

Sea-Based Aviation: A National Naval Responsibility



www.onrnavy.mil

DISTRIBUTION STATEMENT A.
Approved for public release;
Distribution is unlimited



OFFICE OF NAVAL RESEARCH



DEPARTMENT OF THE NAVY
OFFICE OF NAVAL RESEARCH
875 NORTH RANDOLPH STREET
SUITE 1425
ARLINGTON VA 22203-1995

IN REPLY REFER TO:

5000
Ser 35/006
12 April

MEMORANDUM

From: Chief of Naval Research

Subj: APPROVAL - NATIONAL NAVAL RESPONSIBILITY FOR SEA-BASED AVIATION

Ref: (a) Sea-based Aviation: A National Naval Responsibility (Proposal)
(b) Review Board Report, 04 Mar 2011
(c) Sea-based Aviation: Taxonomy
(d) ONR Instruction 5250.1A

1. Upon review of references (a), (b) and (c), I approve the proposal to classify Sea-based Aviation as a National Naval Program. Code 35 is directed to lead a sea-based aviation research program that will become the fifth of ONR's National Naval Programs. The purpose of the Sea-based Aviation National Naval Responsibility is to allow ONR to maintain the health of this Science and Technology (S&T) area so that:

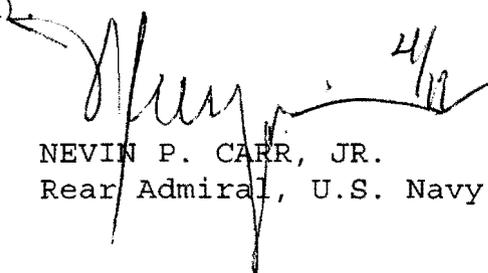
a. A robust U.S. research capability to work on long term S&T problems of interest to the Department of the Navy is sustained,

b. An adequate pipeline of new scientists and engineers in disciplines of unique Navy importance is maintained, and

c. ONR can continue to provide the S&T products necessary to ensure future superiority in integrated naval warfare.

2. A revision to reference (d) shall be made to include Sea-based Aviation as an ONR National Naval Responsibility.

3. Execution, guidelines, and requirements of the Sea-based Aviation National Naval Responsibility program will be in accordance with reference (d).


NEVIN P. CARR, JR.
Rear Admiral, U.S. Navy

Distribution:

ONR Codes: 03I, 03T, 03R, 30, 31, 32, 33, 34, 35

Table of Contents

| | | |
|----------|--|-----------|
| 1 | Sea-based Aviation National Naval Responsibility | 1 |
| 1.1 | NRR Purpose | 3 |
| 1.2 | Statement of Scope..... | 4 |
| 2 | Naval Aviation Operations and Environment | 6 |
| 2.1 | Dynamic Interface..... | 7 |
| 2.2 | High Loading/Light Weight | 8 |
| 2.3 | Corrosion..... | 9 |
| 2.4 | Deck Operations..... | 9 |
| 2.5 | Geometric Constraints & Spotting..... | 10 |
| 2.6 | Shipboard Maintenance..... | 10 |
| 2.7 | Flying Qualities & Performance | 11 |
| 3 | Representative S&T Challenges in Recent Naval Programs..... | 11 |
| 3.1 | Joint Strike Fighter | 11 |
| 3.2 | F-18E—Wing Drop | 13 |
| 3.3 | T-45 Development | 13 |
| 3.4 | Vertical Take-Off and Landing Tactical Unmanned Aerial Vehicle (VTUAV) Airframe..... | 14 |
| 4 | Future Aircraft and New Challenges | 15 |
| 4.1 | Autonomous Vehicle Development and Operation | 15 |
| 4.2 | Next Generation Aircraft..... | 15 |
| 5 | Program Summary..... | 16 |
| 5.1 | Baseline Capability | 16 |
| 5.2 | Program Funding and Trends..... | 19 |
| 5.3 | Scope of Naval Responsibility | 20 |
| 5.4 | Scope, Degree and Stability of Non-Navy Funding | 22 |
| 5.5 | Performer Base | 24 |
| 5.6 | Focus Area Leadership | 25 |
| 5.6.1 | <i>Navy</i> | 25 |
| 5.6.2 | <i>Army</i> | 34 |
| 5.6.3 | <i>Air Force</i> | 35 |
| 5.6.4 | <i>National Aeronautics and Space Administration (NASA)</i> | 36 |
| 5.6.5 | <i>Industry</i> | 37 |
| 5.6.6 | <i>Academic Performers</i> | 39 |
| 5.7 | Knowledge-based Pipeline..... | 41 |
| 5.8 | Facilities and Equipment..... | 44 |
| 5.8.1 | <i>Navy Facilities</i> | 45 |
| 5.8.2 | <i>Army Facilities</i> | 52 |
| 5.8.3 | <i>Air Force Facilities</i> | 53 |
| 5.8.4 | <i>National Aeronautics and Space Administration (NASA) Facilities</i> | 55 |
| 5.8.5 | <i>University Facilities</i> | 58 |
| 5.8.6 | <i>Needed S&T Facilities</i> | 61 |
| 5.9 | Integration with Higher Category Programs..... | 62 |
| 6 | Summary..... | 63 |
| 7 | Acronyms | 64 |
| 8 | Bibliography | 69 |

Acknowledgment of Reviewers

The purpose of this report is to support a detailed review and assessment of the health, currency, and technical superiority of Sea-based Aviation (SBA) Science and Technology (S&T) and to provide sufficient evidence to assist and inform the Chief of Naval Research in making a determination as to the merit of SBA S&T as a National Naval Responsibility (NNR). We wish to thank those who contributed to this report and taxonomy making it as sound as possible and ensuring the report meets institutional standards for objectivity and evidence. We wish to thank the following institutions for their review, comments, technical input, and support of this effort:

- Naval Aviation Enterprise – Chief Technology Office
- Center for Naval Analysis
- Naval Surface Warfare Center - Carderock Division (NSWCCD)
- Naval Air Systems Command
- Air Force Research Lab (AFRL)
- Army Advanced Technology Directorate (AATD)
- NASA Langley Research Center Aeronautics Directorate
- Boeing Corporation
- Northrop Grumman Corporation
- Lockheed Martin Corporation
- Pratt and Whitney Corporation
- General Electric Corporation
- Sikorsky Aircraft Corporation
- Bell Helicopter Textron Inc.

Although the reviewers listed above 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. Responsibility for the final content of this report rests entirely with the editorial team:

Mr. Mike Deitchman
Office of Naval Research, Code 35
Department Head, Naval Air Warfare and
Weapons

Dr. Thomas Beutner (Lead)
Office of Naval Research, Code 351
Director, Aerospace Sciences Research Division

Mr. John Kinzer
Office of Naval Research, Code 351

Dr. Judah Milgram
Naval Surface Warfare Center Carderock

Mr. Bill Nickerson
Naval Air Systems Command

Dr. Charles Alcorn
ManTech Systems Engineering & Advanced
Technology Group

Mr. Michael Hirschberg
CENTRA Technologies, Inc.

Mr. Angelo Collins
CENTRA Technologies, Inc.

Mr. Robert Boyd
ManTech Systems Engineering & Advanced
Technology Group

Mr. Brian Reeves
BD Reeves & Associates

*Cover Design: Mr. Bob Sternberg
QinetiQ North America, Inc.

DISTRIBUTION STATEMENT A. Approved for public release; distribution is unlimited

Sea-Based Aviation: A National Naval Responsibility



Over the next 20 years, nearly every platform in the carrier's air wing will transition to a newer, more capable model. Manned fighters and patrol aircraft will be complemented by unmanned tactical aircraft; rotary-wing aircraft will make up a majority of the Navy's future air force, performing critical anti-surface and anti-submarine warfare, mine countermeasures, and humanitarian assistance missions.

Rhumb Lines November 16, 2010

1 Sea-based Aviation National Naval Responsibility

The maritime environment is both unique and complex, and naval operations are inherently dangerous under even the most benign of circumstances. As a result, the Navy places great emphasis on maintaining vigorous S&T investments in research areas critically important to maintaining U.S. Naval superiority. Many of these areas are uniquely and often solely important to the Department of the Navy and are not adequately supported by S&T investments from industry, the other Services, or other federal sponsors of research. Sea-based Aviation (SBA) is one such critical area requiring a distinctive S&T base to enhance Naval Aviation's role and effectiveness in power projection. Technological advancements and developments by aviation S&T will ensure Naval Aviation can continue to perform its missions and provide decisive military power in the future. The health, strength, and growth of SBA depend on investments made by Navy S&T programs.

ONR must ensure U.S. and world leadership in these unique areas through research, recruitment and education, in order to maintain an adequate base of talent and



Figure 1 USS Abraham Lincoln (CVN 72) underway in the Arabian Sea

"So you want to understand an aircraft carrier? Well, just imagine that it's a busy day, and you shrink San Francisco Airport to only one short runway and one ramp and gate.

Make planes take off and land at the same time, at half the present time interval, rock the runway from side to side, and require that everyone who leaves in the morning returns that same day. Make sure the equipment is so close to the edge of the envelope that it's fragile. Then turn off the radar to avoid detection, impose strict controls on radios, fuel the aircraft in place with their engines running, put an enemy in the air, and scatter live bombs and rockets around. Now wet the whole thing down with salt water and oil, and man it with 20-year-olds, half of whom have never seen an airplane close-up. Oh, and by the way, try not to kill anyone."

-- Senior officer, Air Division

The Self-Designing High-Reliability Organization: Aircraft Carrier Flight Operations at Sea -By Gene I. Rochlin, Todd R. La Porte, and Karlene H. Roberts

Naval War College Review - Autumn 1987

sustain critical infrastructure for research and experimentation. Therefore, ONR has designated certain critical and unique S&T areas as National Naval Responsibilities (NNR).

For the purpose of this report, SBA is defined as the operation of aircraft to, from and on platforms at sea while SBA technology is the technology required to design, develop, and operate aircraft aboard naval platforms. SBA, while traditionally thought of in terms of operations from aircraft carriers, can be more broadly associated with a multitude of sea-based platforms and concepts to include¹:

1. Operations from large deck ships - (i.e., aircraft carriers, Landing Platform Docks (LPDs), Landing Helicopter Docks (LHDs), etc.) with substantial deck space for extensive large scale air operations including fixed wing and/or rotary wing, manned and unmanned air platforms.

2. Operations from small deck ships - (i.e., Guided Missile Destroyers (DDGs), Littoral Combat Ship (LCS), etc.) normally configured to handle only rotary wing aircraft.



Figure 2 The Arleigh Burke-class guided-missile destroyer USS Stockdale (DDG 106)

3. Operations from ships without dedicated takeoff/landing platforms for manned aircraft. Such operations include ships that could support Unmanned Aerial Vehicles (UAVs) launched by catapults/launch tubes/naval guns, etc., special operations craft, Unmanned Surface Vehicles (USVs) and high speed ship concepts.



Figure 3 The littoral combat ship USS Freedom (LCS 1)

4. Self deployed sea-based aircraft concepts - such as seaplanes and flying boats, wing-in-ground effect (WIG) aircraft, submersible aircraft concepts and other hybrid air/sea concepts.

5. Operations from other sea based platforms - such as submarines, submersible and semi-submersible platforms or unmanned vehicles, mobile offshore base (MOB) concepts, buoys with air vehicle components and unmanned sea based platforms (e.g., for refueling and logistical support of unmanned vehicles).

The first two categories reflect the current inventory of naval aircraft while the last three present new CONOPS and emerging S&T challenges.

1.1 NNR Purpose

As SBA approaches the centennial of the first ship based aircraft flight, ONR has identified this area as a potential NNR.

The purpose of an NNR initiative is to allow ONR to meet its responsibilities to maintain the health, currency, and technical superiority of identified Navy-unique S&T in order that:

1. A robust U.S. research capability to work on long term S&T problems of interest to the Department of the Navy is sustained;
2. An adequate pipeline of new scientists and engineers in disciplines of unique Navy importance is maintained; and
3. ONR can continue to provide the S&T products necessary to ensure future superiority in integrated naval warfare.

DISTRIBUTION STATEMENT A. Approved for public release; distribution is unlimited

This report is intended to support a review and assessment of the health, currency, and technical superiority of SBA S&T efforts. The merit of SBA as an NNR is assessed in the areas of:

1. Baseline capability of focus area;
2. Program funding and funding trends;
3. Scope of naval responsibility;
4. Scope, degree and stability of non-Navy funding sponsors;
5. Performer base (academia, government, industry);
6. Infrastructure (focus area leadership);
7. Knowledge-base pipeline (graduate and post-doctoral programs);
8. Facilities and equipment (ships, test tanks, etc.); and
9. Integration with and/or transition to higher category programs.

Of equal importance, this report and associated taxonomy will serve as the foundational guidance for future SBA basic and applied research efforts for ONR which will create and contribute to a vision of naval aviation for the future.

1.2 Statement of Scope

A number of factors were determined to be outside the scope of this assessment. Those factors limited the analyses used in examining and identifying the trends and scope of this NNR proposal.

The S&T challenges associated with SBA are inherently multidisciplinary. Multiple technical disciplines and skill specialties contribute to the S&T base of support for future aircraft designs. An exhaustive catalog of all S&T facilities associated with structures, avionics, materials science, aerodynamics, navigation, sensors, human factors, propulsion, and other disciplines contributing to the next generation SBA capabilities is not possible within the scope of this assessment. This document summarizes unique S&T facilities associated with Naval institutions, including NAVAIR, Naval Research Lab, NSWC Carderock, United States Naval Academy, and Naval Postgraduate School as well as representative non-Navy facilities supported directly by ONR grants to universities. A summary of S&T facilities considered critical to SBA owned by other organizations is also included. An exhaustive list of T&E facilities is not included, although some T&E facilities in which S&T work is also performed are included in this assessment. Typical S&T facilities used in the conduct of research are discussed.

Similarly, the student population contributing to the future workforce for SBA S&T is diverse, drawing from multiple disciplines. As a representative trend for this student population, the number of

DISTRIBUTION STATEMENT A. Approved for public release; distribution is unlimited

degrees granted in the Aeronautical Engineering specialty at the bachelors, masters, and doctorate level is provided. To capture the more diverse student population trends, the number of degrees granted in all Engineering majors is also shown. Within either of these student groups, and indeed in the industrial workforce base, it is not possible to distinguish the trend or population of individuals who are or will be engaged in SBA S&T. Most of these individuals may work on S&T projects which generically enable both sea-based or land based aviation and they may work on SBA efforts at intervals during their careers.

The SBA taxonomy, presented in the appendix is a top-down decomposition, primarily driven by an assessment of whether SBA should be an NNR. This taxonomy addresses the scope of naval responsibility by assessing the technical disciplines, technical challenges, and research topics associated with a range of naval aircraft types. As such, the taxonomy was not exclusive to a particular aircraft type, nor as detailed as a taxonomy of a particular aircraft might be in developing a work breakdown schedule. It does not provide an exhaustive list of technical challenges, but focuses instead on those areas where additional S&T is ongoing or envisioned as necessary to meet next generation aircraft development needs. The taxonomy contains many elements common to all aircraft types and programs, including Air Force and Army aircraft, and commercial aircraft. Many of these elements represent common challenges (CC) broadly addressed by DOD and NASA. However, in many cases, these elements address technical challenges in which the naval requirements are far more stressing than non-sea-based aircraft, and therefore the S&T challenges are identified in the taxonomy as Navy Driven (ND) requirements. In some cases these elements address technical challenges in which the Naval requirements are essentially unique, with little or no other investment associated with the challenge from other DOD or NASA efforts; these S&T challenges are identified as Navy Unique (NU) requirements.

The 5-tiered taxonomy for Naval Aviation is organized as: (Level 1) SBA capability; (Level 2) aircraft types; (Level 3) technical disciplines represented in development of new aircraft; (Level 4) representative technical challenges associated with those disciplines as represented by both current operational aircraft and future aircraft designs; and (Level 5) representative examples of research topics or project-level efforts currently ongoing or envisioned in the future to address the technical challenges. Again, while some areas are important to general aircraft missions and are not uniquely SBA challenges, they are addressed in the taxonomy as they also drive the SBA capability.

Weapons, sensors, and ship design are not addressed in this document except in cases where the interface or capability is directly tied to elements of SBA such as arrestment or takeoff. In addition, the taxonomy does not address all possible aircraft types. Several aircraft concepts have been evaluated for possible SBA roles, including air ships, powered parafoils, submersible aircraft, sea planes, and modular aircraft. These aircraft, to the extent they would be applied to Naval Aviation roles, are still in the conceptual design phase. While their development would surely pose S&T challenges, those challenges would also be tied to the details of the design and the proposed missions and roles of the aircraft.

DISTRIBUTION STATEMENT A. Approved for public release; distribution is unlimited

As a result, the taxonomy has focused on more conventional fixed wing and rotary wing aircraft in an attempt to identify the scope of Naval Responsibility. As new aircraft enter into analysis of alternatives, the technologies associated with them would pose further challenges requiring S&T investments.

The technical challenges of traditional SBA (i.e., associated with operations of manned aircraft from large deck and small deck ships) have been broadly categorized under the following categories:

- Structures
- Propulsion
- Propulsion Integration
- Ship Interfaces & Operations
- Avionics / Electronics
- Air Refueling
- Aerodynamics
- Guidance, Navigation & Control (GNC) / Autopilot / Autonomy
- Design Tools

Additional challenges associated with non-traditional SBA include:

- UAV launch and recovery; autonomy, high-tempo operations.
- UAV operations from non-aviation ships
- Submersible aircraft, hybrid aircraft, powered parafoils, air ships, and reconfigurable aircraft operations and maintenance.

2 Naval Aviation Operations and Environment

Consideration for the shipboard environment, ship interface requirements, and the user's at-sea concepts of operations is critical to the successful design of a naval aircraft. The factors that influence shipboard compatibility are numerous, and their impacts are often underestimated and/or misunderstood.²



Figure 4 An F/A-18 Hornet prepares to launch from the aircraft carrier USS George Washington

DISTRIBUTION STATEMENT A. Approved for public release; distribution is unlimited



Figure 5 F/A-18E Super Hornet assigned to the Gunslingers of Strike Fighter Squadron (VFA) 105



Figure 6 CH-53E Sea Stallion assigned to Marine Medium Helicopter Squadron (HMM) 262, lifts off from the USS Essex

The maritime role of the naval aircraft is complex, demanding, and unique. The ship has a dominant influence on the design of the aircraft. The largest challenge is the dynamic interface between aircraft and ship, requiring a high degree of precision maneuvering to land on the moving ship deck in adverse weather and wind. The materials must resist a highly corrosive environment. The structure and configuration must be large enough to perform the mission and then have the ability to fold into a small footprint to be stored into small hangars leaving enough room for critical maintenance. The air vehicle must be multi-mission capable for a diverse set of mission tasks.³The following sections discuss several unique SBA attributes that pose S&T challenges.

2.1 Dynamic Interface

Using a ship as a landing site creates a very challenging environment for aircraft and pilots (or autopilots). Sea-based aircraft operations must contend with airfield characteristics that lack the desirable aspects of conventional airports, such as long, stationary runways that are unobstructed by nearby buildings. The coupled relationship of the ship and aircraft system that exists during sea-based aircraft launch and recovery operations is often referred to as the “dynamic interface”. A primary factor that affects aircraft during dynamic interface operations is relative wind-over-deck (incoming wind angle and

DISTRIBUTION STATEMENT A. Approved for public release; distribution is unlimited

speed). The wind flowing over the ship structure produces a highly complex turbulent airwake that can affect aircraft performance and consequently pilot (or autopilot) workload. The airwake is a strong function of a range of variables associated with the Ship/Aircraft Interface problem. The variables includes ship geometry (which is often unique even within a class of ships and is very challenging to model), ship motion, sea state, atmospheric winds, ship exhaust system, temporary obstructions on deck, neighboring aircraft and their associated propulsion system effects, etc. These effects are coupled with other aerodynamic phenomena, such as ground effect and gusts that also occur during land-based operations. Shipboard operations is one of the most demanding challenges that the aircraft and pilot or autonomous control system encounters.

Operating rotary wing air vehicles in proximity to ships presents an even more formidable modeling problem than the fixed wing counterpart. Simulating the ship's turbulent airwake and coupling it with the rotor's own wake such that the aircraft realistically responds to the airwake is highly challenging. However, the situation becomes even more complex when the rotor downwash, constrained by the presence of the ship's deck and often a hangar face, is recirculated through the rotor, significantly altering the flowfield and increasing pilot workload. S&T research is investigating a range of modeling options and techniques to capture these effects for real-time and offline simulation, including reduced order modeling, Computational Fluid Dynamics (CFD) overset grid methodologies, and various rotor wake models. Validation of the rotor-airwake predictions is also a key component of this focus area.⁴ Similarly, The ability to characterize and accurately model the atmospheric boundary layer and flow field near the ocean surface in the presence of wind and waves is a unique challenge for sea based aviation

2.2 High Loading/Light Weight

It is well known that the rigors of shipboard launch and recovery operations inflict ground loads upon the airframe that are typically much greater than those experienced during land-based operations. Structural materials and components must be able to withstand these much higher shock and impact loads. However, simply increasing component size is not usually an option due to weight penalty restrictions. Ultra-high strength/low weight designs are required for advanced structures. High loading also creates more stringent material interface compatibility requirements for more resistance to spalling and disbonding of layered/coated structures.



Figure 7 F/A-18C Strike Fighter Squadron 94 (VFA-94)

DISTRIBUTION STATEMENT A. Approved for public release; distribution is unlimited

2.3 Corrosion

Studies of corrosion degradation on structural and material properties due to electrochemical activity have shown that the average ship-board environment is several times more aggressive and damaging than the most aggressive land-based conditions. This is compounded by the reduced damage tolerance due to high impact loads during ship-based take off and landing operations. Galvanic activity from dissimilar materials interfaces is accelerated by the high salt/high moisture atmosphere of SBA. The proximity of high-electromagnetic emitters further drives corrosion reactions not seen in land-based aircraft.



Figure 8 The amphibious assault ship USS Peleliu (LHA 5) transits the South Pacific Ocean in high seas

Corrosion control is the single most important preventative measure that can be taken to combat degradation of the Fleet's aircraft and support equipment. Hence, Corrosion prevention and control continues to be a major cost driver for naval aviation, accounting for \$3B in 2007/2008 see Figure 9⁵

2.4 Deck Operations

A ship's flight deck environment levies unique challenges on naval aircraft design to ensure safe and efficient deck operations. These challenges stem from the close proximity of other aircraft and personnel and the safe handling of aircraft in rough seas. For instance, to prevent movement and collision of aircraft, or worse, a static rollover, aircraft must be designed to ensure proper securing to prevent uncontrolled fore, aft and lateral movement due to the ship's pitch and roll caused by heavy seas. These designs must not impede the aircraft's up-and-away performance. Aircraft must show tolerance to hot gas impingement due to the close proximity of other aircraft. Along with the proximity of other aircraft comes the proximity of the deck crew. Hence, aircraft must be designed with safety in mind, including jet noise reduction. During deck operations, aircraft components such as engine nacelle or a leading edge must withstand low-velocity impacts (e.g. tool drop and non-skid

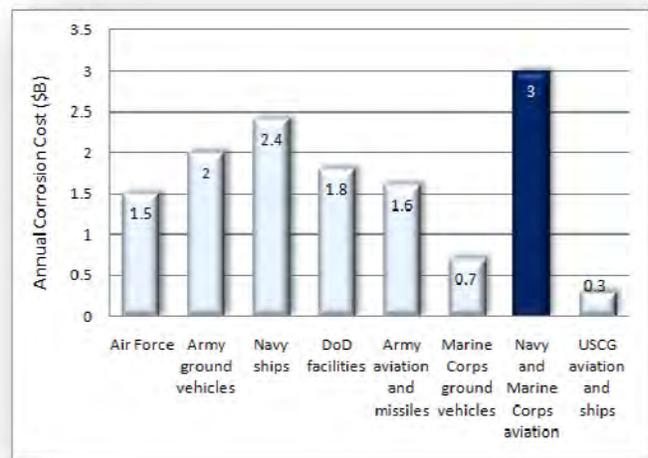


Figure 9 Annual Corrosion Costs

debris) without suffering critical damage. Additionally, unmanned vehicle operations on ships pose new and unique challenges to flight and deck operations.

2.5 Geometric Constraints & Spotting

Geometric constraints are prevalent in the design of naval aircraft; in order for an aircraft to operate effectively within the constrained spaces aboard ship, an aircraft must be an acceptable size and shape. The tight spaces on ship flight decks, elevators, and hangars require compact aircraft. Most aircraft are required to fold in some way to fit the small spaces. Aircraft shape can dictate where aircraft can be parked during pre-launch, post-recovery and for maintenance. Maximizing space often requires wing folding to increase the flexibility of deck handling. Likewise, safe launch and recovery unimpeded from deck obstacles impacts air vehicle geometry such as the placement of wing pylons and stores loading. In addition to flight deck constraints and operations within hangar bays, deck elevators levy additional constraints on naval aircraft, flight operations, and maintenance. Additional geometric constraints are imposed by aircraft designs for ship-based recovery. This includes tailhook to pilot eye offsets, and constraints for pilot visibility on landing.



Figure 10 The amphibious assault ship USS Kearsarge (LHD 3).

2.6 Shipboard Maintenance

Aircraft must have both low physical footprints and maintenance accessible designs for SBA. Limited spares, hazardous material, and work space restrict the complexity and breadth of at-sea maintenance actions. Non-destructive inspection methods to detect and locate damage must also be compatible with ship-board logistics and space constraints.



Figure 11 Aviation Machinist's Mate installs a panel on the aft mount pin of an F/A-18F Super Hornet

DISTRIBUTION STATEMENT A. Approved for public release; distribution is unlimited

Additionally, SBA has unique coatings requirements due to increased corrosive activity of the operational environment causing degradation of material properties not seen on land. The space aboard ship for the storage of hazardous material or other special storage materials is extremely limited. Additionally, the personal protective equipment requirements (to include equipment, safe distances, etc.) for the application or repair of protective coatings may bar their use at-sea.

2.7 Flying Qualities & Performance

Shipboard operations introduce a host of factors not present ashore. Many of these factors have a significant impact on the performance of the aircraft and associated flying qualities. A safe shipboard landing requires the aircraft to fly slow enough to be recovered within the capacities of the arresting gear while not imposing an unacceptably high requirement on the ship to generate wind-over-deck. Slow approach speeds cannot come at the expense of unsatisfactory flying qualities; the aircraft must possess robust waveoff and bolter capabilities (in multiple configurations), when an approach is waved-off (aborted) or when the arresting hook fails to engage the arresting wire (bolter). This also implies that propulsion systems must have sufficient thrust response to meet these requirements in normal and emergency situations.



Figure 12 An F/A-18E Super Hornet assigned to the **Knighthawks of Strike Fighter Squadron (VFA) 136** prepares to land on the **USS Enterprise (CVN 65)**.

3 Representative S&T Challenges in Recent Naval Programs

Several recent aircraft development programs highlight the complexity of designing naval aircraft and provide examples of S&T challenges typical of naval aircraft.

3.1 Joint Strike Fighter

The fact that SBA presents different challenges is most recently evident in the development of F-35C Carrier Variant Joint Strike Fighter (JSF)⁶. The F-35C is the Navy's first stealth aircraft. US Navy carrier operations account for most of the differences between the F-35C and the other JSF variants. The aircraft has larger wing and tail control surfaces to better manage low-speed carrier approaches. The extra wing area is provided by larger leading-edge flaps and foldable wingtip sections. These components attach to the common-geometry wingbox on the production line. A larger wing span provides increased range and payload capability for the Navy variant. The aircraft, on internal fuel alone, has almost twice the range of an F-18C. The design is also optimized for survivability, a key Navy requirement.

DISTRIBUTION STATEMENT A. Approved for public release; distribution is unlimited

The F-35C has an increased-capacity structure for absorbing catapult launches and arrested landings. The aircraft has a carrier-suitable tailhook. Its landing gear has a longer stroke and higher load capacity. Both the US Marine Corps and the US Navy variant have a refueling probe on the right side of the forward fuselage. Weapon loads, cockpit layout, countermeasures, radar, and other features are common with the other variants.



Figure 13 The first F-35C Lightning II carrier variant, the U.S. Navy's first stealth fighter

The F-35C's flight-test program included a series of Field Carrier Landing Practice tests to evaluate the aircraft's handling qualities and performance during carrier approaches and landings at an airfield, and also included up-and-away handling-quality tests and engine transients at varying speeds and altitudes.

The JSF must be able to operate from US and allied shore-based facilities. Considerations for basing suitability and shipboard compatibility in particular, include of a wide range of complex integration issues such as:

- Approach flying qualities
- Catapult hookup
- Deck handling
- Deck spotting
- Elevator compatibility
- Flight deck servicing
- Hangar deck maintenance
- Jet blast effects
- Landing systems
- Ship motion
- Shipboard environment
- Steam ingestion

For the Short Take-Off Vertical Landing (STOVL) variant, lift fans are an enabler of the naval aviation requiring solutions to many complex challenges crossing multiple engineering disciplines. For instance, ensuring efficient aerodynamic lift fan performance in high cross winds or robust designs of lightweight

DISTRIBUTION STATEMENT A. Approved for public release; distribution is unlimited

clutch mechanism to transfer shaft horsepower to the lift fan without chatter or wear while ensuring high life. S&T in these areas is not mature and is needed to predict and minimize costly problems before system development and demonstration occurs.⁷

3.2 F-18E—Wing Drop

Changes made to the F/A-18E/F wing/leading edge extension to reduce drag and increase fuel volume while preserving high lift, including re-introduction of the leading edge “snag” ultimately removed on the earlier model F/A-18s, had unanticipated effects, in particular the wing drop precipitated by unstable shock stall at speeds of 0.6 to 0.9 Mach. In December 1997, the F/A-18E/F program experienced persistent performance problems in high-speed maneuvers that led the Navy to delay FY1998 funding, pending solution of these problems. Asymmetric loss of wing lift caused the plane to roll unexpectedly to the left or right, preventing the pilot from tracking a target. Since this anomaly was apparently related to the wing's leading edge, some feared the wing might have to be redesigned; others thought the problem could be resolved by modifications of the wing. Subsequent flight tests to contrast the airflow patterns between the F/A-18E/F and earlier F-18's verified that there are significant differences between airflow characteristics of the two aircraft. Wind tunnel tests and CFD studies were performed in an effort to identify the root cause. Ultimately, a solution was determined to the wing drop phenomenon by adding a porous wing fairing door and a modified leading edge flap schedule. After successful flight testing of this modification, Secretary of Defense Cohen approved FY1998 funding for procurement of another 20 aircraft on April 3, 1998.⁸ This performance problem was not anticipated during early wing design efforts, was highly non-linear, and was challenging to assess either through simulation or testing. This points to the type of problems that may be encountered in relatively mature technical fields when high performance designs are incorporated.

3.3 T-45 Development

The T-45 aircraft is used for intermediate and advanced Navy pilot training for jet carrier aviation and tactical strike missions. Its genesis is found in the modification of an existing land-based configuration, the British Aerospace Hawk. Conversion of the Hawk aircraft to a naval trainer with carrier capabilities involved considerable Research and Development (R&D). In addition to the necessary strengthening of landing gear components and the



Figure 14 A T-45 Goshawk launches aboard the USS Nimitz (CVN 68)

inclusion of arresting gear, development work was required in numerous areas that were critical for carrier-based operations. Some areas of concern included the handling qualities, engine response characteristics, and stall characteristics of the T-45.

Adapting the Hawk design to the T-45 mission proved more technically challenging than had been estimated. In 1988, following extensive preliminary flight-test evaluations, the Navy cited several major deficiencies in the T-45. The engine lacked thrust and responsiveness, and the aircraft lacked the lateral and longitudinal stability needed for carrier operations. The stall characteristics of the initial T-45 configuration were judged to be unacceptable by the Navy on the basis of a severe wing-drop behavior (aggravated by the increased weight required to strengthen the airframe for carrier operations). During the Navy's flight evaluations, the wing drop was so severe that uncommanded roll motions often exceeded 90 deg. The T-45 Program subsequently adopted a wing redesign, which incorporated wing leading-edge slats. The slats virtually eliminated the wing-drop tendency and lowered the carrier-approach speed to a more acceptable value. A more powerful and responsive engine, a modified rudder and other changes were also added to improve flight characteristics during carrier operations.⁹

This program points to the complex design modifications required to adopt existing aircraft for carrier operations and unanticipated S&T challenges that often emerge when assessing carrier suitability.

3.4 Vertical Take-Off and Landing Tactical Unmanned Aerial Vehicle (VTUAV) Airframe

The VTUAV Fire Scout program was initiated in early 2000 as an unmanned system to provide the Navy an intelligence, surveillance, reconnaissance and targeting capability. The Fire Scout airframe is based on the Schweizer 333 commercial airframe, which had been touted as a reliable, powerful, and cost-effective work horse.

Because of its use in a marine environment, the choice of the Commercial Off-The-Shelf (COTS) airframe was thought to offer a cost-effective and low schedule risk alternative to designing a new airframe. However, some commercial industry practices, such as installing fasteners without primer or sealant, led to corrosion issues in ship-deployed aircraft. For example, in October 2009, two Fire Scouts were deployed for six months on the USS *McInerney* (FFG-8). Within weeks of being exposed to this environment, severe corrosion was reported on both aircraft. Out of 330 discrepancies reported, 42% were attributed to corrosion (VTUAV Fleet Support Team Evaluation of the MQ-8B Post-Military Utility Assessment Aircraft and Support Equipment, dated 08 August 2010). These discrepancies included corrosion on the airframe structure and subsystems (including the main and tail rotor hub assemblies), aircraft antenna mating surfaces, hardware, and connectors/couplers. Corrosion damage was also found in the engine of one of the aircraft, severe enough to require replacement of the flight critical assembly.

DISTRIBUTION STATEMENT A. Approved for public release; distribution is unlimited

Based on the experience of this deployment, it appears that the COTS design of the airframe is not robust enough for the daily operating conditions of the harsh marine environment encountered in long-term Navy ship-board deployment missions.

4 Future Aircraft and New Challenges

4.1 Autonomous Vehicle Development and Operation

Advanced unmanned vehicle systems can offer many opportunities, including surveillance and reconnaissance, target firepower with onboard weapons, and damage assessment. They may serve as communications nodes and sensors for signals intelligence, environmental measurements, and the detection and identification of nuclear, biological, and chemical threats. Recent experiments and evaluations indicate that before the effective deployment of unmanned vehicles, many technical and operational questions remain to be addressed, such as the level of autonomy needed, as well as issues relating to reliability, environmental sensitivity, vehicle integration, and operational training. The technical challenges include size, endurance, speed, recoverability, survivability, altitude, and range, along with onboard and offboard trade-offs related to communications, intelligence, situation awareness (for deconfliction), re-planning capability (needed for threat changes), multiple vehicle control, and human interfaces including mixed operations with manned and unmanned aircraft. Autonomous vehicles clearly have many technological challenges to be addressed in order to enhance their overall utility. Unique to Navy & Marine Corps operations, however, are the S&T challenges associated with the launch, recovery, and deck operations, especially in proximity to manned aircraft and deck crew. Damage-tolerance considerations include redundancy in control paths and features to limit the propagation of damage, aerodynamic designs allowing continued controlled flight with damage to or loss of some airframe elements, and control systems capable of recognizing the loss of control surfaces/actuators or changes to the aerodynamic configuration of the vehicle, compensating or reconfiguring to allow continued flight.¹⁰ Operations on existing deck configurations with hand signals, visual inspection of data and interfaces, and visual cues for landing and waveoff, pose challenges requiring new technical approaches.

4.2 Next Generation Aircraft

To keep pace with ever growing threats across the entire spectrum, SBA must look to new aircraft technologies. This includes tailless aircraft beyond JSF; or '6th Generation' aircraft. These aircraft will face new challenges to their survivability, self defense, and mission effectiveness. New technologies may enable efficiency in all flight regimes; from subsonic to high supersonic for fixed wing aircraft and hover to high speed cruise for rotorcraft. New aircraft will need to carry a diverse suite of both offensive and defensive systems including high power directed energy weapons and networked sensors and electronics. The technology suite to realize this vision include tailless control, structural "morphing" and adaptive features, smart skins, optional manning, and high efficiency compact power sources. Many challenges exist, both universal and navy-unique, to achieve these capabilities. These new

DISTRIBUTION STATEMENT A. Approved for public release; distribution is unlimited

configurations will pose unprecedented stability and control challenges for carrier landings, and will include new maintenance issues never before addressed aboard ship.

Technology advancements are leading to the revival of novel concepts with military applications. Many of these concepts are enabled by advances in controls and autonomy and driven by unprecedented demands for data and enemy threats.

The sphere of naval aviation will continue to expand. Advances in propulsion, materials, and controls technology may enable fan-in-wing air vehicles that take off and land vertically without unduly compromising payload, speed or range. However, the fan-in-wing technologies are far from mature and will require continued investments. Areas of research include robust aerodynamic efficiency under high fan loading and the mitigation of inlet distortion. Other advanced vertical flight concepts – such as fuselage-embedded fans, ejectors, tailsitters, stopped or retractable rotors, tilt wings, tilt propellers, tilt ducts, tilt jets and advanced tilt rotors – are being studied by academia and industry, and each poses unique technical challenges.

Another conceptual design that has recently received interest is the submersible aircraft. Enabled by autonomous operations and serving in an Intelligence, Surveillance, and Reconnaissance (ISR) or strike role, such aircraft might loiter below the surface until called upon, posing new corrosion issues as well as water ingestion challenges for propulsion paths, crush loadings on the aircraft structure at depth and impact loading on splashdown/landing.

There has been a rapid evolution of mobile robotic technology as witnessed by the fielding of unmanned vehicles in many problem areas ranging from battlefield support to homeland security. Military agencies continue to expand the roles that unmanned systems may serve. The evolution of autonomous technologies and their leverage on the battlefield poses many technical challenges for SBA. Aside from the common technical challenges faced from increasing levels of autonomy, there are naval-unique technology challenges in need of further advancement. For instance, the ability of unmanned assets to operate effectively with manned systems on and off the carrier deck.

There has also been an emergence of lighter than air concepts to support naval missions. For such concepts to come to fruition, technology advancement is needed in several key areas including precision station keeping, airship control, and advanced thin film materials.

5 Program Summary

5.1 Baseline Capability

The S&T base supporting SBA is made up of a diverse mix of industry, government laboratories and university researchers. In many cases, these performers also support the S&T base for Army, Air Force, and commercial aviation. For example, the table below shows the current and near term aircraft

DISTRIBUTION STATEMENT A. Approved for public release; distribution is unlimited

operating from USN ships. The suppliers shown all have a production base for other aircraft as well. Aircraft to be fielded in the near future are also shown, including the Joint Strike Fighter F-35C variant Conventional Take-Off and Landing (CTOL). Also included are the Unmanned Carrier Launched Airborne Surveillance and Strike System (UCLASS) aircraft.

Table 1 Current and near term aircraft operating from USN ships

| <u>Aircraft</u> | <u>Fixed/Rotary/UAS</u> | <u>Ship type</u> | <u>Prime manufacturer</u> |
|------------------------|--------------------------------|-------------------------|----------------------------------|
| F/A-18 | Fixed | Carrier | Boeing |
| E-2, C-2 | Fixed | Carrier | Northrop Grumman |
| EA-6B | Fixed | Carrier | Northrop Grumman |
| T-2C | Fixed | Carrier | Rockwell |
| T-45 | Fixed | Carrier | Boeing |
| SH-60, MH-60 | Rotary | All air capable | Sikorsky |
| MV-22 | Tilt-rotor | Amphib | Bell, Boeing |
| MQ-8B Fire Scout | Rotary/UAS | Amphib, LCS | Northrop Grumman |
| Scan Eagle | Fixed/UAS | Multiple | Boeing, Insitu Group |
| UCLASS | Fixed/UAS | Carrier | |
| F-35C (JSF) | Fixed; Carrier | Amphib | Lockheed Martin |
| AV-8 | Fixed | Amphib | Boeing |
| UH-1 | Rotary | Amphib | Bell |
| AH-1 | Rotary | Amphib | Bell |
| CH-53 | Rotary | Amphib | Sikorsky |
| CH-46 | Rotary | Amphib | Boeing Vertol |

DISTRIBUTION STATEMENT A. Approved for public release; distribution is unlimited

Table 2 Aviation Capable Ships

| | | |
|----------|---------------------------|---|
| CVN | Aircraft Carrier | An aircraft carrier is a warship designed with a primary mission of deploying and recovering aircraft, acting as a seagoing airbase. Aircraft carriers thus allow a naval force to project air power worldwide without having to depend on local bases for staging aircraft operations. |
| LHA /LHD | Amphibious Assault Ships | The largest of all amphibious warfare ships; resembles a small aircraft carrier; capable of Vertical/Short Take-Off and Landing (V/STOL), Short Take-Off Vertical Landing (STOVL), Vertical Take-Off and Landing (VTOL) tilt-rotor and Rotary Wing (RW) aircraft operations |
| LPD | Amphibious Transport Dock | LPDs are used to transport and land Marines, their equipment and supplies by embarked air cushion (LCAC) or conventional landing craft and Expeditionary Fighting Vehicles (EFV) or Amphibious Assault Vehicles (AAV) augmented by helicopters or vertical takeoff and landing aircraft (MV 22). |
| LSD | Dock Landing Ships | Dock Landing Ships support amphibious operations including landings via Landing Craft Air Cushion (LCAC), conventional landing craft and helicopters, onto hostile shores. These ships transport and launch amphibious craft and vehicles with their crews and embarked personnel in amphibious assault operations. |
| CG | Cruisers | Modern U.S. Navy guided missile cruisers perform primarily in a Battle Force role. These ships are multi-mission [Air Warfare (AW), Undersea Warfare (USW), Naval Surface Fire Support (NSFS) and Surface Warfare (SUW)] surface combatants capable of supporting carrier battle groups, amphibious forces, or of operating independently and as flagships of surface action groups. Aircraft: Two SH-60 Seahawk (LAMPS III) helicopters. |
| DDG | Destroyers | Guided missile destroyers are multi-mission [Anti-Air Warfare (AAW), Anti-Submarine Warfare (ASW), and Anti-Surface Warfare (ASUW)] surface combatants. Aircraft: Two LAMPS MK III MH-60 helicopters |
| FFG | Frigates | Frigates fulfill a Protection of Shipping (POS) mission as Anti-Submarine Warfare (ASW) combatants for amphibious expeditionary forces, underway replenishment groups and merchant convoys. Aircraft: Two SH-60 Seahawk (LAMPS III) helicopters. |
| LCS | Littoral Combat Ships | LCS is a fast, agile, focused-mission platform designed for operation in near-shore environments yet capable of open-ocean operation. It is designed to defeat asymmetric “anti-access” threats such as mines, quiet diesel submarines and fast surface craft. Aircraft: Two SH-60 Seahawk (LAMPS III) helicopters. Firescout. |
| CLF | Combat Logistics Force | Combat Logistics Force fleet resupply combatant ships at sea. |

DISTRIBUTION STATEMENT A. Approved for public release; distribution is unlimited

Sea Power 21, the Navy's top level vision document addresses five (5) missions:

1. Sea Control
2. Power Projection
3. Strategic Deterrence
4. Strategic sealift
5. Forward Presence

These missions are executed under three Naval Capability Pillars:

1. Sea Strike
2. Sea Shield
3. Sea Basing

All three pillars are enabled by an overarching FORCEnet pillar. FORCEnet provides the collaborative connectivity and enables each of the other Naval Capability Pillars.

Sea-based Aviation belongs in the Enabler pillar, even though sea-based aircraft operations from and around a ship is a capability applicable to all three fundamental pillars. In subsequent sections, specific baseline capabilities of industry and government laboratories will be outlined.

5.2 Program Funding and Trends

The Department of the Navy's Research, Development, Test and Evaluation (RDT&E) budget is shown in Fig. 14 Appropriations steadily increased from FY2002 through 2006; rising to a level of \$6.5B. Appropriations dropped in FY 2008 and have since stabilized between \$5-\$6B. FY 2010 appropriations are the lowest since FY 2004.

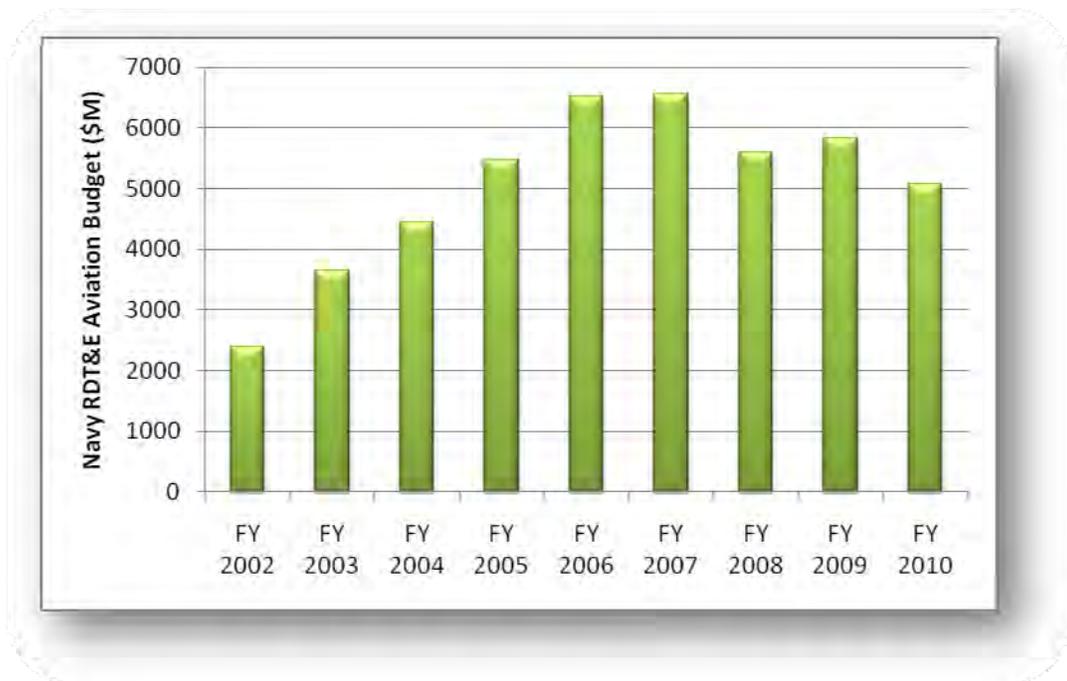


Figure 15 Navy RDT&E Aviation Budget; FY 2002 through FY 2010

5.3 *Scope of Naval Responsibility*

Advances in aviation are the shared responsibility of the Services, NASA, the Federal Aviation Administration, and the industrial and academic base that supports the technologies required to advance the design, manufacture, and operations of new aircraft. Among these organizations, many aspects of the design process draw upon common or shared S&T investment areas, such as advancements in computational fluid mechanics, navigation, control actuators, materials, computational structural analysis, and many other discipline-based tools, techniques and technologies. However, each of these organizations brings some unique elements to the development and operation of new aircraft. The scope of Naval responsibility is captured for this NNR evaluation primarily through the taxonomy included in Appendix A. In the taxonomy, research areas are identified as falling into one of three broad categories:

- 1) Common Challenges. These research areas are common to multiple services, and in some cases to commercial aircraft as well. They represent areas where additional S&T is required to continue to address the barriers to new aircraft designs, however, that S&T is addressed by investments from multiple sources. It is important, however, to recognize that leveraging of other services investments still requires a sufficient investment to utilize and incorporate those investments in Naval designs. In many cases, although these challenges have many elements in common, or the basic research investments support many applications, the specific challenges presented by each of the services drive nuanced investments to support particular S&T challenges.

DISTRIBUTION STATEMENT A. Approved for public release; distribution is unlimited

- 2) Navy Driven. These research areas may have leveraged investments from other organizations, but represent challenges for which the Navy requirements or S&T challenges are driving. In these cases, design solutions utilized by other organizations may be useful but insufficient to address Naval requirements without additional investments or additional progress.
- 3) Navy Unique. These research areas represent areas which are, by their very nature, areas of research posed by the unique operating environment or requirements of the Navy. These S&T challenges may have little leverage from other organization's investments, and must be addressed by Naval S&T. In some cases, the Naval investments may benefit other organizations, but the primary motivation for the research investments is to address Naval requirements.

Navy driven S&T challenges have been identified in each of the disciplines contributing to aircraft design, including structures, propulsion, propulsion integration, ship interfaces and operations, avionics, air refueling, aerodynamics, guidance navigation and control, autonomy, and design tools. These challenges represent an array of S&T challenges that have some commonality with Air Force or Army challenges, but for which the Navy requirements are pacing. Examples include development of composite materials suitable to a maritime environment, development of seals to provide continuity of outer mold lines consistent with next generation fighter aircraft while providing access for shipboard maintenance, development of corrosion resistant materials for all aspects of the aircraft structure and engine, development of precision navigation, jet noise reduction approaches for close proximity operations aboard deck, and development of electromagnetic shielding materials that do not exacerbate the galvanic corrosion of structural materials. The taxonomy in Appendix A summarizes many Navy driven S&T challenges.

Navy unique challenges have also been identified in multiple disciplines. These challenges represent areas where the requirements or constraints are so unique that only a Naval S&T investment is likely to produce an adequate maturity of the technology for future SBA. Examples of these unique challenges include improved structural life predictive models incorporating the effects of both fatigue and corrosion, dynamic interface, advanced materials and coatings research to mitigate wear on launch catapult systems, sensors that can provide prognostic capabilities in the combined thermal and shock environment of a catapult system, multiple technologies associated with wear and efficiency of electromagnetic catapult systems, ship based relative navigation systems and landing aids, automated systems for unmanned aircraft operations aboard deck, sensor technologies for aircraft detection of surface targets in maritime environments, drogue tracking and control algorithms, non-GPS precision navigations systems suitable to carrier deck landings, and simulation-based evaluation tools including better fidelity tools to estimate sortie generation and deck operations. The taxonomy in Appendix A summarizes many Navy unique S&T challenges.

Both Navy-driven and Navy-unique challenges are multidisciplinary, and contribute to multiple aircraft types and missions. The breadth and range of these challenges warrants a continued

DISTRIBUTION STATEMENT A. Approved for public release; distribution is unlimited

investment in the identification of promising new approaches to these problems, and the maturation of new technologies to a point that supports incorporation in new or existing aircraft.

Many other challenges have been identified as common challenges, in which investments by multiple services and NASA may contribute to the maturity of new technologies which address elements required for SBA. These areas are required for next generation sea based aircraft, and also warrant continued support from the Navy. The taxonomy in Appendix A also summarizes these common challenges.

5.4 Scope, Degree and Stability of Non-Navy Funding

Generally, aerospace R&D is classified as basic research, applied research, or development. Development typically accounts for the majority of total R&D research, as was the case in 2007. Development funding accounted for 75.2 percent of aerospace R&D with \$13.9 billion, followed by applied research at \$4 billion, and basic research at \$590 million. The outlook for aerospace R&D is unclear. Although R&D funding has increased steadily, it has trailed all other categories of defense spending. There is also the concern that the level of R&D spending in the aerospace industry will be reduced due to the increasing financial strains faced by both industry and government. Nevertheless, R&D spending remains a top priority for the aerospace industry, as history has proven that short-sighted cuts often produce long-term consequences for U.S. aerospace competitiveness.

Figures 17-19 show overall budget trends for Basic, Applied, and Advanced Development Funding for Aeronautics. These trends represent a roll-up of government and industry funding and are not directed specifically at SBA. The cyclical funding trends shown in these figures pose challenges to recruiting and retaining a skilled workforce and impact long-range S&T Investments.

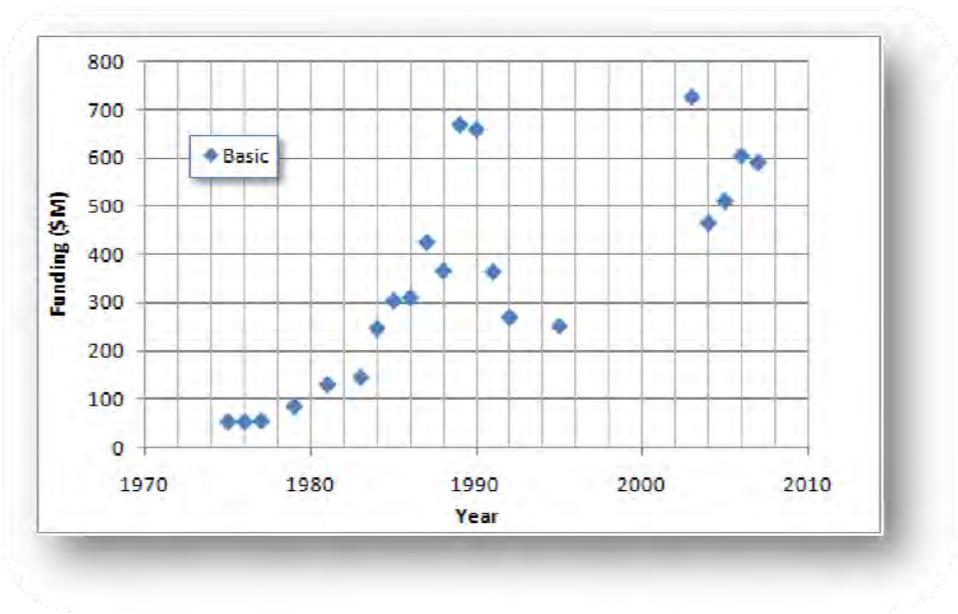


Figure 16 Basic Aerospace R&D Funding

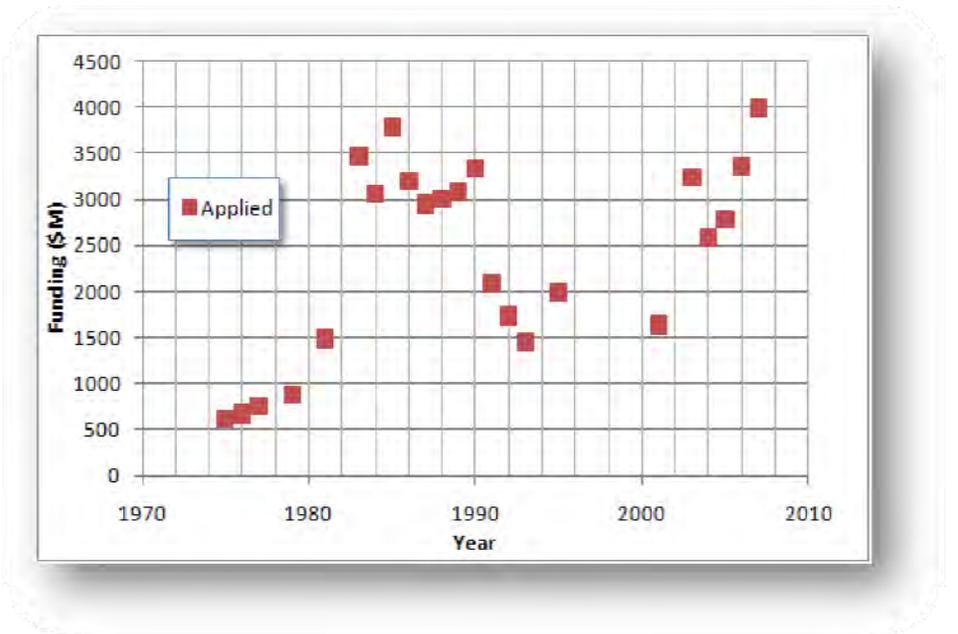


Figure 17 Applied Aerospace R&D Funding

DISTRIBUTION STATEMENT A. Approved for public release; distribution is unlimited

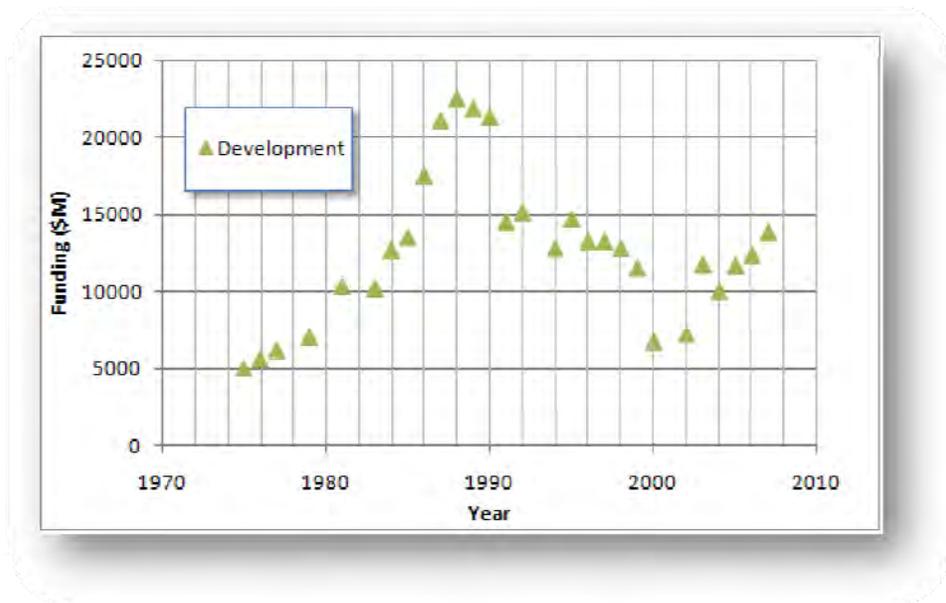


Figure 18 Development Aerospace R&D Funding

Note: The figures above do not correlate with Navy investments due to accounting assumptions, but show trends

5.5 Performer Base

Between 1985 and 2002, Aerospace R&D Science and Engineering positions fell from 140,000 to 20,000 jobs. This number has since recovered and stabilized at roughly 40,000 positions; representing <5% of all industries (manufacturing and non-manufacturing) known to conduct or finance R&D.¹¹

Employment trends are shown in figure 20. Enrollments for seniors in Aerospace Engineering Programs in the United States are shown in Figure 21.

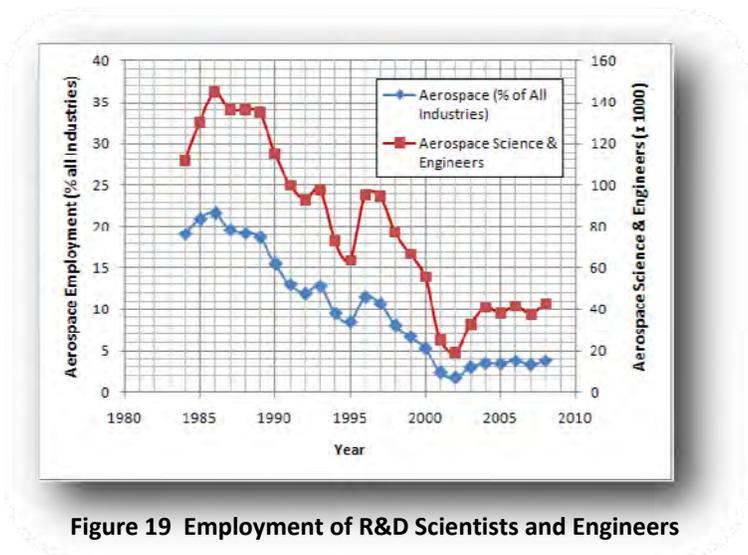


Figure 19 Employment of R&D Scientists and Engineers

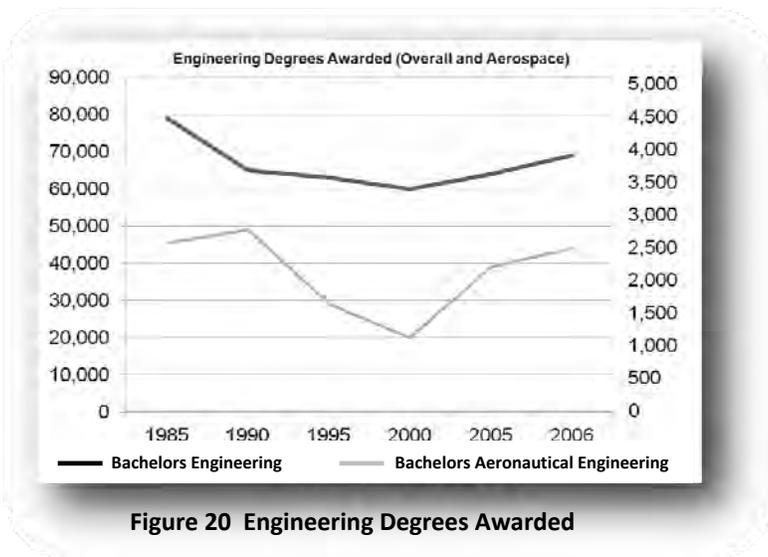


Figure 20 Engineering Degrees Awarded

5.6 Focus Area Leadership

A solid and proven infrastructure exists to foster SBA S&T. The following sections provide a description of those sponsoring and performing S&T related to Naval Aviation.

5.6.1 Navy

5.6.1.1 Office of Naval Research (ONR)

ONR provides S&T solutions for the Navy and Marine Corps and is a key sponsor to SBA future needs. In support of the Naval S&T vision, ONR sponsors scientific research and technology to:

- Pursue revolutionary capabilities for Naval forces of the future
- Mature and transition S&T advances to improve naval capabilities
- Respond to current critical needs
- Maintain broad technology investments both to hedge against uncertainty and to anticipate and counter potential technology surprise. (Source: Naval S&T Strategic Plan)

ONR Code 35 (Naval Air Warfare and Weapons) supports the Navy's power projection needs, fostering the technology development of naval aircraft, structures, propulsion, autonomy, energetics, directed energy and electric weapons. Current and future programs within ONR 35 are directly applicable to SBA needs of the 21st century.

ONR Code 33(Sea Warfare and Weapons) develops and delivers technologies that enable superior warfighting and energy capabilities for naval forces, platforms and undersea weaponry. ONR 33 sponsors advanced materials and fuels programs that support future needs of SBA .

DISTRIBUTION STATEMENT A. Approved for public release; distribution is unlimited

ONR's Innovative Naval Prototypes (INPs) push the boundaries of our nation's technical talent to deliver transformational warfighting capabilities to the U.S. Navy and Marine Corps. INPs reduce the acquisition risk of disruptive technologies and capabilities.

Innovative Naval Prototypes explore high 6.2 and 6.3 technologies that can dramatically change the way naval forces fight. Programs in this category may be disruptive technologies which, for reasons of high risk or radical departure from established requirements and concepts of operation, are unlikely to survive without top leadership endorsement, and, unlike Future Naval Capabilities, are initially too high risk for a firm transition commitment from the acquisition community.

ONR's Future Naval Capability (FNC) program aligns with the pillars of the Chief of Naval Operations' and the Commandant of the Marine Corps' vision for the future-Naval Power 21-and focuses on providing Enabling Capabilities (ECs) to close warfighting gaps. The FNC program provides the best technology solutions to stated Navy requirements by bundling discrete but interrelated S&T products to deliver a distinctly measurable improvement within a five-year time frame.

5.6.1.2 Naval Aviation Enterprise

The Naval Aviation Enterprise (NAE) is a warfighting partnership in which interdependent Naval Aviation issues affecting multiple stakeholders are resolved on an enterprise-wide basis. Between the Navy and Marine Corps, the Enterprise includes over 183,000 people, 3,700 aircraft, and 11 aircraft carriers and executes a budget in excess of \$40 billion. Focusing these resources to provide the United States with the necessary warfighting readiness expected to meet national policy and priorities is a shared responsibility of each member of the Enterprise.

The NAE vision is to be the preeminent partnership of operators, sponsors and providers who champion the efficient delivery of the right force, with the right readiness, at the right time, today and in the future. It is a future state in which the already existing partnership matures to a more inclusive, engaged and proactive membership. The NAE mission is to support Naval Aviation readiness requirements with transparent, cross-functional practices which inform risk-balanced decisions. The Enterprise supports Naval Aviation with practices that lead to better decisions.

5.6.1.3 Naval Aviation Enterprise Chief Technology Officer (NAE CTO)

The Navy's S&T vision is to sponsor scientific research and technology in pursuit of revolutionary capabilities for US Naval forces of the future, mature and transition S&T advances to improve US Naval capabilities, respond to current critical needs and maintain broad technology investments to anticipate and counter potential technology surprises. To support this mission, the NAE S&T portfolio must provide solutions that will enable the future force while simultaneously seizing opportunities to enhance current readiness. The NAE Chief Technology Officer improves on the NAE's ability to align S&T priorities, strategically invest in S&T programs, measure S&T program success and deliver technology solutions to address capability gaps. Specifically, the NAE CTO must¹²:

DISTRIBUTION STATEMENT A. Approved for public release; distribution is unlimited

- Ensure alignment of applicable S&T programs with NAE missions and future capability needs.
- Balance and manage the applicable S&T portfolio in cooperation with ONR and other resource sponsors.
- Communicate the NAE S&T vision and approach to senior decision makers, key stakeholders, S&T partners, customers and performers.

Marine Corps Aviation has its own additional S&T requirements to create and maintain network-enabled and digitally interoperable expeditionary aviation combat elements postured to execute responsive, persistent, lethal, and adaptive full-spectrum operations as directed by Marine Corps or joint force commanders. Marine Corps Aviation S&T is an integral part of the larger Naval Research efforts, and is a collaborative effort between the Deputy Commandant for Combat Development and Integration, the Marine Corps Systems Command, the Program Executive Officer for Land Systems, and ONR.

5.6.1.4 Naval Air Systems Command (NAVAIR) ¹³

NAVAIR's mission is to provide full life-cycle support of naval aviation aircraft, weapons and systems operated by Sailors and Marines. This support includes research, design, development, and systems engineering; acquisition; test and evaluation; training facilities and equipment; repair and modification; and in-service engineering and logistics support. NAVAIR provides support (people, processes, tools, training, mission facilities, and core technologies) to Naval Aviation Program Executive Officers (PEOs) and their assigned program managers, who are responsible for meeting the cost, schedule, and performance requirements of their assigned programs. NAVAIR's affiliated PEOs are:

- PEO for Tactical Aircraft Programs, PEO(T)
- PEO for Air ASW, Assault and Special Mission Programs, PEO(A)
- PEO for Unmanned Aviation and Strike Weapons, PEO(U&W), and
- PEO for Joint Strike Fighter, PEO(JSF), (which alternates service lead with the U.S. Air Force)

NAVAIR is the principal provider for the Naval Aviation Enterprise (NAE), while contributing to every warfare enterprise in the interest of national security.

5.6.1.5 Naval Air Warfare Centers

The NAWCs enhance Naval Aviation technical capabilities and promote technological innovation. Their primary contribution toward future capabilities is made through RDAT&E support to Naval Aviation and DOD acquisition programs, including the accelerated application of science and technology (S&T) and support for DOD initiatives. The NAWCs explore new technology with the goal of developing advantages over current and future adversaries.

The Warfare Centers comprise more than 19,000 civilian, military, and contractor support personnel and facilities aligned to National Competencies operating out of facilities at Patuxent River, Maryland;

DISTRIBUTION STATEMENT A. Approved for public release; distribution is unlimited

Lakehurst, New Jersey; Orlando, Florida; and China Lake and Point Mugu, California, with a total business base of approximately \$4 billion. NAWCAD/WD personnel serve on IPTs and Externally Directed Teams (EDTs) for customers, and provide the expertise to develop, test, acquire, and sustain critical Naval Aviation assets throughout the acquisition lifecycle. The NAWCs also support the interests of national security in the Global War on Terror, and are stewards of some of the nation's most valuable laboratory and test and evaluation assets. NAWCAD/WD leadership is responsible for aligning all aspects of operations with the goals of DOD, the Navy, Naval Aviation Enterprise (NAE), and NAVAIR, as well as Base Realignment and Closure (BRAC) law. NAWCAD/WD is a preeminent technical resource for our Naval Aviation forces.

The core product areas provided include: Air Vehicle, Aircraft Launch and Recovery/Support Equipment (ALRE/SE), Avionics, Human Systems, Propulsion & Power, Prototyping, Weapons and Energetics, Warfare Analysis and Test & Evaluation Resources.

Air Vehicles

NAWCAD Scientists and Engineers provide the technical excellence to support the maritime engineering needs related to technology development, system acquisition, and product support of all Naval Aviation Air Vehicle Engineering. Air Vehicle Engineering consists of the following functional areas: Air Vehicle Engineering, Aeromechanics, Structures, Materials Engineering, Subsystems, and Aerial Vehicle Engineering Science and Technology.

Avionics

NAWCAD provides the engineering personnel, processes, facilities, and equipment required by NAVAIR and the Program Executive Officers to accomplish the technology research, systems development, acquisition, and in-service support of Naval avionics systems, equipment and associated operating software.

This includes providing system engineering, integration, design, analysis, prototyping, tests, evaluation, and Integrated Support Engineering services and products related to mission computers/processors, communication; navigation; controls; displays; mission sensors; instruments; antennas; armament control; electronic warfare; interface devices; electronic data buses; mission planning; aviation-related ship and shore-based electronics; other related systems and equipment; and associated operating software.

Human Systems

NAWCAD provides resources, products, and RDT&E services to optimize the human within the total system, including the entire compliment of aviation support facilities and equipment on aviation capable ships. NAWCAD integrates Human Factors Engineering (HFE); Manpower, Personnel, and Training (MPT);

DISTRIBUTION STATEMENT A. Approved for public release; distribution is unlimited

health hazards; safety factors; medical factors; personnel (or human) survivability factors; and habitability considerations into the system acquisition process.

Propulsion and Power

NAWCAD operates Propulsion and Power facilities that conduct testing of propulsion systems and components for all Navy Aircraft Systems and the systems of the other Services and research agencies.

The facilities are the Propulsion Systems Evaluation Facility (PSEF) which tests every aspect of propulsion systems on many diverse platforms. The PSEF contains 55 test and support areas including: Fuels and Lubricants Test and Laboratory areas, Rotor Spin Facility for Compressors and Turbines, Altitude Environmental Chamber, Helicopter Drive System Facility, Small Engine and Accessory Test Area, and Central Computer Facility. The Aircraft Test and Evaluation Facility (ATEF), commonly called the Hush House, is a test cell for propulsion testing of Fighter and Attack sized aircraft.

In addition to aircraft testing the facility also conducts uninstalled propulsion testing, Night Vision, Weight and Balance and other specialized testing activities. The Outdoor Test Site (OTS), located at Lakehurst, New Jersey, conducts testing outside of full scale propulsion systems such as Gyroscopic and Attitude testing. The Electrical Systems Lab (ESL) provides a full complement of electrical component testing including MIL-STD-704 testing, Environmental and Vibration testing. Testing of the power delivery systems of the aircraft are conducted utilizing mobile labs.

Rapid Prototyping

NAVAIR contains full spectrum capabilities to prototype solutions for rapid response to urgent needs and planned platform upgrades. Solutions run from integrating a radio and antenna to weaponization of a vehicle, to replacing aircraft “steam gages” with a modern glass cockpit in a legacy platform.

NAVAIR onboard capabilities include early project planning, architecture and analysis tools such as Computed Aided Design and Finite Element Analysis system. Designs are machined using NCR machines or 3D printers in fully equipped machine shops. NAVAIR also maintains a full composite material shop capable of producing large composite panels, rocket motor casing and RCS specific radomes. System integration labs are available and are extensively used for system of system projects.

Component and full project testing is all available within NAVAIR from environmental (temperature, pressure, humidity, vibration, RCS) to ranges for flight and weapon drop testing. Performance monitors and instrumentation specialist are resident for project safety and flight clearances. Both developmental and operational test squadrons reside onboard and are utilized for prototype testing prior to projects being sent to theater or the production ready drawing packages sent for competition and production.

DISTRIBUTION STATEMENT A. Approved for public release; distribution is unlimited

Ship / Shore Air Operations

NAWCAD is a provider of Ship and Shore Based Electronic Systems encompassing a wide spectrum of engineering tasks and services including Air Traffic Control, surface based aircraft Identification Systems, Shipboard Exterior Communications, Special Communications requirements (primarily for the Special Operations and Joint Communications), Shipboard Data Link Systems, and specialized Information Technology.

In support of the Fleet, NAWCAD also supports large scale shipboard communication integration, specialized service and systems integration(s) for the various government agencies, the development of advanced interactive electronic training manuals and unique operational computer networking services.

ALRE/SE

NAVAIR Lakehurst is the Aircraft Platform Interface (API) expert. They are responsible for the equipment, systems, processes and expertise needed to assure that aircraft can operate safely and effectively from aircraft carriers, air-capable ships and expeditionary airfields. The major components of the API mission are ALRE and SE. NAWCAD Lakehurst facility is responsible for design, development, evaluation, verification, fielding, and in-service engineering support for Aircraft Launch and Recovery (ALRE) and aircraft/target/weapon Support Equipment (SE). Details of the NAVAIR Lakehurst facility are presented separately later in this report.

ALRE includes: steam catapults, jet blast deflectors, carrier and shore based arresting gear, air-capable ship recovery systems, barricade systems, LSO heads-up display, optical landing systems, wind measuring and indicating systems, marking and lighting, shipboard information systems, shipboard firefighting and certification of aviation facilities.

SE acquisition subject matter experts for 42,000 types of SE; includes: Airframe SE (handling, electrical/hydraulic servicing, maintenance platforms); Armament SE (loading, transport); Propulsion SE (test systems, Maintenance); Avionics SE (early warning, navigation, communications, electro-optics, aircraft wing, radar); and Automatic Test Equipment (avionic test sets, hybrid test systems, consolidated automated support system).

Applicable Technology / Expertise:

- Airframe inspection
- Aviation Facility Certification
- Composite Repair
- Corrosion Control
- Design studies
- Electrical/Hydraulics/Pneumatics Systems

DISTRIBUTION STATEMENT A. Approved for public release; distribution is unlimited

- Electromagnetics
- Expeditionary Airfield Service Unit
- Level of Repair Analysis
- Materials Analysis
- Modeling and Simulation
- Non-Destructive Inspection
- Ship compatibility analysis
- Specifications and Standards
- Stress analysis
- Wind Measurement Technology
- Workload simulation/analysis

Warfare Analysis

NAWC provides the resources to support research and analyses to aid key decision makers in assessing Navy needs and operational requirements. Aviation analysis is conducted in support of early conceptual design and trade studies, requirements generation, acquisition decision making (including AoAs), general naval aviation related analysis and source selection.

Analytical tools include databases and a wide variety of computer-based models and simulations. Personnel skills include the ability to understand and portray naval warfare operations (including joint operations), provide threat and scenario definitions and generate appropriate operational concepts in defined mission areas.

The Warfare Analysis and Integration Department evaluates the military utility of Naval Aviation systems, and within that context assists in determining current and future operational capabilities and requirements. This is accomplished by applying the analytic knowledge and skills of its personnel along with utilizing its analytic tools to integrate multi-disciplinary information across competencies, operations, environments, and intelligence. Quantitative and qualitatively supported information is produced describing how the systems and subsystems supported by the Naval Aviation Enterprise impact the Navy's influence in the battlefield. This is captured in the department's mission statement: "Assess, analyze, and quantify the effectiveness of Naval Aviation technologies, systems, and capabilities in the operational battlespace."

The Warfare Analysis and Integration Department's primary responsibility, as defined in its charter, includes providing the resources, tools and analyses to assess and perform subsystem through family of systems analysis in the following primary areas:

1. Engineering/Engagement/Mission/Campaign Level Analyses
2. Operational Suitability/Effectiveness Analyses

DISTRIBUTION STATEMENT A. Approved for public release; distribution is unlimited

3. Weapon/Warhead System Performance Analyses
4. Aircraft Conceptual Design Analyses
5. Acquisition Program Source Selection Expertise
6. Science and Technology (S&T) Gap Analyses
7. Pre-Milestone A/B Analytic and Decision Support Efforts

Weapons and Energetics:

The Weapons and Energetics Department provides a broad spectrum of science and engineering capabilities that are necessary to support naval weapons research, development, testing and evaluation. "Energetics" includes not only the energetic materials which are at the heart of any weapon system, but the sub-systems which are engineered to manage the output of these materials. Key energetics subsystems are safe and arm devices, warheads, fuzes, and propulsion. The focus of the "Weapons" side of the Department includes the weapon airframes, control systems, integration of sensors, seekers, and communications, and overall integration of the weapon "system".

The Weapons and Energetics division consists of the following four functional areas: Energetics, Airframes, Guidance and Control, and Systems Engineering.

5.6.1.6 Naval Surface Warfare Center - Carderock Division (NSWCCD)

Carderock Division is the U.S. Navy's state-of-the-art research, engineering, modeling, and test center for ships and ship systems. It is the largest, most comprehensive establishment of its kind in the world, serving a dual role in support of both our U.S. naval forces and the maritime industry.

Navy and maritime communities have come to depend on their expertise and innovation in developing advanced platforms and systems, enhancing naval performance, reducing operating costs, and addressing the Navy's evolving mission.

Carderock's core competencies include:

- Design & Integration Technology;
- Environmental Quality Systems;
- Hull Forms & Propulsors;
- Structures and Materials;
- Signatures and Silencing Systems,
- Machinery Systems and Components;
- Vulnerability and Survivability Systems

S&T areas at NSWCCD that support SBA include:

DISTRIBUTION STATEMENT A. Approved for public release; distribution is unlimited

- Analytical and experimental methods for prediction of seakeeping (ship motion) characteristics relevant to shipboard launch and recovery
- Experimental and analytical evaluations of ship aerodynamics to support seakeeping analyses and prediction of wind-over-deck characteristics
- Analytical evaluation of fan-in-wing aircraft
- Analytical and experimental evaluation of ducted fans
- CFD analysis of ships, submarines, and aircraft
- Advanced concept development (e.g., sea based platforms and V/STOL air vehicles)
- Aircraft launch and recovery to/from ships
- Expert systems and advanced data analysis techniques

Current SBA technical gaps being addressed by NSWCCD include:

- Technologies to maximize shipboard launch and recovery environmental envelopes for Naval aircraft.
- M&S to support aircraft launch and recovery analyses.
- Development of high-speed VTOL capability
- Ship design guidance to enhance dynamic interface characteristics including fast, moderate-fidelity methods suitable for application within the design cycle.
- Introduction and utilization of Health and Usage Monitoring Systems (HUMS) and Condition Based Maintenance technologies with the logistics system, including constraints typical of the shipboard environment.

Many of the facilities needed to support the Division's mission are unique in the Navy, the nation or the world. Since workload is variable for individual facilities from year-to-year and because many of the facilities have little or no commercial application, there is little economic incentive for industry to develop or maintain similar capabilities.

Although analytical models and analysis techniques have been developed and are being continually refined, facilities are still needed to validate the models/techniques and to ensure that new ships meet performance specifications on delivery and operational units continue to perform as designed before going in harm's way. Consequently, the Carderock Division is one of the Navy's most facility-intensive research and engineering activities.

Carderock Division facilities are available for use by outside sources (both government and private sector) through Cooperative Research and Development Agreements (CRADA) and Work for Private Party Agreements.¹⁴

DISTRIBUTION STATEMENT A. Approved for public release; distribution is unlimited

5.6.2 Army

5.6.2.1 Army AATD

The Aviation Applied Technology Directorate (AATD) is a Directorate of the Aviation and Missile Research Development and Engineering Center (AMRDEC), and is primarily responsible for investing 6.2 funding toward Army Aviation Science and Technology research. AATD states that its mission is to “Transition critical technologies that enhance and sustain Army Aviation as the premiere land force aviation component in the world.” AATD is located at Fort Eustis, Virginia. The four technical divisions are Platform Technology, Power Systems, Systems Integration and Rapid Prototyping.

The Platform Technology Division exists to transition critical technologies that enhance and sustain Army Aviation in the technology disciplines related to airframe structures, rotors, flight controls and subsystems.

The Power Systems Division explores and develops innovative component technologies needed to advance the state-of-the-art of propulsion systems for rotary wing aircraft, including improving the power density, power-to-weight ratio, and specific fuel consumption of turboshaft engines; and improving the weight, noise, and durability characteristics of rotorcraft power transmission drive systems. This division also develops and tests Aviation Ground Support Equipment and strives to improve aircraft maintenance through the introduction of advanced technologies, diagnostics, business process reengineering, and enabling transition to Condition-Based Maintenance process.

The mission of the Systems Integration Division is to explore, develop, leverage and apply systems integration concepts, technologies, and mission equipment for Army Aviation in the areas of: teaming; autonomy; airspace deconfliction; reconnaissance, surveillance and target acquisition and fire control; architectures; intelligent agents; data fusion and signal processing; decision aiding; information management; survivability management; sensors and weapons; and avionics integration.

The Rapid Prototyping Division provides a "one stop" rapid prototyping approach for demonstrating and transitioning critical technologies that enhance Army Aviation capabilities.¹⁵

5.6.2.2 Aeroflightdynamics Directorate's (AFDD)

The Aeroflightdynamics Directorate (AFDD) is a Directorate of the Aviation and Missile Research Development and Engineering Center (AMRDEC), and is primarily responsible for investing 6.1 funding toward Army Aviation Science and Technology research. AATD advances knowledge and innovative technology in rotorcraft aeromechanics and human-system integration, providing a decisive advantage for Allied forces in Aviation mission worldwide and enhancing U.S. rotorcraft competitiveness. AFDD is primarily located at the Ames Research Center of the National Aeronautics and Space Administration (NASA) at Moffett Field, CA. It also has a contingent at NASA's Langley Research Center in Hampton, VA.

DISTRIBUTION STATEMENT A. Approved for public release; distribution is unlimited

AFDD's mission is in-house execution of Aviation S&T in aeromechanics, flight control, preliminary design, and human-systems integration. AFDD also administers the National Rotorcraft Technology Center, Vertical Lift Research Centers of Excellence, and DoD High Performance Computing Modernization Office Advanced Rotorcraft CFD Modeling and Simulation Institute. Capabilities and competencies include: physics-based modeling, aerodynamics and acoustics, dynamics, comprehensive analysis, flight control, handling qualities, simulation, human-system integration, testing and validation, and design synthesis.¹⁶

5.6.2.3 Aviation Engineering Directorate (AED)

The Aviation Engineering Directorate (AED) is the airworthiness authority for Army-developed aircraft and provides matrix support to Army program managers.

5.6.2.4 System Simulation and Development Directorate (SSDD)

The System Simulation and Development Directorate (SSDD) assists in the evaluation and analysis of new weapon systems, provides technical and simulation support to all elements of the parent organization, project managers, and other government agencies.¹⁷

5.6.2.5 Weapons Development and Integration Directorate (WDI)

The Weapons Development and Integration Directorate (WDI) Directorate exists to conduct research, exploratory and advanced development, technology demonstrations, and provide engineering and scientific expertise in all aspects of weapon system design, development, improvement and integration for the Army.¹⁸

5.6.2.6 Weapons Sciences Directorate (WSD)

The mission of the Weapons Sciences Directorate (WSD) is to plan, perform, supervise, and review basic and applied research in the physical and engineering sciences to support both the missile and aviation missions of AMRDEC.¹⁹

5.6.3 Air Force

5.6.3.1 Air Force Research Laboratory (AFRL)

The Air Force Research Laboratory (AFRL)²⁰ is the scientific research organization of the U.S. Air Force Materiel Command. It is dedicated to leading the discovery, development, and integration of affordable aerospace warfighting technologies; planning and executing the Air Force S&T program; and provides leading-edge warfighting capabilities to U.S. air, space, and cyberspace forces. AFRL is comprised of nine technology directorates, with seven applicable to aviation.

- Air Vehicles Directorate: leads technology investments that support cost-effective, survivable aerospace vehicles capable of accurate and quick delivery of a variety of future weapons or

DISTRIBUTION STATEMENT A. Approved for public release; distribution is unlimited

cargo anywhere in the world. Core technology areas focus on aeronautical sciences, control sciences, structures and integration.

- Directed Energy Directorate: develops, integrates and transitions S&T for high power microwaves, lasers, adaptive optics, imaging and effects.
- Information Directorate: develops information technologies for aerospace command and control, including information fusion and exploitation, communications and networking, collaborative environments, M&S, defensive information warfare and intelligent information systems technologies.
- Materials and Manufacturing Directorate: develops new materials, processes and manufacturing technologies for use in aerospace applications.
- Munitions Directorate: develops, demonstrates and transitions S&T for air-launched munitions.
- Propulsion Directorate: develops air and space vehicle propulsion and power technologies. Focus areas include turbine and rocket engines, advanced propulsion systems, and the associated fuels and propellants for all propulsion systems.
- Sensors Directorate: develops new technologies to find and precisely engage the enemy and eliminate its ability to hide or threaten our forces. Core technology areas include: radar, active and passive electro-optical targeting systems, navigation aids, automatic target recognition, sensor fusion, threat warning and threat countermeasures.

5.6.4 National Aeronautics and Space Administration (NASA)²¹

5.6.4.1 NASA Ames Research Center

NASA Ames Research Center, located at Moffett Field, California, is a leader in information technology research – with a focus on supercomputing, networking and intelligent systems – as well as nanotechnology, fundamental space biology, biotechnology, aerospace, thermal protection systems, and human factors research. The Aeronautics Directorate promotes advances in concepts and technologies for safe and efficient national airspace operations, aeronautics and aerospace systems analysis tools, and new flight vehicle concept and systems. The Directorate also operates national wind tunnel facilities and human-in-the-loop flight simulation facilities for the benefit of NASA and the aerospace industry.

5.6.4.2 NASA Dryden Flight Research Center

The Dryden Flight Research Center, located at Edwards Air Force Base, CA, is NASA's primary center for atmospheric flight research and operations. Six discipline branches — aerodynamics and propulsion; aerostructures; dynamics and controls; flight instrumentation; flight systems; and systems engineering

DISTRIBUTION STATEMENT A. Approved for public release; distribution is unlimited

and integration — provide research and project support engineering to Dryden. In all areas, the expertise covers software, hardware, analysis, modeling, planning and execution of flight, and development of flight or ground test techniques.

5.6.4.3 NASA John H. Glenn Research Center

The John H. Glenn Research Center at Lewis Field, Cleveland, Ohio is focused on technological advancements in spaceflight systems development, aeropropulsion, space propulsion, power systems, nuclear systems, communications and human research. Aeronautics research includes advanced turbine engine propulsion and power systems, turbine engine noise reduction, propulsion control and engine health management, instrumentation systems, avionics, aircraft icing, M&S and alternative fuel systems.

5.6.4.4 NASA Langley Research Center

The Langley Research Center, located in Hampton, Virginia focuses primarily on aeronautical research; more than 40 wind tunnels are used to study improved aircraft and spacecraft safety, performance, and efficiency. Its current focus is on global climate change, access to space and revolutionizing airplanes and the air transportation system.

5.6.5 Industry

S&T advancements spurred by industry innovation are needed to effectively operate in the unique and harsh environment that SBA faces. A significant level of design skills and expertise must also be maintained and continually updated by the NAVY and Industry. While those skills used in the design of land based aviation are similar, the shipboard issues that are peculiar to SBA are dominant in design considerations. Industry will need to retain technically qualified and innovative engineering talent over the long term, so as to have them available for the development of the following generation of naval aircraft.

The aircraft industry plays a critical role in the design and production of both civil and military aircraft. With a combined revenue of over \$200B, it is responsible for more than two million jobs and draws from more than 30,000 suppliers in all 50 states.¹¹ This report touches on the top 5 aircraft manufacturers of sea-based naval aircraft as outlined in Table 1: Lockheed Martin, Northrop Grumman, Boeing, Sikorsky, and Bell.

“The danger exists that Americans may not know enough about science, technology, or mathematics to significantly contribute to, or fully benefit from, the knowledge-based society that is already taking shape around us.”

Rising Above the Gathering Storm: Energizing and Employing America for a Brighter Economic Future - 2007

DISTRIBUTION STATEMENT A. Approved for public release; distribution is unlimited

Additionally, a large number of second and third tier suppliers, and component and equipment manufacturers (including engine manufactures General Electric, Pratt Whitney, Rolls Royce/Liberty Works) conduct vital industry R&D to address fundamentally Navy unique and Navy driven Sea-based Aviation technical challenges.

5.6.5.1 Lockheed Martin Aeronautics Company (LM Aero)

Lockheed Martin Aeronautics is the developer of all of the 5th generation fighter aircraft, which includes the F-22, and the F-35. As the F-35 is the Navy's first stealth fighter, LM Aero's history of stealth aircraft development and fighter technology position the company well in the areas of S&T for Sea-based Aviation. Skill-sets ranging from airframe design, maintenance, composite repair, aircraft sustainment, M&S, reliability and risk analysis, aircraft life analysis, composite damage analysis, and bonded joint design and analysis are areas that can be extensively leveraged by the SBA S&T programs.

5.6.5.2 Northrop Grumman

Northrop Grumman has a tradition in Navy sea-based aircraft design, development, and production going back to the 1931 Grumman FF-1 and up to the X-47B. Northrop Grumman has developed a suite of design tools and methodologies for sea based aircraft, including conceptual design tools for estimating carrier compatibility and spot factor; 6-degree of freedom flight dynamic simulations integrated with ship motion and airwake/burble models, waveoff, bolter, and landing dispersion; and simulations of aircraft operations aboard and around the carrier. They have developed technology to manage UAS operations on and around the carrier, and unique tools for Warfighter evaluations, including all phases of carrier and mission operations.

5.6.5.3 Boeing

Boeing legacy in Sea-based Aviation begins in 1925 with early biplanes and extends to modern supersonic jet aircraft, including trainer, bomber, strike, and fighter types. They are also a provider of fleet support for legacy sea-based aircraft and are industry leaders in the development of autonomous CONOPS, software, and systems. Boeing has demonstrated autonomous operations in the carrier environment. Skill-sets include airframe design; experimental and computational aerodynamics; noise and vibration control; M&S; aircraft subsystems; electromagnetics; advanced composites; reliability and maintainability; and advanced aerial refueling systems.

5.6.5.4 Sikorsky

Sikorsky Aircraft Corporation is a world leader in the design, manufacture and service of military and commercial helicopters. Core U.S. military production programs are based on the Sikorsky H-60 aircraft: the BLACK HAWK helicopter for the U.S. Army and SEAHAWK® helicopter for the U.S. Navy. The CH-53E helicopter and MH-53E helicopter heavy-lift aircraft are flown by the U.S. Navy and Marine Corps to transport personnel and equipment, and in anti-mine warfare missions. Sikorsky is currently developing the next-generation CH-53K helicopter for the U.S. Marines. Sikorsky has developed four

DISTRIBUTION STATEMENT A. Approved for public release; distribution is unlimited

generations of maritime helicopters including the SEAHAWK, SUPER STALLION™ and SEA KING™ helicopters.

5.6.5.5 Bell

Bell Helicopter is a leader in manned and unmanned vertical takeoff and landing aircraft for commercial and military applications, and a pioneer in tiltrotor aircraft. Bell products supporting military applications include the V-22, UH-1, AH-1, OH-58, and the Eagle Eye UAS. Skill-sets ranging from rotorcraft design, maintenance, composite repair, rotorcraft sustainment, M&S, reliability and risk analysis, aircraft life analysis, composite damage analysis, and M&S are areas that can be extensively leveraged by the Sea-based Aviation S&T programs.

5.6.6 Academic Performers

According to the Accreditation Board for Engineering and Technology (ABET), there are currently 68 accredited Aerospace Engineering programs in the United States as shown in Figure 22. This compares to 285 accredited Mechanical Engineering programs and 296 accredited programs for Electrical and Electronics Engineering.²² The largest accredited Aerospace Engineering programs (as indicated by the number of Bachelor's degrees) are shown in Figure 23.²³ Representative programs that have centers of excellence which have received ONR support include Georgia Institute of Technology, The University of Maryland, and Pennsylvania State University.

The Georgia Institute of Technology is a public research university in Atlanta, Georgia, with over 20,000 students. The engineering school was ranked 4th in the nation in the 2010 U.S. News and World Report rankings. There are over 8000 undergraduate and 3800 graduate engineering students.

The University of Maryland, College Park, MD, is a public research university with more than 37,000 students. The University's engineering school was ranked 9th in the 2010 U.S. News and World Report rankings. There are approximately 2,400 engineering undergraduate students and 1,600 postgraduates.

The Pennsylvania State University, located at University Park, PA, is a public research university with more than 45,000 students. U.S. News and World Report ranked Penn State School of Engineering in the top 50 for "Best Undergraduate Engineering Programs" for schools that offer bachelor's or master's as their highest degrees. There are approximately 1,600 engineering graduate students.²⁴

| Accredited Aerospace Engineering Programs | |
|--|---|
| Air Force Institute of Technology | The Ohio State University |
| Arizona State University | The University of Alabama |
| Auburn University | The University of Alabama in Huntsville |
| Boston University | The University of Kansas |
| California Polytechnic State University | The University of Oklahoma |
| California State Polytechnic University | Tuskegee University |
| California State University | United States Air Force Academy |
| Capitol College | University of Arizona |
| Case Western Reserve University | |
| Clarkson University | University of California |
| Daniel Webster College | University of California, Los Angeles |
| Embry-Riddle Aeronautical University - Daytona Beach | University of California, San Diego |
| Embry-Riddle Aeronautical University - Prescott | University of Central Florida |
| Florida Institute of Technology | University of Cincinnati |
| Georgia Institute of Technology | University of Colorado at Boulder |
| Illinois Institute of Technology | University of Florida |
| Iowa State University | University of Illinois at Urbana-Champaign |
| Massachusetts Institute of Technology | University of Maryland College Park |
| Mississippi State University | University of Miami |
| Missouri University of Science and Technology | University of Michigan |
| Naval Postgraduate School | University of Minnesota-Twin Cities |
| North Carolina State University at Raleigh | University of Notre Dame |
| Oklahoma State University | University of Southern California |
| Pennsylvania State University | University of Tennessee at Knoxville |
| Princeton University | University of Texas at Arlington |
| Purdue University at West Lafayette | University of Texas at Austin |
| Rensselaer Polytechnic Institute | University of Virginia |
| Saint Louis University | University of Washington |
| San Diego State University | Virginia Polytechnic Institute and State University |
| San Jose State University | West Virginia University |
| State University of New York at Buffalo | Western Michigan University |
| Syracuse University | Wichita State University |
| Texas A & M University | Worcester Polytechnic Institute |

Figure 21 Accredited Aerospace Engineering Programs in the United States - ABET

DISTRIBUTION STATEMENT A. Approved for public release; distribution is unlimited

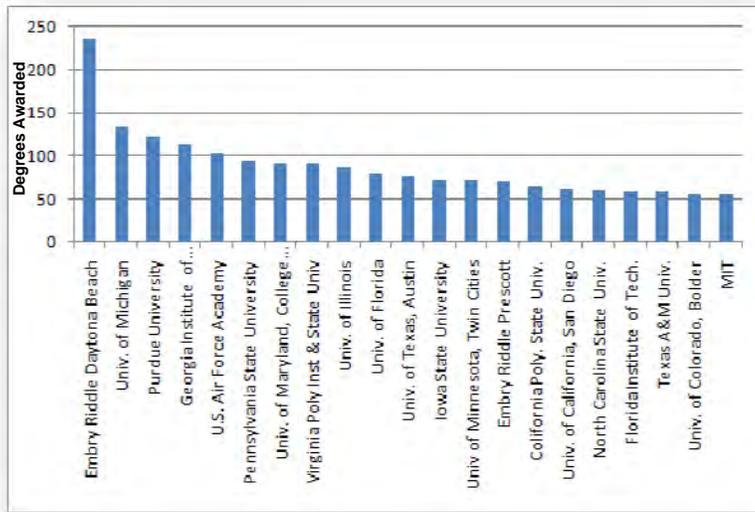


Figure 22 Bachelor degrees awarded - Largest Accredited Aerospace Engineering Programs

5.7 Knowledge-based Pipeline

Trends in degrees awarded for Aerospace Engineering are presented in Figure 24 along with trends in overall Engineering degrees awarded (1985-2006). After a long period of decline from 1985 to 2000, overall Engineering degrees awarded are now experiencing growth. Growth from 2000 to 2006 was a robust 14 percent. Growth in Engineering Masters and PhD degrees awarded is more robust, showing increases above 25% from 2000-2006. Aerospace Engineering Bachelor and Masters degrees awarded from 1995 to 2000 experienced sharp declines; shrinking more than 50% in some cases. In recent years this trend has reversed showing a doubling in degrees awarded from 2000 to 2006. Growth in Aerospace Engineering PhD Degrees awarded, while showing recent growth, is not at the levels experienced for the other degrees shown.²⁵

Trends in engineering degrees by residency have been consistent for the past 10 years. Domestic students receive a much higher proportion of Bachelor’s degrees; 94% in 2009. However this is not the case for Master’s and Doctoral degrees. Foreign nationals proportion of master’s degrees increased for the second consecutive year. The 41 percent representation is the highest share since 2004. The share of doctoral degrees awarded to foreign nationals dipped for the second consecutive year, falling to 59 percent. This is virtually the same percentage seen in 2003 before it reached a high point of 61.7 percent in 2006²⁴.

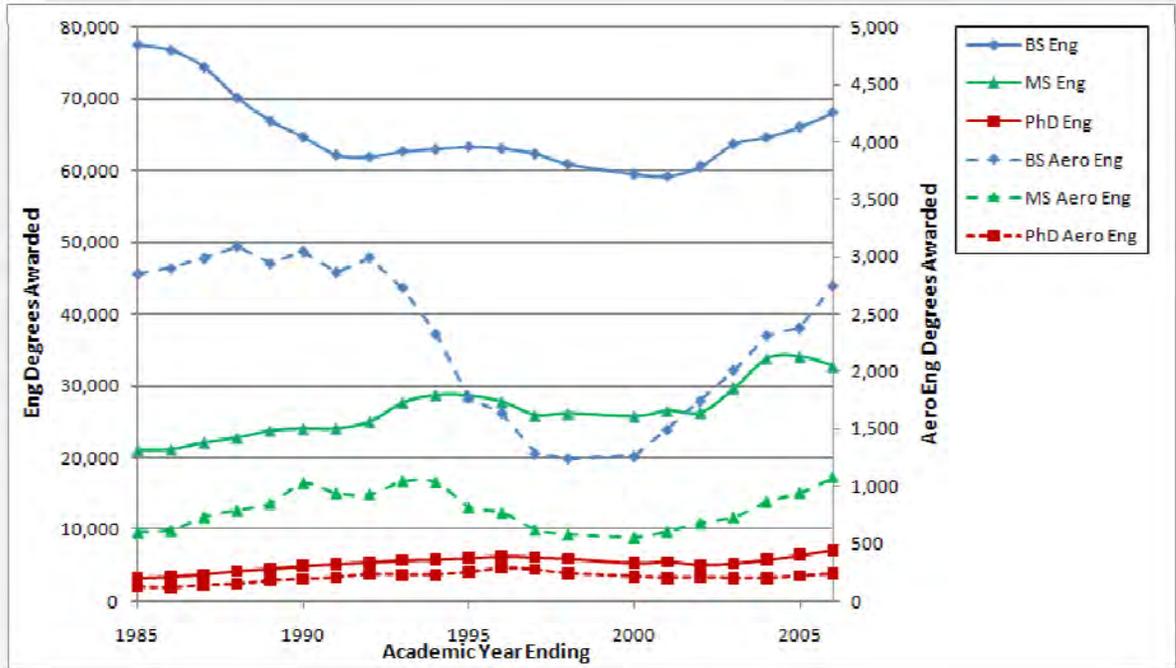


Figure 23 Engineering Degrees Awarded (Overall and Aerospace) from 1985-2006²⁸

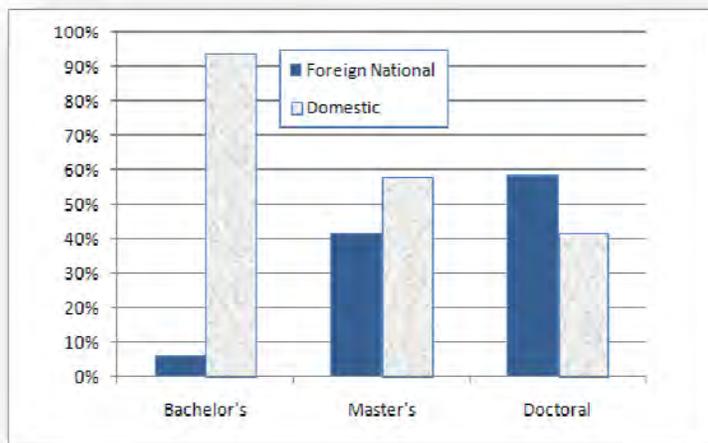


Figure 24 Engineering Degrees by Residency, 2009

Salaries for key R&D engineering positions within the aviation community (Aerospace, Electrical and Mechanical) are shown in Figure 26. In all cases, salaries for R&D positions outpace the overall mean within a given discipline (e.g.; salaries for aerospace R&D positions are higher than the mean salaries for all other aerospace positions). Salaries for key engineering disciplines within aeronautics (Aerospace,

DISTRIBUTION STATEMENT A. Approved for public release; distribution is unlimited

Electrical and Mechanical Engineering) are well above the national average for all other engineering disciplines (\$73,590).²⁶

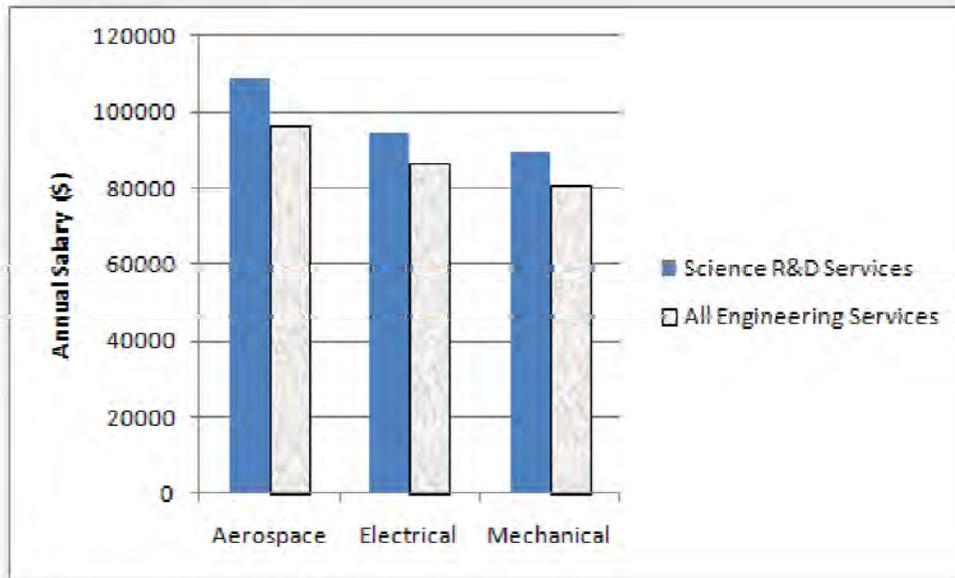


Figure 25 Mean Salaries for Science R&D Services vs. All Engineering Occupations

Post graduation surveys administered by colleges provide information on their effectiveness of placing graduates within industry or graduate school. A sampling of survey data is shown in Figure 27 for a large engineering school - Virginia Polytechnic Institute and State University (Virginia Tech) for the Aerospace Engineering program and Engineering as a whole.²⁷

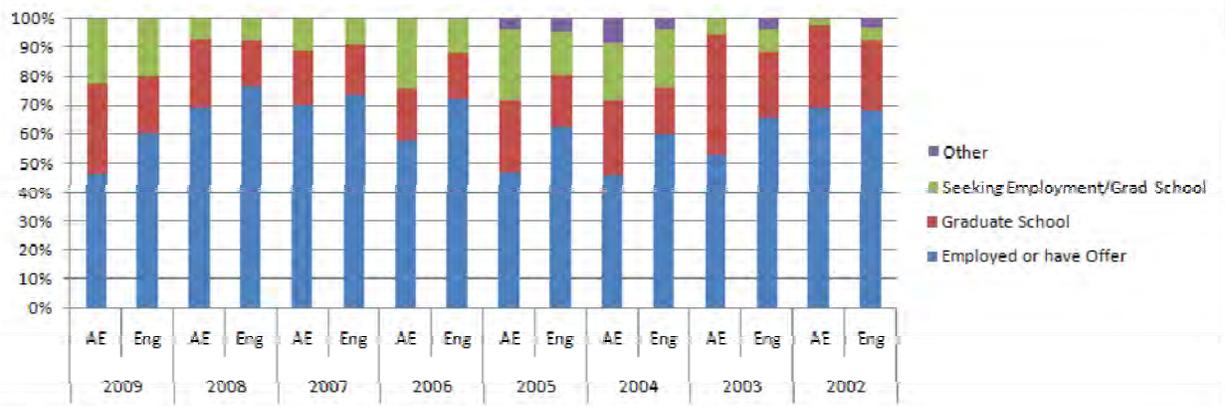


Figure 26 Virginia Tech Engineering Post Graduation Report; Plans or Status after Graduation

DISTRIBUTION STATEMENT A. Approved for public release; distribution is unlimited

Data shows that the percentage of graduates still seeking employment or entry into graduate school is equivalent for Aerospace Engineering (AE) and the overall engineering department (Eng). However, in general, a greater percentage of Aerospace Engineering graduates enter graduate school compared to the Engineering department as a whole.

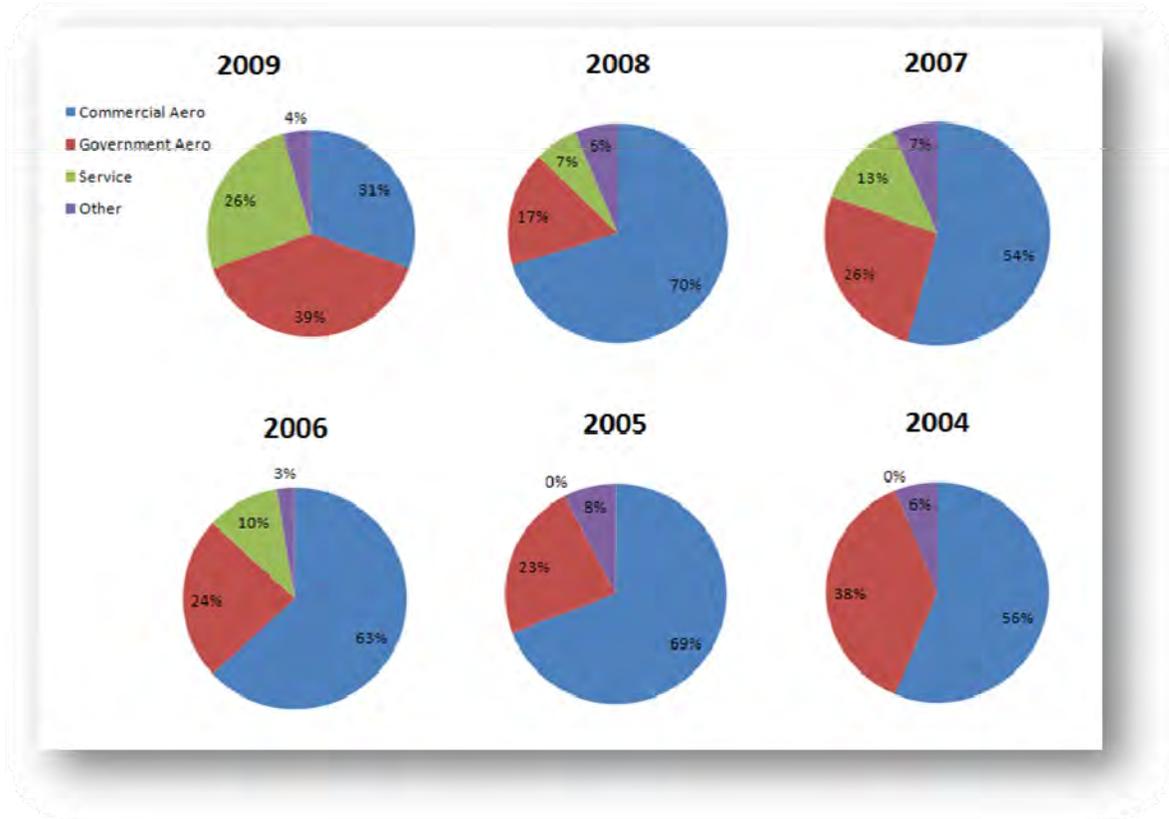


Figure 27 Distribution of Employee Organization for Aerospace Engineering Graduates (VA Tech).

Virginia Tech post-graduation surveys for Aerospace Engineering also reveal that greater than 90% of those employed or that have offers in the first 6-months after graduation find positions within the Aerospace industry or within the Services as indicated by Figure 28. In previous years (prior to 2009), a majority of those entering the job market did so through commercial aerospace companies while the remaining entered either through Government agencies or the Services. In 2009, this trend was broken with even distribution of employees between commercial, Government and the Services.

5.8 Facilities and Equipment

The 2007 National R&D Plan states that “the RDT&E infrastructure used by the nation’s aeronautics community includes both domestic (i.e., national) and foreign assets.” It points out that the national

DISTRIBUTION STATEMENT A. Approved for public release; distribution is unlimited

RDT&E infrastructure includes both Federal and non-Federal assets, and adds that the nation may rely on selected foreign assets in order to satisfy the requirements in that national plan.²⁸

Existing aviation-related facilities (government and private sector) provide significant infrastructure to support research activities related to general performance of Naval aircraft or ship platforms. However, the unique highly-coupled dynamic environment of Sea-based Aviation requires more sophisticated and specialized facilities. The following are examples of facility requirements for enabling research on several Navy-unique aspects of Sea-based Aviation. This list reflects representative infrastructure which supports SBA S&T, but is in no way an exhaustive list of all infrastructures that may contribute to S&T challenges associated with SBA.

5.8.1 Navy Facilities

5.8.1.1 NAVAIR

5.8.1.1.1 Naval Air Warfare Centers Aircraft Division

Air Vehicles

Labs/Facilities

- Aircraft Fire Protection Lab
- Analytical Lab
- Corrosion & Wear Lab
- Firing Tunnel
- Flight Dynamics Lab
- High Temperature Materials Lab
- Indoor Ground Ejection Facility
- Inorganic Coatings Lab
- Mass Properties Facility
- Microstructural Analysis Lab
- Naval Aerodynamics Test Facility (NATF)
- Non-Destructive Inspection Lab (NDI)
- Ordnance Electrical Facility
- **Rain Erosion/Impact Measurement Lab**
- **Rocket Launch/Test Stand Area**
- **Thermal Analysis Lab**
- **Unmanned Systems R&D**

Avionics



DISTRIBUTION STATEMENT A. Approved for public release; distribution is unlimited

Labs/Facilities

- **Advanced Active Acoustics Lab (AAAL)**
- **Airborne Low-Frequency Sonar (ALFS) Lab**
- **Atomic Physics & Optical Research (AMOT) Labs** **Figure 28 NAWC Labs/Facilities**
- **AVX-1 EO Sensor Lab**
- **Charles L. Bartberger Modeling and Simulation Facility**
- **Common Systems Integration Lab (CSIL)**
- **Dan Rosso Lab**
- Electro-Optic System Development Lab
- Electromagnetic Interface Testing Facility
- Environmental Testing
- Facilities for Antennas and RCS Measurements (FARM)
- Fleet Assistance and Support Team (FAST) Lab
- Helicopter Tethered Sonar Development Lab
- Identification Systems
- Information Fusion & Visualization Lab
- Laser Research Lab
- LIDAR R&D Lab
- Magnetic Media Lab
- Magnetics Processing
- Mission Computer & Open Systems Architecture
- Modulated LIDAR Lab
- Night Vision Imaging System Lab
- Photonics and Fiber Optics Processor Lab
- Radar and Computational Electromagnetics Modeling (RACEM) Lab
- Secure Processing Lab
- Sonar Tank Area
- Special Comms Requirements Division

Human Systems

Labs/Facilities

- Advanced Lighting and Transparencies with Night Combat Lab
- Advanced Maritime Technology Center (AMTC)
- Aircrew Accommodation Lab (with Computer Technology Lab)
- Aircrew Environmental Hazards
- Altitude Lab

DISTRIBUTION STATEMENT A. Approved for public release; distribution is unlimited

- Chemical, Biological, Radiological Lab
- Clothing Systems Design Lab
- Cognitive and Automation Research Lab
- Ejection Tower Lab
- Environmental Physiology and Human Performance
- Gas and Fluid Flow Integration Lab
- Helmet Systems Lab
- Helmet-Mounted Displays (HMD)
- Horizontal Accelerator
- Night Vision Device and Cockpit Displays
- Oxygen Lab
- Textile Technology Analysis Lab
- Vision Lab
- Windblast Assessment Facility

Propulsion and Power

Labs/Facilities

- Aircraft Test & Evaluation Facility (Hush House)
- Altitude Environmental Chamber (AEC)
- Battery Laboratory
- Drive Stands
- Dynamics Laboratory
- Fuels and Lubricants Chemistry Lab
- Fuels and Lubricants Facility
- Gyroscopic Test Stand
- Helicopter Drive System Facility (HDS)
- Low Pressure Burner Rig Facility
- Mobile Test Capabilities
- Multi-Purpose Test Stand
- Outdoor Test Site
- Rotor Spin Facility (RSF)
- Small Engine & Accessory Test Area
- Variable Attitude Test Stand

Rapid Prototyping

Labs/Facilities

DISTRIBUTION STATEMENT A. Approved for public release; distribution is unlimited

- Air Vehicle Modification & Instrumentation (AVMI)
- Aircraft Prototype Facility (APF)

Ship / Shore Air Operations

Labs/Facilities

- Electro-Optics/Visual Lab
- Surface/Aviation Interoperability Lab (SAIL)

ALRE/SE

- Team catapult complex includes C13 Mod 0 and C13 Mod 2 low-pressure catapults and a high-pressure steam plant.

- Runway Arrested Landing Site is a 12,000 foot dedicated test runway with installed shipboard-type arresting gear.



Figure 29 An F/A-18E Super Hornet prepares to launch during a test of the Electromagnetic Aircraft Launch System (EMALS) at Naval Air Systems Command, Lakehurst, N.J.

- Jet car track site provides the capability for deadloads approximating aircraft weight to be propelled down mile+ long tracks at speeds up to 250 kts.
- Jet Blast Deflector site duplicates JBDs on carriers for development and evaluation of system upgrades and aircraft compatibility testing.
- Elevated Fixed Platform, a 60x85 ft deck atop a 25 ft high structure creates a realistic landing environment for rotary-wing aircraft

Lab/ Facilities

- Advanced Launch and Recovery Control System (ALRCS) Laboratory

DISTRIBUTION STATEMENT A. Approved for public release; distribution is unlimited

- ALRE Power/Electromagnetic Aircraft Launch System (EMALS)
- Carrier Analysis Laboratory
- Component Analysis Laboratory
- Electronic Component Diagnostic Development Laboratory
- Electro Optics Laboratory
- Integrated Diagnostics Laboratory
- Modeling and Simulation Laboratory
- Product Development Laboratory
- Other Laboratories include the Consolidated Automated Support System (CASS) Product Verification/Evaluation Facility, Cryogenics Rework Facility, Electromagnetic Interference Laboratory

5.8.1.1.2 Naval Air Warfare Centers Weapons Division

Lab/Facilities

- Parachute Range Facilities
- Aeroheat Test Facility
- Materials Engineering Laboratory
- Optics and Laser Research Facility
- Air-breathing Propulsion Research Facility

5.8.1.2 Naval Surface Warfare Center Carderock Division Facilities

- 8x10 ft. Subsonic Wind Tunnel – The Navy’s largest wind tunnel; closed circuit, 160 kt tunnel speed, full 6-axis external balance, internal balances, traversing rig, and inserts for 2D airfoil testing and ship airloads/airwake testing.
- Anechoic Flow Facility – closed circuit wind tunnel with 8x8 ft closed- and open-jet sections. Open-jet section within 23x23 ft. anechoic chamber. Low (0.1%) turbulence level, 120 kt tunnel speed.
- 2x3 ft 75 kt low turbulence wind tunnel.
- Maneuvering and Seakeeping Basin – large (360ft by 240ft) seakeeping test facility, including sophisticated wavemaking facilities for testing sea based platforms in specified sea states and for aircraft ditching and flotation testing.
- David Taylor Model Basin – one of the world’s largest tow tank facilities – over 3000 ft long. Fully enclosed. Five independent carriages with precision speed control up to 50 kt. Suitable for seaplane hull testing and ship seakeeping. Currently proposed as test track for low-turbulence aerodynamic testing of airfoils and complete UAVs.

DISTRIBUTION STATEMENT A. Approved for public release; distribution is unlimited

- Circulating water channel. 10x22 ft water channel, up to 9 kt. Stationary test models and viewing/photography ports. Dye-injection for flow visualization studies.
- Model shops. State of Art automated computer controlled machining and fabrication capabilities to construct high-quality scale models and for rapid prototyping.
- SeaTech Center (High Performance computing facility) - Three compute clusters with up to 127 nodes each.

5.8.1.3 Naval Postgraduate School Laboratories

The following laboratories (not all-inclusive) are available for teaching and research:

- NPS Center for Autonomous Vehicle Research
- Nano/MEMS Laboratory
- Fluid Mechanics and Hydrodynamics Laboratories
- Materials Laboratory
- Scanning Electron Microscopy Lab
- Optical Microscopes Laboratory
- Metallurgical Sectioning/Polishing Laboratory
- Physical Testing (Dilatometer) Laboratory
- Heat Treatment Laboratory
- Corrosion Laboratory:
- Metallurgical Etching Laboratory
- Welding Laboratory
- Materials Processing Laboratory
- Creep Test Laboratory
- Mechanical Test Laboratory
- Ceramics Laboratory
- Composites Laboratory
- Rocket Propulsion Laboratory
- Structural Dynamics Laboratory
- Thermal Engineering Laboratories
 - Convection Heat Transfer Laboratory
 - Electronic Cooling Laboratory
 - Two-Phase Heat Transfer Laboratory
- Turbo-Propulsion Laboratory
- Astronautical Engineering Laboratories

DISTRIBUTION STATEMENT A. Approved for public release; distribution is unlimited

5.8.1.4 United States Naval Academy

- 3.5 x5 ft research-quality subsonic wind tunnel with six-axis external balance and recently renovated,
- Propeller/rotor whirl stand sized for rotors of up to approx. 15 ft. diameter.
- 110 ft. patrol training craft, YP-676, used for in-situ ship airwake measurements and available for UAV shipboard operations demonstrations.

5.8.1.5 Naval Research Laboratory Facilities

- Structural Acoustics In-Air Facility
- Liquid Crystal Fabrication Facility
- Nanometer Characterization/Fabrication Facility
- Fiber-Optic Sensor Facility
- Nanochannel Glass Technology Facility
- Oxide Optical Fiber Fabrication Facility
- Nanoelectronics Processing Facility (NPF)
- Corrosion Engineering and Coatings Characterization Facilities
- Materials Processing Facility
- Electro-Optics (E/O) Mobile Laboratory
- Robot Laboratory
- Marine Corrosion Facility

5.8.1.6 Naval Aerospace Medical Research Laboratory Facility

- Durability of G-Tolerance in the Absence of Repeated G-Exposure

5.8.1.7 NAVSEA Crane Facility

- Elastomer Facility
- Electro-Optics Systems

5.8.1.8 NAVSEA Indian Head Facility

- Head Energetics Manufacturing Technology Center

5.8.1.9 NAVSEA Newport Facilities

- Acoustic Wind Tunnel
- Anechoic Chamber
- Stereolithography Rapid Prototyping Facility
- Propulsion Noise Test System

5.8.1.10 NAVSEA Panama City Facilities

- Prototype Fabrication Facility

DISTRIBUTION STATEMENT A. Approved for public release; distribution is unlimited

- Rapid Prototyping Facility
- Materials Engineering Laboratory

5.8.2 Army Facilities

The U.S. Army Aviation & Missile Research, Development & Engineering Center (AMRDEC) Facilities include the following: ²⁹

- Aviation Flight Support Facility, AATD: large hangar with two helicopter pads at Felker Army Airfield on Fort Eustis.
- Ballistic Test Facility, AATD: two outdoor and one indoor test ranges where full-size aircraft can be tested against ammunition to a maximum of thirty millimeter armor-piercing and high-explosive incendiary ammunition.
- Composite Structures Manufacturing Facility, WDI: specializes in the design, analysis, fabrication and testing of advanced composite structures and materials for both missile and aviation applications.
- Countermeasure Test Facility, AATD: a turboshaft engine test stand capable of operating at full power in a simulated aircraft environment to measure acoustic and/or IR radiation and signature.
- Design and Analysis Facility, AATD: provides engineering design of aircraft components, subsystems and installations.
- Experimental Fabrication Facility, AATD: provides aviation fabrication support to special operations aircraft and for in-house testing and prototype fabrication of Army aviation initiatives.
- Flight Control Technology Laboratory, AED: helicopter flight control technology development lab.
- Flight Research Support Facility, AATD: provides support for R&D flight test and test support activities.
- Materials Facility, WDI: provides support through consultation, quality verification, materials characterization, failure and chemical analysis, mechanical and environmental testing, as well as corrosion prevention & control.
- Redstone Aviation Propulsion Test and Research (RAPTR) Facility, AED: an advanced, ground level turboshaft engine test facility.
- Rotorcraft Advanced System Concepts Airborne Lab (RASCAL) JUH-60A, AFDD: a full authority, fly-by-wire, glass cockpit in-flight simulator used for a wide range of flight control and advanced guidance display work. It is the only helicopter in-flight simulator in the US.

DISTRIBUTION STATEMENT A. Approved for public release; distribution is unlimited

- The ARTS (Army rotor test stand). Designed to support testing of rotors exceeding 12' in diameter.
- Small UAV Facility, AATD: maintains an expendable UAV, as well as smaller radio-controlled model airplanes, for R&D purposes.
- Small Unmanned Aerial Vehicle Laboratory, SSDD: used in R&D of new technologies applicable to small UAV systems.
- Structural Test Facility, AATD: performs both unique aviation component testing and common types of materials testing.
- Vehicle Antenna Measurement Facility (VAMF), AATD: conducts radio-frequency (RF) characterization of communication, navigation, and ASE/ECM antennas and sensors test aircraft.

5.8.3 Air Force Facilities

Air Force facilities include the following:

- Aeroacoustic Research Complex: located at White Sands Missile Range, NM, used to map sound being emanated from aircraft in flight.
- Aerospace Vehicles Technology Assessment and Simulation (AVTAS) Laboratory: applies engineering flight simulation tools to support air vehicle and weapon system technology integration, assessment, demonstration, and transition under realistic mission conditions, on both local and long haul networks.
- Center of Excellence for Computational Simulation: create and guide computation-based design and analysis methods. The basic research group focuses on numerical methods for fundamental fluid physics, aeroelasticity, and electromagnetics, while the applied research group focuses on the practical implementation and application of multidisciplinary computational techniques.
- Center of Excellence for Control Sciences: Conceives, plans, and conducts basic research, exploratory development and demonstrations to advance control technology, including adaptive and cooperative control.
- Center of Excellence for Multi-Disciplinary Technologies: Identifies, develops, and improves critical, military specific air vehicle technology design tools, methods and processes.
- Combustion and Laser Diagnostics Research Complex (CLDRC): provides tools for evaluating advanced combustor concepts.
- Component Research Air Facility (CRAF): provides simulated flight conditions for R&D programs in the turbine engine, advanced propulsion and fuel technology areas.
- Compressor Aero Research Laboratory (CARL): investigate the complex flow phenomena present in transonic compressor designs.

DISTRIBUTION STATEMENT A. Approved for public release; distribution is unlimited

- Compressor Research Facility (CRF): supports exploratory and advanced development efforts in compressor technology, independently evaluating full-scale, multi-stage, one or two-spool three-flow fans and compressors under operating conditions similar to actual flight profiles.
- Discover Wind Tunnel: small subsonic research tunnel.
- Engine Environment Research Facility (EERF): supports R&D testing of the behavior of turbine engine lubricants, fuels and sensors in an actual engine environment.
- Facility for Innovative Research in Structures Technology (FIRST): experimental validation for technologies including structural health monitoring, multifunctional structures, and thermal structures.
- Free Surface Water Tunnel: Driven by a quiet, 2200 GPM axial impeller or as tow tank, with a test section 24 x 18 in. Simulates a low Reynolds number environment with velocity from 1 to 20 in/sec. Flow visualization or particle image velocimetry.
- Fuels Development Research Facilities: enables fundamental R&D if advanced development of fuels, fuel additives and fuel system components.
- Heat-transfer & Aerothermal Laboratory (HAL): conducts fundamental experiments in the areas of turbine aerodynamics, heat transfer and film cooling.
- Helicopter Rotor Facility (inactive): electrically driven whirl test stand used to determine rotor performance at various rotational speeds. This facility is capable of performance and endurance testing of up to 90 ft diameter rotors to 6,000 horsepower and 625 rpm.
- High Pressure Combustion Research Facility (HPCRF): used to develop and evaluate advanced gas turbine engine combustor and augmentor concepts, laser-based diagnostics, and computer models.
- Low Speed Wind Tunnel Facility (LSWTF): a low-speed open-loop induction wind tunnel, has modified to house a linear turbine cascade to study turbine aerodynamics and flow control.
- Low-Pressure Combustion Research Complex (LPCRC): study fundamental, bench-scale combustion processes and gas turbine engine hardware.
- Mechanical Systems Research Laboratory (MSRL): research mechanical systems for aviation gas turbine engines.
- National Aerospace Fuels Research Complex (NAFRC): enables fundamental research, exploratory development and in-house advanced development of fuels, fuel additives and fuel system components.
- Propeller Test Facilities: capable of performance and endurance testing of propellers and other rotating devices to 10,000 horsepower and 10,800 rpm.

DISTRIBUTION STATEMENT A. Approved for public release; distribution is unlimited

- Small-Engine Research Laboratory (SERL): conducts experimental small-scale propulsion and power generation systems research.
- Subsonic Aerodynamics Research Laboratory: 10 x 7 ft test section, capable of Mach 0.2 to 0.5, with low turbulence free stream. Capable of testing a large angle-of-attack range. Advanced flow diagnostics include laser light sheet, PIV and pressure paint.
- Supersonic Research Facility: a continuous flow supersonic tunnel, specifically designed for optical diagnostics of fuel injection (for mixing and penetration), shock boundary-layer interactions, flameholder operation, and other hypersonic-flow components from Mach 1.5 to 5.
- Trisonic Gasdynamics Facility: capable of subsonic and supersonic test conditions, with continuous flow at Mach numbers of 0.3 to 3.0 in a 2 x 2 ft test section with sting, sidewall or blade mounting. Advanced flow diagnostics include Schlieren and laser light sheet.
- Turbine Aero Thermal Basic Research Facility (TATBRF)
- Turbine Engine Fatigue Facility (TEFF): performs structural and vibrational evaluation of turbine engine components.
- Turbine Research Facility (TRF): performs aerodynamic, aerothermal and aeroelastic research on full-scale turbines.
- Vertical Wind Tunnel: a test section of 12 ft diameter by 15 ft height, with a flow velocity up to 176 ft/sec. Only U.S. facility with combined rotary balance/forced oscillation.

AFDD facilities testing of small to mid-scale (6'- 12' diameter) model rotors, include:

- The 7X10 subsonic tunnel (max. speed 300fps).
- Rotor hover test facility.
- The RWTS (rotary wing test stand) used for maximum rotor diameters of 10'.
- NFAC (National Full-Scale Aerodynamics Center, 40X80 and 80X120 tunnels).

5.8.4 National Aeronautics and Space Administration (NASA) Facilities³⁰

NASA facilities include the following:

- 1 x 1 Foot Supersonic Wind Tunnel, Glenn: low-cost testing tool for small-scale research, simulating speeds ranging from Mach 1.3 to 6.0.
- 7 x 10 Foot Wind Tunnel, Langley: This wind tunnel is used for basic and applied research in aeromechanics on advanced and unique technology aircraft and rotorcraft. The test section of this wind tunnel has a maximum speed capability of 100 kt.

DISTRIBUTION STATEMENT A. Approved for public release; distribution is unlimited

- 8 x 6 Foot Supersonic Wind Tunnel, Glenn: NASA's only transonic wind tunnel with propulsion test capabilities, providing test speeds of Mach 0.25 to 2.0.
- 9 x 15 Foot Low-Speed Wind Tunnel, Glenn: the most utilized low speed propulsion acoustic facility in the world and is the only national facility that can simulate takeoff, approach, and landing in a continuous subsonic flow wind tunnel environment.
- 9 x 7 Foot Supersonic Wind Tunnel, Ames: This tunnel is capable of testing at speeds between M 1.55 and 2.55.
- 10 x 10 Foot Supersonic Wind Tunnel, Glenn: providing test speeds of Mach 2.0 to 3.5.
- 11 x 11 Foot Transonic Wind Tunnel, Ames: This tunnel is capable of testing at speeds between M0.20 and M1.45.
- Advanced Subsonic Combustor Rig (ASCR), Glenn: unique high-pressure combustor facility, able to simulate combustor inlet conditions up to 900 psig.
- Aeroelastic Rotor Experimental System (ARES), Langley: a floor-standing rotor system testbed capable of testing rotor systems up to approximately 10-ft diameter. Coupled with the heavy gas test medium and sub-atmospheric operation of the Langley Transonic Dynamic Tunnel, model rotors can achieve simultaneous scaling of Mach, Lock, and Froude numbers.
- Aero-Acoustic Propulsion Laboratory (AAPL), Glenn: provides unique nozzle and fan test rigs to evaluate engine noise-reduction concepts.
- Engine Component Research Laboratory (ECRL), Glenn: small turbine engine research, as well as a unique combustor facility able to evaluate augmentor and afterburner concepts.
- Engine Research Building (ERB), Glenn: the largest and most adaptable test facility complex at GRC, housing more than 60 test rigs. Most aspects of engine development can be studied here with numerous facilities specializing in turbomachinery, tribology, flow physics, combustion, aerochemistry, mechanical components, and heat transfer.
- Flight Loads Laboratory (FLL), Dryden: thermal, structural, ground vibration, and structural mode interaction testing of aircraft and aircraft structural components.
- Hypersonic Tunnel Facility (HTF), Glenn: large-scale hypersonic (Mach 5-7) airbreathing propulsion systems.
- Icing Research Tunnel (IRT), Glenn: one of the world's largest refrigerated wind tunnels dedicated to the study of aircraft icing.
- Large Rotor Test Apparatus, Ames: This test apparatus, used in the NFAC, is used to conduct full-flight envelope tests for full-scale helicopter rotor components with a complete control and drive system. It is sized for rotors up to 52,000 lb thrust and 6000 hp.

DISTRIBUTION STATEMENT A. Approved for public release; distribution is unlimited

- Rotor Test Apparatus, Ames: This test apparatus, used in the NFAC, is used to conduct full-flight envelope tests for full-scale helicopter rotors up to 25,000 lb thrust and 3000 hp, with a complete control and drive system.
- NASA Vertical Motion Simulator, Ames: This facility consists of four interchangeable cabs and computer image generator visuals on top of the world's largest amplitude 6 DOF motion base.
- National Full-Scale Aerodynamics Complex (NFAC), Ames: This facility is used for advanced research and testing of fixed and rotary-wing aircraft at full scale. This facility is the world's largest wind tunnel consisting to two separate test sections (40'x80' and 80'x120') capable of accommodating aerodynamic testing of articles up to full-scale, at speeds of up to 250 kt. Although a NASA facility, it is operated by the US Air Force.
- Propulsion Systems Laboratory (PSL), Glenn: is NASA's only groundbased test facility that provides true flight simulation for experimental research on air-breathing propulsion systems. This continuous flow altitude simulation facility is equipped to conduct full-scale and component testing for base research, advanced aircraft, space transportation, general aviation propulsion, and hypersonic propulsion.
- Research Aircraft Integration Facility (RAIF), Dryden: provides high-fidelity real-time and batch flight simulation capabilities, closed-loop hardware-in-the-loop and vehicle-in-the-loop verification and validation testing, ground vibration testing, and routine aircraft maintenance.
- Tiltrotor Test Rig (TTR), Ames (operational in FY13): will provide ability to test tiltrotors and propellers in horizontal attitude up to 26 ft diameter, with 20,000 lb thrust, at up to 300 kt in the Ames 40 x 80 ft tunnel. Will evaluate prop-rotor performance and efficiency, vibration and dynamic loads, and hub and control loads.
- Western Aeronautical Test Range (WATR), Dryden: a network of facilities used to support aerospace flight research and other missions. These facilities consist of telemetry tracking systems, space positioning systems, audio communication systems, video systems, mission control centers, and mobile systems.
- Wing and Rotor Aeroelastic Testing System (WRATS), Langley: a semi-span 1/5-size aeroelastic tiltrotor model based on the V-22, developed for use in the Langley Transonic Dynamics Tunnel.
- Isolated Rotor Test System (IRTS), Langley: a rotor drive system separate from the fuselage that mounts to the ceiling of the Langley 14 x 22 Foot Wind Tunnel.
- 0.3-Meter Transonic Cryogenic Tunnel, Langley: used for testing airfoil sections and other models at Reynolds numbers up to 100M/ft and Mach numbers from 0.1 to 0.9.
- 8-Foot High Temperature Tunnel, Langley: a combustion-heated hypersonic blowdown-to-atmosphere wind tunnel that provides simulation of flight enthalpy for Mach numbers of 4, 5,

DISTRIBUTION STATEMENT A. Approved for public release; distribution is unlimited

and 7. The test section will accommodate air-breathing hypersonic propulsion systems and structural and thermal protection system components.

- 14 x 22 Foot Subsonic Tunnel, Langley: an atmospheric, closed-return tunnel that can reach a velocity of over 200 kt. It provides an improved understanding of the aerodynamics of V/STOL aircraft. It is also ideally suited for low-speed tests to determine high-lift stability and control, aerodynamic performance, rotorcraft acoustics, turboprop performance, and basic wake and airflow surveys.
- 16 Foot Transonic Tunnel, Langley: an atmospheric, closed-circuit tunnel with a Mach number range of 0.2 to 1.25, and can conducting propulsion airframe integration testing.
- 20 Foot Vertical Spin Tunnel, Langley: a closed-throat, annular return wind tunnel operating at atmospheric conditions. Dynamically scaled, free-flying aircraft models can be tested for spinning, tumbling, and other out-of-control situations.
- Jet Exit Test Facility, Langley: a ground test stand to measure engine nozzle mass-flow rates and nozzle axial thrust.
- Low-Turbulence Pressure Tunnel, Langley: a single return, closed-circuit tunnel that can operate from 1 to 10 atmospheres. LTPT's capabilities of low disturbance, variable density tests and high-lift, multielement airfoil tests are unique in the world. This tunnel is ideal for preliminary

5.8.5 University Facilities

Typical University Facilities are listed below for three universities recognized as Centers of Excellence by ONR currently or in the recent past. These facilities are typical of university S&T facilities; however no attempt has been made to catalog all university facilities that relate to all disciplines associated with SBA.

- **Georgia Tech**³¹
 - 1-m square test section fluid mechanics research laboratory tunnel: has adjustable pressure gradient and programmable pitch traverse for maneuvers.
 - 42" x 42" Low Speed AeroControls Tunnel: an open-return tunnel, with velocity ranging from 10 fps to 78 fps.
 - 9' Hover Facility (rotor test chamber): used for developing prescribed-wake and free wake methods, measurements of vortex core characteristics, thrust, torque, blade surface pressure and wake velocities, and advanced blade tip geometries.
 - Aeroelastic Rotor Test Chamber: a 16-foot hover facility where the rotor blades can be subjected to digitally-controlled higher-harmonic excitation using hydraulic actuators on the pitch links.

DISTRIBUTION STATEMENT A. Approved for public release; distribution is unlimited

- **Aerothermodynamics Research and Technology Laboratory:** research in CFD for high speed aerodynamics and aerothermodynamics.
- **Combustion Laboratory:** supports a broad range of experimental research in combustion process for propulsion and energy conversion.
- **Computational Combustion Laboratory:** research in computational modeling of combustion processes.
- **Flight Mechanics and Controls:** research on a wide range of problems involving the analysis and design of control systems for aerospace and other engineered systems.
- **John J. Harper Wind Tunnel (7' x 9' test section):** used for forward flight studies and utilizes an array of diagnostic techniques for the study of rotorcraft aerodynamic interactions.
- **Structural Dynamics and Smart Structures Laboratory:** conduct research in smart structures.
- **UAV Research Facility:** conducts applied R&D of autonomous aerial vehicles.
- **Vertical Lift Research Center of Excellence:** carry out a wide range of research in rotary wing aircraft technology.
- **Vibration and Wave Propagation Lab:** conducting research in the dynamics of periodic structures and wave propagation in structures.
- **University of Maryland³²**
 - **Advanced Propulsion Research Laboratory (APRL):** fundamental and applied studies on active/passive control of turbulent mixing and combustion processes are conducted to develop advanced combustor technologies.
 - **Alfred Gessow Rotorcraft Center (AGRC):** conducts leading-edge research in rotorcraft aerodynamics, dynamics, acoustics, structures and flight mechanics with unique experimental facilities, including a articulated and bearingless rotor rigs, a small-scale high-speed rotor for aeroacoustic investigations, wind tunnel rotor rig, vacuum chamber, hover tower, wide-field shadowgraphy, 3-D laser Doppler system, anechoic chamber, anechoic flow wind tunnel, model fabrication facility, modern composite lab and extensive smart structures labs.
 - **Composites Research Laboratory (CORE):** provides an environment for educational, research, and development of activities in composite materials and structures.

DISTRIBUTION STATEMENT A. Approved for public release; distribution is unlimited

- Film Cooling Research Laboratory: a unique experimental facility equipped with minimally intrusive diagnostics for experimental characterization of film cooling flows (Particle Image Velocimetry, Infrared thermography, fast-response microthermocouples), as well as high fidelity numerical codes.
- Glenn L. Martin Wind Tunnel: a state-of-the-art low speed wind tunnel with a test section 7.75 x 11 ft, capable of speeds up to M0.3. The tunnel is used to perform extensive development tests for a wide range of vehicles and other systems and is well suited for conducting major research efforts in low speed aerodynamics and hydrodynamics.
- Morpheus Laboratory: a dynamic research facility focused on aerospace applications of smart materials and structures.
- Vacuum chamber for testing rotor dynamics.
- **Penn State**
 - Vertical Lift Research Center of Excellence: more than 30 faculty and 60 graduate students work on projects related to dynamics, aerodynamics, acoustics, flight control and simulation, icing, HUMS, and advanced design of rotary-wing vehicles. Technical thrust areas include drivetrain technologies, smart structures, advanced materials, active control of noise and vibration, and high-performance computing.
 - Adverse Environment Rotor Test Stand: reproduces icing environments to test new anti-icing and de-icing concepts, as well as ice accretion analysis validation and ice adhesion strength measurements to different coatings.
 - Aeroacoustics: Anechoic flow-through jet noise facility, anechoic chamber with full environment, reverberant room and additional rotating noise facilities.
 - Computer Cluster facility: with 2007 processors, the potential computational power approaches 75 Tflops.
 - Structures and Materials: High temperature bi-axial tension/torsion testing facility, fiber optic interferometer, hydraulic testing machine with environmental chamber (for materials characterization, including fatigue, over a broad temperature range), vacuum chamber for damping characterization, ultrasonic inspection system, elastomeric characteristic test facility, autoclave (3 foot diameter x 7 foot length), computer-controlled filament winding machine, pultrusion machine, braiding machine for composite materials manufacturing.
 - Turbomachinery: 3' diameter large scale axial flow compressor facility (single-stage), 3' diameter large scale axial flow turbine facility with modern blading, multi-stage research

DISTRIBUTION STATEMENT A. Approved for public release; distribution is unlimited

compressor facility (500hp), 10" torque converter facility with rotating flow instrumentation, centrifugal compressor test facility.

- Wind and water tunnels include: a low-turbulence subsonic wind tunnel, 250 ft/sec, with six-component strain gauge balance (3.25 x 5 foot test section); low-turbulence boundary layer tunnel (16 x 16 inch test section); supersonic wind tunnel (6 x 6 inch test section) for speeds of Mach 1.4 to 4.0; laminar flow water channel (1.5 x 2.5 foot test section); supersonic free shear layer facility (2 x 5 inch test section) for Mach 1 to 2 and Mach 2 to 4; and convective heat transfer tunnel with real-time color image processing.
- Experimental Fluid Dynamics: Research activities include gas dynamics, aero-and-hydro-acoustics, hydrodynamic stability, cavitation, and unsteady flow control.

5.8.6 Needed S&T Facilities³³

Critical S&T facilities needed to support new or emerging research related to Sea-based Aviation that are not available include the following:

- A rotor test stand for the Navy's 8x10 wind tunnel to allow independent experimental evaluation of emerging rotor system designs.
- Wind tunnel facilities to support multi-body / multi-flowfield conditions, such as:
 - Multi-flowfield capabilities to simulate ship airwakes and interaction with downwash from rotorcraft or other powered lift aircraft; ship hot stack gas simulation
- Multi-body capabilities (e.g., two stings with controllable motion) to simulate both the ship and the aircraft such as in aircraft launch and recovery and to simulate sling loads for Vertical Replenishment (VERTREP) conditions.*
- Wind tunnel facilities with the capability to prescribe the boundary layer to simulate various atmospheric boundary layer conditions at sea.*
- Wind tunnel facilities with large and/or open test section to allow for testing of directed thrust or engine exhaust jet streams.*
- Motion based test platforms to simulate ship motions in high sea state to be used to evaluate aircraft/UAV launch and recovery onto a moving platform and for evaluation of control systems for VERTREP.
- Submerged launch facility to simulate launch of air platforms from underwater systems.*
- Facilities to conduct tests related to aircraft ditching at sea.*

DISTRIBUTION STATEMENT A. Approved for public release; distribution is unlimited

- Test facility for investigation of unsteady aerodynamics, including dynamic stall.

** Existing Navy facilities at Carderock partially address this need.*

5.9 Integration with Higher Category Programs

The Office of Naval Research Discovery & Invention portfolio makes broad investments in basic and applied research to increase fundamental knowledge, fosters opportunities for breakthroughs and provide technology options for future naval capabilities and systems. Discovery & Invention programs nurture creativity and seek a balance between risk, opportunity, and potential naval impact. As such, ONR serves as the Department of the Navy's science and technology provider for S&T solutions for Navy and Marine Corps needs in order to, "plan, foster, and encourage scientific research in recognition of its paramount importance as related to the maintenance of future naval power, and the preservation of national security"; and to "manage the Navy's basic, applied and advanced research to foster transitions from S&T to higher levels of research, development, test, and evaluation."

Transition of technologies to the fleet and acquisition are top priorities. ONR emphasizes transition centric programs and methodologies including efforts covering manufacturing methods used to build naval warfare systems, programs that stimulate advantageous government-industry partnerships, and an investment portfolio focusing on requirements pull by the fleet and acquisition. ONR continues to provide the S&T products necessary to ensure future superiority in integrated naval warfare.

The following programs are representative highlights of past and present programs that have, or may integrate with and/or transition to higher category programs. This list is by no means exhaustive.

- The Integrated High Performance Turbine Engine Technology (IHPTET) initiative is a joint DoD/NASA/Industry effort, with the objective of developing and demonstrating advanced engine technologies capable of more than doubling turbine engine power-to-weight ratio and reducing specific fuel consumption by 40% over modern production engines. Many of the programs significant developments transitioned to the JSF include: Supercooled Turbine, Thermal Barrier Coatings, Fan Aeromechanical Design, Reduced Pattern Factor Combustor, Turbine Dampers, and Light Weight Materials.
- The Turbine Engine Technologies (TET) effort is comprised of two products, materials and engines. These products will deliver advanced materials, designs, components and integration technologies for turbine engines leading to improved cost, efficiency, and performance of turbopropulsion for naval aviation. Once tested, these technologies will be ready for incorporation in advanced turbine engines such as those for the F-35 Lightning II.
- The Variable Cycle Advanced Technology (VCAT) program seeks to provide naval aviation with the benefits of variable/adaptive cycle turbine propulsion technology. VCAT will identify and mature critical, relevant variable/adaptive cycle system technologies for next generation carrier-based TACAIR/ISR systems.

DISTRIBUTION STATEMENT A. Approved for public release; distribution is unlimited

- Jet Noise Reduction (JNR): Through long-term research, the JNR project aims to understand the physics of jet noise associated with high-performance military aircraft, identify materiel/non-materiel solutions to reduce noise, develop and transition technologies in support of the Warfighter and the community.
- UAV Heavy Fuel Engine Program: The heavy fuel engine program is developing a highly efficient small, lightweight and reliable, engine for small unmanned air systems that operate on logistically available fuels; allows for extension of the vehicle endurance capabilities and is suitable for military operational environments.
- The Autonomous Aerial Cargo/Utility System (AACUS) will develop advanced autonomous capabilities to enable unmanned/ optionally manned VTOL air systems of the future to be fully capable of reliable, responsive cargo delivery to distributed forces in demanding conditions.
- The Selectable Output Weapons program is designed to greatly improve the operational flexibility of smart bombs currently used in close air support roles. It will support rules of engagement requiring low collateral damage.
- Advanced Helicopter Main Rotor Blade Coatings program seeks to improve erosion resistance and extend the life of the rotor blades, these coatings will increase on-wing time and reliability, reducing maintenance, fuel consumption and power conversion efficiency of helicopters.
- Next Generation Airborne Electronic Attack (NGAEA) project is developing high-risk, highpayoff technologies for the Navy's Next Generation Jammer (NGJ). NGAEA is advancing the technology readiness of broadband radio frequency (RF) antenna arrays; high power solid state RF power amplifiers; RF beam formers; and advanced RF excitors (i.e. techniques generators) in support of Navy and Marine Corps airborne electronic attack missions. New electronic warfare technologies will ensure the survivability of aircraft, provide increased threat awareness, counter enemy RF-based systems and support operations against asymmetric threats.
- Integrated Hybrid Structural Hybrid Management System (IHSMS) is a network of small, wireless, energy harvesting sensors distributed throughout a helicopter's metal and composite structure, gathering and reporting strain, vibration, and temperature data to a central processor for loads monitoring and structural life and health management.

6 Summary

This report has summarized the current health and status of SBA and identified multiple S&T challenges posed by the development of next-generation sea-based aircraft, including both fixed and rotary wing platforms.

The continued technical superiority of the US Navy, and the underlying industrial, laboratory, and academic base that supports SBA is dependent upon stabilized resources, maintenance of basic and

DISTRIBUTION STATEMENT A. Approved for public release; distribution is unlimited

applied research efforts addressing the S&T challenges, a balanced theoretical and experimental infrastructure, and sustained support for centers of excellence addressing the identified S&T challenges.

It is recommended that Sea-based Aviation be recognized as an NNR.

7 Acronyms

| | |
|-------------|--|
| AAAL | Advanced Active Acoustics Lab |
| AACUS..... | Autonomous Aerial Cargo/Utility System |
| AAPL..... | Aero-Acoustic Propulsion Laboratory |
| AATD | Aviation Applied Technology Directorate |
| ABET..... | Accreditation Board for Engineering and Technology |
| AE | Aerospace Engineering |
| AEC | Altitude Environmental Chamber |
| AED | Aviation Engineering Directorate |
| AFDD | Aeroflightdynamics Directorate |
| AFRL..... | Air Force Research Lab |
| AGRC..... | Alfred Gessow Rotorcraft Center |
| ALFS | Airborne Low-Frequency Sonar |
| ALRCS..... | Advanced Launch and Recovery Control System |
| ALRE..... | Aircraft Launch and Recovery |
| AMOT..... | Atomic Physics & Optical Research |
| AMRDEC..... | Aviation and Missile Research Development and Engineering Center |
| AMRDEC..... | Aviation & Missile Research, Development & Engineering Center |
| AMTC | Advanced Maritime Technology Center |
| AoA | Analysis of Alternatives |
| APF | Aircraft Prototype Facility |
| API | Aircraft Platform Interface |
| APRL..... | Advanced Propulsion Research Laboratory |
| ARES..... | Aeroelastic Rotor Experimental System |
| ARTS..... | Army rotor test stand |
| ASCR | Advanced Subsonic Combustor Rig |

DISTRIBUTION STATEMENT A. Approved for public release; distribution is unlimited

ATEF Aircraft Test and Evaluation Facility
 AVMI Air Vehicle Modification & Instrumentation
 AVTAS Aerospace Vehicles Technology Assessment and Simulation
 BRAC Base Realignment and Closure
 CARL..... Compressor Aero Research Laboratory
 CASS..... Consolidated Automated Support System
 CG Cruisers
 CLDRC Combustion and Laser Diagnostics Research Complex
 CLF Combat Logistics Force
 CORE Composites Research Laboratory
 COTS Commercial Off-The-Shelf
 CRADA..... Cooperative Research and Development Agreements
 CRAF Component Research Air Facility
 CRF Compressor Research Facility
 CSIL Common Systems Integration Lab
 CTOL..... Conventional Take-Off and Landing
 DD Destroyer
 DDG Guided Missile Destroyers
 E/O Electro-Optics
 ECRL..... Engine Component Research Laboratory
 EERF Engine Environment Research Facility
 EMALS..... Electromagnetic Aircraft Launch System
 EPT Externally Directed Team
 ERB Engine Research Building
 FARM Facilities for Antennas and RCS Measurements
 FAST Fleet Assistance and Support Team
 FIRST Facility for Innovative Research in Structures Technology
 FLL Flight Loads Laboratory
 HAL Heat-transfer & Aerothermal Laboratory
 HDS Helicopter Drive System

DISTRIBUTION STATEMENT A. Approved for public release; distribution is unlimited

HFE Human Factors Engineering

HMD..... Helmet-Mounted Displays

HPCRF High Pressure Combustion Research Facility

HTF Hypersonic Tunnel Facility

HUMS..... Health and Usage Monitoring Systems

IHPDET..... Integrated High Performance Turbine Engine Technology

IHSMS Integrated Hybrid Structural Hybrid Management System

IPT Integrated Planning Team

IRT Icing Research Tunnel

IRTS..... Isolated Rotor Test System

ISR Intelligence, Surveillance, and Reconnaissance

JBD Jet Blast Deflector

JNR Jet Noise Reduction

JSF Joint Strike Fighter

LCS Littoral Combat Ship

LHD Landing Helicopter Docks

LPCRC..... Low-Pressure Combustion Research Complex

LPD Landing Platform Docks

LSD Dock Landing Ships

LSO Landing Signal Officer

LSWTF Low Speed Wind Tunnel Facility

LTPT Low-Turbulence Pressure Tunnel

MSRL..... Mechanical Systems Research Laboratory

NAE Naval Aviation Enterprise

NAE CTO Naval Aviation Enterprise Chief Technology Officer

NAFRC..... National Aerospace Fuels Research Complex

NASA..... National Aeronautics and Space Administration

NASC..... Naval Air Systems Command

NATF Naval Aerodynamics Test Facility

NAVAIR Naval Air Systems Command

DISTRIBUTION STATEMENT A. Approved for public release; distribution is unlimited

NAVSEA..... Naval Sea Systems Command
 NAWCAD..... Naval Air Warfare Center - Aircraft Division
 NAWCWD Naval Air Warfare Center - Weapons Division
 NDI Non-Destructive Inspection
 NFAC National Full-Scale Aerodynamics Complex
 NGAEA Next Generation Airborne Electronic Attack
 NGJ Next Generation Jammer
 NNR National Naval Responsibility
 NPF Nanoelectronics Processing Facility
 NPS Naval Postgraduate School
 NRL Naval Research Lab
 NSWCCD Naval Surface Warfare Center - Carderock Division
 ONR Office of Naval Research
 OTS Outdoor Test Site
 PEO Naval Aviation Program Executive Officers
 PEO(A)..... PEO for Air ASW, Assault and Special Mission Programs
 PEO(JSF)..... PEO for Joint Strike Fighter
 PEO(T)..... PEO for Tactical Aircraft Programs
 PEO(U&W) PEO for Unmanned Aviation and Strike Weapons
 PSEF Propulsion Systems Evaluation Facility
 PSL Propulsion Systems Laboratory
 R&D..... Research and Development
 RACEM..... Radar and Computational Electromagnetics Modeling
 RAIF..... Research Aircraft Integration Facility
 RAPTR Redstone Aviation Propulsion Test and Research
 RASCAL Rotorcraft Advanced System Concepts Airborne
 RDT&E..... Research, Development, Test and Evaluation
 RF Radio frequency
 RSF Rotor Spin Facility
 S&T Science and Technology

DISTRIBUTION STATEMENT A. Approved for public release; distribution is unlimited

SAIL Surface/Aviation Interoperability Lab
 SBA Sea-based Aviation
 SE Aircraft/target/weapon Support Equipment
 SERL Small-Engine Research Laboratory
 SSDD System Simulation and Development Directorate
 SSDD Small Unmanned Aerial Vehicle Laboratory
 TACAIR Tactical Aviation
 TATBRF..... Turbine Aero Thermal Basic Research Facility
 TEFF Turbine Engine Fatigue Facility
 TET Turbine Engine Technologies
 TRF Turbine Research Facility
 TTR Tiltrotor Test Rig
 UAV Unmanned Aerial Vehicle
 UCLASS..... Unmanned Carrier-Launched Airborne Strike and Surveillance
 USNA..... United States Naval Academy
 USV Unmanned Surface Vehicles
 V/STOL Vertical / Short Take-Off and Landing
 VAMF Vehicle Antenna Measurement Facility
 VCAT Variable Cycle Advanced Technology
 VERTREP Vertical Replenishment
 VTOL Vertical Take-Off and Landing
 VTUAV..... Vertical Take-Off and Landing Tactical Unmanned Aerial Vehicle
 WATR Western Aeronautical Test Range
 WDI Weapons Development and Integration Directorate
 WRATS Wing and Rotor Aeroelastic Testing System
 WSD Weapons Sciences Directorate

DISTRIBUTION STATEMENT A. Approved for public release; distribution is unlimited

8 Bibliography

- Aeronautics Science and Technology Subcommittee. (2007). *NATIONAL PLAN FOR AERONAUTICS RESEARCH AND DEVELOPMENT AND RELATED INFRASTRUCTURE*. Committee on Technology - National Science and Technology Council.
- Assistant Secretary of the Navy (Research, Development, and Acquisition). (2010). *Status and Future of the Naval R&D Establishment*. Public Briefing.
- Calhoun, G. L. (2000). *PILOT-VEHICLE INTERFACE*.
- Center for Naval Analysis. (2010). *Sea-Based Aviation as a National Naval Responsibility*.
- Committee on Prospering in the Global Economy of the 21st, Committee on Science, Engineering, and Public Policy - National Research Council. (2006). *Rising Above the Gathering Storm: Energizing and Employing America for a Brighter Economic Future*. The National Academies Press.
- Gibbons, M. T. *Engineering by the Numbers*. American Society for Engineering Education - www.asee.org/colleges.
- Harney, R. J. (2005). *Ship Suitability Testing – Preparing for the Future*.
- NAVAIR. *AIR 4.3, 4.4T, 4.5, 4.8, CORE CAPABILITIES DOCUMENT - DRAFT*.
- Naval Studies Board - National Research Council. (2006). *Identification of Promising Naval Aviation Science and Technology Opportunities*. Washington, DC: The National Academies Press.
- NSWCCD - Sea Based Aviation Group Code 5300. (2010). *Sea Based Aviation-A National Naval Responsibility*. Naval Surface Warfare Center Carderock.
- Office of Naval Research. (2010, July 26). ONR INSTRUCTION 5250.1A. *DEPARTMENT OF THE NAVY SCIENCE AND TECHNOLOGY NATIONAL NAVAL RESPONSIBILITY INITIATIVE*.
- Office of Science and Technology Policy. (2006). *National Aeronautics Research and Development Policy*. National Science and Technology Council.
- The Office of Naval Research. (2008). *The Naval Science and Technology (S&T) Strategic Plan*.
- US Marine Corps. (2009). *US Marine Corps Strategic S&T Plan*.

¹NSWCCD - Sea Based Aviation Group Code 5300. (2010). *Sea Based Aviation-A National Naval Responsibility*. Naval Surface Warfare Center Carderock.

-
- ² Ryberg, E; “The Influence of Ship Configuration on the Design of the Joint Strike Fighter”
- ³ Requirements Engineering By the Numbers 2009, Michael T. Gibbons. American Society for Engineering Education. for Maritime Vertical Lift Aircraft (Marinization) – December 2010
- ⁴ August 26, 2010 - AIR 4.3 Core Capabilities Document
- ⁵ Naval Aviation Enterprise Corrosion Prevention Team; 2009 U.S. Army Corrosion Summit
- ⁶ Source: <http://www.globalsecurity.org/military/systems/aircraft/f-35c.htm>
- ⁷ “P&W JSF Engine Damaged in Test”; Flight International Article May-2007
- ⁸ Navy F/A-18E/F Super Hornet and EA-18G Growler Aircraft: Background and Issues for Congress AND NASA Contributions to F/A-18 E/F
- ⁹ [globalsecurity.org](http://www.globalsecurity.org) and GAO Report: T-45 Training System; The Navy Should Reduce Risks before Procuring More Aircraft
- ¹⁰ August 26, 2010 - AIR 4.3 Core Capabilities Document
- ¹¹ Aerospace Facts and Figures 2009; Aerospace Industries Association of America, Inc.
- ¹² Naval Aviation Enterprise Science and Technology Objectives
- ¹³ http://www.navair.navy.mil/nawcad/index.cfm?fuseaction=home.content_detail&key=Facilities
- ¹⁴ <http://www.navsea.navy.mil/nswc/carderock/default.aspx>
- ¹⁵ <http://www.redstone.army.mil/amrdec/RD&E/AATD.html>
- ¹⁶ <http://www.redstone.army.mil/amrdec/RD&E/AFDD.html>
- ¹⁷ <http://www.redstone.army.mil/amrdec/RD&E/SSDD.html>
- ¹⁸ <http://www.redstone.army.mil/amrdec/RD&E/WDI.html>
- ¹⁹ <http://www.redstone.army.mil/amrdec/RD&E/WSD.html>
- ²⁰ <http://www.af.mil/information/factsheets/factsheet.asp?id=148>
- ²¹ <http://www.nasa.gov/centers>
- ²² <http://www.abet.org/AccredProgramSearch/AccreditationSearch.aspx>
- ²³ Engineering By the Numbers 2009, Michael T. Gibbons. American Society for Engineering Education.
- ²⁴ <http://grad-schools.usnews.rankingsandreviews.com/best-graduate-schools/top-engineering-schools/rankings>

DISTRIBUTION STATEMENT A. Approved for public release; distribution is unlimited

²⁵ http://www.nsf.gov/statistics/nsf08321/content.cfm?pub_id=3785&id=2

²⁶ Bureau of Labor Statistics Occupational Employment Statistics May 2009:
<http://www.bls.gov/oes/current/oes170000.htm>

²⁷ Virginia Tech Post Graduation Reports:
<http://www.career.vt.edu/scripts/PostGrad2006/Report/PostGraduationReportByMCU.asp?College=05&Major=AE&Cohort=2003-2004&SortBy=>

²⁸ Office of Science and Technology Policy, National Science and Technology Council, "National Plan for Aeronautics Research and Development and Related Infrastructure," December 2007, p. 34.

²⁹ <http://www.redstone.army.mil/amrdec/RD&E/AMRDEC-Facilities-2008.pdf>

³⁰ <http://www.redstone.army.mil/amrdec/RD&E/AMRDEC-Facilities-2008.pdf>,
http://facilities.grc.nasa.gov/documents/Facility_Book2.pdf,
http://www.nasa.gov/centers/dryden/pdf/285865main_capabilities_brochure.pdf

³¹ <http://www.ae.gatech.edu/research/labs>

³² <http://www.aero.umd.edu>

³³ "Capability of the AFRL Wind Tunnels," March 2008, RBO-08-101 and <http://www.wpafb.af.mil/AFRL>

