Directorate
AO	Autonomous Operations (FNC)
AMCM	airborne mine countermeasures
ATC	automatic target classification
ATD	advanced technology demonstration
ATP	Aircraft Technology Program
ATR	automatic target recognition
BAA	broad area announcement
C2	command and control
C3	command, control, and communications
C4I	command, control, communications, computing, and intelligence
CBM	condition-based maintenance
CFD	computational fluid dynamics
CNO	Chief of Naval Operations
CONOPS	concept of operations
COTS	commercial off-the-shelf
CRAD	contract research and development
CRW	canard rotor wing

DARPA	Defense Advanced Research Projects Agency
D&I	discovery and invention
DNS	direct numerical simulation
DOD	Department of Defense
DUST	drive-up simulated testbed (Patriot)
EFM	enhanced fighter maneuverability
EMD	engineering and manufacturing development
ESG	Executive Steering Group
ESTOL	extremely short takeoff and landing
FACIA	fatigue- and corrosion-insensitive aircraft
FC&D	flight control and dynamics
FNC	Future Naval Capability
HMD	helmet-mounted display
IFF	identification, friend or foe
IHPTET	Integrated High Performance Turbine Engine Technology (program)
IMATE	integrated maintenance test and evaluation
IPD	integrated product development
IR&D	industry research and development
JSF	Joint Strike Fighter
LES	large-eddy simulation
LO	low observable
MEMS	microelectromechanical systems
MRE	multirole endurance
MUST	maximizing usable service time
NASA	National Aeronautics and Space Administration
NASTRAN	NASA structural analysis
NAVAIR	Naval Air Systems Command
NAWCAD	Naval Air Warfare Center, Aircraft Division
NIMA	National Imagery and Mapping Agency
ONR	Office of Naval Research
OPNAV	Office of the Chief of Naval Operations
OUSD	Office of the Under Secretary of Defense
PMA	program manager (aviation)
R&D	research and development
RANS	Reynolds average Navier-Stokes

RWV	rotary-wing vehicle
SEAD	suppression of enemy air defense
SLAE	structural life attainment and enhancement
S&T	science and technology
STOL	short takeoff and landing
STOVL	short takeoff and vertical landing
TCS	Time Critical Strike (FNC)
TOCR	Total Ownership Cost Reduction (FNC)
TUAV	tactical uninhabited aerial vehicle
UAV	unmanned aerial vehicle
UCAV	unmanned combat air vehicle
UCAV-A	Unmanned Combat Air Vehicle-Air Force (program)
UCAV-N	Unmanned Combat Air Vehicle-Navy (program)
USAF	U.S. Air Force
USCG	U.S. Coast Guard
USMC	U.S. Marine Corps
VECTOR	vectoring extremely short takeoff and landing control, tailless operational research
VSTOL	vertical short takeoff and landing
VTOL	vertical takeoff and landing
VTDP	vectored thrust ducted propeller
VTOL	vertical takeoff and landing
VTUAV	vertical takeoff and landing tactical uninhabited air vehicle
V&V	verification and validation