Report of the Panel to Review the V-22 Program

April 2001

DEPARTMENT OF DEFENSE
PANEL TO REVIEW THE V-22 PROGRAM
1235 Jefferson Davis Highway, Suite 940
Arlington, Virginia 22202-3283

Tel: (703) 602-1515
Fax: (703) 602-1532

April 30, 2001

Chairman
John R. Dailey

Panel Members
Norman R. Augustine
James B. Davis
Eugene E. Covert

Executive Secretary
Gary J. Gray

MEMORANDUM FOR THE SECRETARY OF DEFENSE

SUBJECT: Report of the Panel to Review the V-22 Program

The Panel to Review the V-22 Program is pleased to present its final report as requested in Secretary Cohen's December 15 memorandum. The Panel addressed many factors that affect flight safety and combat effectiveness of the V-22 aircraft. The report includes our findings, conclusions and recommendations.

We would specifically like to thank the following organizations for providing the requisite information and knowledge to allow the Panel to comprehend the issues and make meaningful recommendations in a very short timeframe: the V-22 Program Office; the Marine Medium Tiltrotor Training Squadron – 204 (VMMT-204); the United States Marine Corps; the United States Air Force; the United States Special Operations Command (SOCOM); the Naval Air Systems Command; the Naval Safety Center; the Helicopter Marine Experimental (HMX-1) Squadron; the Director, Operational Test and Evaluation, Office of Secretary of Defense; and the General Counsel, Department of Defense.

The Panel believes the V-22 aircraft has a unique capability and is the only existing aircraft that can fulfill the mission requirements of the Marine Corps and SOCOM. We believe that the requirement is justified and that the V-22 aircraft has demonstrated its ability to satisfy the requirement.

The Panel found no evidence of an inherent safety flaw in the V-22 tiltrotor concept. We recommended that the program be continued, but restructured. The Panel found that the V-22 aircraft lacks the maturity needed for full-rate production or operational use and made recommendations for corrective action.

On behalf of the entire Panel, I thank you for giving us the opportunity to serve the Department of Defense in this serious matter.

John R. Dailey

Attachment:
As stated

PANEL STAFF

Gary J. Gray

Executive Secretary

PROFESSIONAL STAFF

Raymond E. Schwartz, III, Col, USMC

Carl A. (Andy) Steel, Col, USAF

Bryan O'Connor, Consultant, Futron Corporation

ADMINISTRATIVE SUPPORT STAFF

Hector O. Nevarez, Ph.D., Administrative Director, ViStar Corporation

Carolyn F. Duke, Administrative Assistant, ViStar Corporation

Douglas Pang, Systems Analyst, ViStar Corporation

Sam Nayar, Systems Analyst, ACS Defense, Incorporated

EXECUTIVE SUMMARY

The Secretary of Defense, citing safety and operational testing issues, established an independent review of the V-22 Program. He appointed General John R. Dailey, USMC (Retired), Mr. Norman R. Augustine, General James B. Davis, USAF (Retired), and Dr. Eugene E. Covert to the Panel to Review the V-22 Program. The charter called for an examination of relevant factors as they relate to safety and combat effectiveness.

The Panel visited contractor engineering and production facilities, the V-22 training squadron, and United States Special Operations Command Headquarters. The review included public inputs, discussions with the Government and contractor program managers, engineers and test pilots. Panel members also flew the engineering and training simulators and examined operational aircraft as well as the production lines. Briefings were given on a variety of technical issues by Navy and contractor engineers, safety professionals and test pilots.

The V-22 completed its Operational Evaluation with mixed results. On one hand, the aircraft satisfied all 13 of its Key Performance Parameters (including range, speed, and payload). On the other hand, the aircraft fell short of requirements for reliability, availability, and maintainability suggesting that the aircraft and its logistics support system have not yet matured to the point of adequate supportability.

The need for a capability of the type the V-22 was designed to satisfy appears to be justified, and by its demonstrated performance, the V-22 has shown unique potential to meet that need. There is no evidence that the V-22 concept is fundamentally flawed, however, the aircraft is not ready for operational use in a number of key respects, chief among them system reliability, and maintainability. Further, the Program shows signs of underfunding as evidenced by inadequate MV-22 spares and logistics support in the out-years, the use of aircraft for maintenance trainers, and a lack of reserves for program contingencies.

Based on its findings, the Panel recommends that the Department proceed with the V-22 Program, but temporarily reduce production to a minimum sustaining level to provide funds for a Development Maturity Phase. The report contains a number of specific recommendations regarding upgrades to the reliability and maintainability of the hydraulic system, improvement and verification of technical publications and aircrew procedures. Various operational restrictions should be imposed until the Development Maturity Phase has progressed to the point where known risk issues have been properly addressed and confidence in aircraft reliability, maintainability and logistics supportability have returned. Finally, the spares and logistics support for the Program should be fully funded in order to allow the Marines and Special Operations warfighters the best opportunity to make use of the demonstrated capabilities of the aircraft.

RECOMMENDATIONS

SAFETY IMPLICATIONS OF THE TILT ROTOR CONCEPT

Recommendation: Continue to develop mitigation strategies to limit the potential for autorotation and the risk (probability and severity) of asymmetric thrust conditions.

THE MIRANA ACCIDENT AND VORTEX RING STATE

Recommendation: Use the results of the planned high-rate-of-descent flight tests to update operating limitations, procedures, the Naval Aviation Training and Operating Procedures Standardization (NATOPS) manual, pilot training (including the flight simulator), and a cockpit warning system.

Recommendation: Configure the pilot training simulator with the capability to provide vortex ring state training to the maximum extent possible based on model limitations and information available. At a minimum, include avoidance training.

Recommendation: If testing indicates poor natural aerodynamic warning, the aircraft should be configured with a cockpit warning system.

Recommendation: Develop techniques and procedures for inter-aircraft coordination during formation-decelerating conversions.

Recommendation: If flight test results point to the need for flight limitation that includes airspeed of 40 knots indicated airspeed or less, procure or develop a more accurate airspeed indication system for the aircraft.

THE NORTH CAROLINA ACCIDENT AND FLIGHT CONTROL SYSTEM RELIABILITY

Recommendation: Improve hydraulic system component reliability.

Recommendation: Take steps to mitigate the risk of loss of hydraulic system integrity (e.g., chafing, fittings, leaks, vibration).

Recommendation: Develop techniques, tools, and methods for timely identification of hydraulic-line chafing.

Recommendation: Add acoustic sensors to the test nacelle and reevaluate the adequacy of current test nacelle environmental instrumentation in light of recent reliability problems.

Recommendation: Assess the process used by V-22 contractors to predict component reliability numbers and take steps to improve.

Recommendation: Develop appropriate controls (design and life-cycle support) for all exceptions to the flight control redundancy requirements (not just those that are single-point failures).

Software Reliability

Recommendation: Conduct an independent flight control software development audit of the V-22 Program with an emphasis on integrated system safety.

Recommendation: Conduct a comprehensive flight control software risk assessment prior to return to flight.

Recommendation: The V-22 Program should not return to flight until the flight procedure and flight control software test cases have been reviewed for adequacy and have been evaluated in the integrated test facilities.

AUTOROTATION

Recommendation: Reassess the requirement for autorotative flight in view of the low need, low probability of improvement and the existence of alternatives.

Recommendation: Reassess the capability of the V-22 to conduct power-off-glides. Explore design and operational techniques to optimize power-off-glide capability (e.g., minimize proprotor drag commensurate with auxiliary power requirements).

Recommendation: Ensure that the full flight simulator used by pilots at Marine Corps Air Station, New River accurately emulates both autorotative and power-off-glide simulations to the degree required for effective pilot training.

Recommendation: Reassess the requirement for (and priority of) autorotative flight in view of the low probability of improvement and the existence of alternatives.

DOWNWASH EFFECTS ON TACTICAL OPERATIONS

Remote Area Operations

Recommendation: Continue to develop procedures and techniques for the high downwash "desert brownout" situation, and incorporate them into the training manuals and syllabi.

Recommendation: Restrict tactical unit night operations in landing zones that have the potential for brownout until procedures and techniques are developed and approved.

Personnel Deployment/Recovery from Hover (in and out of ground effect)

Recommendation: Revalidate the requirements for personnel deployment and recovery operations.

Recommendation: If the requirements remain valid, then incorporate appropriate hoist and ladder systems into the aircraft as soon as possible.

Recommendation: Conduct follow-on testing and evaluation to address tactics, techniques, and procedures to be used in the conduct of personnel deployment and recovery operations.

External Load Operations

Recommendation: Conduct follow-on test and evaluation to further refine tactics, techniques, and procedures and to ensure that external operations can be conducted safely and effectively.

PILOT TRAINING

Recommendation: Provide adequate funding for aircrew ground training, aircraft simulators, and upgrades to training devices.

Recommendation: Publish updates to the MV-22 NATOPS manual, and verify with VMMT-204 pilots before the first operational flight to support pilot/squadron transition and re-currency training.

Recommendation: Convene an out-of-cycle NATOPS manual conference prior to the first squadron operational flight to assure consistency and adequacy of emergency procedures and operational limitations. Develop an expeditious process to incorporate changes from this conference and from ongoing test and evaluation activities.

CRASHWORTHY FUEL TANKS

Recommendation: Configure (by retrofit or test) all operational aircraft with crashworthy fuel cells at the first opportunity (see later recommendation with respect to retrofit funding),

and, in the meantime

Recommendation: Communicate the interim risk acceptance rationale to the operational community.

PRODUCTION QUALITY

Quality Trends

Recommendation: The contractors, Defense Contract Management Agency, and Services need to remain actively involved in quality assessments and improvements.

Recommendation: Take appropriate steps to resolve quality-related findings of the Tiger Team as soon as their results are available.

OPERATIONAL TEST CREW SELECTION AND ASSIGNMENT

Recommendation: As the testing program proceeds, test managers (contractor, Naval Air Systems Command (NAVAIR), and operational) should continue to ensure the appropriate experience and qualifications of all flight crewmembers.

Recommendation: As V-22 development and testing continue, all responsible organizations should take all reasonable steps to ensure that operational test aircrews are not subjected to undue risk. Thoroughly assess all known and suspected high-risk flight regimes.

Recommendation: Until the aircraft is ready for deployment, flying should be restricted to mission-essential personnel. Assess operational risk factors before authorizing increased risk flights (e.g., assaults, night flying, weather flying, etc.).

SYSTEM SAFETY

Organization and Process

Recommendation: Develop a consistent approach to measuring overall risk level in development and operational programs to aid decision makers in risk trades. Consider use of probabilistic risk assessment techniques to comply with the most recent risk category definitions published by the Naval Air Systems Command.

Director, Operational Test and Evaluation (DOT&E) Safety Issues and "Implications" vs. NAVAIR Safety Risk Posture

Recommendation: To aid decision makers, the Defense Operational Test and Evaluation organization and Navy Operational Test and Evaluation Force should consider the use of standard risk indices (i.e., Risk Assessment Codes) when reporting safety issues.

RELIABILITY AND AVAILABILITY

Recommendation: Reassess and revalidate the current set of V-22 reliability and availability requirements to assure appropriate expenditure of resources on engineering changes.

MAINTAINABILITY

Recommendation: Modify the nacelle to improve the spacing/protection of critical components, maintenance working space, access, and the overall maintainability of this critical aircraft area. The redesign activity for this modification should include at least the following:

a. More quick-access panels;
b. High-reliability alternatives to the Mini-Mark fastener;
c. User-friendly inspection access for critical parts and other exceptions to the flight control system redundancy design requirement;
d. Shortening of the hydraulic lines between switching valves and swashplate actuators (if feasible).

INTERACTIVE ELECTRONIC TECHNICAL MANUAL (IETM)

Recommendation: Assess the options for V-22 technical publications (electronic and paper).

Recommendation: Provide adequate developmental support to the training squadron for the selected system.

Recommendation: Properly validate and verify the technical publications as soon as possible.

Recommendation: Transition as soon as possible from the Universal Numbering System to the standard Work Unit Code logistics system.

Recommendation: Standardize performance, support, testing, and funding requirements for electronic technical manuals across all platforms and Services.

MAINTENANCE AND AVAILABILITY REPORTING NAVAL AVIATION LOGISTICS COMMAND MANAGEMENT INFORMATION SYSTEM (NALCOMIS) (OPTIMIZED)

Recommendation: NAVAIR should correct the deficiencies and incompatibilities that are resident in the NALCOMIS (Optimized) system as soon as possible.

Recommendation: NAVAIR should provide a set of guidelines and metric algorithms to all organizations that use NALCOMIS readiness data for planning, budgeting and other resource decision-making.

DIAGNOSTIC CAPABILITY

Recommendation: Fix the individual deficiencies associated with Aviation Maintenance Event Ground Station (AMEGS), IETM, and NALCOMIS (Optimized). After each system demonstrates adequate reliability, integrate these three systems as soon as possible.

Recommendation: In the short term, expedite software cross-references for AMEGS and IETMs.

Recommendation: Provide appropriate training on AMEGS for the VMMT-204 maintainers.

Recommendation: Expedite the plan to reduce the V-22 false-alarm rate in both the aircraft and ground systems, with priority on aircraft software.

MAINTENANCE TRAINING

Recommendation: Fully fund and support the maintenance training system.

Recommendation: Consider the eventual replacement of the aircraft being used as maintenance trainers with maintenance trainers designed for that purpose.

Recommendation: Retrofit and modification of maintenance training aircraft (when appropriate) should occur at the same time or prior to those changes being incorporated in tactical aircraft.

Recommendation: Adequately budget for maintenance-training aircraft spares.

THE JOINT PROGRAM AND SYSTEMS ENGINEERING

Recommendation: Constant attention must be paid by both the Navy and the Bell Boeing Joint Program Office to the potential for lapses in systems engineering integration discipline as team members try to solve problems outside of established processes.

Recommendation: As the program proceeds, both NAVAIR and the contractors should ensure a high level of continuity in the program's Integrated Product Teams, Analytic Integration Teams, and key management positions.

Design Trades

Recommendation: For the next phase of system and requirements reviews, risk trades, and engineering changes, the program should assess its trade-study priorities and perform updates consistent with today's priorities—i.e., safety, reliability, and maintainability.

Risk Management

Recommendation: The Defense Systems Management College risk management course should use the V-22 Program risk management process as an example of how to incorporate risk into everyday program management.

PROGRAM COMMUNICATIONS

Recommendation: Review information flow requirements between the V-22 Program, Bell Boeing, and the customer, and develop a funded plan to increase the responsiveness to operator needs. (Attention needs to be given to meeting similar requirements for the Air Force and Special Operations Command (SOCOM) during CV-22 introduction).

Recommendation: Supplement the standard formal reporting to and from the Osprey Support Center with informal feedback to facilitate the exchange of information to and from the operators.

Recommendation: Both the Government and Bell Boeing should increase the management visibility of the Osprey Support Center and decrease the turnaround time for relevant problem-resolution status.

Recommendation: Bell and Boeing CEOs, the V-22 Program Manager, and the Joint Program Office meet monthly to review program status until the current concerns are resolved.

PROGRAM DEVELOPMENT RESERVES

Recommendation: A funding reserve should be provided and protected during the DoD budget process for unknown contingencies for CV-22 development and to address the additional design and development and the Development Maturity Phase recommended by the Panel.

CV-22 BLOCK 0 DEVELOPMENT

Recommendation: Remove the CV-22 Block 0 funding ceiling and fund at the required levels. Retain the funds in the program until the Secretary of Defense considers the Panel's specific recommendations.

ENGINEERING PRODUCTION CHANGES

Recommendation: Temporarily reduce production to a minimal sustaining rate until both the aircraft design and manufacturing processes mature. Funds generated by this reduction in aircraft should be protected in the DoD budget and made available for a "Development Maturity Phase" and increased production engineering changes. (See subsection 4.8 Program Funding).

Recommendation: Establish an Aircraft Procurement Navy-5 funding line and provide funds. Assure that CV-22 retrofit is covered with funding line and funds, as appropriate.

SPARES AND LOGISTICS SUPPORT PLANNING AND PROVISIONING

Recommendation: Fund spare parts levels and logistics support based on the results of the independent cost estimate and actual experience to date.

Recommendation: Fund additional engineering change proposals to improve reliability and to reduce spare parts requirements.

PROGRAM FUNDING

Recommendation: Proceed with the V-22 Program as the best alternative for the stated mission need.

Recommendation: To address the specific actions identified in this report, temporarily reduce the production rate to a minimum sustainable level and reprogram funds that are freed to the Research, Development, Test, and Evaluation account to apply to the Development Maturity Phase. Incorporate resulting changes into the production line as early as possible. Funds generated by this reduction in aircraft should be protected in the

DoD budget and made available for the Development Maturity Phase and increased production engineering changes.

Recommendation: Once the Development Maturity Phase is complete, establish a maximum economic production rate and buy out the remaining aircraft with firm, fixed-price, multiyear procurements to help recover total program cost and schedule.

SUMMARY CONCLUSIONS AND RECOMMENDATIONS

Summary Recommendation: Validate and prioritize requirements; delete those that are invalid or that rank poorly in cost/ benefit terms.

SAFETY

Summary Recommendation: Improve reliability, then verify by extensive test/fix/test in challenging environments.

Summary Recommendation: Expand safety risk assessments to include off-nominal conditions, with emphasis on flight control software, and hydraulic and power train systems. Retrofit crashworthy fuel cells into all operational aircraft.

Summary Recommendation: Extend high-rate-of-descent testing, formation flying (and other deferred flight tests as appropriate) to sufficiently define and understand the high-risk portion of the flight envelope under all appropriate flight conditions. Add a VRS cockpit warning system and appropriate simulator training.

Summary Recommendation: Make the flight manuals correct, explicit, and simple.

OPERATIONAL EFFECTIVENESS AND SUITABILITY

Summary Recommendation: Fix the existing maintenance publications system or adopt a new approach, such as the system currently being used by the F-18 or the one planned for the AH-1.

Summary Recommendation: Provide better physical access to obstructed areas for inspection and maintenance by ground crews, and substantially refine the diagnostics system.

Summary Recommendation: Explore the suitability and limitations of the aircraft in such activities as tactical formation approaches, fast roping, and desert/night operations.

PROGRAMMATICS

Summary Recommendation: Proceed with the V-22 Program, but temporarily reduce production to a minimum sustaining level to provide funds for a Development Maturity Phase, and keep to a minimum the number of aircraft requiring retrofit.

Summary Recommendation: Implement a phased approach to return to operations with flight-readiness reviews before each phase.

Summary Recommendation: Purchase adequate spares and logistics support.

Summary Recommendation: Establish sufficient funding reserves to permit the Program Office to deal with unforeseen and unforeseeable circumstances without disrupting the entire flow of the program.

Summary Recommendation: Increase formal and informal feedback among all members of the V-22 team.

Summary Recommendation: Initiate monthly executive-level program management meetings and continue throughout the Development Maturity phase. These meetings should involve the Chief Executive Officers of both Bell and Boeing, the Navy Program Manager, representatives of the users (Marine and Special Operations Command), and the Joint Program Office Director. Action items should be assigned and monitored.

Table of Contents

TABLE OF FIGURES

TABLE OF TABLES

INTRODUCTION

BACKGROUND

On December 11, 2000, an aircraft assigned to the Marine Corps' first operational MV-22 Osprey squadron crashed during a night training mission in a wooded area near Jacksonville, North Carolina, killing all four Marines on board. This was the second fatal accident for the new aircraft in 8 months, the previous mishap having been during a night Operational Evaluation (OPEVAL) test flight in Arizona, resulting in the loss of 19 Marines. The Marine Corps suspended flight operations until the most recent accident was fully understood and any new safety risk could be dealt with for the remaining aircraft.

The Assistant Secretary of the Navy for Research, Development and Acquisition was scheduled to make a full-rate production decision in early December, but the mishap, as well as several suitability issues raised during OPEVAL, caused the Marine Corps to request that the decision be delayed until the mishap investigation was completed.

On December 15, the Secretary of Defense, citing the mishap and testing issues, established an independent review of the program, which was termed The Panel to Review the V-22 Program. He appointed General John R. Dailey USMC (Retired), Mr. Norman R. Augustine, and General James B. Davis, USAF (Retired) to the Panel.

In a follow-up memorandum, the Secretary of Defense approved the Panel's charter and added a fourth member, Dr. Eugene E. Covert. The charter required that the Panel report its findings and recommendations to the Secretary of Defense and estimated a 3- to 4-month effort (depending on the availability of mishap investigation results).

The Panel charter is attached as Appendix A.

THE PANEL

The Panel to Review the V-22 Program consists of four members: General John R. Dailey, USMC (Retired); The Honorable Norman R. Augustine; General James B. Davis, USAF (Retired); and Dr. Eugene E. Covert. Genenearal Dailey is the Panel Chairman. The Panel was established subject to the Federal Advisory Committee Act (FACA).

In accordance with FACA guidelines, the Department of Defense (DoD) appointed Mr. Gary J.Gray to serve as the Panel's Designated Federal Official, and also as the Panel Executive Secretary. The Panel was also authorized a small professional and administrative staff. The biographies of the Panel and key staff members are provided in Appendix B.

OBJECTIVE AND SCOPE

As established in the Secretary's charter, the purpose of The Panel to Review the V-22 Program is to conduct an independent, high-level review of the V-22 Program to include safety of the aircraft, recommend any proposed changes or corrective actions, and report the results to the Secretary of Defense. The charter listed five factors as they might affect safety and combat effectiveness of the aircraft:

1) Training
2) Engineering and design
3) Production and quality control
4) Suitability to satisfy operational requirements
5) Performance and safety of flight

In conducting the "high-level" review, the Panel assessed all aspects of the program with concentration on the five general factors above. The Panel had neither the resources nor the charter to perform detailed investigations of recent mishaps, nor to provide exhaustive analyses or audits of any of the known technical or programmatic issues facing the V-22 Program. Rather, the Panel kept its findings to the major issues, using the experience and expertise of its members and staff to recommend general solutions to significant problems related to safety, effectiveness, and programmatics.

APPROACH

The Panel used the technical staff to coordinate briefings and site visits during the assessment. They invited officials from the Government and contractor program offices to brief them on history and current status of all aspects—technical and programmatic—of the V-22 Program. To get the user perspective, they visited the Marine training squadron at MCAS New River, Jacksonville, North Carolina, and the Special Operations Command Headquarters at Mac Dill Air Force Base, Tampa, Florida. They also visited contractor engineering and production facilities in Philadelphia, Fort Worth, and Amarillo. They exercised engineering and training simulators; received V-22 maintenance training lectures; and talked with production line supervisors, Marine and Air Force pilots, and maintainers. The Panel talked with Navy and contractor engineers, safety professionals, and test pilots on a variety of technical issues.

The Panel organized into subpanels to analyze the various issues that surfaced during the fact-finding events. As a FACA Panel, they received a great deal of unsolicited input from members of the public, Government, and industry. Twice during the review, the Panel held open meetings, once to receive input from the public and once for formal deliberations. The schedule of fact-finding and open deliberations is included in Appendix C.

Consistent with FACA guidelines, the Panel used publicly available information from previous studies, Mishap Investigation Reports (MIRs), and cost and alternative assessments. For neither of the two most recent major accidents has the MIR been released, so the Panel based its findings on its own interviews and the results of the two relevant Judge Advocate General investigations. The Panel coordinated its review with an ongoing Defense Department Inspector General (IG) investigation concerning alleged falsification of certain aircraft material readiness information in the V-22 training squadron at Marine Corps Air Station New River, North Carolina. A letter confirming the consistency of Panel findings with that investigation is attached as Appendix D.

The results of the Panel's review are described in general terms in Section 1 (General Observations) and Section 3, (Summary Conclusions and Recommendations). Specific discussion, conclusions, and recommendations are included in Section 2 (Specific Findings).

HISTORY

THE TILTROTOR CONCEPT

The idea of using a tiltrotor concept for an aircraft dates back to the late 1940's and early 1950's. The first successful demonstration of tiltrotor feasibility was with the Bell Textron XV-3 under contract with National Aeronautical and Space Administration (NASA) and the Army. This 4,800-pound research aircraft was powered by a single, internally mounted radial reciprocating engine. It used a combination of transmissions, driveshafts, and gearboxes to drive the wingtip-mounted rotors and to rotate them up and forward for helicopter and airplane mode, respectively. From the mid-1950's through the early 1960's, the XV-3 made 250 test flights, including 110 full conversions from helicopter mode to airplane mode and back.

THE XV-15 PROTOTYPE

Once the XV-3 demonstrated the feasibility of tiltrotor, NASA and the Army proposed the development of a new tiltrotor aircraft—the XV-15, awarding Bell Textron a contract to build and test two aircraft in July 1972. The XV-15 weighed 13,000 pounds and was powered by two turboshaft engines. The aircraft flew in helicopter mode in May 1978 and airplane mode in July 1979. By 1981, the test team had expanded the aircraft's envelope to 21,000-feet altitude and 300 knots cruise airspeed, and the Department of Defense formally began the Joint Services Advanced Vertical Lift Aircraft (JVX) Program. The goal of this program was to meet the needs of all four military services for a vertical takeoff and landing (VTOL), medium lift transport aircraft. In 1982, the Joint Services Technical Assessment concluded that tiltrotor technology was the optimal candidate to meet the joint Services' needs.

THE V-22 OSPREY

The Deputy Secretary approved initiation of the program after a Milestone 0 Review in December 1981 to satisfy the multi-mission, multi-Service need. The Army led the original program. In 1982, the program was transferred to the Navy when the Army withdrew from the program because of affordability.

In April 1982, Bell Helicopter Textron and Boeing Helicopters teamed to pursue the JVX program jointly. A year later, they received a preliminary design contract to validate the design and to reduce risk in the aircraft's full-scale development (FSD) phase. In 1984, the Government designated the JVX as the V-22. Shortly thereafter, the Secretary of the Navy chose the name "Osprey" for the new aircraft.

FULL SCALE DEVELOPMENT

Under the oversight of the Naval Air Systems Command, Bell Boeing began preliminary design work in June 1985. With successful completion of the Preliminary Design Review, the Government formally approved Full Scale Development (FSD) at the Milestone II Review in April 1986. The objective of the program was to develop the V-22 with the intent of producing 913 aircraft for the Army, Navy, Marine Corps, and Air Force. The plan called for Initial Operational Capability (IOC) for the Marine Corps version in 1992. Critical Design Review was held in December 1986. Seventeen months later, the first FSD aircraft was rolled out, and it made its first flight on March 19, 1989. A month after the first flight, the Secretary of Defense determined that the V-22 was not an affordable program, and he requested no more funds for development. Production was terminated in December 1989. Congress disagreed with the Administration's decision and continued to fund FSD, including development efforts to mature the tiltrotor technology, upgrade the drive system, and continue flight test using the FSD aircraft. It was during this time (June 1991) that the first V-22 was lost in a vertical takeoff accident due to miswiring of the flight control system rate gyros. Then, a second FSD aircraft and its seven military and contractor occupants were lost due to a nacelle fire during landing approach to the airfield at Quantico Marine Base, Virginia in July 1992. Following an analysis in October 1992, the Navy ordered continuation of V-22 development. Bell Boeing, a joint venture of Bell Helicopter Textron, Fort Worth, Texas, and Boeing Helicopter, Philadelphia, Pennsylvania, was awarded a contract for the Engineering and Manufacturing Development (EMD) of four production-representative MV-22 aircraft.

ENGINEERING AND MANUFACTURING DEVELOPMENT (EMD)

The objective of EMD was to mature the design of the MV-22 through flight test of production-configured aircraft, to continue to fly two of the FSD aircraft on a risk reduction program, and to complete operational testing in support of a go-ahead for full production (Milestone III). The plan called for Initial Operational Capability (IOC) for the MV-22 in the second quarter of Calendar Year (CY) 2001. The total production planned are as follows: 360 MV-22, Marine Corps variants; 50 CV-22, Special Operations Command variants; and 48 HV-22, Navy variants. The System Design Review, Preliminary Design Review, and Critical Design Review were accomplished by December 1994. The first CV-22 flew in February 2000, 3 months before the end of the MV-22 EMD flight test.

LOW RATE INITIAL PRODUCTION

In April 1997, after a successful Defense Acquisition Board review, the Under Secretary of Defense for Acquisition and Technology authorized the V-22 to proceed into Low

Rate Initial Production (LRIP). At the same time, he directed the CV-22 Overarching Integrated Product Team (OIPT) to review the CV-22 Program prior to full funding of production and report back to him. Future V-22 production decisions were delegated to the Navy, subject to the satisfaction of defined exit criteria. Subsequent reviews and approvals were conducted by the Assistant Secretary of the Navy (Research, Development and Acquisition) in March 1998, March 1999, and March 2000 (LRIP Lots 1, 2, and 3). At the March 2000 review, the Navy provided approval for MV-22 Lot 4 full funding and MV-22/CV-22 Lot 5 Advanced Acquisition Contract production funding. The first V-22 major accident in nearly 8 years killed 19 Marines in April 2000, when an Operational Evaluation (OPEVAL) pilot lost control of the aircraft during a high-rate descent to a desert runway at night. Following OPEVAL, the Assistant Secretary of the Navy (Research, Development and Acquisition) decided to postpone the Milestone III decision pending resolution of reliability and availability deficiencies that were raised during OPEVAL. Then, in December, another fatal accident occurred during a training mission when a Low Rate Initial Production aircraft assigned to the first operational squadron crashed during a routine night approach near New River, North Carolina. Pending the results of the latest mishap investigation, the V-22 aircraft are grounded, and the Milestone III decision awaits the results of that investigation as well as the findings of this Panel.

SECTION 1: GENERAL OBSERVATIONS

In reviewing the V-22 Program, the Panel noted an aircraft that had completed its Operational Evaluation with mixed results. On one hand, the MV-22 satisfied all 13 of its Key Performance Parameters, thus introducing a new technology to the United States arsenal with unprecedented range, speed, and payload and combat survivability capabilities for its mission. On the other hand, poor demonstrated availability and maintainability results suggest that the aircraft and its logistics support system have not yet matured to the point of adequate supportability. Further, its reliability and safety have caused the Department of Defense to question its technological maturity. In addressing this dichotomy, the Panel found it appropriate to answer eight fundamental questions. These questions are answered in the text below, followed by specific findings that treat them in more detail.

QUESTION 1: IS THERE A NEED FOR A CAPABILITY SUCH AS THAT OFFERED BY THE V-22?

In the evolving global geopolitical circumstances wherein confrontations among major powers seem somewhat less likely and engagements involving smaller groups ranging from terrorists to mid-sized nations seem more probable, the type of capability identified for the V-22 would seem to be important. Such a capability includes the capacity to deploy rapidly over long distances and to engage in surprise operations by virtue of the flexibility inherent in an extended operating range and the ability to carry out missions in a single period of darkness. As an example, the Desert One mission involved 2 days of hiding in the desert…a mission that could have been carried out by a V-22-like aircraft in a single period of darkness. The high political stakes involved in such missions make it imperative that they be carried out successfully when undertaken.

QUESTION 2: ARE THERE REASONABLE ALTERNATIVES TO THE V-22?

There are no existing aircraft capable of carrying out the V-22 mission, although there are aircraft, or combinations of aircraft, that can carry out lesser missions or execute the V-22 end mission with more time and reduced probability of success. Existing inventory aircraft are aging and will require replacement in the years ahead. Most of the current generation of aircraft are out of production and would be costly to reintroduce into production. New developmental programs likely would focus on technology and concepts very similar to that represented by the V-22.

Past experience indicates that the greatest source of waste in defense acquisitions is in stopping partially completed programs, a practice that usually merely exchanges known problems associated with the current developments for unknown problems associated with the yet-to-be-developed systems. That is, if the operational need is legitimate and the fundamental concept being pursued is sound, one is generally best served by seeking to resolve whatever problems have been encountered in the ongoing development. The two caveats noted are, however, vitally important.

QUESTION 3: IS THE V-22 CONCEPT OR ITS IMPLEMENTATION FUNDAMENTALLY FLAWED?

The V-22 is a very complex flying machine, both aerodynamically and mechanically. This is a consequence of the need for multiple proprotors, the need to limit the diameter of the proprotors to allow safe shipboard clearance, the requirement to fold the wings and proprotors to permit compact storage aboard crowded ships, and the need to tilt the engine nacelles. There have been five major accidents involving the V-22, and its predecessor, the XV-15, that resulted in extensive loss of life and loss of aircraft. Of those, the basic causes in one instance was entirely unrelated to the unique concept of the V-22, two were related only in a highly indirect manner to that concept, and two were aggravated by the side-by-side proprotor V-22 configuration. None had as its fundamental cause the tiltrotor concept. It appears that there is no basic inherent flaw in the tiltrotor approach, although such a configuration does tend to be unforgiving because of its propensity to roll when certain malfunctions (other than engine failure) occur that affect one side of the propulsion system and not the other. To date, the XV-15 and the V-22 have accumulated approximately 6,000 total flying hours.

QUESTION 4: DOES THE V-22 PROVIDE THE PERFORMANCE CAPABILITY NEEDED TO ACCOMPLISH THE PRESCRIBED MISSIONS?

The V-22 has demonstrated the ability to meet the prescribed missions within the uncertainty band inherent in performance requirement measures. Certain tactical usage questions remain to be resolved, such as fast-roping, tactical formation approaches, and night desert operations.

QUESTION 5: IS THE V-22 ADEQUATELY RELIABLE TO INITIATE OPERATIONS?

The V-22's reliability at this point is clearly inadequate to be utilized by operational units now or in the immediate future. Higher than predicted component failure rates and lack of appropriate attention to flight-critical hardware have combined to reduce dependability and increase risk. To attempt to push the aircraft in this state into routine operations would further discredit the basic concept of the tilt-rotor aircraft and very likely result in the inability to carry out the prescribed missions and possibly produce further casualties.

QUESTION 6: IS THE V-22 MAINTAINABLE BY OPERATIONAL UNITS?

At the present time, the V-22 falls far short of being a tactically maintainable aircraft due to the confluence of a number of factors, which include the inadequacy of spares, a non-functional technical manual system, an unreliable diagnostics system, and poor accessibility to critical components in the nacelles.

QUESTION 7: IS THE V-22 AFFORDABLE?

The V-22 is a very expensive aircraft. Nonetheless, it is unlikely that any new aircraft capable of carrying out a mission in the general regime of that specified for the V-22 would cost significantly less. Indeed, any new aircraft of comparable performance would likely cost more, even if sunk costs were excluded in the comparison (as they should be in addressing future economic decisions). It is, of course, difficult to make a case for the V-22 as compared to the purchase of two CH-47s except for those missions that simply cannot be conducted by CH-47s (of which there are a number). However, overall costs, including personnel, support aircraft, etc., make the argument for the V-22 more compelling.

Given the relatively small procurement quantities affordable with today's overall defense acquisition budget, it is in fact extremely difficult to make a case for <u>any</u> new development of <u>any</u> type. Under the current circumstances, one must presumably consider new developments in the context not only of purchasing a limited number of new articles of equipment but also in terms of purchasing an "insurance policy" that permits modern, more capable systems to be put into production more quickly should the need arise in the decades ahead.

QUESTION 8: HAS THE DEPARTMENT OF DEFENSE ACQUISITION PROCESS SERVED THE V-22 DEVELOPMENT WELL?

The answer to this question is clearly "no." To begin with, the process has not permitted the creation of financial reserves to deal with unforeseen and often unforeseeable contingencies that arise even in the best-managed development activities. The 2-year cycle required to obtain additional funding (even if the funding is then available) in DoD acquisitions is incompatible with the pace of the change in technology and the schedule of reasonable development pursuits. As a result, in the case of the V-22, funding limitations, aggravated by contractor performance shortfalls, have resulted in such occurrences as the use of production aircraft to serve as maintenance trainers, insufficient spares, and inadequate technical publications and other logistics support.

In addition, the V-22 Program was initially structured to introduce a number of new capabilities simultaneously, thereby compounding the risk associated with the program. These new capabilities include a conceptually new design (a compound aircraft), an all-electronic maintenance manual system, a unique logistics numbering system, and a new operational-readiness reporting system…all while seeking to fulfill multi-Service needs and being vulnerable to an inadequate supply of spares (dictated by budgetary constraints). The consequences of these circumstances have been exacerbated by the fact that communications between users and developers, particularly contractors, have been sufficiently limited (not uncommon in DoD development activities) to the extent that confidence and morale among those who will be called upon to maintain and operate the system is low…often simply due to lack of information (in both directions).

DoD budgeting practices that invariably underestimate the impact of inflation in the economy tend to further exacerbate funding issues. DoD testing of new systems has evolved over the years to become largely a report card for possible program cutbacks or cancellations, such that engineering tests for the sake of exploring and verifying designs are no longer pursued to an adequate extent. Finally, programs having met system performance goals tend to transition from the development phase into limited and then full production and subsequent operation prior to having adequately demonstrated the all-important operational characteristics of mission reliability and field maintainability.

SECTION 2: SPECIFIC FINDINGS

This section is organized into four subsections:

1. The Need for the V-22—a summary of the many requirements and alternatives analyses conducted over the last 20 years;
2. Safety—a discussion of the several safety issues and mishaps, and Panel findings regarding the safety of the tiltrotor concept and of the specific V-22 design;
3. Combat Effectiveness—the Panel's findings in the area of operational suitability;
4. Programmatics—a discussion of various program management and resources findings.

1 THE NEED FOR THE V-22

The stated need to replace medium lift helicopters for multiple-Service use is well documented in a series of studies conducted over the last 20 years. U.S. Marine Corps CH-46E and CH-53D medium lift helicopters began military service in the early 1960s and are now experiencing technical obsolescence; escalating maintenance costs; reduced reliability, availability, and maintainability (RAM); and significant performance degradation. Current and projected CH-46E and CH-53D deficiencies include the following:

1) Inadequate payload, range, and airspeed
2) Lack of ability to communicate, navigate, and operate in adverse weather conditions, day or night
3) Lack of self-deployment or aerial refueling capability
4) Inability to operate in a Nuclear, Biological, Chemical (NBC) environment
5) Insufficient threat detection and self-protection capabilities
6) Unacceptably high maintenance and inspection rates
7) Limited communication capability for embarked troop commanders

Marines support the MV-22 Program because the aging CH-46E and the CH-53D provide limited or no capability to perform many of the missions in which the MV-22 is most effective. The V-22 alternative also supports the Marine Corps' doctrine of Expeditionary Maneuver Warfare, crisis response, and naval forward-presence operations.

The U.S. Special Operations Command (SOCOM) uses a variety of fixed- and rotary-wing aircraft to perform special operations missions, the oldest of which are the MH-53J/M Pave Low medium lift helicopters with an average age of 30 years. The current inventory of aircraft lacks the self-deployment capability and performance required to maximize the probability of success for assigned clandestine missions, especially those that must be conducted during one period of darkness. Current and projected SOCOM aircraft deficiencies include the following:

1) Inadequate combat radius and speed to execute multiple, concurrent major theater war and national missions without incurring additional support requirements (e.g., strategic airlift, in-flight refueling sorties, and associated logistics tails) all resulting in an increased operational signature.

2) Inadequate growth potential for emerging, self-protection aircraft systems due to space/weight and design limitations.

Air Force and SOCOM support for the CV-22 is based on a mission need, first stated in 1981, that, from the current options, only the CV-22 aircraft can satisfy. The CV-22's distinct advantage over helicopters in speed, range, payload, and increased survivability provides greater operational effectiveness. If restricted to using existing helicopters, SOCOM would not be able to accomplish some missions, and others would incur a much greater operational risk and still require force structure changes. The CV-22 requires less sustainment infrastructure and strategic airlift than helicopter alternatives. SOCOM already has reduced tanker and helicopter infrastructure in anticipation of receiving the CV-22.

The result of the Service needs was a Joint Operational Requirements Document (JORD) with 19 Key Performance Parameters (KPPs) (13 of which are unique to the MV-22), and nearly 300 other requirements. The major KPPs were the requirement for V/STOL capability, 500-mile range, 240-knot cruise speed, self-deployability, shipboard compatibility and the ability to carry 24 combat equipped troops.

While the Panel did not review Special Access Programs or Defense Advanced Research Projects Agency (DARPA) studies, the Panel is unaware of any existing or conceptual aircraft capable of carrying out the V-22 mission as defined by the JORD. There are a number of existing aircraft that could carry out lesser missions or execute the V-22's end mission with more time or reduced probability of success. Existing inventory aircraft are aging and require replacement in the years ahead. Most of the current generation of aircraft are out of production and would be costly to reintroduce into production. New development programs likely would focus on technology and concepts very similar to that represented by the V-22.

Conclusion: The helicopter assets that the V-22 was designed to replace are aging and approaching obsolescence. For the Marine Corps and SOCOM, the combination of speed, range, payload, survivability, and self-deployability demonstrated by the V-22 offer the warfighter the greatest probability of success of any existing or envisioned alternatives while minimizing casualties.

2 SAFETY

2.1 OVERVIEW

Two MV-22 aircraft and 23 Marines were lost in an 8-month period, just as the aircraft was completing its OPEVAL and just as the first operational squadron was preparing to take on its role of introducing the aircraft to the Fleet Marine Force (FMF). That brings to four the total number of V-22 losses since first flight in March of 1989 (three losses prior to fleet introduction). To put the safety history of the V-22 in perspective, Table 1 compares major (Class A) mishaps for the pre-fleet introduction years of several other new aircraft types.

Aircraft Type	Years	Flight Hours	Class A Mishaps	Cum. Rate (Mishaps per 100,000 flt hours)
V-22	1989 - 2000	3883	3	77
F-14A	1970 - 1973	3813	3	79
F-16A	1975 - 1979	3993	2	50
F-18 A/B	1978 - 1982	4922	3	61
H-60 (all types)	Not Available	Not Available	1	Not Available

Source: Naval Safety Center; Headquarters Marine Corps Safety Office

Note: All data are for development and operational testing phases.

Table 1: Comparative Mishap Rates during Pre-Fleet Introduction

Although the number of V-22 mishaps during pre-fleet introduction is not inconsistent with those of recent new fighter types, it is higher than the only other medium lift helicopter, and the number of fatalities is higher than all of the others in the comparison combined. Questions that are raised by the recent mishaps include the following:

1) Is there an inherent safety flaw in the V-22 tiltrotor concept?
2) Is flight crew training and assignment adequate?
3) Is system reliability adequate?
4) Is the system safety program adequate?
5) Is the quality program adequate?

To address these questions, the Panel reviewed the findings of the major mishaps (including one XV-15 and four V-22 losses [three pre- and one post-fleet introduction]), as well as all reported hazards, minor mishaps, and safety-related deficiency reports during testing. The Panel also heard from Government and contractor system safety engineers, test pilots, operational aircrew, maintenance crew, quality managers, system engineers, and experts on the subject of high-rate-of-descent hazards in rotorcraft. The Findings section includes discussions of V-22 unique safety issues, the safety implications of V-22 reliability deficiencies, and the V-22 Program's approach to system safety engineering. The Panel was sensitive to the fact that neither Mishap Investigation Report (MIR) for the last two major mishaps has been released. The Panel did not conduct an independent investigation of either mishap; however, the results of the public portions of the Judge Advocate General (JAG) reports, along with limited discussions with engineers and pilots, were used to develop findings that relate to mishap causal factors.

2.2 SAFETY IMPLICATIONS OF THE TILTROTOR CONCEPT

The Panel examined the reports summarizing the five major tiltrotor mishaps to address the question of inherent tiltrotor technology risk. Each mishap had its own particular cause factors. The Panel examined not only all of the mishaps but also the current safety risk posture as represented by the system safety program. To provide balance, the Panel also examined those unique features of tiltrotor technology that mitigate risks common to helicopters. In its assessment, the Panel compared those aspects of the V-22 that are unique to the tiltrotor concept with a notional medium lift, shipboard-based assault helicopter designed with today's state-of-the-art systems and materials.

TILTROTOR MAJOR MISHAPS

1) In 1992, one of two Bell XV-15 prototype aircraft crashed due to a maintenance error. A safety wire was left off a castellated nut that secures the proprotor to the governor linkage. When the governor disconnected, the proprotor surged to the maximum pitch setting and rolled the aircraft on its back. The aircraft was low when this happened, and the crew survived the inverted impact. This failure cannot be considered tiltrotor unique, as such a maintenance error could cost loss of any aircraft; however, the roll response was unique to the tiltrotor configuration.

2) In 1991, Engineering Manufacturing Development (EMD) Aircraft 5 was lost during vertical takeoff on its first flight due to a miswiring of two of three rate gyros in the flight control system. The reverse gyro feedback caused the pilot to lose roll control shortly after liftoff, and the aircraft crashed wing and proprotor first. The aircrew survived the mishap, and there was no post-crash fire. This type of production or maintenance error would pose a safety risk to any fly-by-wire aircraft and is therefore not a tiltrotor-unique hazard.

3) A fatal accident in 1992 at Marine Corps Base, Quantico, Virginia was caused by the nearly simultaneous loss of an engine and the pylon mounted drive shaft that was providing redundant power to that engine's proprotor. Seven crewmembers and contractor passengers were lost. The reason for the engine failure was compressor stall and fire due to oil ingestion. Oil had leaked from the proprotor gearbox area and pooled in the lower inlet lip area, dumping into the engine during nacelle conversion. The uncontained fire quickly destroyed the

interconnect driveshaft. The only part of this story that would be considered unique to the tiltrotor configuration is the concept of rotating the engine up to a vertical position. NAVAIR has since mitigated that risk for subsequent aircraft by the addition of fluid drains and interconnect fire protection.

4) The April 2000, Mirana, Arizona, mishap was a case in which the mishap pilot, while flying as wingman on a night formation approach, developed a high sink rate at low speed and most likely entered a regime of disturbed aerodynamics called vortex ring state (VRS) or power settling. The result was asymmetric loss of lift and accompanying roll at too low an altitude to recover before ground impact. All rotorcraft have the propensity for VRS-induced power settling, but the tiltrotor has several characteristics that are inherently unique—some good, some bad:

Good Characteristics

- Relatively high disc loading theoretically means that the tiltrotor needs a higher sink rate than a comparable size helicopter does to enter VRS (V-22 tests will verify).
- If the altitude is high enough, the roll-off will cause the aircraft to exit VRS (self-correcting), whereas some helicopters must be manually flown out of VRS (again, V-22 tests will verify).
- Rapid rotation of the nacelles only a few degrees promises to be a good way to avoid impending VRS relatively quickly (assuming pilot warning is adequate).

Bad Characteristics

- Relatively high disc loading makes it easier to develop a high rate of descent in a tiltrotor craft as compared to an equivalent helicopter (confirmed by pilots).
- The tendency for the tiltrotor to respond to asymmetric VRS with an uncommanded roll will pose a higher risk of adverse outcome if it happens at low altitude (wing-first impact for the tiltrotor vs. hard landing for the helicopter).

5) The December 2000 mishap in North Carolina resulted from a loss of a hydraulic line, causing degradation in system redundancy, combined with an inappropriate flight control software design feature (one that had gone unnoticed in laboratory tests or flying aircraft for over four years). The mishap occurred during a routine night-practice instrument approach. This hardware-failure-combined-with-software-defect scenario would pose a safety risk to any fly-by-wire aircraft. However, during the V-22 mishap, the yaw excursions that came from the asymmetric response of one proprotor compared with the other was part of the loss-of-control situation. It is difficult to envision a similar directional control situation for a helicopter configuration, although a like response could be

expected from a two-engine, fly-by-wire, propeller-driven aircraft with a similar combination of failures.

MINOR MISHAPS AND HAZARD REPORTS

There have been 36 minor incidents reported to the Safety Center by the Defense Contract Management Agency (DCMA) and the flight test community since September 1998. The most serious of these are listed:

1) In October 1998, an aircraft aborted a flight for failure of the Engine Air Particle Separator (EAPS) hydraulic quick disconnect. The hydraulic leak sprayed throughout the nacelle area, causing smoke but no fire.

2) Three days later, the same aircraft experienced a small fire in the nacelle external to the engine compartment when the EAPS hydraulic line failed.

3) In February 1999, during shipboard trials, the test pilot experienced roll pilot induced oscillations. There was no damage, as the pilot waved off the approach. The flight control software was modified to correct a lateral axis flight control problem.

4) In February 2000, an aircraft experienced a fire in the right nacelle. Maintenance error was involved in this incident, as hydraulic fluid leaked from a B-nut on a pressure elbow reducer.

Of the remaining incidents, 4 involved the loss of a piece of the aircraft in flight, 11 were ground-support equipment damage incidents, 6 were maintenance errors, 2 were bird strikes, 1 was a flying quality complaint during external load testing, and 8 were minor design deficiencies.

The Naval Safety Center database contains four hazard reports covering the time from June through August 2000. The most serious of these is in-flight loss of the interconnect drive shaft due to a coupling failure. As this is a backup system only, the crew was able to make a safe landing. One hazard report covers in-flight opening of the cabin door, and two discuss in-flight loss of hardware: one prop blade tip cap and one proprotor blade grip fairing.

The Panel heard from OPEVAL pilots that on at least two occasions they had experienced large uncommanded roll excursions while flying in formation (probably due to flying through the lead aircraft's disturbed air). These instances were not written up as hazard reports but are being treated by the Naval Air Systems Command as potential issues with regard to formation flight distance limitations. During development testing, the formation flying was limited to that required to ensure a safe distance limitation for conduct of OPEVAL tactical maneuvers.

The V-22 incidents and hazards are not dissimilar from those associated with fixed-wing and helicopter configurations. None of them is entirely unique. If the comparison is limited to helicopters, then the roll oscillations at the ship and the roll excursions in formation flight would have to be considered unique to the tiltrotor concept. All of the others appear to be generic in both cause and effect.

TILTROTOR-UNIQUE RISK AREAS

The Panel reviewed NAVAIR's current listing of open and closed V-22 Safety Action Records (SARs) for those risk issues that could be considered uniquely inherent in the tiltrotor concept. None of the high-risk issues is tiltrotor unique. Of all the medium-risk issues, approximately 5 percent are directly or indirectly tied uniquely to the tiltrotor concept, as compared to a notional fly-by-wire medium lift helicopter. The most relevant examples are listed in Table 2.

Safety Action Record Title	Comments
Departure from Conversion Attitude Control	Failure of automatic flight control system during conversion could cause loss of control
Failure Conversion Actuator	Loss of conversion capability: must land at last nacelle angle setting; could cause loss of aircraft if no runway available and nacelles at low (high speed) angle
Uncommanded Wing Stow Lock Pin Retraction	Wing movement in flight could result in loss of control
Longitudinal Trim Change with Nacelle Angle Change	Negative (aft stick) trim during accelerating transition poses risk of loss of flight path performance during low-light-level or instrument conditions (helicopters need forward stick during accelerating transition)
Invalid Angle of Attack	Bad signal to flight control system could cause improper flight control response and loss of control
V-22 Autorotation Characteristics *	Relatively high disc loading makes autorotation more problematic than for equivalent weight helicopter
Power Settling *	See Mirana mishap discussion above

* Autorotation and power settling per se are not unique tiltrotor risks, but depending on altitude, once in autorotation or power settling situation, tiltrotor configuration lends itself to a potentially worse outcome than for equivalent helicopter configuration.

Table 2: Tiltrotor-Unique Safety Risk Issues

POSITIVE SAFETY ASPECTS OF TILTROTOR

Of the 11 enhancing characteristics reported by the OPEVAL test team, 4 involved tiltrotor-unique safety features:

1) The high airspeed (demonstrated 258 knots maximum cruise speed) significantly reduces susceptibility to ground fire during the en route portion of the mission.

2) The rapid decelerating transition capability gives the aircraft lower vulnerability to enemy ground fire in the landing zone.

3) The expanded range inherent in the tiltrotor concept gives the Marine Expeditionary Unit or Special Operations Force more mission coverage, and by its nature, that same capability gives the pilot more options for landing sites, both nominal and emergency.

4) Pilot situational awareness in the landing environment is enhanced through the use of nacelle conversion vice pitch attitude to decelerate.

Of the operational performance capabilities the tiltrotor concept enables, several have positive safety implications:

1) The ability to transition to airplane mode after an engine failure and perform a precautionary landing on a runway means there should rarely be a need for two-engine-out autorotation.

2) Lack of tail-rotor further reduces the need for autorotation capability (compared to single-rotor helicopters).

3) Lack of dependency upon a synchronization driveshaft for safe flight (compared to tandem-rotor helicopters, for which failure of the synchronization shaft with rotors turning is catastrophic).

4) Substantial separation of engines (less chance that one adverse event will take out both engines).

Conclusion: Tiltrotor technology introduces several safety-related challenges, as well as safety enhancements, to the medium lift mission.

Conclusion: When considered in total, tiltrotor-unique risks do not appear to be prohibitive.

Conclusion: All known tiltrotor-unique risks appear to be manageable through design modifications and operational procedures and techniques.

Recommendation: Continue to develop mitigation strategies to limit the potential for autorotation and the risk (probability and severity) of asymmetric thrust conditions.

Specific recommendations are included in Subsections 2.3 The Mirana Accident and Vortex Ring State, 2.5 Autorotation, and 2.6 Downwash Effects on Tactical Operations.

2.3 THE MIRANA ACCIDENT AND VORTEX RING STATE

In April 2000, an MV-22 was destroyed, killing 19 Marines at a simulated remote landing site at the Mirana Arizona airport during a night OPEVAL exercise. The pilot of the second of a flight of two MV-22s lost control of the aircraft during a high-sink-rate descent and was unable to regain control before hitting the ground in a nose-down inverted attitude.

The Judge Advocate General investigation (Lt. Col. Morgan letter 5830, B 0525, July 21, 2000) listed two causal factors:

Primary Cause: The mishap aircraft's flight profile in the terminal area (high descent rate/low airspeed) most likely resulted in the aircraft experiencing a vortex ring state (power settling) and/or blade stall condition, which resulted in departure from controlled flight and the subsequent mishap.

Contributing Factor: Nighthawk 71's (Flight Lead) poor crew coordination and situational awareness were contributing factors to the mishap.

The pilots involved were members of the Multi-service Operational Test Team (MOTT) assigned to HMX-1, the Marine Corps' Quantico, Virginia, based rotary-wing operational test squadron. The four pilots involved were all highly experienced in other aircraft types, with V-22 flight time ranging from 86 to 97 hours each. Each was fully qualified and current. Three of the four pilots had extensive CH-53 helicopter backgrounds before joining the V-22 Program. The fourth, the right-seat pilot-in-command of the mishap aircraft, was an experienced C-130 pilot with just over 50 hours in helicopters before joining the V-22 team.

The lead aircraft pilot was preparing to land his two-aircraft formation at a specified landing spot on the Mirana airfield, but the combination of tailwind, late execution of his en route letdown, and the night-time environment all contributed to his setting up a higher-than-normal rate of descent. Meanwhile, the wingman was having difficulty maintaining position during the decelerating transition. He was 11 seconds behind the leader in initiating his nacelle conversion, the leader having begun his conversion without signal, and having used maximum 8 degrees per second nacelle rotation rate. As the lead aircraft slowed to Vertical Takeoff and Landing (VTOL) mode, the wingman found himself ballooning to an 800 (+) feet per minute (fpm) climb, followed directly by a 3900 (+) fpm descent, presumably to try to maintain position on the lead aircraft. As the two aircraft approached 40 knots, the wingman was too far forward (3 o'clock high, according to the lead aircraft crew chief). He was moving back to his proper 45-degree azimuth position when he apparently entered vortex ring state, lost control, and crashed.

Vortex Ring State (VRS) is a phenomenon wherein the combination of low forward speed and high rate of descent causes the upward flow of air around a rotor to approach the same velocity as the downwash produced by the rotor. When this happens, the rotor loses lift, and addition of power makes the lift loss worse. Vortex ring state could be considered an intermediary state between a power-on, lift-producing state, and a power-extraction, autorotating state.

The Panel was briefed on the subject of High Rate of Descent (HROD)/low-speed flight characteristics by the helicopter aerodynamics instructor at the Naval Test Pilot School and the Bell Boeing lead test pilot for the V-22. One of the key points they made was that, although the V-22 has proprotors (highly twisted roots like propellers, and long flat blades like rotors), it should be considered a helicopter when it comes to low-speed HROD operations. Like all helicopters, the V-22 can experience VRS or "power settling" when it approaches flight conditions in which very low forward speed is combined with a high rate of descent and the addition of power. Once experienced, the only way to recover from the situation is to increase forward speed, avoid adding power, and fly out of the condition. The mishap showed that the V-22, with its wingtip-mounted proprotors, could enter an asymmetrical VRS condition if the pilot (or the automatic flight control system) applies directional (yaw) control when the aircraft is close to the VRS boundary. In VTOL mode, directional control is achieved by differential rotor plane change—the proprotor plane inside the turn pitches backward, and the proprotor plane outside the turn pitches forward. In effect, the directional control will cause the inside proprotor to enter VRS (and lose lift) as the outside proprotor stays out of it (and continues to produce lift). The resulting asymmetric lift condition causes an uncommanded roll and, depending on altitude available for recovery, potential loss of the aircraft. The pilot and the automatic stability augmentation system can exacerbate this roll when they try to counter it with a roll command in the opposite direction. When the mishap aircraft lost control, its flight condition was 40 knots, in excess of 2000-fpm sink rate, descending through 300 ft. altitude.

In 1995, The V-22 System Safety Program produced a Safety Action Record (SAR) titled "Loss of Thrust/Lift, Loss of Proprotor Thrust, Settling" based on several hazard analyses. The risk level assigned was 1D (potentially catastrophic, remote probability of occurrence). The SAR included several thrust loss situations, including power settling. There was no mention of roll response or asymmetric VRS. The control listed for this hazard was "Training."

Power settling, is a phenomenon well known to helicopter pilots. All military helicopter pilots receive training and demonstrations of power settling in basic flight training. Marine helicopter student pilots are taught the 800/40 warning in ground school, and it is repeated in the TH-57 (basic trainer) Naval Aviation Training and Operating Procedures Standardization (NATOPS) manual. Depending on the type of rotorcraft, it manifests itself as a substantial loss of lift, most commonly preceded by a very noticeable aerodynamic vibration. If it happens at high enough altitude, the pilot, feeling the warning vibration, can usually fly out of it by lowering the nose, avoiding addition of power, picking up forward speed, and then flying out of the condition. If it happens at too low an altitude, the result is a hard landing or worse. Helicopter pilots are trained to stay away from high sink rates at low speeds, not only because of this phenomenon, but also to be in a better position to react to an untimely engine failure. According to Naval Safety Center records, there were six Navy/Marine Corps helicopter power-settling mishaps from 1988 to the present, including five Class C (hard landings with some damage) and one Class A (total loss) mishap. The Naval Safety Center analyst believes there may have been more VRS mishaps that were misdiagnosed as "settling with power" or other causal factors.

Due to a wording error, the preliminary V-22 NATOPS manual in effect at the time of the mishap included nothing on the subject of power settling or VRS. There was a warning to avoid sink rates in excess of 800 fpm at airspeeds below 40 knots calibrated airspeed (KCAS) that was erroneously placed in the "Emergency Procedures" paragraph entitled "Settling with Power." Settling with power is not power settling. It manifests itself as a higher than desirable sink rate when the power available is less than the power required. (Of interest in the area of communications is that both the system safety analyst who wrote the 1995 SAR on power settling, and the NAVAIR engineer who wrote the NATOPS warning were former Army trained helicopter pilots. In the Army and Air

Force, the terms "power settling" and "settling with power" mean exactly the opposites of the same terms in Naval aviation). The NAVAIR Interim Flight Clearance in effect at the time of the mishap did not include any warnings or operating limits related to power settling. The mishap investigation report is not officially released yet, but Panel discussions with several members of the MOTT suggest that there may have been less than appropriate concern for power settling among OPEVAL pilots prior to the mishap. The poor coverage of the topic in NATOPS may have been a contributor. Three of the four pilots involved in the mishap were experienced CH-53 pilots. The fourth had the most recent formal training in VRS in the helicopter transition-training program. All four were handpicked based in part on demonstrated flying skills. Although they undoubtedly violated a warning in the NATOPS, it is not obvious from their actions that the pilots clearly understood the safety threat.

In other helicopter manuals, power settling is discussed in the "Flight Characteristics" sections. Of the USMC helicopters in use today, only the UH-1 and AH-1 NATOPS contain a warning and a airspeed and vertical speed reference (40 KCAS and 800 fpm) similar to the V-22 warning. The warning is printed in the "Flight Characteristics" section rather than in the "Emergency Procedures" section. There is no warning and no specific sink rate or airspeed limit in the CH-53 or CH-46 NATOPS. None of the helicopter manuals includes any reference to power settling or low-speed sink-rate limits in the "Operating Limitations" section. After the mishap, NAVAIR changed the V-22 NATOPS to include a discussion of VRS in the "Flight Characteristics" section and warnings and to add new procedures (including the need to minimize lateral directional inputs) under the title "High Rate of Descent in VTOL mode" in the "Normal and Emergency Procedures" sections. The change also made specific mention of 800-fpm sink rate in the "Operational Limits" section, and it substituted 80-degree nacelle for the old 40 KCAS, a point that some pilots told the Panel may be unnecessarily restrictive. The same warning also was added to the NAVAIR Interim Flight Clearance for the remainder of OPEVAL.

Another issue that must be considered with respect to VRS in the V-22 is the aircraft's propensity for rapid development of sink rate and the rotary-wing-common problem with airspeed indicator inaccuracies at and below 40 knots indicated airspeed (KIAS). During OPEVAL, test pilots demonstrated on a flight simulator that by pulling the thrust control lever all the way back, the aircraft could go from level flight to 3000 fpm (+) sink rate within 3 seconds at 40 KIAS with nacelles at 90 degrees. In addition, as is the case with all helicopters, standard airspeed indicator systems suffer from disturbed air flow at low forward speeds. Any warnings or flight limitations need to consider that point, and program officials should be alert for improvements in airspeed sensing and indicating technologies if VRS risk mitigation is to be effective.

During development testing before the accident, the integrated test team, consisting of contractor and Patuxent River developmental test pilots, flew a limited number of test points to verify that the 800 fpm at 40 knots or less NATOPS warning was safe. For safety purposes, these tests were conducted above 10,000 ft. The tests included 10 data points below 40 knots, 7 of which were at sink rates above 800 fpm. The worst cases tested were 1700 fpm at 8 knots and 1600 fpm at 40 knots. Receiving assurance from the MOTT that the 800/40 limit would be acceptable for the OPEVAL, NAVAIR chose not to continue the testing to explore the V-22 VRS characteristics or natural warning signs. After the mishap, NAVAIR called for a thorough investigative flight test program to find the boundaries of VRS, characterize its handling qualities, and establish the basis for a new flight limitation, if appropriate, pilot procedures, and, if warranted, a cockpit warning system. The fleet grounding temporarily stopped work on this series of tests at 57 data events. The test pilots to date have entered full VRS seven times, all below 40 knots, and at sink rates between 2,600 and 3,900 fpm. They have noted some thrust fluctuation as they approach the VRS threshold, but in general, there appears to be less aerodynamic warning than exists in most helicopters as they approach power-settling conditions.

When the testing is completed, its results will be used to determine an appropriate flight envelope that allows mission accomplishment and at the same time provides adequate margin for such factors as turbulent air, various wind conditions, and formation flying. The apparent limited warning of impending power settling causes some to suggest the need for a cockpit aural warning. Most also see the need to modify the simulator to support VRS avoidance training. To go beyond that and actually provide realistic VRS simulation probably would be a difficult (and possibly unnecessary) enhancement because it would necessitate the addition of highly complex aerodynamics modeling, a task that other aircraft trainers have found to be impractical.

In summary, the V-22 community appears to have been poorly prepared for the situation that caused the Mirana accident. The NATOPS manual did not properly address VRS; the test program had not fully defined it; and although the engineering and system safety program forecast power settling for the V-22 in the right circumstances, they failed to forecast the violence of the roll response, or to clearly communicate the issue to one another. The accident itself has made the entire community aware of the real potential and disastrous consequences of VRS. That fact alone is the biggest single risk mitigator for this hazard in the future, but it must be followed by appropriate testing, procedures, flight limits, cockpit cues, and especially training, or this same mishap will happen again as memory of the mishap dims and the rotary-wing experience level and quality of the pilots reduces to normal levels. The unwritten root cause of the mishap may have been poor communications among engineers (power settling vs. settling with power) and between the operators and the engineers, a topic covered in subsection *4.3 Program Communications.*

Conclusion: Performance of the mishap flight crews was inconsistent with the risk of vortex ring state (power settling) in the V-22.

Conclusion: Although the current 800-foot-per-minute sink rate at 80 degree nacelle angle or less flight limitation may offer adequate safety margin, the envelope, warning signs, and flight characteristics of V-22 vortex ring state are still not well defined.

Recommendation: Use the results of the planned high-rate-of-descent flight tests to update operating limitations, procedures, the NATOPS manual, pilot training (including the flight simulator), and a cockpit warning system.

Recommendation: Configure the pilot training simulator with the capability to provide vortex ring state training to the maximum extent possible based on model limitations and information available. At a minimum, include avoidance training.

Recommendation: If testing indicates poor natural aerodynamic warning, the aircraft should be configured with a cockpit warning system.

Conclusion: Night formation flight approaches require inter-aircraft coordination, especially during early nacelle conversions.

Recommendation: Develop techniques and procedures for inter-aircraft coordination during formation-decelerating conversions.

Conclusion: If future operating limitations include a 40-knot indicated airspeed (or less) limit, then the V-22 airspeed indication system may not be adequate, as it is unreliable below 40 kts.

Recommendation: If flight test results point to the need for flight limitation that includes airspeed of 40 kts indicated or less, procure or develop a more accurate airspeed indication system for the aircraft.

2.4 THE NORTH CAROLINA ACCIDENT AND FLIGHT CONTROL SYSTEM RELIABILITY

In December 2001, an MV-22 crashed in North Carolina during a routine training mission. The mishap investigation is ongoing, but the Panel received a briefing by the Senior Member of the Mishap Board on preliminary results, and late in its study was able to review the recently released JAG investigation report. The factors involved in the mishap include both a hydraulic line failure and a flight-control-system software anomaly that was introduced when the pilot repeatedly reset the flight control system. Neither one of these two failures by itself would necessarily result in a mishap, but the combination produced a loss of control, airspeed, altitude, and aircraft and crew.

The V-22 Flight Control System (FCS) is a complex integrated fly-by-wire system with redundant computers, command paths, electric power, and hydraulic actuation systems. It also has an automatic fault detection, isolation, and redundancy management system. The JORD does not specify an overall FCS reliability number, but it does specify triply redundant FCS computers and an overall mission reliability of at least 85 percent for a 3-hour mission (threshold). The NAVAIR-detailed requirement for the V-22 specifies a total FCS reliability of one catastrophic failure in 10 million flight hours. Compliance with this requirement is demonstrated by analysis, which is the industry standard for this type of requirement. It is based on the system architecture (including redundancy), as well as predicted reliabilities for all components. Table 3 compares the V-22 requirement with other aircraft requirements. It should be noted that the V-22 reliability standard is stricter than the Military Standard (MIL STD) suggests, for either transport or rotary-wing aircraft.

Type Aircraft (Reference)	Reliability (prob. of catastrophic failure)
V-22 (NAVAIR spec)	1×10^{-7} failures per flight hour
C-17 (USAF spec)	1×10^{-7} failures per flight hour
Class III military transport (MIL-F-9040D)	5×10^{-7} failures per flight hour
Rotary-wing aircraft (MIL-F-9040D)	25×10^{-7} failures per flight hour
F-18 (NAVAIR spec and MIL-F-9040D fighter)	100×10^{-7} failures per flight hour
Boeing 777 (Federal Aviation Regulations)	0.01×10^{-7} failures per flight hour

Table 3: Comparison of Flight Control System (FCS) Reliability Requirements

HARDWARE REDUNDANCY:

One goal of the FCS design is to keep the aircraft in an "operational" state after the first failure (where operational means no degradation in handling qualities), and "safe" after the second failure (where safe means capable of safe flight to landing). This Fail-Operational, Fail-Safe (FO/FS) objective was met in most instances; however, as is the case with most aircraft, there are exceptions. One category of exception comprises mechanical parts known as the Critical Parts List. A critical part is defined by NAVAIR (SD-572-1) as "one, the single failure of which during any operating condition could cause loss of the aircraft or one of its major components, loss of control, … or which may cause significant injury to occupants of the aircraft." The current list includes approximately 70 single-point failure points in the proprotor and associated drive system and 30 in the landing gear system. It is debatable whether failures in the landing gear system would necessarily result in catastrophic loss of the aircraft considering the slow speed of most takeoff and landing evolutions. It is clear, however, that certain proprotor and proprotor-drive-system mechanical failures could result in catastrophe if they occurred in flight. Every aircraft has a Critical Parts List, and the size of the V-22 list is not remarkable. The contractor is required to provide extra risk mitigation for the parts on the Critical Parts List. These parts are designed with high-design margins and reliability and are given special attention by the quality control and Government oversight inspectors.

The second category of exception to FO/FS is the first failure that results in less than operational capability. The hydraulic line failure that was a cause factor in the December mishap is an example of such an exception. Most of the hydraulic system is FO/FS. After loss of a single hydraulic system upstream of the nacelle-mounted switching valves, the system automatically switches to the backup hydraulic system with no loss of control power (FO). However, if, as in the mishap, the failure happens in the short stretch of line between the switching valve and the actuator, one of the two hydraulic systems that normally power the actuator is automatically isolated. As a result, all actuators to that swashplate are slower and are somewhat sluggish compared to their normal operation. For this case, the proprotor on the affected side reacts to control inputs slower than the rotor on the non-affected side. This condition has been shown in simulations to be a degraded but flyable mode of flight (FS); and pilots are trained in the proper techniques and procedures in their flight simulator. The NATOPS describes the handling qualities as “severely degraded” and advises landing as soon as possible.

A previous similar hydraulic failure was discussed by the Panel in its April 18 public deliberation as being indicative of the low priority the V-22 community seemed to place on the exceptions to the FO/FS requirement. In February 2000, an OPEVAL V-22 experienced a hydraulic 2/3 failure on the right side (the December North Carolina mishap began with a hydraulic 1/3 failure on the left side), and the pilot was able to land without incident. The line was replaced and the aircraft returned to service. The difference in that case was that the failure happened shortly after liftoff, and the pilot simply set the aircraft back down on the same long runway from which he had just lifted off. Had there been a high crosswind or gusty conditions, the pilot might have had more difficulty. Another difference in the February case was that the pilot did not perform the flight control reset procedure prescribed by NATOPS for such failures because he was so close to landing, and did not have time to do it. That kept him from having the software induced complication experienced by the mishap pilots. The North Carolina mishap showed that the degraded system is relatively intolerant of unpredicted flight software anomalies, not just the predicted subsequent hydraulic failures, wind conditions, or improper pilot procedures.

It is not uncommon for aircraft (especially rotorcraft) hydraulic systems to suffer leaks or worse failures. For that reason, the V-22 hydraulic system was designed with multiple redundancies in order to meet the 10^{-7} goal. Most other helicopters are designed with dual redundant flight control systems, some of which have reduced flying qualities after the first failure. This extra level of redundancy in the V-22 design should provide the pilots with an extra level of safety, and confidence than they are used to in legacy systems. Unfortunately, the as-installed reliability of the V-22 hydraulic system components is being adversely affected by the close proximity of the hydraulic lines to other lines, structure, and wire bundles with unexpectedly abrasive cover materials. The cramped spaces and high vibration and acoustic environment of the engine nacelles can cause failure of clamps and fasteners (e.g. “click-studs”), and chafing of the hydraulic lines, as well as other parts. This fact makes the need for redundancy even more important to flight safety and suggests the need for even more than the normal safeguards for those redundancy exceptions.

Due to its location and to the limited placement of inspection panels on the nacelles, the line that suffered the failure in the mishap was not inspectable. The titanium hydraulic tube failure was caused by rubbing by a plastic-coated electric wire in close proximity. Had the entire length of the tube been visible to the maintenance inspector, and had wear been detectable (which is not clear in the present design), the mishap might have been avoided. Whether it is with better access panel placement or borescopes, the maintainers need to be able to see these critical "exceptions" to hydraulic system redundancy.

Conclusion: The V-22 flight control hydraulic components are experiencing failures at higher rates than predicted. Flight safety is, therefore, highly dependent on the redundancy features in the system.

Recommendation: Improve hydraulic system component reliability.

Recommendation: Take steps to mitigate the risk of loss of hydraulic system integrity (e.g., chafing, fittings, leaks, vibration).

Recommendation: Develop techniques, tools, and methods for timely identification of hydraulic line chafing.

Recommendation: Add acoustic sensors to the test nacelle and reevaluate the adequacy of current test nacelle environmental instrumentation in light of recent reliability problems.

Conclusion: Inaccurate predictions of component reliability affect spares planning, squadron staffing, and flight safety.

Recommendation: Assess the process used by V-22 contractors to predict component reliability numbers and take steps to improve.

Conclusion: Current Naval Air Systems Command policy requires that special attention (material, tolerances, quality inspections, tracking, etc.) be applied to all single-point failure modes in the flight control system, but it does not require any special attention be given to other exceptions to the redundancy design criterion.

Recommendation: Develop appropriate controls (design and life-cycle support) for all exceptions to the flight control redundancy requirements (not just those that are single-point failures).

SOFTWARE RELIABILITY

The fly-by-wire flight control system is highly dependent on high quality computer hardware and software. The logic that is the basis for the many flight control laws and algorithms must be consistent with the overall requirement for FO/FS. This implies that if the aircraft suffers any single failure in the electrical, mechanical, or hydraulic parts of the system, there cannot be any software logic characteristic or failure that would result in an unsafe condition. The integrated flight control system must be designed, analyzed, and tested with these facts in mind.

Boeing has the lead role in development and testing of the integrated flight control system. Their Philadelphia facility has the capability to conduct integrated hydraulics, flight loads, and software testing using the Flight Control System Integration Rig. Before the mishap, the facility had limited pilot-in-the-loop capability, and they had not tested the software against the particular degraded hydraulics state experienced in the North Carolina mishap. During the downtime, and in response to the preliminary mishap investigation results, Boeing has upgraded the capabilities of the integrated simulation facilities and is in the process of validating a set of off-nominal and failure scenarios that had been checked only by analysis during the 1996 validation and verification of the flight software. Boeing also has begun validating all flight control system emergency procedures with pilot-in-the-loop simulation runs. In addition, the company is holding an integrated flight control system review with participation from “graybeard” experts from within and outside the company to review the requirements and the implementation of the requirements in the design.

Conclusion: The North Carolina mishap identified limitations in the V-22 Program’s flight control software development and testing. The complexity of the V-22 flight control system demands a thorough risk analysis capability, including a highly integrated software/hardware/pilot-in-the-loop test capability.

Recommendation: Conduct an independent flight control software development audit of the V-22 Program with an emphasis on integrated system safety.

Recommendation: Conduct a comprehensive flight control software risk assessment prior to return to flight.

Recommendation: The V-22 Program should not return to flight until the flight procedure and flight control software test cases have been reviewed for adequacy and have been evaluated in the integrated test facilities.

2.5 AUTOROTATION

The JORD states that the V-22 must be capable of performing a survivable emergency landing with all engines inoperative, and identifies the requirement for the aircraft to be capable of conducting a power-off glide/autorotation. The Panel members heard from the Director of Operational Test and Evaluation that, "Basic rotorcraft engineering analysis indicates that the V-22 will have a difficult time achieving a stable autorotation following a sudden power failure at high power settings, and that the probability of a successful autorotational landing from a stable autorotative descent is very low." According to a white paper provided by the V-22 Program Office, the capability of the V-22 to perform autorotations was examined during the developmental phase of testing. "V-22 developmental testing included autorotative descents in the aircraft and autorotations to landing in the simulator…The V-22 has demonstrated stable autorotative descents as described above in flight test and offers enough control to the pilot to touchdown at a survivable rate of descent, but evaluations in the simulator have shown limited repeatability of making a safe landing at the touchdown phase. This is largely due to the small amount of energy in the rotor system available to the pilot for managing descent rate and speed at touchdown."

The proprotor disc of the V-22 is relatively small when compared with those of helicopters. The size of the disc was defined in large part by the requirement to accommodate shipboard operations. The twisted proprotor blades were designed as a compromise that would permit hover performance in the helicopter mode and turboprop cruise performance in the fixed-wing mode. From an autorotative perspective, these designs result in higher rates of descent, higher airspeeds, and less rotor energy at the bottom of an autorotation available to convert to lift. This necessitates run-on landings at higher airspeeds (60kts) than helicopters at the bottom of the autorotative descent. NATOPS contains preliminary procedures (currently being revised) for autorotation. While not fully tested in Developmental Test (DT), the intent is to give the pilot the procedures that would maximize the probability of a favorable outcome should an autorotation occur. FMF pilots are not cleared to conduct autorotations except in emergencies; practice autorotative descents also are not allowed. All pilot training for autorotation and airplane mode power-off glide is via simulator.

While autorotations may be problematic for the V-22, development test pilots have concluded from simulation and high altitude tests that an airplane mode glide landing can be performed with repeated success to a hard surface runway. They believe its performance will be similar to other fixed-wing aircraft with similar glide characteristics. V-22 pilots receive simulator training in the proper techniques for unpowered airplane mode landings, but as with autorotations, they do not yet practice them in the aircraft.

The probability of the V-22 being forced to execute an autorotation vice a power-off glide is low. The combination of high engine reliability, large separation between engines, lower vulnerability to ground fire than CH-46/53 predecessors, and the lack of a tail-rotor make the chances of an autorotation lower for the V-22 than for a typical helicopter. It also must be stated that the V-22 is a hybrid aircraft designed to an employment concept requiring 70 percent of its airborne life to be spent in airplane mode and only 30 percent of its airborne time spent in conversion or helicopter mode. To further reduce the possibility that the aircraft would be forced to perform an autorotation, V-22 pilots are trained to transition to (or stay in) airplane mode after a single engine failure. Helicopter and conversion modes are allowed to accommodate landing, but this proactive strategy places the aircraft into the safest possible posture should the second engine or interconnect drive shaft (ICDS) fail. One note of concern, however, is that according to the NATOPS emergency procedure for single engine flight, at the conclusion of the airplane mode flight, aircraft should be landed vertically. According to the Bell Boeing test pilot, this discontinuity is probably due to the lack of experience among the V-22 community with glide landings, and the lack of sufficient developmental test in this area.

Conclusion: The V-22 has less autorotative capability than most helicopters and more than any fixed-wing aircraft.

Conclusion: The high disc loading of the V-22 limits the potential for improvement to its autorotative capability.

Conclusion: The V-22 has less power-off glide capability than most fixed-wing transport aircraft and more than any helicopter.

Conclusion: Employment concept, design features, and pilot training will limit the probability of an autorotation having to be conducted.

Recommendation: Reassess the requirement for autorotative flight in view of the low need, low probability of improvement and the existence of alternatives.

Conclusion: The V-22 community does not appear to place enough emphasis on the glide-landing capability of the aircraft as an alternative to autorotation, especially in the one-engine-out procedures.

Recommendation: Reassess the capability of the V-22 to conduct power-off glides. Explore design and operational techniques to optimize power-off glide capability (e.g., minimize proprotor drag commensurate with auxiliary power requirements).

Recommendation: Ensure that the full flight simulator used by pilots at Marine Corps Air Station, New River accurately emulates both autorotative and power-off glide simulations to the degree required for effective pilot training.

The NATOPS procedure includes procedures for two engine-out cases, but not for the case where an engine and interconnect drive shaft (ICDS) are lost. The V-22 System Safety Manager indicated that, based on commercial failure data for the Rolls Royce Allyson AE 1107C engine, the probability of two engine failures within the same one-hour flight is predicted to be 1×10^{-10}. A similar analysis predicts failure of one engine coupled with an ICDS failure at 4×10^{-8}. This scenario caused loss of an aircraft and crew in 1992 at Quantico, Virginia. Of note here is that the chance of the V-22 losing one engine and having a subsequent ICDS failure is almost two orders of magnitude greater than the probability of the aircraft having a dual engine failure, yet the NATOPS procedures do not cover that case.

Conclusion: There are no emergency procedures in NATOPS for a single-engine failure coupled with an ICDS failure, a situation that would require a power off glide landing or an autorotation.

Recommendation: Reassess the requirement for (and priority of) autorotative flight in view of the low probability of improvement and the existence of alternatives.

2.6 DOWNWASH EFFECTS ON TACTICAL OPERATIONS

During briefings conducted in January and in a subsequent white paper presented to the Panel, the Director of Operational Test and Evaluation raised concerns that the high-velocity, turbulent downwash field generated by the V-22 had direct negative consequences on several of the V-22's required functions. These included: remote operations to unprepared surfaces, personnel deployment and recovery in a hover, and external load operations. In addition, the V-22 Commander, Operational Test and Evaluation Force (COMOPTEVFOR) OPEVAL report identified downwash effects as a major deficiency for the successful deployment of the aircraft. The report stated, "…because of 'brown out' conditions, experienced pilots found it very difficult to land in a desert environment at night while using Night Vision Devices (NVDs). Downwash also impacted all direct-assault missions utilizing ropes. Techniques for ropers will have to be developed to enhance their capability to fight once on the platform." Separate discussions with USMC and USAF OPEVAL pilots yielded a variety of opinions on the level of risk associated with downwash and the potential to be able to successfully mitigate the risk with the development of tactics, techniques, and procedures (TTPs).

There is no question that the high disk loading of the V-22 generates strong downwash effects. The question that must be addressed is, "Can the negative consequences addressed by DOT&E and the OPEVAL report be overcome adequately by tactics, techniques, and procedures (TTPs)?" The answer to this question will require a considerable amount of additional testing.

REMOTE AREA OPERATIONS

Landing a helicopter at night in a desert environment using Night Vision Goggles (NVGs), has always been an extremely challenging task for aircrew. With its indiscernible shifts in topography, varied soil composition, and constantly changing illumination effects resulting from changes in the reflectivity of the terrain, desert NVG flying poses many risks. Over the years, significant improvements have been made to both the capabilities of aircraft NVD systems and the associated TTPs to utilize them.

The V-22 incorporates the latest in NVD technology, to include the latest generation of NVGs, an NVG Head-Up Display (HUD), and Forward Looking Infra-Red Radar (FLIR). While these NVD systems will help in the development of TTPs during desert operations in follow-on testing, an important advantage of the V-22 is it's expanded area of influence. The V-22 will be able to range a significantly greater number of acceptable landing zones than a helicopter. Landing zone selection will be one of the considerations when mitigating the risks of downwash-induced brownout, although there will be occasions when a sand or snow landing is the only choice, and for those cases, appropriate techniques will be required.

Conclusion: The downwash in the V-22 is inherently greater than in most helicopters;

however,

Conclusion: The V-22 is configured with Night Vision Device capability and has the range to reach a far greater number of landing zones than a helicopter.

Conclusion: Testing in a desert environment, particularly at night, to date has been insufficient to fully develop appropriate techniques and procedures.

Recommendation: Continue to develop procedures and techniques for the high-downwash "desert brownout" situation, and incorporate them into the training manuals and syllabi.

Recommendation: Restrict tactical-unit night operations in landing zones that have the potential for brownout until procedures and techniques are developed and approved.

PERSONNEL DEPLOYMENT/RECOVERY FROM HOVER (IN AND OUT OF GROUND EFFECT)

The OPEVAL report, in its evaluation of alternate insertion and extraction techniques, reported, "Of all of the operational scenarios, the one in most jeopardy is direct action assaults because of downwash and safety concerns." The JORD requires that the aircraft have the capability to employ the following:

- Two fast ropes off the ramp and one out the cabin door to quickly deploy personnel in a hover. (Threshold)

- Fast Rope Insertion and Extraction System, Stabilized Extraction Rigging, and rope ladders through both the ramp and cabin door. (Threshold/USSOCOM)

The MV-22 demonstrated the capability to effectively employ one fast rope off the ramp and one fast rope out of the aft cargo hook opening, but it did not demonstrate the capability to fast rope out of the cabin door. Additionally, to reduce the effects of downwash, hover altitudes of 65 to 75 feet were maintained, which exposed both the aircraft and ropers to potential threats for a greater period of time. The V-22 Operational Test Director agreed that fast rope proved to be the most difficult of the Alternate Insertion/extraction (AIE) operations conducted during OPEVAL. Follow-on test and evaluation will be conducted to develop TTPs, in an effort to address AIE operations.

A number of lessons were learned during fast-rope operations conducted during Military Operations in Urban Terrain (MOUT) evaluations as part of OPEVAL. It was found that the extremely stable hovering characteristics of the MV-22 were an enhancing feature during rope operations. Pilots also developed the technique, during this testing, of positioning the engines off the edge of the rooftop to reduce downwash effects on the ropers. It also was noted that downwash had the potential to be enhancing for some areas of low-intensity conflict. It may be an effective method to use to control unarmed crowds.

The Program Office does not believe that fast-roping operations from the cabin door is an option worth pursuing and has recommended a JORD change for an alternative location to meet this requirement. The Rappel mission and the Special Patrol Insert and Extraction (SPIE) mission were executed effectively by the MV-22, although rappelling was not accomplished through the cabin door. The V-22 was assessed as having the capability to meet the ORD requirement for helocast (personnel or small boat exit out the aft ramp) by traditional techniques under daylight conditions. Night helocasting was not accomplished due to the lack of a precision (coupled) hover. Over-water recovery of a Special Operations Force (SOF) team was not evaluated because of the lack of both a rope ladder system and a suitable hoist. The OPEVAL report did assess these missions to be at risk due to the anticipated effects of downwash. The Program Office indicates that there is currently no suitable certified rope ladder either available or planned. It is currently investigating improvements to the hoist (the development of which is unfunded) and alternate locations for its incorporation.

The concept of personnel deployment from a hovering V-22 has been partially demonstrated. Several JORD requirements in this area remain to be demonstrated but could be jeopardized due to the high downwash velocities and lack of side cabin door and hoist capability.

Conclusion: The concept of personnel deployment from a hovering V-22 has been only partially demonstrated, and techniques and procedures need to be developed.

Recommendation: Revalidate the requirements for Personnel Deployment and Recovery operations.

Recommendation: If the requirements remain valid, then incorporate appropriate hoist and ladder systems in to the aircraft as soon as possible.

Recommendation: Conduct follow-on testing and evaluation to address tactics, techniques, and procedures to be used in the conduct of Personnel Deployment and Recovery operations.

EXTERNAL LOAD OPERATIONS

The white paper from DOT&E states that while external load operations conducted during OPEVAL demonstrate that such operations are possible, "they remain a significant challenge." The paper goes on to state that, "New procedures and training may mitigate this problem, but the safe and effective accomplishment of this key USMC mission requirement remains a serious concern." The OPTEVFOR report of OPEVAL did not consider this to be an issue, but there are some unknowns concerning the proper procedures to minimize the chance of injury to the ground crew while working in the downwash on external payload activities.

Conclusion: While external load capability was demonstrated successfully during OPEVAL, there remain several challenges to its successful operational introduction.

Recommendation: Conduct follow-on test and evaluation to further refine tactics, techniques, and procedures and to ensure that external operations can be conducted safely and effectively.

2.7 PILOT TRAINING

The Panel examined the pilot and aircrew training system for adequacy. Panel members received briefings from the Program Office and from VMMT-204, and ground school and simulator training personnel. Panel members also flew training sessions in the flight simulator, and reviewed the MV-22B Training and Readiness (T&R) manuals, the NATOPS flight manual, and the VMMT-204 Flight Standardization Manual.

The MV-22 pilot and crew chief flight training syllabi are contained in Volumes 8 and 10, respectively, of the MV-22B Tiltrotor, NATOPS flight manual, which is currently in draft form for final staffing. These volumes provide the templates for standard MV-22 units and define the squadron's core capability and basic aircrew qualification requirements, as well as the sorties required to maintain core skills. They also contain the Programs of Instruction (POIs) for basic, transition, and refresher aircrews, as well as POI for instructor aircrew. The aircrew T&R syllabi use the stairstep approach to training throughout all four phases of flight training—combat capable, combat ready, combat qualified, and full-combat qualification. VMMT-204 is tasked with conducting all combat-capable training. The other three phases of flight training will be conducted in tactical squadrons. While Volumes 8 and 10 are well thought out and provide a logical sequential approach to training and readiness, they do include a number of sortie requirements that will require waivers until appropriate flight clearances are received. These include defensive air combat maneuvers, night externals, air-to-air gunnery, and certain alternative insertion and extraction techniques.

The requirements for aviation ground and simulator training are integrated within each of the four phases of flight training. Aircrew will not fly an aircraft or simulator event without first completing the corresponding Integrated Multimedia Instruction (IMI) lesson or lessons for the event. The IMI, a series of computer-based interactive lesson plans, demonstrated to the Panel members during their visit, is state-of-the-art and is a significant improvement over previous ground training tools used by training squadrons.

Simulator flights are used to begin each stage of training and prior to the introduction of a new skill. The amount of simulator flight time flown by pilots during combat-capable training is consistent with that flown in fixed-wing syllabi but is significantly greater than that currently flown in helicopter syllabi. The capability of the new generation of simulators has been maximized in the MV-22 syllabus without sacrificing actual aircraft flight time during training. Current simulator capability at MCAS New River for the MV-22 ranges from the Cockpit Procedural Trainer (CPT), an instrument trainer with no visual or motion capability, to the Operational Flight Trainer (OFT), the device used to train the initial cadre of students. Although it is a full-motion simulator, the OFT does not compare to the capability demonstrated by the newest simulator at New River the Full Flight Simulator (FFS). The FSS is a state-of-the-art industry standard and is a Federal Aviation Agency (FAA) Level D simulator built by Flight Safety International. The FSS is fully "networkable," meaning pilots under instruction will be able to man multiple networked devices and train together. The USMC Simulator Master Plan outlines the requirement for four FFSs and three Flight Training Devices (FTDs) to be built at Marine Corps Air Station New River. The FTD is an FSS equivalent by every measure except motion. It also will have the capability to be networked.

The FSS uses actual aircraft mission computers, whose software is modified at the same time that actual aircraft on the flight line are modified. Flight control software in the FSS is emulated as opposed to using actual flight control computers. This is a cost-savings initiative; flight control software is much more stable than mission computer software is. The Panel is concerned that changes in aircraft flight control software will be emulated concurrently for the FSS. Often, this area does not receive adequate attention.

Future training plans call for students destined for the V-22 community to receive some amount of two-engine turboprop experience. The Panel views this as a good approach, considering the amount of time the V-22 will spend in the airplane mode and the need for the pilots to feel comfortable with the airplane-mode, single-engine procedures and power-off glide procedures.

Conclusion: The MV-22 aircrew flight training syllabi and their integration with ground training and simulator flights appear to have been well thought out and documented.

Conclusion: The IMI ground training and Full Flight Simulators are state of the art.

Conclusion: The MV-22 Standardization Manual adequately addresses flight standardization within VMMT-204.

Conclusion: Although adequate now, historical precedent suggests that funding may not remain stable throughout upcoming budget cycles.

Recommendation: Provide adequate funding for aircrew ground training, aircraft simulators, and upgrades to training devices.

The MV-22 Flight Standardization Manual developed by VMMT-204 promulgates standardized procedures to be used for the conduct of instructional flights within the squadron. The manual is intended as a supplement to the NATOPS Flight Manual, the Instrument Flight Manual, the MV-22 Tactical Manual, and the MV-22 T&R Manual. The manual was drafted by pilots who participated in both developmental and operational testing of the V-22 and contains descriptions of flight maneuvers that are not described or covered in sufficient detail in these manuals. The MV-22 Tactical Manual, identified in Volume 8 as NWP 3-22.5, has not yet been published. A draft Operational Tactics Guide (OTG) is under development by the Advanced Tilt-Rotor Training Unit (ATTU). The ATTU was developed to aid in the transition of USMC squadrons to the MV-22. After the first MV-22 tactical squadron completes ATTU training, the OTG will be forwarded to the MV-22 Tactical Manual Model Manager, MAWTS-1, where it will be reviewed and published.

NAVAIR is currently the Model Manager for the MV-22B NATOPS manual. The preliminary manual was first published in August 1999, just prior to the beginning of OPEVAL. The Panel found the relatively large size of the MV-22B NATOPS manual to be consistent with the fact that the V-22 is a complex aircraft and the first operational tiltrotor aircraft. The OPEVAL report stated that the manual "lacked adequate content, accuracy, and clarity." This is unsatisfactory, but not unusual for a preliminary NATOPS manual. However, implementing appropriate changes to the NATOPS manual should have been expedited initially. Since OPEVAL, eight interim changes have been incorporated into the NATOPS manual. At the latest MV-22B NATOPS manual conference in October 2000, more than 1,400 changes were made to the manual. The updated manual is scheduled to be published in May 2001.

The Panel agrees with the Program Office that once the magnitude and frequency of the changes to the manual decrease, VMMT-204 should assume the responsibility as model manager for the MV-22 NATOPS.

Conclusion: At this early stage in its development, the relatively large size of the V-22 NATOPS manual is considered consistent with the fact that the V-22 is a complex aircraft and is the first operational tiltrotor aircraft.

Conclusion: The V-22 NATOPS manual is undergoing the same developmental growth experienced by previous new aircraft manuals; however, because of the challenges currently facing the MV-22, extraordinary effort needs to be placed on the NATOPS manual so that it reaches the necessary level of maturity before training resumes.

Recommendation: Publish updates to the MV-22 NATOPS manual, and verify with VMMT-204 pilots before the first operational flight to support pilot/squadron transition and re-currency training.

Recommendation: Convene an out-of-cycle NATOPS manual conference prior to the first squadron operational flight to assure consistency and adequacy of the "Emergency Procedures" and "Operating Limitations" sections. Develop an expeditious process to incorporate changes from this conference and from ongoing test and evaluation activities.

2.8 CRASHWORTHY FUEL TANKS

The JORD requires that the aircraft fuel tanks, both permanent and auxiliary, be crashworthy. The tanks must be self-sealing and nitrogen inerted. The aircraft in the first two Low Rate Initial Production (LRIP) lots (aircraft 11 through 22) are configured with extensible fuel bladders in the sponsons. The extensible tanks are designed to dissipate energy by expanding or deforming under crash loads, thus minimizing the chance of bladder leak. The auxiliary tanks were still in development during OPEVAL, so the test aircraft was configured with an interim non-operational auxiliary tank on a waiver. The extensible wing tanks have yet to be tested for crashworthiness.

When subjected to the MIL STD 65-ft. drop test, the sponson extensible fuel tank passed, but because it was not configured in a test sponson for the drop, the results are inconclusive. The Program Office changed the sponson tank design effective with Lot 3 and subsequent to a non-extensible design. When tested, the new design failed, developing a small leak. The tank was redesigned and successfully tested; however, the new design will not be installed until the LRIP Lot 4 (aircraft 30 and subsequent). Due to lack of retrofit funding, the program had to satisfy itself that flying the earlier aircraft with non-compliant sponson fuel tanks would be acceptable. The program conducted a risk assessment and determined that the marginal additional risk to the operators of flying the early LRIP aircraft with non-compliant sponson fuel tanks was medium (RAC 1D).

During the Panel's visit to VMMT-204, flight crew personnel expressed concern about the program decision to fly the LRIP Lots 1-4 aircraft indefinitely with non-compliant sponson fuel cells. This is another case where communications among operators and engineers may be lacking; however, some of the concerned aircrew were witnesses to the Mirana mishap, and they want assurance that they are not taking undue risk. It should be noted both of the recent accidents involved impact forces significantly higher than anything that even compliant fuel tanks could tolerate. No one thinks compliant fuel tanks would have prevented those fires.

Conclusion: Although the program risk assessment satisfied the Program Manager that the non-compliant sponson fuel cells are safe for flight, the concerns expressed by the training squadron should be addressed and communicated.

Recommendation: Configure (by retrofit or test) all operational aircraft with crashworthy fuel cells at the first opportunity (see later recommendation with respect to retrofit funding),

and, in the meantime,

Recommendation: Communicate the interim risk acceptance rationale to the operational community.

2.9 PRODUCTION QUALITY

The Panel received briefings from the Program Office and contractor managers on the status of the V-22 Quality Program. Among the topics discussed at the production plants was the history of quality issues during EMD and LRIP, as well as several quality-improvement efforts that are under way. The Panel also received briefings from the Defense Contract Management Agency (DCMA) managers at Bell and Boeing. They accompanied the Panel on its tours of the production line and discussed their roles in providing quality oversight for the Program Manager.

QUALITY TRENDS

Quality of the production aircraft was a sizable problem for the program early in LRIP. One of the first LRIP aircraft had nearly 150 discrepancies upon receipt by the operational unit. While many of those discrepancies were paperwork problems, there were a substantial number of hardware defects. The first part of the OPEVAL was adversely affected by a variety of production quality issues (configuration problems and assembly defects). This was the reason the OPEVAL results were stated separately for the two parts of the test period (before and after February 22, 2000).

One of the reasons for early program quality issues was the tight tolerances and cramped quarters in the nacelle. Another was the transition of final production from Fort Worth to Amarillo, with a completely new workforce. As LRIP continued to produce aircraft, the quality deficiencies went down until today, the quality performance learning curves at all three contractor locations appear to be as planned or better. For example, the number of "customer squawks" decreased by 35 percent from 1999 to 2000 at the Amarillo facility, compared to a goal of 15 percent. Extensive technical and quality assurance surveillance along with manufacturing product audits already have been coupled with fleet readiness drivers to improve the quality of delivered aircraft. A DCMA and Boeing quality assurance report reduced discrepancies from a high at Aircraft No. 18 of 1,882 discrepancies to a low of 260 discrepancies with aircraft No. 29.

Although most quality trends have been improving over the last two years, there have been some stubborn problems in the quality area. Three examples are listed:

1) Click-studs (fasteners that are glued to the composite structure to secure various items on the airframe; e.g., acoustic blankets, wire bundles, brackets, etc.

Observation:

- Improper surface preparation for bonding of click-studs to composite aircraft structure results in failed mounting brackets for subcomponents.

Corrective action:

- Redesign to reduce the overall requirement for click-studs;
- Implemented new tooling to maintain closer location tolerances for installing click-studs; and
- New installation procedures and adhesives are being evaluated.

2) Non-standard manufacturing

Observation:

- Improper drilling and trimming of panels that prevent interchangeability

Corrective action:

- Tools verified to facility gage;
- Inspection added immediately following trim;
- Created 3-D models of the nacelle assembly, including all contours and edge of parts (periphery) (EOPs) identifying 20 to 30 mismatches;
- Procured a laser radar system to verify tool EOPs to the nacelle models (delivery March 12, 2001); and
- Trim tools are being redesigned to assure consistent trimming of the panels; also, additional locators are being added to the assembly fixtures to assure proper locations.

3) Wiring harness and hydraulic line routing anomalies (not in accordance with blueprints).

Observation:

- Special emphasis on nacelles; and
- 24 Liaison Engineering Trouble Action Requests (LETARS) generated on hydraulic and electrical installations.

Corrective action:

- Special inspections initiated;
- Electrical and hydraulic training initiated;
- Installation and Inspection Instruction developed;
- Top-down engineering audit of nacelles in progress;

- Nacelle audit identified design and manufacturing enhancements that are being addressed by Bell and NAVAIR; and
- Expanded engineering audit in progress for the fuselage, wing, and empennage.

These quality problems are part of the current listing of "Top Readiness Drivers" listed in Appendix F.

CONTINUOUS IMPROVEMENT FOCUS

Bell and Boeing have in place a system of continuous process improvements. Bell's development of an Operations Improvement Strategy to focus the organization into Centers of Excellence has resulted in an improvement of core manufacturing competencies. The investment in high-tech equipment and personnel training programs has improved manufacturing quality, throughput, and schedule compliance to a level at which the companies are now industry leaders in composite materials construction. Boeing also showed the Panel several quality improvement changes that are in work on the plant floor or planned.

TIGER TEAM

Shortly after the North Carolina mishap, Bell Boeing established a "Nacelle Tiger Team" to reassess the reliability, maintainability, and quality problems associated with the nacelle, especially with respect to the hydraulics system. In April 2001, the Tiger Team role was expanded to examine the entire aircraft. The ongoing V-22 Tiger Team has given the program preliminary indications that production and manufacturing variances may still be a problem. Such variances in aircraft construction can seriously affect reliability and maintainability, as each aircraft would have unique configurations. Placement of nacelle panel drill holes, click studs (bonding and location), wire harness, and hydraulic routing anomalies have all been addressed. Apparently, standardization issues are being resolved. Results of the Tiger Team analysis will determine the actual status.

Conclusion: Bell Boeing Managers, the V-22 Program Manager, DCMA representatives and the Services appear to be paying special attention to the top fleet degraders, and to other quality issues in production and final assembly;

however,

Conclusion: Preliminary results of the Tiger Team, including quality and configuration variances in the nacelles, indicate a potential concern that needs to be addressed carefully.

Recommendation: The contractors, Defense Contract Management Agency, and Services need to remain actively involved in quality assessments and improvements.

Recommendation: Take appropriate steps to resolve quality-related findings of the Tiger Team as soon as its results are available.

2.10 OPERATIONAL TEST CREW SELECTION AND ASSIGNMENT

During a segment covering the V-22 on "60 Minutes," a close relative of a crewmember who died in the Mirana mishap commented that her Marine was not a test pilot and thus should not have been involved in the test flight. An OPEVAL pilot's widow at one of the Panel's open meetings made a similar comment. The Panel staff talked to the Commanding Officer of the Fleet Replacement Squadron and the Marine Corps' rotorcraft operational test squadron, HMX-1 about this issue to determine whether the OPEVAL may have violated longstanding test crew assignment policies.

The V-22 operational test and evaluation (OT&E) aircrew were all volunteers assigned to Marine Helicopter Test Squadron One (HMX-1) in Quantico, Virginia. Pilots and crew chiefs from HMX-1 were assigned to the first three OT&E events (OT IIA, B, and C) from 1994 through 1997, where there was limited flight activity. Then, in anticipation of more flying, Headquarters Marine Corps held a V-22 OT&E pilot selection board in early 1997 to bring in another six dedicated V-22 operational test pilots for the upcoming OT IID and E (OPEVAL) events scheduled for late 1998 and 1999, respectively. The following requirements were listed as selection criteria used by the board:

- Captain or major with at least 6 years of commissioned service;
- Qualified helicopter or C-130 aircraft commander;
- Active duty, completed first operational squadron tour;
- Willing to commit to 4 years' service following transition; and
- Tactical endorsement.

Using these criteria, the V-22 OT&E Selection Board picked six pilots (out of 120 volunteers) for assignment to HMX-1 and its MOTT in March 1997. They began their training later in the year under the supervision of the earlier chosen (nine) operational test pilots and the V-22 Development Test (DT) pilots (military and contractor) who had been flying the FSD and EMD programs at Philadelphia, Fort Worth, and Naval Air Warfare Center (NAWC) Patuxent River. To accrue their flying time, they were formally designated as "DT copilots" and were authorized to fly on low-risk DT flights. Enlisted flight crewmembers were also volunteers having been assigned to HMX-1 for duties involving operational flight test of CH-46, CH-53, and MV-22 aircraft.

In accordance with longstanding HMX-1 policy, the training syllabus for aircrew was typical of any transition training program in an operational squadron, with 98 simulator flights and 31 aircraft flights required to qualify as a Tiltrotor Aircraft Commander (TAC). The squadron also provided training for its aircrew involving standard test planning and report writing. By its nature, OT&E is flown by operational aircrew with fresh fleet experience within a NAVAIR developed and defined flight envelope. There is neither a need nor a desire for them to be trained engineering test pilots. Moreover, it was not policy to fly MOTT crewmembers on developmental flights, even with experienced DT pilots. There was a single exception to this rule during DT, when one of the MOTT pilots flew as co-pilot on a combination training and data-gathering flight. This exception to policy was approved by both the MOTT and NAWC chains of command, based on the low risk involved with that particular flight.

Operational test flying does not expand the flight envelope or develop or certify new procedures. That work is left to the DT flight crew and engineers working for NAVAIR. The purpose of OPEVAL is to evaluate the aircraft in as close to an operational environment as is feasible within the limits cleared by NAVAIR at that point. Obviously, any major safety related issues should have been raised in design, analysis, simulation, experimental flight test, and development flight test. Before OPEVAL, NAVAIR conducted an extensive Flight Readiness Review, the purpose of which was to decide if the envelope cleared to date was adequate to demonstrate operational requirements, and if the aircraft was safe to hand over to operational test crews.

Part of this issue could be a perception by the public that the OPEVAL aircrews were being forced by the system to participate in developmental flight test inappropriately. In retrospect, the lessons learned from the Mirana mishap are the type of lessons that are more appropriately predicted and verified during engineering analysis, wind tunnel, flight simulation and developmental flight test. OPEVAL should not be discovering major safety issues, and so it is understandable why the public questions have been raised. However, at the time of crew assignment, it appears that the standards for crew selection, assignment and training were adhered to by HMX-1. The crewmembers were highly skilled, well trained volunteers. They are all aware that the reason the Service goes to all the trouble to pick experienced, highly qualified people for HMX-1 is that operational testing of a new aircraft carries with it higher risk (in the form of uncertainty) than exists in other well established aircraft. This same thinking must be included when it comes time to fly combat troops in the aircraft on demonstrations and operational tests, and the question should be asked, is it necessary to the test or mission to have real troops in the back?

Conclusion: The process for crew selection, training, and assignment to V-22 OPEVAL test flights was consistent with longstanding policy.

Recommendation: As the testing program proceeds, test managers (contractor, NAVAIR, and operational) should continue to ensure the appropriate experience and qualifications of all flight crewmembers.

Conclusion: By its nature, early operational testing is characterized by a level of risk higher than that of fleet operations (thus the requirement for experienced aircrew) but less than that of the development test phase.

Recommendation: As V-22 development and testing continue, all responsible organizations should take all reasonable steps to ensure that operational test aircrews are not subjected to undue risk. Thoroughly assess all known and suspected high-risk flight regimes.

Recommendation: Until the aircraft is ready for deployment, flying should be restricted to mission-essential personnel. Assess operational risk factors before authorizing increased risk flights (e.g., assaults, night flying, weather flying, etc.).

2.11 SYSTEM SAFETY

ORGANIZATION AND PROCESS

The Panel staff members were briefed on the system safety engineering discipline as practiced by the V-22 Program. The Navy System Safety Manager is located at the Naval Air Warfare Center (Aircraft Division), Naval Air Station Lakehurst, New Jersey, along with all of the NAVAIR rotary-wing system safety engineers. This geographic setup is an obvious challenge that the System Safety Manager and the program staff acknowledge as unfortunate but workable. (Note: the fixed-wing system safety engineering staff is located at Patuxent River, very close to NAVAIR headquarters.) The System Safety Manager's primary point of contact in the Program Office is the Assistant Program Manager (APM) for System Engineering (Class Desk), who serves as the chairman of the System Safety Working Group (SSWG).

As is normally the case with new aircraft, the JORD has no specific overall safety requirement in terms of predicted mishap rates or probabilistic risk levels. Nor does the aircraft detailed specification specify an overall probabilistic risk prediction or goal. However, many of the JORD requirements have direct safety implications. For example, the flight control system design is required to show by analysis a catastrophic failure probability of one in 10 million flight hours. Other requirements for factors such as handling qualities, egress capability, flight control system redundancy, etc., are all part of the safety requirements. In addition, the V-22 detailed specification requires adherence to MIL STD 882B, the DoD system safety process bible. (Note: the current version is 882D, a substantially less prescriptive standard than the B version used by the V-22 Program. The system safety engineer's job is to manage the program's efforts in compliance with that standard.)

According to the System Safety Manager, the program has complied with the MIL STD guidelines to perform preliminary hazard analysis, various types of final hazard analyses, and safety assessments as part of the NAVAIR system engineering program throughout the several phases of aircraft development, test, and operations. From these analyses, as well as other sources of Navy operational and safety reporting information (Hazardous Material Reports [HMRs], Engineering Investigations [EIs], Quality Deficiency Reports [QDRs], and Hazard Reports [HAZREPs]), the system safety team identifies and analyzes safety risks. The team members categorize the risks using a standard NAVAIR matrix (severity and predicted frequency of occurrence) and then report these risks to the program and track progress made in mitigation. They have what appears to be an active Government/contractor team consisting of the APM (System Engineering) and the System Safety Manager, plus three system safety engineers each from Bell and Boeing and one from Rolls Royce.

The key element of the system safety reporting and tracking system is the Safety Action Record (SAR). The SAR is issue based. It describes in summary detail the safety threat or issue of interest, including history and origin (i.e., results of a design hazard analysis, results of an engineering investigation requested by an operational squadron, or a hazard resulting from a mishap). The SAR then describes the system safety assessment of risk both at the time it originally appeared in the SAR system and at the current time after most recent mitigation actions are complete. A SAR stays "open" as long as there are outstanding mitigation actions. Once the program has determined that no other actions are warranted, the SSWG formally closes the SAR. A recent summary of closed SARs by risk level is shown in Figure 1.

		1	2	3	4
		CATASTROPHIC (Fatal Injury or System Loss)	***CRITICAL*** (Severe Injury or Major Damage)	***MARGINAL*** (Minor Injury or Minor Damage)	***NEGLIGIBLE*** (No injury or Minor Damage)
A	***FREQUENT*** (Likely to Occur Frequently)				
B	***PROBABLE*** (Will Occur Several Times in the Life of the Program)				
C	***OCASIONAL*** (Likely to Occur Sometime in the Life of the Program)	2	3		
D	***REMOTE*** (Unlikely, but Possible to Occur in the Life of the Program)	80	19	3	
E	***IMPROBABLE*** (So Unlikely, it can be Assumed Occurrence may Never be Expected)	64	13	2	

Source: Naval Air Systems Command Jan '01 Safety Action Records

Figure 1: V-22 System Safety Program: Closed Risk Status

One of the Panel's staff members recently completed a detailed assessment of the system safety program as practiced by another NAVAIR program, the AV-8B. By comparison, the V-22 system safety program appears to be better managed and more robustly supported than the AV-8B system safety program, although the latter has improved substantially since the assessment. Of long-term concern is the lack of travel funds for operational personnel in the Marine Corps. Although squadron support of the SSWG is good now, history says that in time, it will find itself a mostly-NAVAIR-engineer activity, with little or no operational support.

Conclusion: The V-22 System Safety Program appears to be appropriately staffed and engaged with other engineering activities.

Conclusion: The number and type of risk issues being tracked by the program do not appear to be abnormal for an aircraft at this stage of development;

however,

Conclusion: The program uses an overly conservative standard to define the "remote" risk level for its various safety issues; the result is that the risk-level categories by themselves are of limited use to the decision maker in risk mitigation trades.

Recommendation: Develop a consistent approach to measuring overall risk level in development and operational programs to aid decision makers in risk trades. Consider use of probabilistic risk assessment techniques to comply with the most recent risk category definitions published by the Naval Air Systems Command.

DOT&E SAFETY ISSUES AND "IMPLICATIONS" VS. NAVAIR SAFETY RISK POSTURE

During his January 12 briefing to the Panel, the DOT&E Director showed a series of charts that listed 724 subsystem or component failures that occurred during the 9-month, 522-sortie OPEVAL. The charts highlighted a substantial number of these failures (177) as having "safety implications." In preparation for the staff visit, the Panel asked the NAVAIR System Safety Manager to review the DOT&E conclusions with the intent of describing the safety implications.

The NAVAIR assessment pointed out that the DOT&E analysts had used Maintenance Action Forms (MAFs) to list the failures. These forms are the documents used by the operational maintenance technicians to record the failure and its circumstances, usually immediately after the flight is completed. Some of the MAFs result from pilot discrepancies and others from post-flight inspection by the maintenance team. MAFs by themselves are not reported to NAVAIR and are not usually a data source for the system safety engineer unless they are included as backup information in an Engineering Investigation (EI) or Hazard Report (HAZREP) or other safety related report to NAVAIR.

In his review of the MAFs, the System Safety Manager determined that approximately 15 of the failures related to SARs, all of which are categorized as medium risk. He saw nothing new in the data, which correlated to the relatively low incidence of safety-related reporting during OPEVAL. In other words, the failures addressed by the OPEVAL maintenance team were not the kind that would lead to hazard reports to NAVAIR and the Naval Safety Center. An example was the hydraulic system, in which hydraulic leaks (relatively common in the V-22) were listed as potential fire hazards. This issue has a long system safety history in the program, including substantial redesign after the loss of a Full Scale Development aircraft in 1992 due to what was most likely a nacelle hydraulic leak fire. Since that time, the SAR that covers "fire due to hydraulic leaks" has been downgraded to a Category 1D risk in the NAVAIR system, which acknowledges that although hydraulic leak fire is in fact a risk, it is not a high risk, as currently understood, controlled, and accepted by the program. In addition, apparently nothing happened in OPEVAL in the way of new failure modes, sites, or characteristics to change that status.

Conclusion: Although at least one new safety issue (VRS) came out of the Operational Test and Evaluation of the V-22, there were neither new safety issues nor changes in V-22 hazard risk-level assignments because of the Director, Operational Test and Evaluation analysis of the tests.

Recommendation: To aid decision makers, the Director, Operational Test and Evaluation organization and Navy Operational Test and Evaluation Force should consider the use of standard risk indices (i.e., Risk Assessment Codes) when reporting safety issues.

3 OPERATIONAL EFFECTIVENESS AND SUITABILITY

3.1 OVERVIEW

The recent OPEVAL gave the V-22 a mixed grade with respect to its capability to perform its mission. The aircraft did well in the performance-related demonstrations, including cruise speed, range, self-deployment, shipboard compatibility, and internal and external payload capability. The aircraft met or exceeded all Key Performance Parameters, along with 90 percent of the threshold requirements of the Joint Operational Requirements Document, against which it was evaluated during flight test. A listing of results is included as Appendix G. The most important shortcomings were in the reliability, availability, and maintainability areas. The Director, Operational Test and Evaluation (DOT&E) analysis of the V-22 test results concluded that the aircraft is "operationally effective, but not operationally suitable."

The following are the major questions to be answered in this area:

- Does the V-22 provide the performance capability needed for the missions?
- Is the V-22 maintainable by operational units?
- Is the maintenance training adequate?
- Are the reliability and availability adequate?

The Panel reviewed the results of the OPEVAL and Government and contractor developmental tests and conferred with V-22 Program officials, contractor engineers, and production personnel. The Panel also examined production and operational flight hardware, flew several engineering and training simulators, reviewed maintenance publications and reporting and training systems, and held discussions with military maintainers and crew chiefs to understand the nature of the aircraft and its support systems and its deficiencies.

3.2 RELIABILITY AND AVAILABILITY

The DOT&E report cited substantive reliability deficiencies as part of the reason for its conclusion that "operational testing has failed to confirm the operational suitability of the MV-22." The three primary measures of system reliability were Mean Flight Hours Between Abort (MFHBA), Mission Reliability (MR), and Mean Flight Hours Between Failure (MFHBF). MFHBA is measured as the number of flight hours divided by the number of mission aborts. MR is the ratio of missions completed without an abort to total missions flown. MFHBF was calculated by dividing the total flight hours by the total number of failures (all failures, major and minor). (Note: the DOT&E report used the term Mean Time Between Failure [MTBF] throughout, even though only actual flight time was measured).

Because of several potentially non-representative production-related difficulties encountered by the test team in the early months of the OPEVAL (October 1999 through February 22, 2000), the DOT&E report lists these measurements before and after that date. Although the better numbers occurred in the second period, the report still found concern with the demonstrated MFHBF. Table 4 shows the results of the OPEVAL for the three requirements.

Measure	USMC Requirement		Entire MV-22 OPEVAL (804 flt hrs)	Since Feb 22 (540 flt hrs)
	Threshold	Objective		
MFHBA	17.0 hours		13.9 hours	18.0 hours
MR	85%		81%	85%
MFHBF	1.4 hours	2.0 hours	0.6 hour	0.7 hour

Table 4: Reliability Results: MV-22 OPEVAL

For reference, CH-46, CH-53D, and HH-60H are currently showing 0.89, 0.82, and 1.32 MFHBF, respectively.

Of the nearly 1,200 non-production failures that occurred during the 804.5 hours of testing, more than a third were with flight control (including hydraulics) and drive and proprotor systems. Table 5 shows the number of failures for each of the top 10 contributors by subsystem.

Affected Subsystem	Number of Failures	Primary Contributor
Hydraulic Power System	170	Fluid level imbalances
Drive System	80	Gearbox temperature exceedances
Proprotor System	76	Sheared pins, cracked panels, fairing damage
Flight Controls	69	Swashplate actuator hydraulic leaks
Flight Control Computers	69	Multifunction displays
Fuel System	61	Leaks
Wiring	53	Harnesses and brackets
Landing Gear	52	Tire wear
Nacelle Assembly	48	Mini Mark fasteners
Electrical Power	47	Batteries

Table 5: OPEVAL Subsystem Failures

In his discussion of this topic with the Panel, the Program Manager pointed to two reasons for the substantial underachievement in MFHBF: 1) a very late 30 percent increase in the JORD requirement for MFHBF (1999), well after the design for the Low Rate Initial Production (LRIP) aircraft used in OPEVAL was complete; and, 2) poorer than expected performance by the hardware in the nacelle due to the severe vibration (and acoustic) environment faced by the 5000-psi hydraulics system. The 30 percent increase in JORD requirement happened because of a plan by OPTEVFOR to measure failure rates against flight hours rather than operating hours, as originally planned. The Program Office and Services did not change the threshold number to account for the measurement difference. Estimates are that approximately 30 percent of all operational time is on the ground (maintenance and pre- and post-flight operations).

The fixes for OPEVAL reliability problems are in various stages of design, test, and installation. Appendix F shows a prioritized list of "top fleet readiness drivers," including background, issues, and actions as of February 28, 2001.

The program has plans addressing all of the major reliability challenges, and a schedule showing the system meets the 1.4-hour threshold in 2003. Figure 2 shows the timeline and several of the important reliability initiatives in work to allow the aircraft to meet the MFHBF threshold.

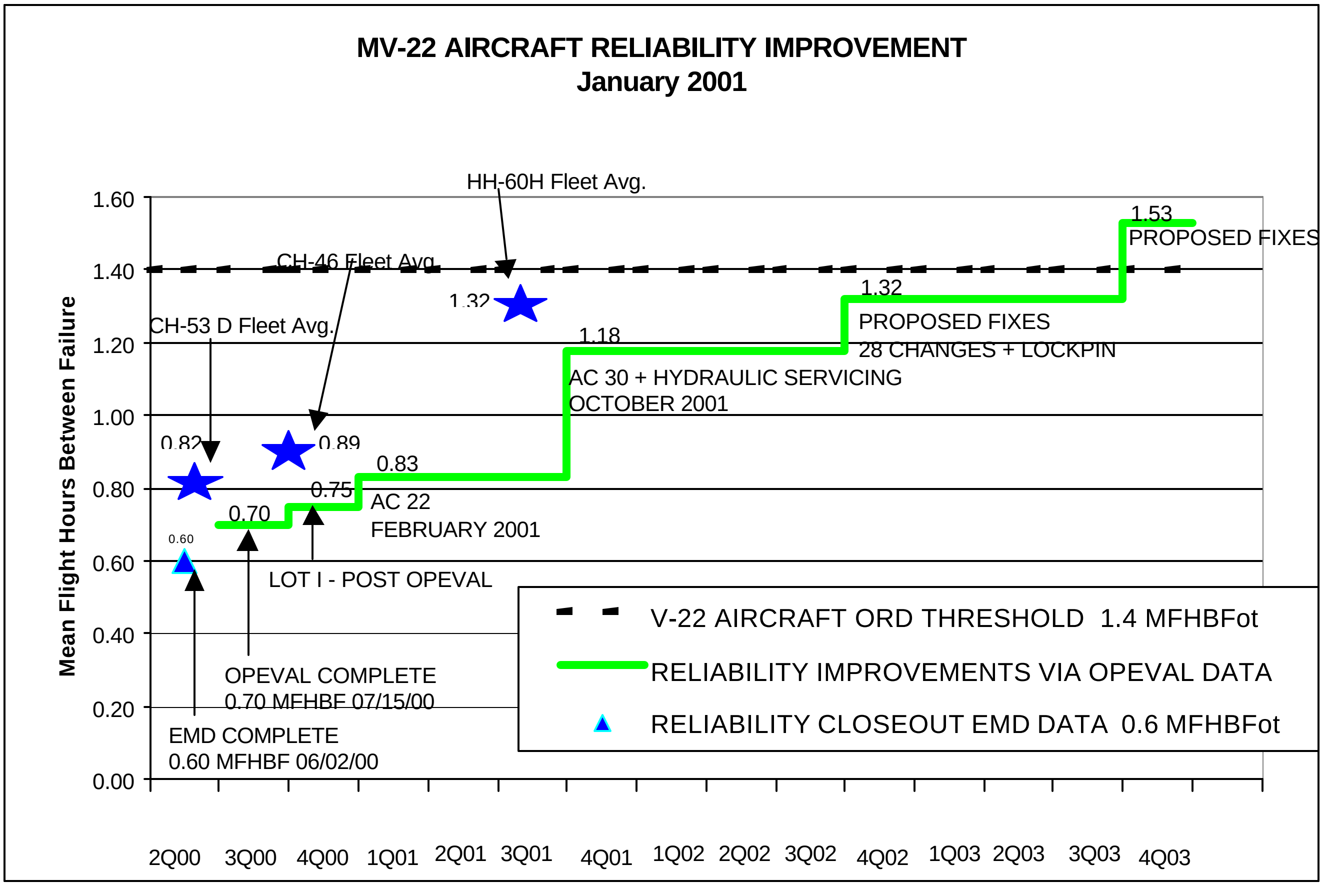


Figure 2: MV-22 Reliability Improvement Plan

The plan results in a 218 percent improvement in MFHBF performance. Of note is that the planned reliability upgrades only improve MFHBA from 18 to 23 hours, or 128 percent. This difference suggests that some amount of time and effort will be spent on reliability improvements that are not necessarily important to mission accomplishment.

Conclusion: The operational availability of the V-22, as demonstrated in the Operational Evaluation, is inadequate. However, not all measures used by the test team are equally important (i.e., mean time between failure vs. mean time between abort).

Recommendation: Reassess and revalidate the current set of V-22 reliability and availability requirements to assure appropriate expenditure of resources on engineering changes.

3.3 MAINTAINABILITY

The V-22 fell short of its maintainability requirements during OPEVAL with 18.6 maintenance man hours per flight hour MMH/FH compared to a threshold of 11 hours or less. For reference, the CH-46 fleet average is 15.8 hours. One of the biggest contributors to this number was the time spent on hydraulics system discrepancies, and nacelle related problems.

During its visit to the Fleet Replacement Squadron at New River, the Panel heard from the maintainers that one of their biggest challenges is conducting work within the nacelle. They said that several factors made maintenance and inspection of the nacelles very difficult: tight quarters; poor inspection access; inadequate access panel fasteners; and interference between hydraulic lines and other potentially abrasive structures, lines, and wire bundles.

Among other things, the nacelle houses the engine, accessories, engine-driven gearbox, and rotor drive system. It also includes hydraulic flexible and rigid hydraulic lines carrying 5,000-pounds per square inch (psi) fluid, as well as proprotor flight control system actuators and critical mechanical components. One of the reasons for the relatively high 5,000-psi operating pressure is to allow for smaller actuators that help minimize nacelle size (and drag). Mechanics with maintenance experience on other rotorcraft told the Panel members that the V-22 nacelle is the tightest engine/rotor system working space they had experienced.

The normal maintenance access panels give the maintainer only a limited view or access to the nacelle components. To gain access to some of the important parts of the nacelle, they must unfasten a multitude of “Mini-Mark” Government Furnished Equipment (GFE) structural panel fasteners. These fasteners have a very poor record on the V-22. During OPEVAL, for example, they were one of the most common failures. Moreover, when a mini-mark fastener breaks, pieces of it often fall into the nacelle area, creating the potential for foreign-object damage. To completely open all access panels on a single nacelle takes in excess of 11 man hours, not counting fastener failure/replacement time. The Mini-Mark fasteners are required for structural load panels, but apparently, not all of the panels carry loads. This raises the question, “Why not redesign the non-structural loaded panels for quicker, more reliable fasteners for maintainer-friendly access to the nacelle?”

Other factors that add to the maintenance challenge with the nacelle are lack of consistent configuration from one airframe to the next, the high failure rate of the click studs (covered in reliability section of this report), poor maintenance publications, and the normal operational issues that apply to all types of aircraft (poor lighting, weather conditions, oil, dust, etc.).

NAVAIR and Bell Boeing engineers and technicians attached to the Osprey Support Center provide the squadron personnel special support in New River. In addition, the NAVAIR initiated Tiger Team is examining all aspects of the nacelle, including those affecting maintainability.

Conclusion: The tight fit of critical hardware, lack of adequate quick access, and poor reliability of access panel fasteners combine to make the nacelle a significant maintainability challenge. The effect, at best, is high maintenance man hours and, at worst, missed critical failure precursors.

Recommendation: Modify the nacelle to improve the spacing/protection of critical components, maintenance working space, access, and the overall maintainability of this critical aircraft area. The redesign activity for this modification should include at least the following:

a. More quick-access panels
b. High-reliability alternatives to the Mini-Mark fastener
c. User-friendly inspection access for critical parts and other exceptions to the flight control system redundancy design requirement
d. Shortening of the hydraulic lines between switching valves and swashplate actuators (if feasible)

3.4 INTERACTIVE ELECTRONIC TECHNICAL MANUAL (IETM)

During the Panel's visit to VMMT-204 they were briefed on and given a demonstration of the IETM, which has taken the place of paper maintenance publications within the squadron's maintenance department. The Panel was struck by the poor demonstrated performance and capability of this system and requested and received additional briefings from Bell Boeing and the Program Office. The questions that need to be answered are: "Can the V-22 IETM be fixed? Is it worth fixing? Are there alternatives to IETM that are worth pursuing?"

IETM has been designed to be an interactive database that will contain all of the maintenance publications and the configuration data for every aircraft in a squadron. When fully developed, it will integrate multiple information sources into a single system, thus providing a wealth of information to the maintainer. Its electronic interfaces will reduce manual data entry. It has the potential to be integrated with The Naval Aviation Logistics Command Management Information System (NALCOMIS) and with The Aircraft Maintenance Event Ground Station (AMEGS). Updated IETM "drops" will be done electronically every 45 days, ensuring that the squadron has the latest changes to its technical manuals. It will provide the squadron with the capability to rapidly and easily deploy detachments, minimizing pack-up requirements. It will assist maintenance training by providing graphics and text on a portable electronic display device (PEDD) that is easily transportable.

The problem is that IETM as currently fielded does not meet the requirements of the Marines in the maintenance department of VMMT-204. The issues with IETM observed by the Panel are the same issues identified in both the COMOPTEVFOR OPEVAL Report and the DOT&E Beyond LRIP Report: IETM does not provide adequate content, accuracy, organization, and clarity to fully support maintenance activities.

Additionally, although the process to update and correct deficiencies with IETM is in place, it responds too slowly to adequately support the fleet. For example, since February 2000, VMMT-204 has submitted 447 Technical Publication Deficiency Reports (TPDRs), of which 164 remain open. The turnaround time for TPDRs ranges from 2 to 3 months.

The Joint Integrated Maintenance Information System (JIMIS) developed by Grumman Melbourne Systems to support the J-STARS Program was chosen in 1993 for authoring and presentation of IETM software for the V-22 Program. The JIMIS software was provided to the V-22 Program for IETM as Government Furnished Equipment (GFE). Boeing Helicopter is the lead integrator for IETM. Significant deficiencies addressed during OPEVAL and witnessed by the Panel included the following:

Incomplete data

- No Integrated Parts Breakdown;
- No mirror image graphics for multiple systems; and
- No schematics for fuel, hydraulics, or electrical systems.

Inaccurate maintenance procedures

- Numerous tasks are documented under the wrong; system/subsystem listing;
- Erroneous torque values; and
- Inconsistent part number references.

Poor organization of data and procedures, and lack of clarity

- Non-user-friendly navigation system; and
- Differences in Bell and Boeing references (schematics).

Poor integration of logistics support

- V-22 is the only aircraft using the Universal Numbering System (UNS); and
- No technical or support manuals are available for UNS.

As stated in the OPEVAL report, "Maintenance of the MV-22 was hampered by the immaturity and lack of clarity of the IETM. Without accurate IETM, maintainers spent many hours troubleshooting fixes to problems that should have been readily identified. Utilizing IETM also proved to be a cumbersome process due to the poor organization of the manuals. When coupled with the inaccuracies of the IETM, an exorbitant number of man hours were expended trying to determine correct maintenance procedures." IETM hardware and supporting software is immature and developmental in nature; significant development and testing needs to be accomplished before it is ready for fleet introduction. Further, maintenance personnel within VMMT-204 estimate that, on average, 15 percent of maintenance time is lost due to IETM deficiencies. Some of the more complicated tasks can involve substantially more IETM-unique lost time than that.

Conclusion: As currently fielded, IETM fails to meet the needs of organizational maintenance.

Conclusion: Significant development and testing is required for IETM as designed prior to operational deployment.

Recommendation: Assess the options for V-22 technical publications (electronic and paper).

and if an electronic publication approach is the best alternative, and the training squadron continues to be the best place to develop it,

Recommendation: Provide adequate developmental support to the training squadron for the selected system.

Importantly, as the contractor validated 100 percent of the maintenance procedures prior to OPEVAL, only 15 percent was actually accomplished on the aircraft, and the remainder was validated through tabletop review or simulation. While this may be the standard practice for validation, it apparently missed important flaws in the data.

Conclusion: Based on the poor performance of the IETM thus far, technical publication validation was inadequate. Additionally, NAVAIR and the Program Office have not yet verified the same technical publication procedures in the IETM. This process needs to be accomplished as soon as possible.

Recommendation: Properly validate and verify the technical publications as soon as possible.

The poor integration of logistics support within IETM is another area of concern to the Panel. The V-22 is the only naval aircraft that utilizes the Universal Numbering System (UNS). UNS is a numbering system for referencing technical data, aircraft systems, and related aircraft equipment. The IETM, using UNS logic, was designed to provide a functional numbering system consistent across all data; provide audit trail methodology in developing quick, easy, and accurate fault detection/isolation; and pursue Joint Service Operational Requirements. The Navy canceled UNS conversion in 1996; however, the V-22 Program Office determined that it would be financially infeasible to go back and reestablish the Logistics Support Analysis (LSA), Logistics Support Analysis Record (LSAR), and other infrastructure to support a return to the standard Work Unit Code (WUC) used by all other naval aircraft. The V-22 Program is using the UNS structure as its work unit code equivalent. The structure forms the basis of the Logistics Control Number (LCN). The LCN ties the UNS information to the LSAR, which is used for provisioning, publications, maintenance plans, task analysis, and analysis of data failure. This numbering structure has been rolled directly into IETM and is used to help navigate within IETM. Unfortunately, because UNS is task based and was constructed to support troubleshooting, individual parts are split into functional UNS buckets. What this means, according to a V-22 IETM Limitations Document published by Naval Aviation Depot Cherry Point on 13 March 2001, is that “essentially, there is no good way to search for parts data in the IETM.”

Currently, neither a fleet UNS manual nor a V-22 UNS users' guide exists. Both of these documents are in development, with no estimate of a completion date available. VMMT-204 maintainers are working with AIR 3.0 and SPAWAR personnel to overcome reporting problems associated with UNS.

Conclusion: Use of UNS rather than WUC will create long-term difficulties for the V-22 Program. The maintenance and upgrades of a logistics system that is unique within naval aviation has limited potential to succeed and will prove very costly. Additionally, when deployed, the V-22 logistics system will be incompatible with the logistics system of other aircraft in a composite squadron.

Recommendation: Transition as soon as possible from the Universal Numbering System to the standard Work Unit Code logistics system.

During the Panel's review of the IETM, both Bell and Boeing provided briefings on other IETM systems undergoing development. The Boeing effort for F-18 has been successful, although it apparently had its own startup problems. Bell is beginning an effort to bring electronic technical manuals to the AH-1 Program using a standard work unit code logistics base and a different set of application software than either the F-18 or the V-22.

Conclusion: There appears to be no standardization or specified requirements within DoD for Integrated Electronic Technical Manuals, and each program office is on its own to determine the solution that works for them and what they can afford. This can impact deployed units that share the same organizational and intermediate level maintenance facilities (e.g. amphibious ship with composite squadron).

Recommendation: Standardize performance, support, testing, and funding requirements for Electronic Technical Manuals across all platforms and services.

3.5 MAINTENANCE AND AVAILABILITY REPORTING NALCOMIS (OPTIMIZED)

On February 26, 2001, the Panel members received a briefing on the Naval Aviation Logistics Command Information System (NALCOMIS (Optimized)), the Navy's new automated maintenance management system, by the Assistant Commander for Logistics for NAVAIR. VMMT-204 was the first USMC squadron to utilize NALCOMIS (Optimized), and there had been a significant reduction in reported aircraft readiness by Navy squadrons that had transitioned to the new system of maintenance data management.

NALCOMIS (Optimized) is part of the Navy's initiative to fully automate its aviation maintenance environment. As planned, the system will provide Navy planners with total asset visibility, to include total numbers of aircraft, location, and material condition. It will track utilization so that it can quantify requirements and trend reliability to determine readiness and refine budget requirements. More specifically, NALCOMIS (Optimized): reports maintenance transactions in near real-time, tracks actual equipment configuration data, locates parts and material through connectivity with supply departments, allows instant access to readiness data by authorized users on the network, maintains electronic log books, and includes standard interfaces for aircraft-specific diagnostic programs (F/A-18E/F, V-22, JSF).

NALCOMIS (Optimized) began Developmental Test in April 2000, at the same time it was introduced at VMMT-204. Operational Test of the system was scheduled to begin in March 2001. Briefers told the Panel that due to the accuracy and reporting discipline inherent in NALCOMIS (Optimized), squadrons utilizing the new system could expect to see reductions in both Mission Capable (MC) and Full Mission Capable (FMC) rates. HSL-40, the first unit to adopt NALCOMIS (Optimized), reported in November 1999 MC and FMC rates of 64.4 and 63.3, respectively, under legacy NALCOMIS. Then, one year later, under NALCOMIS (Optimized), it reported MC and FMC rates of 26.6 and 16.7. Under the new system, Direct Maintenance Man Hours (DMMH) also could be expected to drop significantly. In fact, HSL-40's data indicates that these rates were effectively cut in half. Other documented effects include a rise in both Not Mission Capable Maintenance (NMCM) and Not Mission Capable Supply (NMCS) rates. While the drop in reported readiness rates was expected with the move to a more rigorous system of analysis, the problem the Navy is working with is how to quantify the new readiness numbers relative to the Chief of Naval Operations' established MC and FMC readiness goals, which were based on legacy NALCOMIS. What does an MC rate of 26.6 percent, measured in NALCOMIS (Optimized), mean in terms of the ability of a squadron to accomplish its mission?

The Panel's visit to VMMT-204 included a briefing on NALCOMIS (Optimized), during which numerous issues and concerns were identified. These included the following:

1) The system complies with the 4790.2H Naval Aviation Maintenance Publication (NAMP), which has not yet been published. The fleet is working from the 4790.G. No information or waivers were provided to the Marine Aircraft Wing or the squadron granting permission to deviate;
2) There is currently no way to correct invalid data. The system is allowing errant work orders to be transmitted;
3) Lack of system reliability requires the Maintenance Administration Work Center to back up all documentation manually;
4) Reports generation is not user-friendly;
5) Responsiveness to identified system Trouble Reports is time-consuming because of the requirements to approve, design, and implement the fix;
6) No contingency exists to fix or fly aircraft if the new system fails. No paper copies of records exist; and
7) The system does not currently interface with either V-22 aircraft diagnostic systems or the V-22 IETM.

Conclusion: NALCOMIS (Optimized) is experiencing a high number of deficiencies in the squadron environment.

Recommendation: NAVAIR should correct the deficiencies and incompatibilities that are resident in the NALCOMIS (Optimized) system as soon as possible.

On April 10, 2001, the Navy's Commander of Operational Test and Evaluation stated that, "based on operational testing and identified deficiencies of NALCOMIS (Optimized) from March 13, to date, an unsatisfactory outcome is likely for this FOT and E (follow-on-test and evaluation)." He recommended that the system be decertified and that all fielding stop. Observations of NALCOMIS (Optimized) performance identified problems associated with mission failures, training inadequacies, and data transfer integrity. Additionally, the lack of understanding of the significance of MC and FMC rates under NALCOMIS (Optimized) and the inability to effectively compare those rates to CNO readiness goals has resulted in the squadron having to report its readiness rates using both Legacy NALCOMIS and NALCOMIS (Optimized).

Conclusion: Inclusion of NALCOMIS (Optimized) with draft documentation in VMMT-204, as it faced the requirement to field a new aircraft without verified maintenance publications, coupled with an immature IETM, clearly complicated the challenge.

Conclusion: Baseline data for NALCOMIS (Optimized) has not yet been developed to properly evaluate performance of reporting units.

Recommendation: NAVAIR should provide a set of guidelines and metric algorithms to all organizations that use NALCOMIS readiness data for planning, budgeting and other resource decision-making.

3.6 DIAGNOSTIC CAPABILITY

The object of the diagnostics test conducted on the V-22 during OPEVAL was to determine whether the V-22 diagnostic capability would be adequate, reliable, and accurate. The DOT&E evaluation stated that "since the vast majority of fault detections were invalid (i.e., false alarms) the diagnostic system overall was of little, if any, assistance to the operation or maintenance of the aircraft." The Panel received a demonstration of the diagnostic capability of the aircraft while visiting VMMT-204. Based on this demonstration, the Panel requested and received additional briefings on the V-22 diagnostic capability from both Bell Boeing and the Program Office to determine the adequacy of the V-22 diagnostic system.

The V-22 Operational Requirements Document requires that the aircraft have a Data Storage System (DSS) able to accommodate the downloading of maintenance data in 15 minutes or less to support maintenance debriefings, allow the rapid sorting and correlation of data points, and provide effective guidance for maintenance personnel. The V-22 accomplishes this task with its mission data loader (MDL), which, at periodic intervals during flight, automatically records built-in-test (BIT) data results, engine performance parameters, and other data. Upon landing, aircrew and maintenance personnel download these flight data to the Data Transfer Module DTM. The DTM cartridge is then removed from the aircraft and is used to download information to an Aircraft Maintenance Event Ground Station (AMEGS). AMEGS reads both Vibration and Structural Life Engine Diagnostics (VSLED) and Full-Authority Digital Engine Control (FADEC) data.

Maintainers at VMMT-204 spoke very highly of the diagnostic capabilities of this system. They recounted one instance in which AMEGS-displayed VSLED data indicated higher than normal vibrations emanating from an engine drive shaft. The resulting inspection revealed an improper washer stack-up. OPEVAL results stated that the V-22 diagnostic system demonstrated the capability to be adequate, reliable, and accurate. Both fault detection (FD) and fault isolation (FI) exceeded their threshold and objective values, but the false alarm (FA) rate failed by a large margin, as indicated in Table 6.

Measure	Threshold/Objective	Demonstrated in OPEVAL
Fault Detection	> .70 / .85	.92
Fault Isolation	> .70 / .85	.87
False Alarm Rate	< .25 / .15	.92

Table 6: Results of OPEVAL Diagnostics

The FA rate is the probability that a diagnostic Built-in-Test (BIT) will indicate a failure when none has occurred. FA rate is calculated as the number of incorrect diagnostic failure indications divided by the total number of diagnostic failure indications. The FA rate continues to plague maintenance troubleshooting as well as flight operations. While the warnings and cautions displayed to the aircrew are considered accurate, the excessive amount of advisories has created excessive aircrew workload and inaccurate readiness indications. To help reduce the maintenance workload while FA improvements are being developed, a “ghost list” was created to identify specific conditions under which an identified fault did not indicate a system problem. The “ghost list” is displayed on the AMEGS for easy reference.

A deficiency of the AMEG system identified by both the MOTT and VMMT-204 maintainers is that the system displays only six-figure Hex fault isolation codes. Two associated problems with this system are: 1) only the contractor can decode these codes; and 2) the maintenance publications contained in the IETM used by troubleshooters uses UNS codes that are logistics based. The lack of integration among AMEGS, IETMS, and NALCOMIS (Optimized), is identified in the DOT&E report as follows:

> AMEGS, VSLED, and IETMS were not integrated with each other or with the Naval Aviation Logistics Command Management Information System (NALCOMIS). Each stand-alone system required manual transfer of common data elements from one system to another. Manual processes introduced additional errors, added maintenance delay time, and reduced the utility of BIT systems.

Integration of these disparate systems will take some time to accomplish. In the interim, the Program Office has developed a ground-based fix for the AMEGS hex code problem that will be incorporated on the aircraft. AMEGS version 2.2.1 will be released in May and will provide a cross-reference table automatically tying the IETM logistics UNS codes to the hex codes currently displayed by the AMEGS. This integrated system will provide maintainers with a greater degree of troubleshooting capability. In the long term, UNS codes are being considered for addition into the aircraft's Mission Computer AMEGS database, allowing codes to be displayed on the maintainer flight summary in the cockpit. This system will also significantly enhance the ability of the aircrew to identify potential maintenance problems in flight.

Conclusion: The AMEGS has the potential to be a powerful diagnostic tool for the maintainer, but the marginally integrated AMEGS, IETM, and NALCOMIS systems, all of which suffer from their own development problems, create undue workload for the maintainer in identifying and understanding system performance and maintenance issues.

Recommendation: Fix the individual deficiencies associated with AMEGS, IETM, and NALCOMIS (Optimized). After each system demonstrates adequate reliability, integrate these three systems as soon as possible.

and,

Recommendation: In the short term, expedite software cross references for AMEGS and IETMs.

and,

Recommendation: Provide appropriate training on AMEGS for the VMMT-204 maintainers.

There is a strong synergistic relationship between detecting and isolating a fault and a false alarm. Therefore, the Program Office is not willing to arbitrarily reduce the detection and isolation capability of the diagnostic system in an effort to reduce the false-alarm rate. The Program Office does have a plan in place to reduce the number of false alarms. JVX Application System Software (JASS) Release 2.6 will fix 28 false-alarm indications. The software is scheduled for release for flight test in August 2001 and to the fleet in November 2001. Additionally, AMEGS Version 2.2, which was completed in February of this year, has the capability, when selected, to remove from the display those items on the "ghost list," making it easier to see the remaining indications. Training is ongoing at MCAS New River on the new version of AMEGS. Other initiatives that the Program Office is taking include an analysis of additional software such as diagnostic file filters, hardware changes, and the incorporation of subsystem software updates that have less propensity to trigger false alarms and remove the need for reference to the "ghost list."

Conclusion: The timing of improvements in the current plan to reduce the false-alarm rate is inadequate to meet program needs.

Recommendation: Expedite the plan to reduce the V-22 false-alarm rate in both the aircraft and ground systems, with priority on aircraft software.

3.7 MAINTENANCE TRAINING

Consistent with its charter to review the adequacy of V-22 training, the Panel received briefings from the Program Office on the V-22 maintenance training system. Additionally, both Bell and Boeing and personnel from VMMT-204 and the Fleet Replacement Enlisted Skills Training (FREST) unit located at MCAS New River in Jacksonville, North Carolina, briefed Panel members.

In 1996, the Department of the Navy invested $41million with Bell Boeing for the development and procurement of the Naval Aviation Maintenance Trainer Suite (NAMTS) for the V-22. NAMTS was to be located at the FREST schoolhouse. The mission of the V-22 FREST is to "provide consolidated/co-located tiltrotor maintenance training, in partnership with the Air Force, utilizing state-of-the-art training systems and strategies." NAMTS was to consist of four composite maintenance trainers (CMTs) and four composite maintenance procedures trainers (CMPTs) that were designed to replicate more than 1,335 maintenance tasks. Reflectone was chosen as the contractor for NAMTS through full and open competition in 1997. Reflectone subsequently stopped work on the project in December 1999 and was officially released from the contract through a no-fault mutual rescission signed in May 2000. With $14 million remaining from the original investment of $41million, Bell Boeing and PMA-205 (the Program Manager responsible for V-22 maintenance training systems) agreed that low-fidelity Parts Task Trainers would be built and that separate contracts would be let for an Integrated Multimedia Instruction (IMI) suite and high-fidelity CMTs. These three separate systems were to be integrated into a maintenance training system to replace the cancelled NAMTS. Until the CMTs were received, VMMT-204 would provide two to three aircraft to the FREST to allow maintenance students to complete their hands-on training. Boeing's initial bid for the CMTs was $130 million, which was determined to be unaffordable by the Program Office, and the development of CMTs was cancelled. Bell Boeing was awarded a $20 million contract to develop an IMI capability for the V-22. IMI consists of three subsystems: an instructor-led classroom Computer-Aided Instruction (CAI) curriculum, Interactive Course Ware (ICW) that is self-paced and instructor supervised, and a computer management system to oversee the process of IMI and to handle such responsibilities as student enrollment, data collection and reporting, and testing.

The current maintenance-training system calls for the use of actual aircraft in the place of CMTs. PMA-205 will be responsible for converting three aircraft to trainers with fault insertion capability. Each conversion is expected to take 6 weeks. The first aircraft conversion is scheduled to begin in October 2001. In the interim, VMMT-204 will supply additional LRIP aircraft to meet the FRESTs training requirements. The second part of the maintenance training system, the Part Task Trainers (being built by both Bell and Boeing), is in the process of being developed and fielded. The FREST currently has a Powerplant Part Task Trainer in place, and Boeing is working on the fielding of Part Task Trainers for Sponsons, Landing Gear, and the Airframe. Delivery of these systems is expected to take place over the next 18 months. The final part of the maintenance training system, IMI, is currently being delivered to the FREST. Bell is expected to complete delivery of its portion of the software by June 01 and Boeing by September 01. The Panel members were shown the capabilities of IMI during a briefing at MCAS New River on 5 March 2001. IMI is a state-of-the-art system that is a quantum leap over current maintenance training systems.

Conclusion: Until adequate maintenance training systems are in place, the loss of NAMTS will have an impact on the capability of both VMMT-204 and the FREST to accomplish their missions of training pilots and maintainers. The three systems procured should address this deficiency adequately if they are properly funded and supported.

Recommendation: Fully fund and support the maintenance training system.

Regarding the use of actual aircraft as maintenance trainers, the Panel members recognize that there are both advantages and disadvantages. Among the advantages are:

1) Actual aircraft have a higher physical and functional fidelity;
2) The maintenance of the trainers will mirror that of operational aircraft;
3) Ground support equipment will not have to be modified;
4) Spares will be available through the supply system; and
5) Hardware and software configuration can be simplified through the utilization of the ECP process.

The disadvantages of utilizing actual aircraft as maintenance trainers are as follows:

1) Early production aircraft generally require numerous modifications before configuration stabilizes. The training aircraft supplied to the FREST will require these modifications, which will take them out of service for a certain length of time, thus necessitating augmentation by aircraft from VMMT-204 and the resultant downturn on operational readiness;
2) The Panel is concerned whether the actual aircraft being used for maintenance trainers are properly spared;

3) Additional ground support equipment will be required to be purchased, maintained, and supported by the FREST; and

4) Aircraft components are not designed to withstand the multiple remove and replace cycles required for training, and the associated cost and quantity of spares may be excessive and must be planned and budgeted for.

Conclusion: There are advantages and disadvantages to using actual aircraft as maintenance trainers,

however,

Conclusion: Under the best circumstances, a real aircraft cannot replace a properly engineered maintenance trainer. The disadvantages outweigh the advantages and complicate the maintenance training for the other services,

and,

Conclusion: To be effective, maintenance trainers must be properly funded for spares and fleet modifications.

Recommendation: Consider the eventual replacement of the aircraft being used as maintenance trainers with maintenance trainers designed for that purpose.

Recommendation: Retrofit and modification of maintenance training aircraft (when appropriate) should occur at the same time or prior to those changes being incorporated in tactical aircraft.

Recommendation: Adequately budget for maintenance-training aircraft spares.

4 PROGRAMMATICS

4.1 OVERVIEW

The Panel reviewed the V-22 program, including its structure, budget and schedule, and considered recommendations to improve upon it. In summary, the program was proceeding as well as can be expected, given the significant fiscal constraints, and the plan to introduce not only a new aircraft but also a new and unique maintenance and logistics support concept at the same time.

The V-22 Risk Management Program and Systems Engineering processes are success stories despite significant challenges posed by the joint venture arrangement of having two prime contractors to deal with instead of a prime contractor/subcontractor arrangement. Intense communications are required to have success in these areas;

however, it was obvious to the Panel that greater communication was required with the user community to keep them informed of program actions.

A common theme the Panel found throughout its assessment was inadequate resources to execute the planned program. Inadequate resources in development and early production essentially delayed program maturity. Once fielded, spares and support were inadequate to sustain fleet operations and are projected to remain low throughout the life of the program. To accommodate a higher cost than originally planned, yearly aircraft procurement rates were reduced to live within near-term budget constraints.

4.2 THE JOINT PROGRAM AND SYSTEMS ENGINEERING

The two major mishaps in 2000 and the results of the OPEVAL show that many of the issues and challenges of the V-22 Program cut across traditional design and development disciplines. Inadequate integration of flight control hardware, software and pilot human factors was an issue in the North Carolina mishap. Technical publication development and validation is another systems engineering issue. Further, the assurance disciplines of system safety, reliability, maintainability, and quality all depend upon a solid and open systems engineering approach for success. A potential threat to good systems engineering and integration is the relatively unusual 50/50 joint program work share (design and production) used by the two prime airframe contractors, Boeing Helicopters and Bell Helicopter Textron. Considering the number of cross-functional issues in the program, the Panel reviewed the organizational and management approach of the V-22 Program to determine if this dual prime concept with shared integration responsibilities might be putting an undue strain on the program's systems engineering efforts. The Panel also looked at how the V-22's design trades and risk management are accomplished.

ORGANIZATIONAL APPROACH

Bell and Boeing split the engineering and production work and the profits 50/50. They have a joint process for transferring work for cases in which it looks like the 50/50 split is challenged, or when one company's skills were more suitable for a given task than those of the other were. Contractor interface with the Government is through a Joint Program Office (JPO) located near the NAVAIR Program Office at Patuxent River. The JPO is a relatively small office with representatives from both companies. (NAVAIR has a separate contract with Rolls Royce Allison for engine production and support). The JPO is headed by a Program Director, who is a Bell or Boeing employee on a rotating basis. The Bell and Boeing Program Managers at their respective sites in Fort Worth and Philadelphia report programmatically to the Program Director.

The systems engineering effort for the NAVAIR Program is headed by the Deputy Program Manager Systems Engineering (Class Desk). On the contractor side, The V-22 Systems Engineering Management Plan for Engineering and Manufacturing Development (EMD) (last changed in 1993) outlines the organizational structure and the various responsibilities for the contractor team members. Systems engineering tasks and activities are pervasive throughout the program and fall under the overall responsibility of the Technical Director, who reports to the JPO Program Director. The NAVAIR contractor team uses Integrated Product Teams (IPTs) and Analysis and Integration Teams (AITs) with negotiated leadership and participation by the Government and the two companies, according to their respective responsibilities and strengths.

Although the responsibility for systems engineering falls on the Bell Boeing JPO, that office has no systems engineering capability beyond management. Both Bell and Boeing provide the staff and functional policy guidance for all systems engineering tasking at their respective sites. Each company has its own techniques, formats, and organizational heritage for the various systems engineering disciplines; however, the Systems Engineering Plan specifies the process and standards to be used by the joint program. Where there is conflict, the JPO policy takes precedence. The breakdown of design responsibilities by company is shown in Appendix G. Each company, through the IPT and AIT structure, handles its unique integration and assurance issues. Integration issues that cross company boundaries such as electrical systems, flight control system, maintenance publications, and crew training, are managed by the JPO, again through IPTs and AITs with joint membership and reporting to the JPO Technical Director.

This organizational approach to systems integration and program management carries with it the risk of omission. The JPO does not have a systems engineering staff of its own, so there is some degree of delegation and decentralization of the discipline, a real challenge for the JPO technical director and Navy Class Desk. In discussions with the key people involved, it was apparent to the Panel that any risk to systems engineering inherent in the dual prime contractor approach is at least partly mitigated in the V-22 Program by a combination of positive factors:

- Strong systems engineering management by the NAVAIR Program Office;
- Close coordination of issues among all organizations by the contractor JPO;
- An active inclusive risk management program;
- Good communications and working relationship between Bell and Boeing team members (at all levels); and
- Dedication to the concept by upper management in both companies.

And most importantly, according to NAVAIR, Bell, and Boeing managers,

- Continuity and corporate knowledge among the key members of the team (many of whom have been on the project in excess of 10 years).

As time goes on, and people on the Government and contractor side move to other positions, it will be important to maintain continuity and corporate knowledge. By its nature, a single prime contractor who is also the systems integrator is generally the optimal approach to systems engineering; however, at this late date, and in view of the importance of consistency in the program, the Panel sees no value in changing basic contractual or organizational structure. However, NAVAIR should take steps to minimize the threat to key personnel continuity through the critical post-OPEVAL development and early production phases still ahead.

Conclusion: The Bell Boeing Joint Program Office is a critical feature in the V-22 contractor organization, especially with regard to program integration.

Recommendation: Constant attention must be paid by both the Navy and the Bell Boeing Joint Program Office to the potential for lapses in systems engineering integration discipline as team members try to solve problems outside of established processes.

Conclusion: Possibly the most important ingredient in the V-22 Program's systems engineering effort is continuity among its key personnel.

Recommendation: As the program proceeds, both NAVAIR and the contractors should ensure a high level of continuity in the program's Integrated Product Teams, Analytic Integration Teams, and key management positions.

DESIGN TRADES

One of the key features of the EMD Systems Engineering Plan was its treatment of trade studies. Early in development, trade studies were used to weigh the effects of various design solutions against the requirements. No program has the luxury in funding, time, or even technical feasibility to maximize its design across all requirements; there are always optimization trades to be done. The V-22 systems engineering program prioritized the various design requirements by category, putting the highest weight on those design requirements related to range, shipboard compatibility, speed, and payload capability. They ranked reliability and maintainability requirements at roughly half the weight of the major performance measures. Safety-related requirements were spread throughout the weighting scale, with human factors at just over half of the maximum weight factor, and crashworthiness, handling qualities, and one-engine-inoperative performance at the lower end of the scale. This relative ranking can easily justify a decision to develop a 5000-psi hydraulic system with its component weight and volume (thus payload, range, and speed) advantages, even at the expense of reliability and maintainability.

Although most design trades for EMD were conducted in the early to mid-1990s, there continues to be a need for requirements updates, risk mitigation strategies, design upgrades, engineering changes, etc., for an aircraft at this early stage. Considering the nature and importance of the flight test supportability discrepancies and mishap investigation results, the program would do well to update the trade study weights consistent with current priorities, as necessary. This update would provide proper and consistent guidance to the engineering team for its ongoing systems engineering activities.

Conclusion: Although the V-22 was not intentionally designed to be unreliable or unmaintainable, the results of the OPEVAL are relatively consistent with the systems engineering trade study weighting scheme…***the aircraft performed as it was designed!***

Recommendation: For the next phase of system and requirements reviews, risk trades, and engineering changes, the program should assess its trade-study priorities and perform updates consistent with today's priorities—i.e., safety, reliability, and maintainability.

RISK MANAGEMENT

In considering the long history of technical, cost, and schedule issues with the V-22 Program over the years since inception, the Program Manager has refined the risk management process, making it an integral part of overall program management. In the briefing and ensuing discussion, it was clear to the Panel that this program has taken classical risk management to a level not often seen in large Government programs. In any number of programs, risk management, if formally done, is treated as a distinct process, in addition to, rather than as an integral part of system engineering. Most often, it is accomplished by designating a program management team member as part-time "risk manager." Some of the larger programs hire support contractors to provide process support, or in some cases, independent analysis support (independent of the prime contractor). Some major programs have an IPT (e.g. Naval Sea Systems Command Program Executive Officer Carriers) or a standing risk board (National Aeronautics and Space Administration (NASA) Space Station Program) that meets periodically to discuss and assign status to risks, but they are not necessarily part of the engineering change process or the everyday program management system. According to the V-22 Program Manager, he is the Risk Manager, and his philosophy is to "create an open, honest, risk-aware culture in which risk management is considered to be a normal, healthy aspect of sound overall program management."

The program has a large risk-management support team of approximately 20 full-time-equivalent people from several program office support contractors. They help the process by running the systems, managing the electronic risk database, providing independent risk assessments as required, and tracking the status and mitigation plans. Because the risk process is integral to the program management process, the Program Manager believes it allows him the best chance of heading off problems before they happen, or at least minimizing their probability and/or severity when avoidable.

The scope of the V-22 risk management program is broad. Anything that can threaten technical performance, cost, or schedule is fair game. Safety risks are handled independently by the NAVAIR system safety team, using MIL STD 882 standards and the System Safety Working Group chaired by the Class Desk. However, if a safety issue comes out of that process as an "unacceptable risk," it is tracked and worked by the program in the risk management process as a technical risk. A safety issue is not passed off to the program; however, as the system safety team independently tracks the status and mitigation efforts and continues to independently reassess risk level as new modifications or controls are put in place.

The analysis part of the V-22 risk management process is usually qualitative in nature, with the exception of certain quantitative specification compliance issues (i.e., reliability and performance requirements). Because of this, the program does not treat risks statistically, nor are mathematical uncertainties used as they are in some programs. The categorization of risks uses the three-level ranking technique common to many programs: high, moderate, and low. Although the program uses risks to create "risk adjusted" cost projections, its officials have had some trouble finding a reasonable approach to risk adjusted schedule prognostications. The Program Manager stated that they have gone through several starts and stops with various techniques for applying risk to program schedules in a quantitative way, and all have fallen short.

The Program Manager points to cost and schedule performance indicators consistently over 99 percent (better than most other programs managed by the Naval Air Systems Command). He believes that future success in the program depends on its continued integrated, open processes. He pointed out that the risk management process received high marks in an independent audit chartered by the Assistant Secretary of the Navy for Research, Development and Acquisition (ASN (RDA) in March 1994, and that the system is even better today.

Conclusion: The V-22 Program risk management approach appears to be robustly supported by management and appears unusually well coordinated with other program activities. In spite of its minimal use of state-of-the-art quantitative risk assessment techniques, it appears to be better coordinated and managed than risk management systems found in other major programs.

Recommendation: The Defense Systems Management College risk management course should use the V-22 Program risk management process as an example of how to incorporate risk into everyday program management.

4.3 PROGRAM COMMUNICATIONS

During visits to both Government and contractor facilities, the Panel members were struck by the lack of awareness by officials of both organizations with some of the issues and concerns being raised by the Marines and Airmen of VMMT-204. More significantly, many of the VMMT-204 personnel did not know if their technical issues were being addressed. The latter concern was becoming a morale problem. The issues of concern covered three areas: the aircraft, the maintenance system, and enlisted maintenance training.

As mentioned in the VRS discussion, the knowledge among MOTT pilots of the risk of VRS in the V-22 was limited before the Mirana mishap. Although the engineering community was aware of the potential and had a formal Safety Action Record on the subject, this level of understanding was not shared by all of the pilots. The lack of understanding of the system safety program and its functions is not unique to the V-22.

During a Harrier program system safety risk assessment in 1999[1], this lack of connection between system safety and squadron level aviation safety was very apparent. Factors included: lack of system safety training at the Naval Safety School; lack of formal ties between risk acceptance rationale and risk controls; insufficient participation (usually due to lack of travel money) in the System Safety Working Group; and lack of policy guidance from the Chief of Naval Operations. The answer pursued by the Harrier program was to improve informal communications and increase travel funding for squadron participation in safety reviews. If the V-22 Program and operational community do not take special care to maintain a strong communications link between the operators who take the risks and the Program Manager who accepts the risk on their behalf, there will be ample opportunity in the future for another avoidable mishap.

The loss of the second V-22 in December 2000, followed by the grounding of the squadron and the appointment by the Secretary of Defense of this Panel, as well as the ongoing DoD Inspector General Investigation, all have had an impact on the members of VMMT-204. Significant concern was expressed during the Panel's visit with the squadron that the problems that they had been dealing with for some time were not being addressed adequately. The combined NAVAIR Fleet Support Team (FST) and Joint Program Office (JPO), Osprey Support Center (OSC) located at MCAS, New River works closely with the squadron every day to help with problems, communicate issues to and from NAVAIR and the contractor facilities, and otherwise facilitate communications.

Conclusion: While standard legacy reporting processes are being used properly, they appear to be inadequate to the expressed desires of the operators.

Recommendation: Review information flow requirements between the V-22 Program, Bell Boeing, and the customer, and develop a funded plan to increase the responsiveness to operator needs. (Attention needs to be given to meeting similar requirements for the Air Force and SOCOM during CV-22 introduction).

Issues that result in changes to the aircraft are another source of frustration for the operators. Specific complaints included: Mini-Mark fasteners that fell apart and created both a foreign-object damage hazard and high workload for maintainers; lack of adequate inspection panels on the aircraft (particularly around the nacelle area); and oil leaks from the engine. Although the normal reporting system for such anomalies appeared to be intact and working, the lag time, or lack of status updates on engineering changes, was an area of concern to the operators.

One example of poor feedback was the case of the steel sleeve that was installed on the Interconnect Drive Shaft as an interim heat protective measure after the 1992 accident at Quantico. This sleeve was later removed when the permanent fixes were installed in the aircraft nacelle to reduce the probability of hot air reaching the shaft in the event of an

[1] AV-8B Risk Management Process Review, an Independent Assessment by Futron Corporation, dated. 31 May 1999.

engine fire. Apparently, the crew chiefs had grown to appreciate the risk mitigation offered by the sleeve, and they had concerns when modified aircraft arrived without a sleeve and with little or no explanation at their level. Another example was the information received by the squadron that their aircraft probably would not be retrofitted with new crashworthy sponson-mounted fuel tanks, while other squadrons would have the new tanks installed at the factory. This expressed concern probably overstates the problem, but armed with limited information, the Marines were rightfully troubled.

Finally, the Panel heard from several sources that the relationship between the developmental and operational test pilot communities was less than cooperative; causing an environment that was not always conducive to good communications. Part of that problem is an apparent long-standing prohibition by OPTEVFOR of sharing all but the most serious information with NAVAIR during the conduct of OPEVAL. Such things as hardware failures and maintenance problems are held for months before being relayed to the developers. Further, there has been a historic problem throughout Marine Corps tactical aviation with operators failing to write hazard reports (HAZREPs) for close calls, minor incidents, etc. These things are usually a judgment call, and in the press of operations, often operators do not bother with the HAZREP because there was no injury or damage. At the very least, these communications problems can be frustrating to the engineering and aviation safety community and their efforts to improve the aircraft.

Conclusion: There is not enough communication of engineering change activities from the engineering community to the operators and visa versa, considering the state of the V-22 in its development and introduction.

Recommendation: Supplement the standard formal reporting to and from the Osprey Support Center with informal feedback to facilitate the exchange of information to and from the operators.

Another area of concern revolves around the maintenance department and the challenges that it faces in dealing with the new IETM electronic publication system, the AMEGS, and the new NALCOMIS (Optimized) reporting system. These systems would be a challenge to introduce to a well-established legacy aircraft, but trying to develop them while introducing a new aircraft has turned out to be something more. Again, the communications systems for all of these areas are established and working, but the operational maintainers involved are not necessarily updated on the status of their anomaly and deficiency reports until much later than would be the case if they were active participants in a development test program.

Other areas of concern are late delivery of the ground maintenance training system and the overall uncertainties of the program exacerbated by the ongoing limited distribution mishap, JAG, and IG investigations and press speculation.

It was clear to the Panel that both the Program Office and Bell Boeing are aggressively working to resolve all of the issues that were addressed by the squadron and that they are trying to touch the operators through an actively engaged OSC. However, the squadron personnel are not adequately being informed of the status of relevant issues (particularly safety-related issues) in a timely manner. In a well-established operational squadron environment, the formal communications links and reports are generally adequate for their purpose. For an aircraft system at this stage in its development, and with this level of uncertainty for its immediate and long-term future, there is a need to keep the participants "in the loop" to a greater extent than the formal reporting systems would allow. More informal updates, factory visits by the operators (some already completed at this writing), and frequent squadron visits by the engineers and managers would help. Eventually, when the aircraft is flying, and the Marines and Airmen are busy training and building new squadrons, this need for extraordinary communications will subside, and, with the possible exception of the system safety program, the formal reporting system should suffice.

The maintainers of VMMT-204 gave the OSC high marks for the cooperation and support provided to them. Both the Government and Bell Boeing need to be more proactive in utilizing the OSC as a conduit to VMMT-204. In addition, the OSC should act as a conduit for the vetting of VMMT-204 concerns to both organizations. They probably will not be able to step beyond normal reporting by themselves; they will need program and contractor management help.

Conclusion: The Osprey Support Center appears to be an appropriate vehicle to improve the communications flow throughout the operations and engineering and support community;

however,

Conclusion: The management attention provided by the contractors appears to be at too low a level, and the feedback for operational problems is too limited and slow.

Recommendation: Both the Government and Bell Boeing should increase the management visibility of the Osprey Support Center and decrease the turnaround time for relevant problem-resolution status.

Recommendation: Bell and Boeing CEOs, the V-22 Program Manager, and the Joint Program Office meet monthly to review program status until the current concerns are resolved.

4.4 PROGRAM DEVELOPMENT RESERVES

The V-22 Program lacked funding reserves to address unexpected contingencies during development. Design maturity was effectively delayed because needed changes could not be made during development and were deferred to production. In addition, reserves during early production were insufficient, thereby delaying design maturity further. (See Subsection 4.6 Engineering Production Changes.)

Resources to address unforeseen and unforeseeable circumstances that occur, even in the best-managed development programs, are required or design maturity is effectively deferred to the production phase. Additional reserves during the development phase are much more efficient since changes can be made quickly and do not force costly production cut-ins and even more costly retrofit. The complexity of the V-22 aircraft also suggests that a higher level of reserves is required.

The Navy's unwritten budget policy for development is to cut any management reserves from any budget requests prior to submission to the Office of the Secretary of Defense. Since there is a 2-year window to obtain additional resources through the traditional budget process, the program went through significant program restructures to accommodate shortfalls. These shortfalls resulted in such actions as modified training devices and deferred spares and logistics support. CV-22, which is still in development, is still not fully funded to the current estimate and does not have any development reserves.

Conclusion: Reserves are needed to address unknowns for even the best managed programs. No reserves for V-22 development and early production resulted in a lack of design maturity commensurate with proposed full-rate production in December 2000. CV-22 probably will have some unknown contingencies arise that are not funded.

Recommendation: A funding reserve should be provided and protected during the DoD budget process for unknown contingencies for CV-22 development and to address the additional design and development and the Development Maturity Phase recommended by the Panel.

4.5 CV-22 BLOCK 0 DEVELOPMENT

In December 1994, the Deputy Secretary of Defense specified the funding responsibilities for the V-22 Program. The Navy would fund MV-22 development and production. The Navy also would fund CV-22 development with no cost limit specified. The Air Force would fund the basic MV-22 airframe. The United States Special Operations Command (SOCOM) would fund CV-22 special operations forces unique equipment.

On April 4, 1997, the Under Secretary of Defense for Acquisition and Technology approved the Navy's request to enter low-rate initial production and associated documentation. In addition, future production decisions were delegated to the Navy.

The Navy and SOCOM negotiated an agreement that split the JORD requirements into a baseline CV-22 aircraft needed for Initial Operational Capability (IOC) and the preplanned product improvement program (now Block 10, which SOCOM accepted as its responsibility). In November 1997, the Navy and SOCOM signed an agreement whereby the Navy agreed to fund the CV-22 development effort for the Block 0 program to a maximum amount of $560 million (raised from $550 million). CV-22 Block 0 EMD projected cost increases are estimated at $657 million, or $97 million over the cap. The Program Manager projects that the funding cap will be exceeded by June 2002, with no source for additional funds identified.

Conclusion: The funding cap restricts accomplishment of minimal essential requirements for Initial Operational Capability. If the cap is removed, funding responsibility must be identified. Because the aircraft is currently grounded and the monthly spending rate has slowed, the program is vulnerable to funds migrating to other

Service programs. If this occurs, funds may not be available to complete necessary work recommended by this Panel.

Recommendation: Remove the CV-22 Block 0 funding ceiling and fund at the required levels. Retain the funds in the program until the Secretary of Defense considers the Panel's specific recommendations.

4.6 ENGINEERING PRODUCTION CHANGES

If the aircraft design does not mature in development (see previous issue on Funding Reserves in Development), aircraft modifications in LRIP aircraft will be necessary and more extensive. The Department of the Navy typically allows 2 percent of the program budget for engineering changes at mature production, with higher rates allowable prior to that point. Mature production is usually defined as the point at which full-rate production is initiated. The 2 percent rate does not consider the complexity of the aircraft system and the changes required based on fleet or production line experience. The budget allowance for V-22 production engineering changes in the first four LRIP lots was less than 1 percent (cumulative rate).

Additionally, in order to modify a fielded MV-22 (retrofit), a separate funding line (Aircraft Procurement Navy-5) and full funding is required. To date, neither the funding line nor the funds has been established. Since CV-22s are not in production, retrofit is not an issue at this time; however, CV-22 will need to avoid this same problem.

Conclusion: Engineering changes have not been adequately funded during LRIP. Temporarily reducing the production rate to a minimum sustaining rate would free up funds for further development efforts. It also would allow engineering changes to be incorporated into the production line as soon as possible. However, reducing aircraft allows the funds to be vulnerable to other Service priorities. If this occurred, the funds would not be available for further development efforts.

Recommendation: Temporarily reduce production to a minimal sustaining rate until both the aircraft design and manufacturing processes mature. Funds generated by this reduction in aircraft should be protected in the DoD budget and made available for a Development Maturity Phase and increased production engineering changes. (See subsection 4.8 Program Funding).

Conclusion: Aircraft retrofit of fielded aircraft will be required for MV-22 and CV-22.

Recommendation: Establish an Aircraft Procurement Navy-5 funding line and provide funds. Assure that CV-22 retrofit is covered with funding line and funds, as appropriate.

4.7 SPARES AND LOGISTICS SUPPORT PLANNING AND PROVISIONING

The V-22 aircraft provides a significant advancement in warfighting capability. However, the introduction of this technology into the military logistics system must be supported with adequate spare parts and support. The adverse impact of inadequate spare parts on readiness was demonstrated during OPEVAL, as components failed at higher rates than predicted and spare parts levels were inadequate. Lack of replacement parts for frequently failed components resulted in delivery delays to the users and/or cannibalization of other aircraft on the production line at Amarillo, Texas, to support Operational Evaluation and recently the operational training squadron. The initial support allowance list was projected at approximately 1,600 components. The current spare parts requirement now stands at more than 6,000 components.

More than $700 million in spares funding was reduced in the out years by allowing five amphibious ships to share two sets of V-22 spares. A Naval Center for Cost Analysis (NCCA) independent cost estimate for spares, including those spares budgeted in the Navy Inventory Control Point account, was roughly $840 million ("then-year" dollars) higher than the Navy Fiscal Year (FY) 2002 Budget Estimate Submission for FY 2001 through FY 2013. The NCCA estimate did not take into account any sharing of spares aboard ship, but rather, estimated spares based on a percentage of recurring flyaway cost after examining historical spares costs on other Navy rotary and fixed-wing aircraft.

In addition, the NCCA assessment of logistics support (other than spares) was roughly $550 million (then-year dollars) higher than the Navy FY 2002 Budget Estimate Submission in support cost for FY 2001 through FY 2013. This included training equipment, technical publications, and other Integrated Logistic Support (ILS) and Government Production Engineering Support. These estimates were based on examining historical ILS costs on Naval rotary and fixed-wing aircraft as a percentage of recurring flyaway adjusted to reflect MV-22 unique program requirements (e.g., power by the hour vice tradition engine depot rework).

The Navy routinely funds spare parts to a level of approximately 85 percent of the program manager's requirement. The rationale for the Navy's approach is twofold: 1) a high level of unique spare parts that are redesigned or replaced result in excess unusable inventory, and 2) assumed commonality between platforms could yield cross-program efficiencies. However, the Navy's approach does not take into account the introduction of a new technology or capability. As the year progresses and actual rates develop, the Navy can and does supplement programs in need. In fact, the V-22 Program has received 100 percent of its requested funds based on the Navy's spares model, albeit later than needed. The problem is that actual spares requirements have tended to be higher than predicted by the model.

Conclusion: Production line experience and field data collected at VMMT-204 indicate that spare-parts availability was inadequate to sustain fleet operations.

Conclusion: The independent cost estimate by the Naval Center for Cost Analysis indicates that planned funding for spares and logistics support in the out years is insufficient.

Recommendation: Fund spare-parts levels and logistics support based on the results of the independent cost estimate and actual experience to date.

Recommendation: Fund additional engineering change proposals to improve reliability and to reduce spare parts requirements.

4.8 PROGRAM FUNDING

V-22 PROGRAM COST

In the FY1996 President's Budget submission, the Department of Defense increased its total funding commitment from $6.6 billion (which did not include production) to $52.9 billion. This change added 523 total aircraft, including 425 for the Marine Corps' MV-22 variant, 50 for the Special Operations Command's CV-22 variant, and 48 for the Navy's HV-22 variant.[2] Although this was a large investment by any measure, much of the required funding was outside the Future Years Defense Program period (FY 1996 – FY 2002) that was under consideration at that time.

The FY 2001 President's Budget (the most current budget approved by Congress) is substantially less, at $38.1 billion. This reduction was primarily in procurement and was due to the lowering of the inflation indices in the FY 1997 President's Budget, a reduction of 65 aircraft in the FY 1999 Quadrennial Defense Review (QDR), and aggressive cost-reduction efforts.[3]

The savings attributed to lower Office of Management and Budget (OMB) inflation indices are substantial at over $6 billion. Recent experience negotiating the FY 2001 production contract, currently on hold, suggests that these indices are optimistic and that contractors are experiencing significantly higher rates (5 percent versus 2 percent for Office of Management and Budget). The above factors and aggressive cost reduction efforts resulted in a reduction in average procurement unit cost from $87.9 million in the FY 1996 President's Budget to $67.3 million in the FY 2001 President's Budget (composite unit cost in then-year dollars of all variants). This was a significant unit cost reduction, particularly when logic would suggest that the QDR reduction of 65 aircraft would increase the average unit cost.

Yearly budget execution is another matter. In FY 2000, two V-22 aircraft were deferred annually from the planned procurement profile in order to award the FY 2000 procurement contract within the budgeted dollars. This slide in aircraft to the out years

[2] Comparison of December 1993 and December 1994 Selected Acquisition Reports (SARs).

[3] Comparison of December 1994 and December 1999 SARs.

resulted in an increase in the total procurement program of almost $900 million.[4] A similar deferral of aircraft annually and increase in total procurement would have been required to award the FY 2001 procurement contract with the available FY 2001 budget dollars. These FY 2001 potential increases were primarily due to: higher inflation and rates recently negotiated by the Defense Contract Management Command, a reduction in the anticipated learning curve efficiencies, and increased content.

Based upon the reliability and maintainability issues discussed in earlier sections of this report, the Panel believes the program is not mature enough for full-rate production or operational use. The Program should restructure by reducing production to a minimum sustainable level in order to provide funds for a Development Maturity Phase. This approach will also keep the number of aircraft requiring retrofit of any changes to a minimum. This Development Maturity Phase should be characterized by a phased approach to return to operations, including flight readiness reviews before each phase. To begin the Development Maturity Phase, the FY 2001 quantity must be reduced, and a congressional reprogramming request will be required to convert those procurement dollars to Research Development Test and Evaluation (RDT&E) dollars. The FY 2002 procurement quantity also must be reduced and converted to RDT&E, ideally in a revised FY 2002 President's Budget submission.

COST OF ALTERNATIVES

As mentioned in Subsection 1: The Need for the V-22, the Panel reviewed past studies, all of which compared the V-22 with existing aircraft or notional upgrades to existing aircraft. The Panel members were unaware of any future design ideas that could be considered reasonable alternatives nor did they review any Defense Advanced Research Projects Agency (DARPA) studies or Special Access Programs. Previous studies of alternatives for the stated mission of the V-22 have consistently shown that the V-22 capabilities exceed those of the alternatives. However, it is also consistently the most expensive. Table 7 shows a cost comparison of the V-22 with other potential helicopter alternatives.

Aircraft	Average Unit Flyaway Cost FY 2001 Constant $ M
MV-22	$47.6 – $51.4
CH-53 (Upgraded)	$42.8 –$43.3
CH-53E	$36.3 – $37.1
EH-101	$33.8
S-92	$25.2 – $27.2
UH-1Y	$9.4 – $10.0

[4] Comparison of December 1998 and December 1999 SARs.

CH-60	$20 – $22

Note: Currently the Office of the Secretary of Defense, Program Analysis and Evaluation Division, is updating the analysis of alternatives to the V-22. These cost data presented are consistent with their ongoing analysis.

Table 7: MV-22 and Possible Alternative Costs

The lower cost for the MV-22 is the baseline program (Milestone III, December 2000). The upper limit assumes a restructured program that slows production for several years to allow for additional design iterations and testing. The V-22 sunk cost is approximately $12 billion in then-year dollars through the end of 2001.

CH-46E and CH-53D alternatives are not shown because reintroducing these aircraft into production is not feasible. They are out of production and the alternatives described above are already in production or minimal efforts would be required to get them back into production.

To complete its look at alternatives, the Panel also reviewed a recent DoD assessment on the industrial base implications of V-22 cancellation. While not a factor in the Panel's conclusions, the analysis showed that Bell U.S. operations would be the most seriously impacted should the program be canceled. Not only would cancellation put the viability of Bell's Fort Worth and Amarillo facilities in doubt, it could be prohibitive to their ability to remain in the military helicopter market. V-22 is very important to the Boeing Philadelphia facility, where cancellation would cause a loss of capability and result in a very strong dependence on the Comanche program for continued viability. V-22 termination would also likely create discrete supplier base issues—particularly for those that rely on V-22 for a large percentage of their business base. A review should be done to ensure that technologies important to other DoD programs are not lost. Finally, at facilities doing both V-22 and other DoD work, the cost (primarily due to increased overhead apportionments) of these other DoD programs will increase. The effects of the Panel's recommended restructure will have to be evaluated in more detail by the Department.

Conclusion: The V-22 is the most expensive option; however, it is also the most capable and the only alternative that is capable of performing all of the stated missions of both the Marine Corps and Special Operations Command.

Recommendation: Proceed with the V-22 Program as the best alternative for the stated mission need.

Conclusion: Reducing yearly production rates and sliding aircraft to the out years allows the program to proceed without impacting other near-term DoD priorities; however, deferral of aircraft and a lower yearly profile will cause the total program procurement cost, and resulting average unit procurement cost, to increase substantially.

Recommendation: To address the specific actions identified in this report, temporarily reduce the production rate to a minimum sustainable level and reprogram funds that are freed to the Research, Development, Test, and Evaluation account to apply to the Development Maturity Phase and increased production engineering changes. Incorporate resulting changes into the production line as early as possible. Funds generated by this reduction in aircraft should be protected in the DoD budget.

Conclusion: Higher production rates in the out years, coupled with multiyear procurement, could offset the additional cost of deferring aircraft to later years.

Recommendation: Once the Development Maturity Phase is complete, establish a maximum economic production rate and buy out the remaining aircraft with firm, fixed-price, multiyear procurements to help recover total program cost and schedule.

SECTION 3: SUMMARY CONCLUSIONS AND RECOMMENDATIONS

The need for a capability of the type the V-22 was designed to satisfy appears to be justified, and by its demonstrated performance, the V-22 has shown unique potential to meet that need. There is no evidence that the V-22 concept is fundamentally flawed; however, the aircraft is not ready for operational use in a number of key respects, chief among them system reliability and maintainability.

At this point, the soundest management approach for the V-22 Program is to restructure the program by temporarily reducing production to a minimum sustaining level while simultaneously initiating a Development Maturity Phase. Until completed, restrictions should be placed on operations. Passenger flights, night operations, and selection of aircrew all should be limited until the phase has progressed to the point where known risk issues have been properly addressed and confidence in the maintenance program has returned. The Development Maturity Phase should be initiated immediately and substantially completed prior to significant production or deployment.

The Development Maturity Phase should consist of subphases with a flight-readiness review by high-level Government and contractor leaders for each stage of operations (developmental flight test, operational flight test, training squadron operations, and start and deployment of the first tactical squadron). The Development Maturity Phase should focus on the following factors:

NEED

Summary Recommendation: Validate and prioritize requirements; delete those that are invalid or that rank poorly in cost/ benefit terms.

SAFETY

Summary Recommendation: Improve reliability, then verify by extensive test/fix/test in challenging environments.

Summary Recommendation: Expand safety risk assessments to include off-nominal conditions, with emphasis on flight control software, and hydraulic and power train systems. Retrofit crashworthy fuel cells into all operational aircraft.

Summary Recommendation: Extend high-rate-of-descent testing, formation flying (and other deferred flight tests as appropriate) to sufficiently define and understand the high-risk portion of the flight envelope under all appropriate flight conditions. Add a VRS cockpit warning system and appropriate simulator training.

Summary Recommendation: Make the flight manuals correct, explicit, and simple.

OPERATIONAL EFFECTIVENESS AND SUITABILITY

Summary Recommendation: Fix the existing maintenance publications system or adopt a new approach, such as the system currently being used by the F-18 or the one planned for the H-1 upgrade program.

Summary Recommendation: Provide better physical access to obstructed areas for inspection and maintenance by ground crews, and substantially refine the diagnostics system.

Summary Recommendation: Explore the suitability and limitations of the aircraft in such activities as tactical formation approaches, fast roping, and desert/night operations.

PROGRAMMATICS

Summary Recommendation: Proceed with the V-22 Program, but temporarily reduce production to a minimum sustaining level to provide funds for a Development Maturity Phase and keep to a minimum the number of aircraft requiring retrofit.

Summary Recommendation: Implement a phased approach to return to operations with flight-readiness reviews before each phase.

Summary Recommendation: Purchase adequate spares and logistics support.

Summary Recommendation: Establish sufficient funding reserves to permit the Program Office to deal with unforeseen and unforeseeable circumstances without disrupting the entire flow of the program.

Summary Recommendation: Increase formal and informal feedback among all members of the V-22 team.

Summary Recommendation: Initiate monthly executive-level program management meetings and continue throughout the Development Maturity phase. These meetings should involve the CEOs of both Bell and Boeing, the Navy Program Manager, representatives of the users (USMC and USSOCOM), and the Joint Program Office Director. Action items should be assigned and monitored.

Appendix A –

Charter and Memorandum From the Secretary of Defense

OFFICE OF THE UNDER SECRETARY OF DEFENSE

3000 DEFENSE PENTAGON
WASHINGTON, DC 20301-3000

ACQUISITION AND TECHNOLOGY

MEMORANDUM FOR SECRETARY OF DEFENSE
DEPUTY SECRETARY OF DEFENSE

THROUGH: UNDER SECRETARY OF DEFENSE (ACQUISITION, TECHNOLOGY AND LOGISTICS)
PRINCIPAL DEPUTY UNDER SECRETARY OF DEFENSE (ACQUISITION, TECHNOLOGY AND LOGISTICS)
DIRECTOR, DEFENSE RESEARCH AND ENGINEERING

FROM: DIRECTOR, STRATEGIC AND TACTICAL SYSTEMS
Approved by: Deputy Director, Land Warfare
Prepared by: Gary Gray//OUSD(A&T)/S&TS/LW/January 3, 2001 /697-0638

SUBJECT: V-22 Review Panel Charter

PURPOSE: To obtain your approval of the charter.

DISCUSSION:

- On December 15, because of the V-22's accident history and other testing issues, you appointed an independent high-level panel to review of the program. (Tab B)
- General John R. Dailey (USMC Retired) will serve as panel chair. Norman R. Augustine, General James B. Davis (USAF Retired), and Dr. Eugene R. Covert will be the other members serving on the panel.
- Attached is the charter that establishes the panel, subject to the Federal Advisory Committee Act requirements for filing and publication of the charter.

COORDINATION: ARA; Comptroller; Legislative Affairs; Director, Administration and Management; and General Counsel concur. See Tab C.

RECOMMENDATION: Approve the attached charter at Tab A.

SECDEF Decision:

______ Approved

SECDEF HAS SEEN
JAN 5 2000

______ Disapproved

______ Other: ______

14717-2001

CHARTER
PANEL TO REVIEW THE V-22 PROGRAM

A. Official Designation: Panel to Review the V-22 Program

B. Objective and Scope of Activity: Conduct an independent, high-level review of the V-22 program to include safety of the aircraft and recommend any proposed changes or corrective actions, and report the results to the Secretary of Defense. The panel shall comply with the Federal Advisory Committee Act (FACA), as amended, 5 USC, App.II, and DoD Directive 5105.4, the "DoD Federal Advisory Committee Management Program."

C. Period of Time Required: It is estimated that the panel members will take three-to-four months to complete their work.

D. Official or Sponsoring Proponent to Whom the Committee Reports:
Secretary of Defense.

E. Support Agency: The Under Secretary of Defense for Acquisition, Technology, and Logistics will provide the Designated Federal Official, who will also serve as Executive Secretary for the Panel. The Secretaries of the Military Departments, Chairman of the Joint Chiefs of Staff, and Director, Administration and Management, will provide cooperation and assistance to the panel as it carries out its review.

F. Duties and Responsibilities: The panel should address the following factors, as they affect strategy and combat effectiveness:

- Training
- Engineering and design
- Production and quality control
- Suitability to satisfy operational requirements
- Performance and safety of flight

G. Membership. The panel will be composed of four members. General John R. Dailey (USMC Retired) will serve as panel chair. Mr. Norman R. Augustine, General James B. Davis (USAF Retired), and Dr. Eugene E. Covert will be the other members serving on the panel. All members have substantial expertise, knowledge, and experience necessary in matters related to the V-22 review. Travel and per diem entitlements will be honored as prescribed in Chapter 57, Title 5 U.S.C.

H. Estimated Annual Operating Costs in Dollars and Work-Years: It is estimated that total cost for travel, per diem, consultant fees, and staff support will not exceed $600,000 and 1.0 staff-years.

I. Number of Meetings: The Panel will meet as often as necessary to fulfill its responsibilities within the three-to-four month time frame.

Termination Date: Thirty days after submission of the report of the Panel

Date Charter is Filed:

THE SECRETARY OF DEFENSE
1000 DEFENSE PENTAGON
WASHINGTON, DC 20301-1000

DEC 15 2000

MEMORANDUM FOR GEN (RET) JOHN R. DAILEY, USMC
MR. NORMAN R. AUGUSTINE
GEN (RET) JAMES B. DAVIS, USAF

SUBJECT: Review of the V-22 Program

On December 11, 2000, an MV-22 crashed, killing all 4 Marines on board. The cause of the accident is unknown at this time. The V-22 has experienced three other accidents since 1991. The Marine Corps suspended flight operations and requested a delay of the full-rate production decision until the cause of the most recent accident is fully understood.

The V-22 aircraft are intended to meet the Marine Corps amphibious and vertical assault mission, the Navy strike rescue mission, and the special operations needs of the Air Force and Special Operations Command (SOCOM). Variants of these aircraft will replace or supplement a range of aging platforms. As a result, the V-22 will make up a sizable component of our modernization program and warfighting capability.

The V-22's accident history and other testing issues necessitate that we undertake an independent, high level review of the program. You are hereby appointed to conduct this review, to include safety of the aircraft, and to recommend any proposed corrective actions. You should complete your review and report to the Secretary of Defense as soon as possible. Specifically, you should address the following factors, as they affect safety and combat effectiveness:

- ⇒ Training
- ⇒ Engineering and design
- ⇒ Production and quality control
- ⇒ Suitability to satisfy operational requirements
- ⇒ Performance and safety of flight

SIGNER'S COPY

By copies of this memorandum, I request the Secretaries of the Military Departments, Chairman of the Joint Chiefs of Staff, and Director, Administration and Management, to provide full cooperation and assistance to the panel as it carries out its review. I have asked General Dailey to serve as the Chair of the group. The Under Secretary for Acquisition, Technology and Logistics will provide an executive secretary for the panel.

cc: Secretary of the Army
Secretary of the Navy
Secretary of the Air Force
Chairman of the Joint Chiefs of Staff
Director, Administration and Management

APPENDIX B

PANEL MEMBERS AND STAFF BIOGRAPHIES

GENERAL JOHN R. DAILEY

John R. (Jack) Dailey, retired United States Marine Corps general and pilot, assumed the duties of director of the National Air and Space Museum in January 2000. General Dailey comes to the Museum from the National Aeronautics and Space Administration (NASA), where he had been the Associate Deputy Administrator since retiring from the United States Marine Corps in 1992. At NASA, he led the Agency's reinvention activities.

His career in the Marine Corps spanned 36 years and included extensive command and staff experience. He has flown over 6,000 hours in a wide variety of aircraft and helicopters. During two tours in Vietnam, he flew 450 missions. He was promoted to the rank of general and named Assistant Commandant of the Marine Corps in 1990. He has numerous personal decorations for his service in the Marine Corps and NASA.

While at NASA, General Dailey served on the President's Management Council, co-chaired the Aeronautics and Astronautics Coordinating Board, and was a national delegate to the Research and Technology Organization supporting NATO. He also serves as national commander of the Marine Corps Aviation Association and is a member of the Early and Pioneer Naval Aviators Association ("Golden Eagles").

General Dailey was born on February 17, 1934, in Quantico, Virginia, and earned his Bachelor of Science degree at the University of California, Los Angeles, in 1956. He and his wife, the former Mimi Rodian of Copenhagen, Denmark, live in Fairfax, Virginia. They have two grown children, Lisa Bader and Nils Dailey.

HONORABLE NORMAN R. AUGUSTINE

Norman R. Augustine was born in Colorado, attended East Denver High School and Princeton University where he graduated with a BSE in Aeronautical Engineering magna cum laude, an MSE, and was elected to Phi Beta Kappa, Tau Beta Pi and Sigma Xi. He holds honorary doctorate degrees in a variety of fields from many colleges and universities.

Beginning in 1965, he served in the Pentagon in the Office of the Secretary of Defense as an Assistant Director of Defense Research and Engineering. Joining the LTV Missiles and Space Company in 1970, he served as Vice President, Advanced Programs and Marketing. In 1973 he returned to government as Assistant Secretary of the Army and in 1975 as Under Secretary. Joining Martin Marietta Corporation in 1977, he served as Chairman and CEO from 1988 and 1987, respectively, to 1995, having previously been President and Chief Operating Officer. He served as President of Lockheed Martin Corporation upon the formation of that company in 1995, and became Chief Executive Officer on January 1, 1996, and later Vice Chairman and Chairman. He served as President of Lockheed Martin Corporation upon the formation of that company in 1995 and became Chief Executive Officer on January 1, 1996, and later Vice Chairman and Chairman. Mr. Augustine is Chairman and Principal Officer of the American Red Cross, is a former member of the Policy Council and Chairman of the Education Task Force of the Business Roundtable and a former Chairman of the National Academy of Engineering.

Mr. Augustine is co-author of *The Defense Revolution* and *Shakespeare In Charge* and author of *Augustine's Laws* (printed in four languages) and is listed in *Who's Who in America* and *Who's Who in the World*. He is married to the former Meg Engman of Stockholm, Sweden, and they are the parents of a son, Greg, an electrical engineer, now deceased, and a daughter, René, an attorney serving as Counsel to the Senate Judiciary Committee and married to Mark Alanie, an investment banker and former NBA player.

GENERAL JAMES B. DAVIS

In August of 1993, General J. B. Davis concluded a 35-year career with the United States Air Force as a combat fighter pilot, commander and strategic planner and programmer. He has served as a commander of a combat fighter wing, of the U.S. Air Force's Military Personnel Center, Pacific Air Forces, and United States Forces Japan. On the staff side, he served as the Director and Programmer of the U.S. Air Force's personnel and training, Deputy Chief of Staff for Operations and Intelligence Pacific Air Forces, and served his last two years on active duty as the Chief of Staff, Supreme Headquarters Allied Powers Europe (NATO).

During his military career he has had extensive experience in operations, intelligence, human resource management, and political/military and international affairs. He has commanded a nuclear capable organization of about 6,000 personnel and a joint service organization of about 60,000 personnel and several sizes in between.

After retirement from the military, General Davis has remained involved in his area of expertise, lecturing and speaking on international and aviation affairs. In February 1995, General Davis was nominated by the Speaker of the House of Representatives and confirmed by the Senate to sit on the Presidential Base Closure and Realignment Commission that reviewed the Secretary of Defense's closure list for 1995. In July 1995, the commission sent recommendations to the President Clinton, which were accepted and became law. Additionally, General Davis served on the Congressional Commission on Servicemember's and Veteran's Transition Assistance (The Dole Commission.) He is currently the president of a Japanese corporation and is the CEO of the American subsidiary. He served as the "Safety Czar" for Value Jet Airlines and continues to assist commercial airlines in strategic planning.

General Davis has a BS degree in Engineering from the U.S. Naval Academy, a Masters degree in Public Administration from Auburn University at Montgomery, has attended multiple professional schools and is a National Defense University Capstone Senior Fellow.

DR. EUGENE E. COVERT

Dr. Eugene E. Covert attended the University of Minnesota and earned his Bachelor of Aerospace Engineering and Master of Science degrees. He was awarded the Sc.D. from the Massachusetts Institute of Technology (MIT).

He currently serves as the Director of the MIT Center for Aerodynamic Studies and the Wright Brothers facility. He is the T. Wilson professor emeritus in the Department of Aeronautics and Astronautics at MIT. From 1952 to 1996 he has held positions as T. Wilson Professor of Aeronautics, MIT, Professor, Department Head, Associate Professor, Research Engineer and Associate Director. He has had a long and distinguished career in MIT.

Dr. Covert was Chairman (1982-1986) of the USAF Scientific Advisory Board, member of the NASA Aeronautics Advisory Committee (1985-1989), Vice Chairman and Chairman of the Aeronautics and Space Engineering Board (1988-1990), and National Research Council Committee on NASA Program Changes (1981 to present).

In addition to being the chief scientist of U.S. Air Force, Dr. Covert has also served as Chairman of the Air Force Scientific Advisory Board, as a member of the NASA Aeronautics Advisory Committee, and as Chairman of the AGARD Power and Energetics Panel.

He has served as a consultant for the Defense Science Board (1987-1994), Hercules Aerospace Corporation (1963-1994), Alliant Technology (1997-1998), Sverdrup Technology, Inc. (1976-present), United Technology corporation 1987-1990, Lockheed-Martin (1994-1997), TASC (1994-1998) and IDA (1995-present).

He is an honorary fellow of the AIAA, a Fellow of the Royal Aeronautical Society and the AAAS, and a member of the National Academy of Engineering. He is listed in *American Men and Women in Science, Who's Who in America, Who's Who in American Education, Who's Who in Science and Engineering, and Who's Who in the East.*

GARY J. GRAY

For almost 10 years, Mr. Gary has had oversight responsibility for DoD's high visibility rotary wing programs. Mr. Gray has considerable expertise in the Department of Defense's Planning, Programming and Budgeting System and participated in the 1997 Quadrennial Defense Review. In December 2000, Mr. Gray was assigned as Executive Secretary to the Secretary of Defense's high-level, independent Panel to Review the V-22 Program.

Mr. Gray moved to the Office of the Secretary of Defense (OSD) in the Office the Assistant Deputy Under Secretary for Land Warfare (in February 1989, as a participant in a Rotational Development Assignment). Since working in OSD, Mr. Gray's experience has broadened substantially. In addition to continuing his work on tank ammunition, he has expanded duties to include tactical missile systems, combat vehicles, tactical data systems and helicopter/tiltrotor systems.

He acquired technical management experience in 1978 as lead engineer for a 120MM kinetic energy tank round which was a cooperative effort with the Federal Republic of Germany (GE) and culminated in a successful Feasibility Demonstration in Germany within six months. Mr. Gray continued as Lead Engineer until accepting a systems engineering position as Program Director for the 105MM Tank Gun Enhancement Program for upgrading the M1 and M60A3 tank fleets. Mr. Gray transferred to the Office of the Project Manager for Tank Main Armament Systems in January 1983 as Deputy, and later, Senior Item Manager for the 105 Tank Gun Enhancement Program. Between these two roles, he contributed to the Type Classification of a new 120MM KE round, which was used extensively in Operation Desert Storm. In April 1988, he accepted the position as Senior Item Manager for the Armament Enhancement Initiatives Program where across-the-board responsibilities included programming and budgeting, streamlined acquisition and Congressional liaison.

Mr. Gray was born in Bayonne, NJ. His degrees include a Bachelor or Science in Mechanical Engineering in 1975 and a Master of Science in Management Engineering in 1979. Mr. Gray did his Master's thesis on *Management of a Producibility Study* based on his assigned responsibilities and practical experience. Both degrees are from the New Jersey Institute of Technology in Newark, NJ. Mr. Gray is married with two children and lives in Vienna, Virginia.

COLONEL CARL A. STEEL, USAF

Colonel Carl A. (Andy) Steel is Commander of the 305th Support Group, McGuire Air Force Base, New Jersey. As Commander, he is responsible for approximately 1,100 people and a $2.2 billion physical plant consisting of 500 facilities and 1,900 family housing units. He directs the base civil engineering, security forces, services, communications, and mission support squadrons.

Colonel Steel was a distinguished graduate of the Pennsylvania State Reserve Officer Training Corps program in 1978 after receiving a Bachelor of Medical Sciences degree. He is a command pilot with over 3,000 flying hours in the UH-1N and the B-52H.

His degrees include: 1978 -Bachelor of Medical Sciences, Pennsylvania State University; 1981-Master of Business Administration, Troy State University; 1981-Squadron Officer School, Maxwell Air Force Base; 1991-Master of National Security and Strategic Studies, Naval War College; 1995-Air War College, Maxwell Air Force Base.

His assignments include: 1978 – 1979: Student, Undergraduate Helicopter Training, Fort Rucker, Alabama; 1979 - 1982: UH-1N pilot, Detachment 9, 67 Air Rescue and Recovery Service, Zaragoza AB, Spain; 1982 – March 1984: Instructor/Evaluator Pilot and Chief of Operational Analysis, 1550 Aircrew Training and Test Wing, Kirtland AFB, New Mexico; August 1984 – April 1985: Special Events Project Officer, Washington DC; April 1985 – April 1986: Executive Officer, Office of the Deputy Chief of Staff for Plans and Operations, Headquarters United States Air Force, Washington, DC; April 1986 – February 1987: Student, Fixed-Wing Qualification Program & Bomber Qualification Training, Combat Crew Training and Test Wing, Randolph AFB, Texas and Castle AFB, California; February 1987 – August 1990: Pilot/Flight Commander/Operations Officer, 20th Bomb Squadron, Carswell AFB, Texas; August 1990 – August 1991: Student, Naval War College, Newport, Rhode Island; August 1991 – August 1993: Deputy, Chief of Assignments, Air Force Colonel's Group, Pentagon; August 1994 – July 1995: Student, Air War College, Maxwell AFB, Alabama; July 1995 – June 1997: Commander, 85th Flying Training Squadron, Laughlin AFB, Texas; June 1997 – July 2000: Director, Manpower, Personnel, and Administration Directorate, Headquarters, United States European Command, Stuttgart, Germany; August 2000 – Present: Commander, 305th Support Group, McGuire AFB, New Jersey

COLONEL RAYMOND E. SCHWARTZ III, USMC

Colonel Raymond E. Schwartz III, USMC, was commissioned in June 1977 upon graduation from Fairfield University in Fairfield, Connecticut. He was designated a Naval Aviator in October 1979 and upon completion of initial training in the CH-46 Medium Assault Helicopter at MCAS New River in Jacksonville, North Carolina, was transferred to HMM-265 in Kaneohe, Hawaii, for service with the Fleet Marine Force. His subsequent assignments included tours at Marine Aviation Weapons and Tactics Squadron One (MAWTS-1) in Yuma, Arizona, from 1984-88; Operations Officer for HMM-165 from 1988-91 (Desert Shield/Storm); Air Officer for the 3rd Marine Regiment 1991-92; Air Command and Staff College 1992-93; Assistant for USMC programs and POM systems coordinator for the Director Air Warfare N88C 1993-96; Executive Officer and Commanding Officer HMM-263 1997-99; National War College 1999-2000.

Colonel Schwartz holds a Bachelor of Arts in Political Science from Fairfield University 1977; Masters in Political Science from Auburn University 1993, and a Masters in National Security Strategy from the National War College, 2000.

He is presently serving as the Deputy, Marine Aviation Plans, Policy and Budget Branch, HQMC.

BRYAN O'CONNOR

Mr. Bryan O'Connor has over 25 years in leadership and staff positions in aerospace operations, research and development and flight-test. As a Marine pilot, he performed duties as Aviation Safety Officer for the first U.S. Marine Corps Harrier squadron. He led the team that performed the first Navy Preliminary Evaluation of the YAV-8B, Harrier II prototype. He served as Deputy Program Manager (Acquisition) for the AV-8B Program at NAVAIRSYSCOM. He participated in two missions as a NASA Space Shuttle Pilot Astronaut. He founded and led the NASA Spaceflight Safety Panel. Upon retirement from the Marine Corps in 1992, he served as Deputy Associate Administrator for Space Flight and Director of the Space Shuttle Program. He led the team that redesigned the International Space Station. He accumulated over 5000 hours in over 40 types of operational and R&D fixed wing and VSTOL aircraft, and nearly six million miles in 253 orbits of the earth in the Space Shuttle. He is the recipient of several awards including the Distinguished Flying Cross and the NASA Distinguished Service Medal. Member of Marine Corps Aviation Association, American Institute of Aeronautics and Astronautics, Association of Space Explorers, and Society of Experimental Test Pilots.

Mr. O'Connor has a BS in Engineering, United States Naval Academy, 1968; an MS Aeronautical Systems, University of West Florida, 1970; he attended the Aviation Safety Officer Course; Naval Postgraduate School; and the Naval Test Pilot School, 1976. Other formal training includes various management courses at NASA, University of Houston and George Washington University.

He is currently a leader of Futron Corporation's Washington, D.C. based Engineering Division, as well as the Aerospace Safety and Dependability Franchise. He is responsible for the technical content of the company's system safety, reliability and technical risk management services. He served as program manager for U.S. Marine Corps aviation risk management studies in support of the Harrier Review Panel. He is a lead consultant on FAA Reusable Launch Vehicle Safety study. He was an advisor to DOE on nuclear safety issues, and to NASA on a variety of safety and risk management issues, including a major probabilistic risk assessment for the International Space Station.

APPENDIX C

PANEL FACT-FINDING ACTIVITIES

January 11 and 12, 2001	Fact-finding Briefings, Program Overview
February 26, 2001	Fact-finding Briefings, Mishap Briefings, New Readiness Reporting System
March 5-8, 2001	Fact-finding Trips
	V-22 Training Squadron, Marine Corps Air Station, New River, NC
	Special Operations Command, Tampa, FL
	Bell Helicopter, Fort Worth and Amarillo, TX
	Boeing Helicopter, Philadelphia, PA
March 9, 2001	Open Meeting: Public Comments
April 12 and 13, 2001	Fact-finding Briefings, Final Information Requests
April 18, 2001	Open Meeting: Panel Deliberations

APPENDIX D

INSPECTOR GENERAL MEMORANDUM FOR CHAIRMAN

INSPECTOR GENERAL
DEPARTMENT OF DEFENSE
400 ARMY NAVY DRIVE
ARLINGTON, VIRGINIA 22202-4704

APR 30 2001

MEMORANDUM FOR CHAIRMAN, PANEL TO REVIEW THE V-22 PROGRAM

SUBJECT: Panel to Review the V-22 Program

This responds to your staff's verbal request of April 25, 2001, for information regarding the allegation that aircraft flight status records at the Tilt-Rotor Training Squadron 204, Marine Corps Air Station, New River, North Carolina, were falsified. Although our investigation is nearly complete, it remains active and therefore, I cannot provide you information concerning the results at this time. However, I have read the Panel's draft report and it is my opinion that none of the information gathered by the Panel contradicts information that we have independently developed during our investigation to date.

I trust you will find this information helpful to your review. Should you have any questions, please contact me or Mr. James L. Pavlik, (703) 604-8300.

Robert J. Lieberman
Deputy Inspector General

APPENDIX E

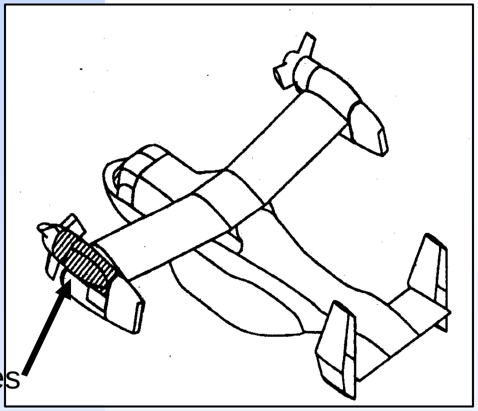
TOP TWELVE FLEET READINESS DRIVERS

24April 2001

Top 12 Fleet Readiness Drivers

	Nomenclature
1	Hydraulic Lines
2	ICDS Inspection
3	Constant Frequency Generator #1
4	EAPS
5	Click Studs
6	Swashplate Actuators
7	Mini-mark fasteners
8	Blade Fairings
9	Interface Units
10	Bonding Straps
11	IRS Transition Panel
12	Lower Crew Door

#1 Readiness Driver
Hydraulic Lines



Location of Chafed Tubes

Chafing

Background

• Chafing against electrical harnesses, clamps, baffles, structures, etc, primarily in the nacelles. This is driving excessive removal rates.

Issues

• Damage limits too conservative (?).
• Clearance requirements not always being met.
• IETM.
• Tubes are not readily available in supply.
• O, I and D-levels do not have the capability to manufacture tubes.

Actions

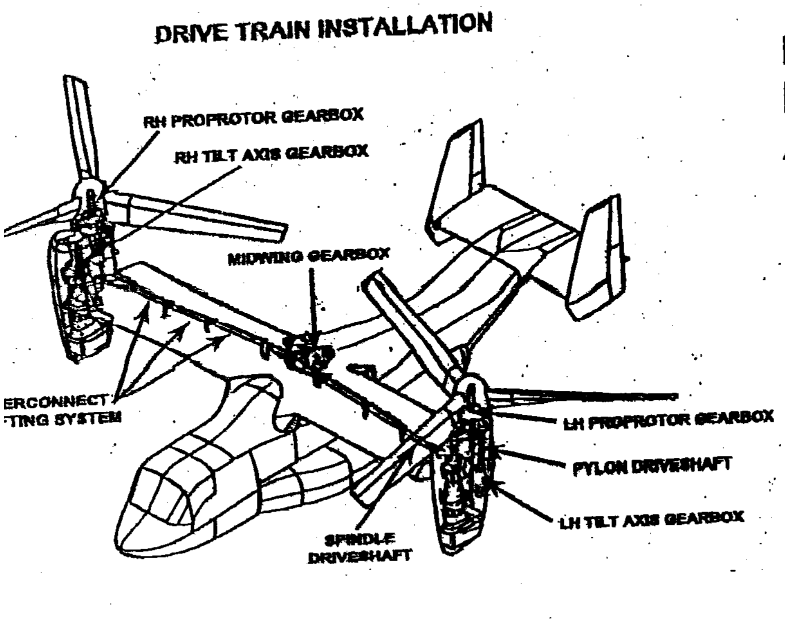
• Lab examination of environment conditions for hydraulic line clamps.
• NAVAIR testing to expand damage limits.
• Review of clearance requirements in work. A/C 21, EI's, etc.
• Wrap hydraulic lines with teflon tape, centered around support clamp locations.
• Update IETM.
• Bell-Boeing will establish suitable substitute matrix for Rynglok en fitting replacements to welded end fittings.

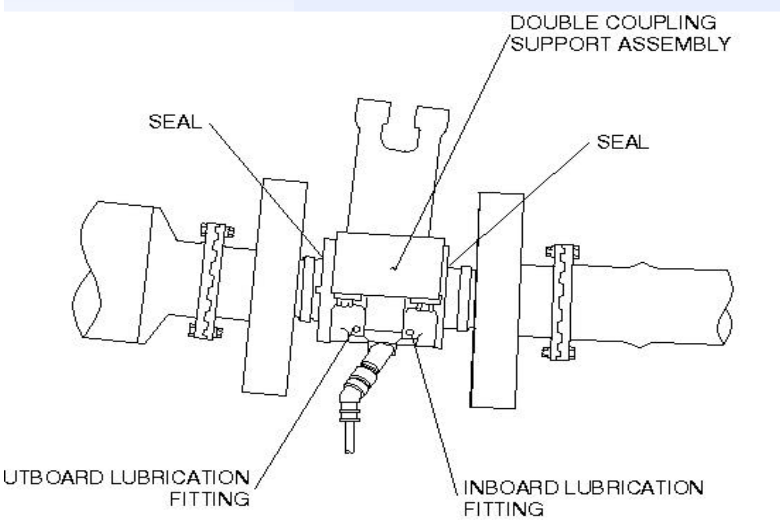
#1 Readiness Driver
Hydraulic Lines (Cont.)

Status 24 April 2001

- Review data from Amarillo nacelle inspections.
- Test to evaluate environment conditions and permanent fixes on hyd line clamps-ECD May 02.
- Test to expand damage Limits - ECD Aug 03.
- Bell is working on IETM update for teflon addition - ECD May 01.
- MALS-26 to have manufacture capabilities - ECD May 01
- NADEP CP will have capability to manufacture tubes upon receipt of Bell-Boeing suitable substitute matrix and bend data.

#2 Readiness Driver
Interconnect Drive System (ICDS)





Background:

- Failure of ICDS coupling in flight. A/C landed safely. VSLED system failed to detect failure. Investigation revealed a loose retainer assembly caused the lock ring to break, allowing the curvic joint to separate.
- EI indicated need for 3 changes: increased torque, removal of Dry Film Lubricant, Improved Lock Ring design

Issues:

- 35 hr recurring torque inspection prior to mod completion.

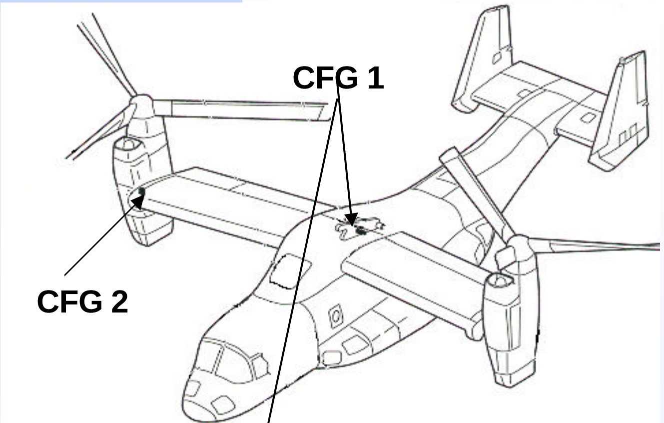
Actions:

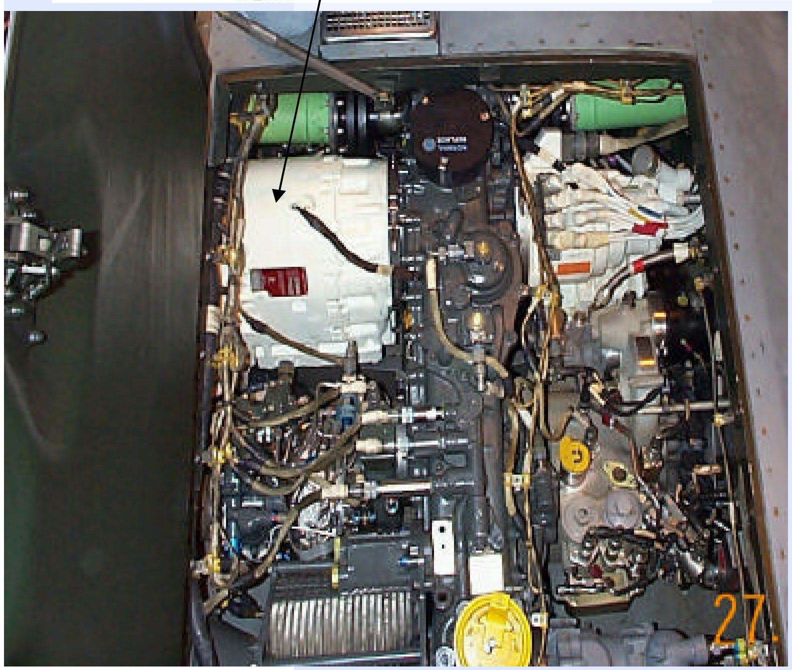
- Remove Tiolube 70 Dry Film Lubricant.
- Redesign and install new lock ring.
- Increase torque value.
- Eliminate the recurring 35 Hour inspection after modification.
- Improve the probability of early detection of curvic joint failures using VSLED data.

Status: 24 April 2001

- Engineering Change Proposal (ECP) has been approved to incorporate changes and modify fielded aircraft. ECD fleet incorp expected by 7/01. Estimated TAT for fleet couplings is now 6 weeks from original estimate of 2 weeks.
- ICDS from 165433, 165435, & 165441 shipped to Bell for incorp. Mod complete and shipset for 165441 received by fleet. 2nd shipset to Fleet ECD: 4/24/01.

#3 Readiness Driver
Constant Frequency Generator #1





Looking forward above MWGB

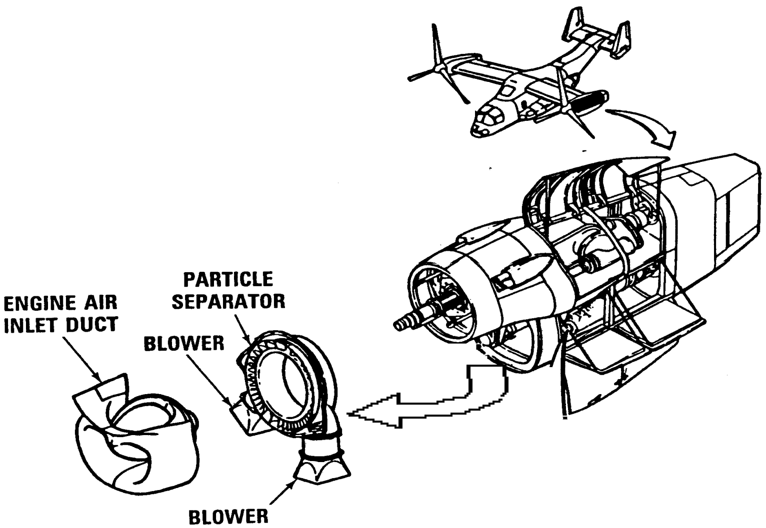
Background:
- Two CFGs per aircraft provide AC power
- Only CFGs installed in position 1 are failing

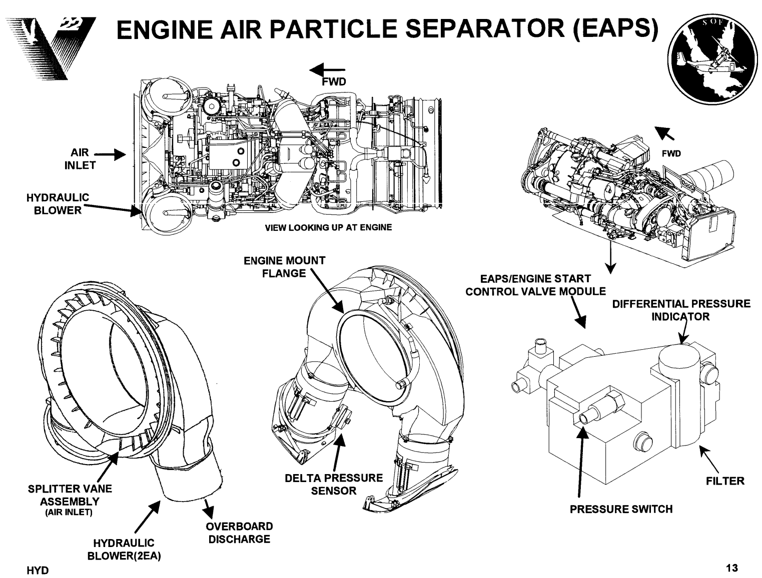
Issues:
- Failure due to rain and possibly moisture
- Generator directly under hinge; rain water drips into Mid-Wing Gear Box (MWGB), falls onto the CFG and seeps into Generator Control Unit (GCU)

Actions:
- Interim: seal GCU via Accessory Bulletin
- Permanent: redesign internal components to prevent water related failures
- Seal access panel or divert rain water

Status: 24 April 2001
- Accessory Bulletin 912 released to the fleet
- Interim generator fix being implemented; all available generators are modified
- Contract in work for long term internal fix
- RAMEC to seal hinge tested in Amarillo; final evaluation pending water test report
- New vendor Lot 6 (more robust requirements)

#4 Readiness Driver EAPS Overview





Background

- High frequency of EAPS failure warnings
- Low reliability of EAPS blowers
- High frequency of shaft seal leakage

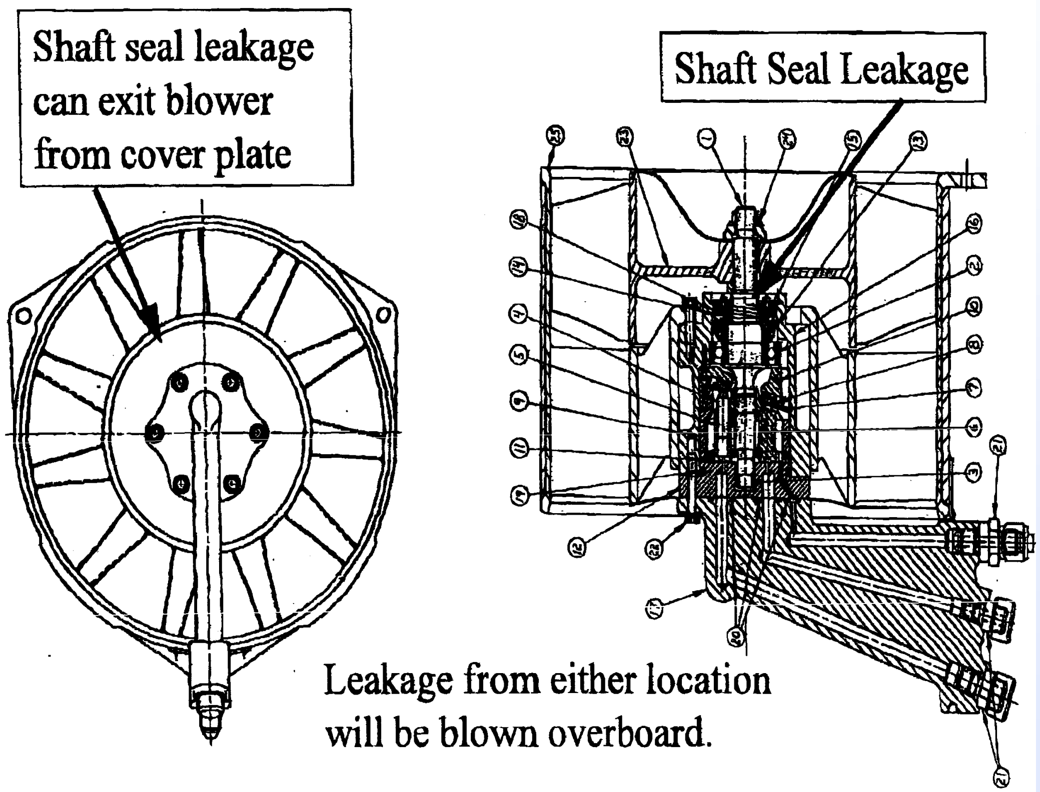
Issues

- Design discrepancies of internal blower motor parts
- Pneumatic delta-P sensors unreliable
- Shaft seal design under modification

Actions

- Vendor has modified blowers to the “B” model to improve reliability
- “B” model is installed on fleet acft via AVB-908
- Pneumatic pressure switches to be replaced with hydraulic pressure switches (ECP V-22-0187)
- Shaft seal design improvements suggested in new “C” model, still under consideration

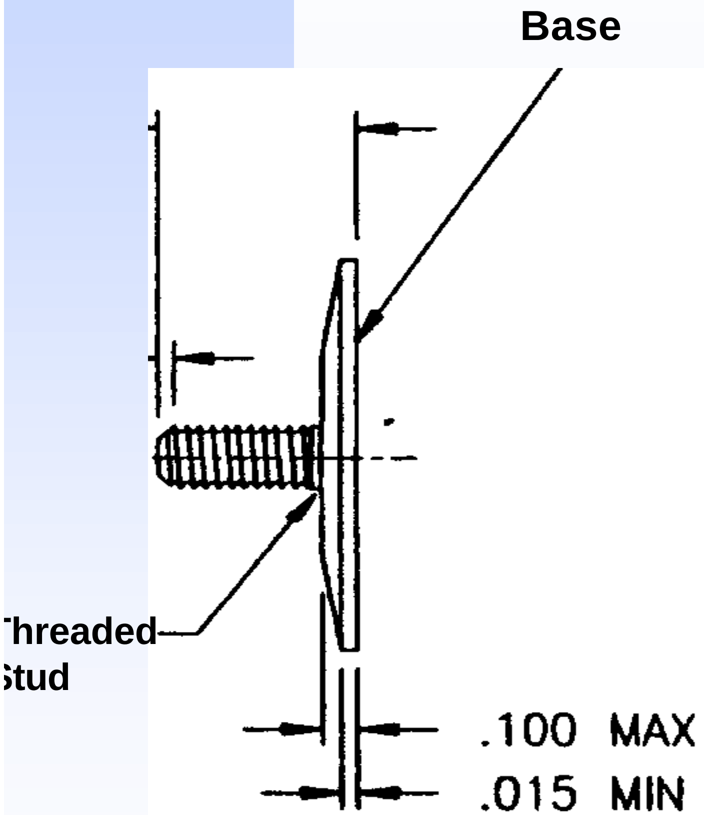
#4 Readiness Driver
EAPS Status



Status: 24 April 01

- Accessory Bulletin (AYB) 908 to replace unmodified blowers with reworked blowers that serial numbers end with “B” suffix has been released. AYB-908 complete on A/C 165433, 165435, 165437, 165438, 165439, 165441, 165442
- Awaiting Bell-Boeing proposal for funding and approval of ECP V-22-0187
- Proposed “C” shaft seal design change waiting authorization

5 Readiness Driver Clickstuds



Background

• Clickstuds bonded to the structure to secure various items on the airframe (ie., acoustic blankets, wire bundles, etc.) are disbonding from structure.

Issues

• Manufacturing and field repair bonding quality.

• Field repair room temperature cures require 5-7 days.

• Fleet requests authorization to reposition clickstuds, when required.

Actions

• Improve factory and field bonding techniques.

• Evaluate room/low temp. & rapid curing repair adhesives.

Status: 24 April 2001

• Additional training for manufacturing and fleet repair personnel on adhesive bonding techniques.

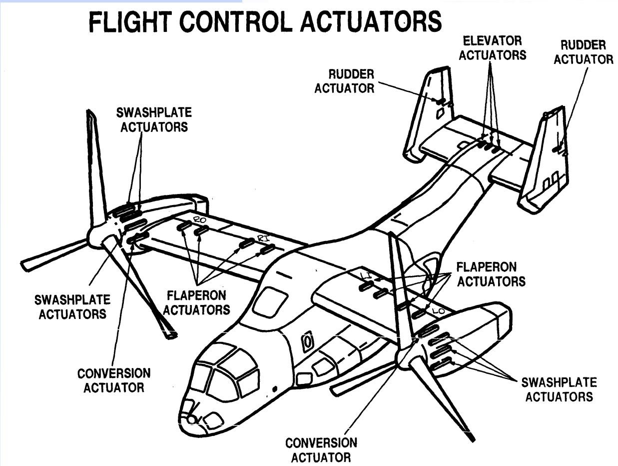
• Ongoing evaluation of alternative materials.

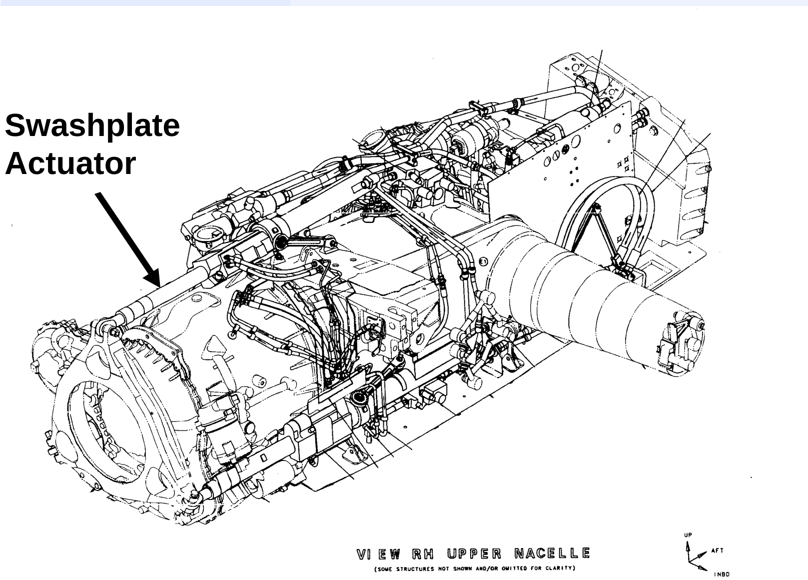
• ERAC 42 released

• ADHG sets delivered to VMMT-204

• Clickstud repositioning currently requires Engineering disposition

#6 Readiness Driver
Swashplate Actuator





Background

• Swashplate Actuators experiencing hydraulic leaks and PFBIT failures

Issues

• Swashplate actuator leaks

• Discrepancy exists between the PFBIT and the Acceptance Test procedures.

Actions

• Design Change to Dash 115 removes MCV dynamic seals for leakage improvements

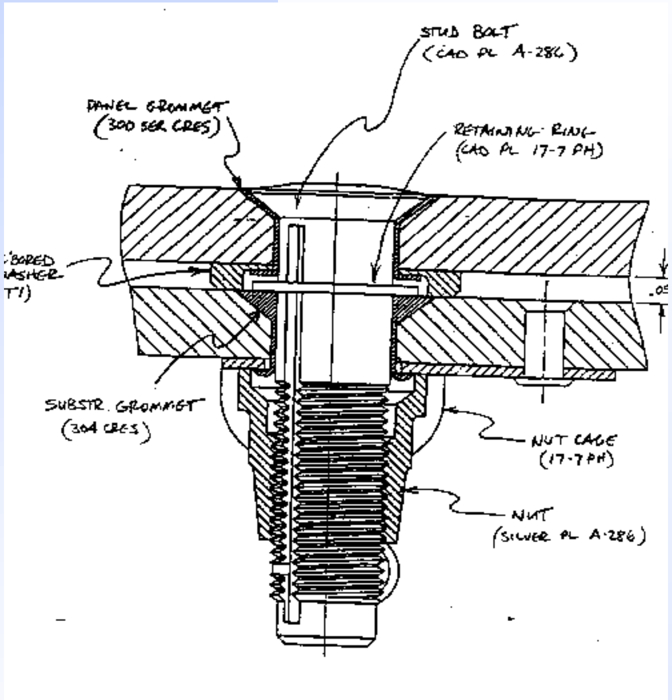
• ERAC 39 increases LVDT PFBIT tolerance with an accompanying software change to supercede the ERAC workaround

Status 24 April 2001

• CCP 10716 authorized incorporation of improved -115 actuators for Lot 4 delivery

• PFBIT software change has been incorporated into FCC software version 12 and retrofit into version 11.3

#7 Readiness Driver
Mini-Mark IV Fasteners



Typical Mini-Mark IV

Background

• Alternate fastener from FSD. However, high failure rate coupled with prodigious application is driving excessive maintenance

Issues

• Nutcage and retaining ring failures
• High procurement/replacement cost
• FOD hazard

•**Actions**

• Fairchild effort to improve fastener reliability
• Bell/Boeing study to reduce quantity of Mini-Mark IV and replace with standard fasteners
• SBIR to evaluate improvements and alternative designs

Status: 24 April 2001

• OEM and Bell/Boeing studies on-going
• SBIR in Phase I
• Reviewing alternatives from 01Mar01 mtg w/ Fairchild
• Fairchild, Bell-Boeing, FST and VMMT-204 met on 11 Apr 01 at Bell.

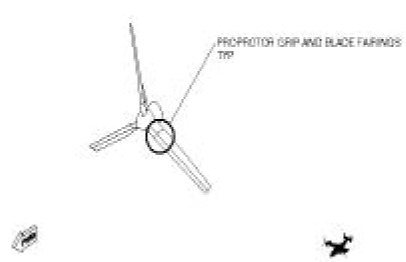
#8 Readiness Driver
Blade Fold Fairings

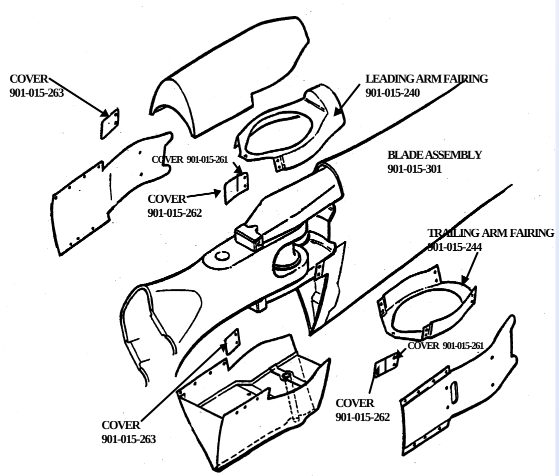
Background: Blade faring interference during blade fold operations have resulted in a significant number of cracked leading/trailing arm fairings and covers.

Issues:
- **High fairing failure rate**
- **Insufficient spares to respond to the current blade fairing failure rate**
- **Excessive maintenance man-hours and aircraft down time**

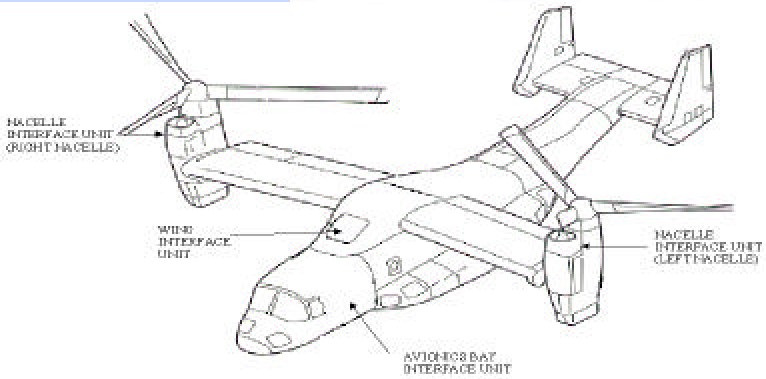
Actions:
- **Investigate the failure cause.**
- **If feasible, develop field level repairs.**

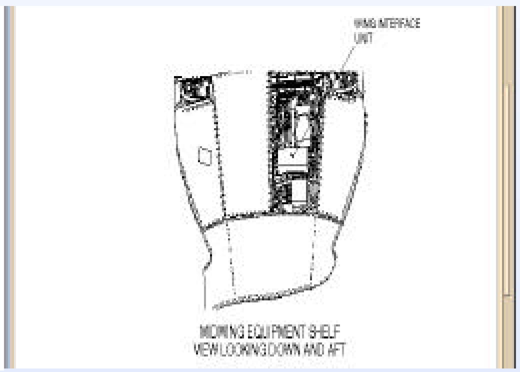
Status: 24 April 2001
- **Engineering investigations have identified the most likely cause of cracke fairings to be interference that occurs during the fold cycle.**
- **Bell PCA approved.**
- **ECP pending.**
- **Fairing Trim data available, waiting for Bell to provide trim data for Blade.**
- **Bulletin for fairing trim is in final coordination.**

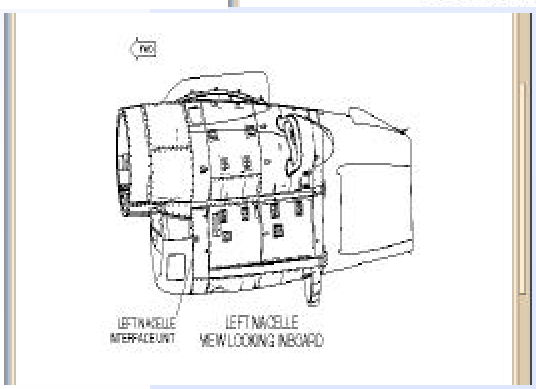




#9 Readiness Driver
Interface Units







Background:

- IUs provide data bus interface for equipment not data bus compatible (MIL-STD-1553)
- Four IUs per aircraft (avionics bay, wing, 2 in nacelle)

Issues:

- Failures due mostly to internal Resistor Network (RN) failures
- IUs failures was assigned 1D RAC because failures could result in a safety of flight risk.
- Due to quality discrepancy in manufacturing process
- Results in moisture intrusion and component failure

Actions:

a. Vendor (Vishay) has been drop as the vendor.

b. Ohmcraft has been brought on as the new vendor because Network Resistors manufacture by Ohmcraft have proven to be more reliable..

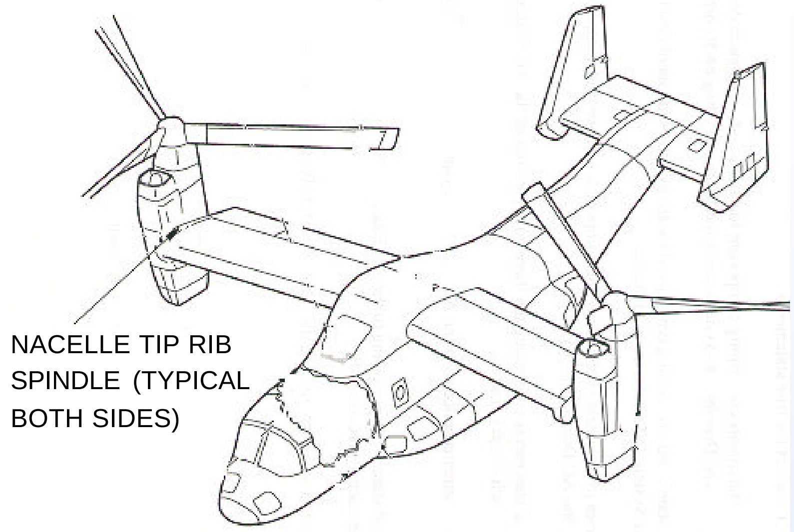
c. Boeing and Gov't to determined the method of which to retrofit the IUs.

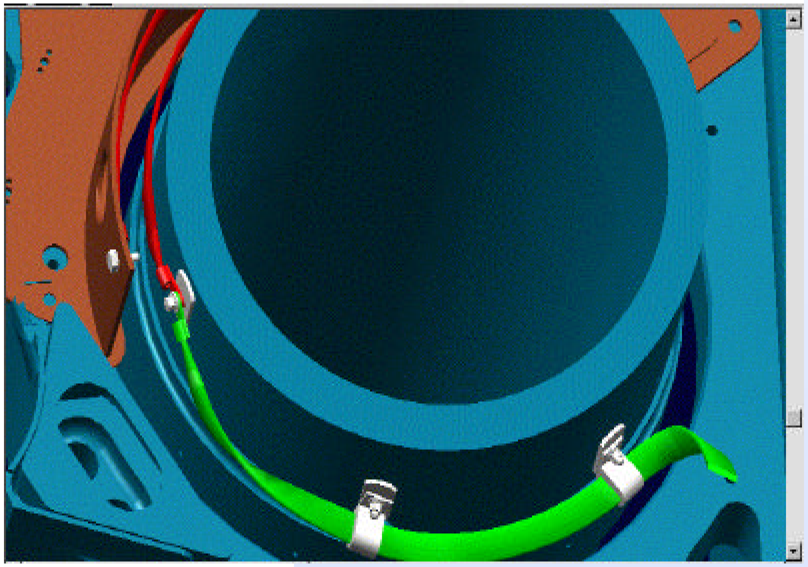
1. Replace RN that are flight critical and the rest by attrition.
2. Perform a 100% retrofit of all IUs.

Status: 24 April 2001

- Deliver improved IUs with new aircraft (tail # not defined)
- ASB is in development to retrofit IUs with Ohmcraft resistors.
- Resistor networks will be replaced with a Discrete Resistor in A/C 52

#10 Readiness Driver
Bonding Straps





Nacelle Tip Rib Spindle Straps

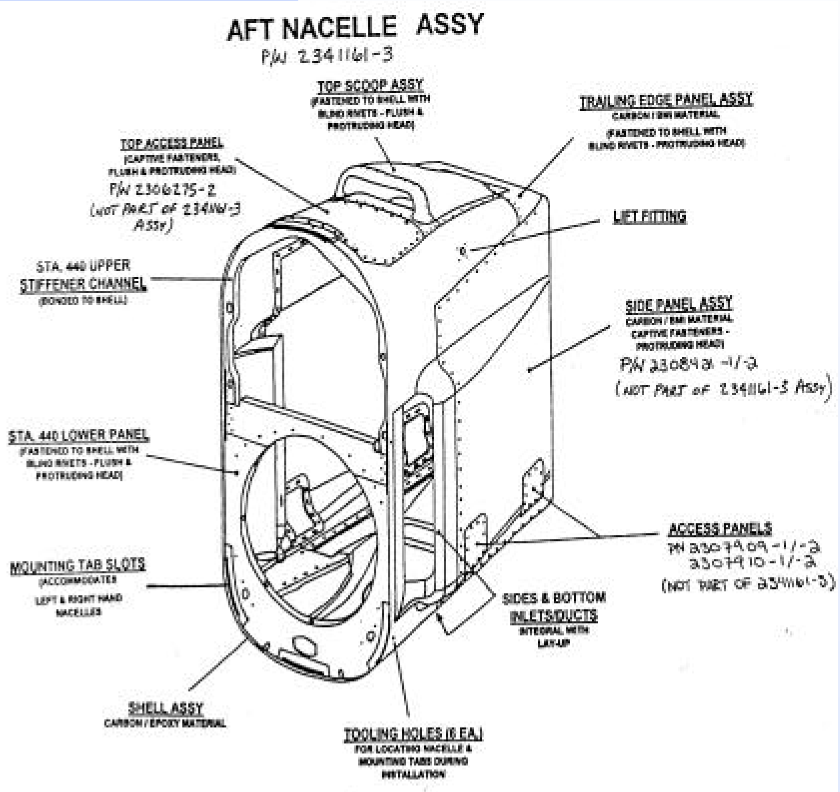
Background:
- Straps provide lightning path between the nacelle and wing
- Strap failures during OPEVAL and in Fleet
- Consumable items with no repairs
- FST provided procedures for straps for O-Level manufacture
- Performed EI (#WC2EI-V22-00-0162)
- Manufacture procedures developed for ALL bonding straps

Issues:
- Straps continue to fail
- Majority of failures pertain to 120-172 style straps

Actions:
- Short Term - FST provide authorization for shrink sleeve on terminal ends for manufactured and supply straps
- Long Term - Investigate new material/design for straps. Investigate Bell Wiring be cog for straps instead of Airframes.

Status: 24 April 2001
- Investigating new material/designs and routing for straps as part as overall Nacelle Inspection task
- Bell revising Bell Standard 120-172 to correct the usage of the wrong size terminal lug for width of straps

#11 Readiness Driver
IRS TRANSITION PANEL



Background

• Composite structural panels on IR suppressor are suffering heat and vibration damage.

Issues

• Heat damage and vibration causes frequent replacement of cooling panels and transition ducts.

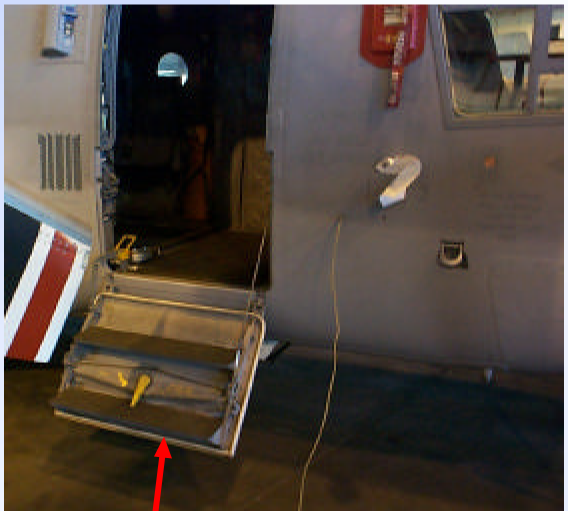
Actions

• Long term design change in work.

Status: 24 April 2001

• Honeywell investigating solutions for heat damage.

#12 Readiness Driver
Lower Cabin Door



Lower Cabin Door

Background

• While in hover the lower main cabin door fell open.

• Investigation revealed that the flush latch and assembly was broken. Pins had retracted and door unlatched.

Issues

• Latch and handle assembly does not latch door securely.

• Upper door and lower door are difficult to close.

Actions

• EI request submitted by VMMT 204 to V22 FST.

• Preliminary EI response shipped exhibit to Boeing for engineering investigation.

Status: 24 April 2001

• Final Bell EI report complete.

• Design changes currently in work to change handle material, step material,relocate door fittings and add witness holes.

• Boeing and FST inspected all aircraft at VMMT-204 on April 4-5. Found seals interfering with closing doors, excessive force required to engage pins, tracks badly damaged, rivets pulling through in track, and spring to retract pins into door ineffective.

• Detailed report of findings expected week of 16 April.

APPENDIX F

JORD SUMMARY

JORD Requirements

Num	(M)V (C)V (B)oth	Requirement	Current Status G/Y/R	Status Lot 5 G/Y/R	Status Lot 6 G/Y/R	Status Lot 7 G/Y/R	Status Lot 8 G/Y/R	Comments
012	C	The aircraft will have the ability to operate from air capable ships without reconfiguration or modification.	Y	Y	G			Port elevator on LHA has been demonstrated. Retractable refuel probe will allow use on all elevators.
017	B	The total time to execute a short notice launch shall be less than 60 minutes (T)/15 minutes (O) of mission receipt.	G					
018	C	Regardless of facilities available, the aircraft must have the capability to scramble launch with equipment necessary for flight operations within 30 minutes (T)/15 minutes (O) from crew arrival at the aircraft.	G					AWAITING CV IOT&E
019	B	The aircraft and its components must be protected from and be resistant to the effects of sand and dust	Y	Y	Y	Y	G	FINAL SDC IMPELLER FIX AND WINDSHIELD FIXES FURTHER OPERATIONAL TESTING REQUIRED
020	B	The aircraft and its components must be protected from and be resistant to the effects of snow and ice (T).	G					
021	B	The aircraft and its components must be protected from and be resistant to the effects of salt-laden air (T).	G					SINGLE POINT ENGINE RINSE WILL BE VALIDATED IN MV FOT&E
022	B	The aircraft must be capable of operations in temperatures ranging from +120 deg F/49 deg C to -65 deg F/-54 deg C (T). The aircraft must be capable of operating in +120 deg F/49 deg C to -20 deg F/-29 deg C range without modification kits or additional support equipment to cool, heat, or operate the aircraft. Modification kits may be used to achieve operations in temperatures below -20 deg F/-29 deg C.	G					OPEVAL DID NOT TEST EXTREME LOW TEMP. COMPONENT AND SUBSYSTEM QUALIFICATION TESTING DEMONSTRATED COMPLIANCE
023	B	The aircraft shall be capable of operations in moderate icing without adaptive kits (T).	R	R	R	G		Limited icing evaluation to be conducted at Pax winter of 00-01. Natural icing tests scheduled winter 01-02.
025	M	USMC Maximum Cruise Airspeed - 240 KTAS (T)/270 KTAS (O) at 3000 ft MSL/91.5 deg F/33.05 deg C, maximum designed gross weight (internal payload), and maximum continuous power.	G					

<u>CURRENT STATUS</u>
G Full Capability Exists or Threshold Met
Y Limited Capability Exists
R No Capability or Threshold Not Met

<u>STATUS ARROW</u>
↑ Ahead of Recovery Plan
→ Recovery Plan on Schedule or Not Required
↓ Behind Recovery Plan

<u>PROJECTION OF STATUS FOR LOT PRODUCTION</u>
G Complete or Meets Production Lot with Low Risk
Y Current Plan Meets Production Lot with Low or Medium Risk
R Current Plan Does Not Meet Production Lot
N/A CV Specific Requirement to Be Tested in CV OT-IIH

JORD Requirements

Num	(M)V (C)V (B)oth	Requirement	Current Status G/Y/R	Status Lot 5 G/Y/R	Status Lot 6 G/Y/R	Status Lot 7 G/Y/R	Status Lot 8 G/Y/R	Comments
026	C	USSOCOM Maximum Cruise Airspeed - 230 KTAS (T)/250 KTAS (O) at sea level, 0 ft PA, 59 deg F/15 deg C, in moderate turbulence, and at mission gross weight per defined mission profile.	G					CV IOT&E
028	B	Instantaneous G Loading - +3.5 to -1 instantaneous G's in fixed wing mode, and +3.0 to -0.5 instantaneous G's in the helicopter mode.	G					OPEVAL DID NOT RECORD G'S DURING TESTING.
029	B	Air Combat Maneuver (ACM) - The aircraft must be capable of performing air combat maneuvers (ACM) (T).	R					FLIGHT TEST, ANALYSIS, SIMULATION PLANS IN PLACE (UNFUNDED FY-03 ISSUE)
031	B	Shipboard short takeoff (STO) with a maximum takeoff roll of 300 ft, all engines operating, with the mission profile specific weights, with 15 knots of headwind across the deck.	G					
032	B	Ground-based STO from a dry/hard runway and clear a 50 ft obstacle, with a maximum takeoff roll of 3000 ft, all engines operating, at maximum gross weight, zero wind, 89.8 deg F/0 ft pressure altitude.	G					
033	B	One Engine Inoperative - The aircraft must be capable of operating at not less than 1,000 ft MSL (T)/7,500 ft MSL (O) using maximum continuous power, with the payload and 60% of the fuel required at engine start for the applicable mission profile.	G					
034	B	Power Off Glide/Autorotation - The aircraft must be capable of performing a survivable emergency landing with all engines inoperative (T).	Y					POWER-OFF GLIDE (GREEN), AUTOROTATION (RED) NATOPS PROCEDURES IN PLACE
037	B	Internal Payload, Cargo - Must carry an 8000 lb/3629 kg (T)/10,000 lb/4536 kg (O) internal load.	G					
038	B	Internal Payload, Cargo Space - Space must be sufficient to allow for the safe transportation of one light vehicle with trailer and sufficient seating for 4 personnel (1 air crew member and 3 vehicle crew members) with a combined maximum gross weight of 8,000 lbs/3629 kg.	G					

JORD Requirements

Num	(M)V (C)V (B)oth	Requirement	Current Status G/Y/R	Status Lot 5 G/Y/R	Status Lot 6 G/Y/R	Status Lot 7 G/Y/R	Status Lot 8 G/Y/R	Comments
039	B	Internal Payload, Cargo Space - Space must be sufficient to allow for the safe transport of four tandem-loaded 48" X 48" skid boards/platforms or two 463L half pallets (54" X 88") with a maximum gross weight of 4,000 lb/1814 kg (T)/5,000 lb/2268 kg (O)	G					Cargo rollers redesigned in A/C 19 and subsequent. VALIDATE IN OT-IIIA
040	B	Internal Payload, Cargo Space - The aircraft shall use, to the maximum extent possible, existing material handling equipment (MHE) for upload/download of internal cargo when required.	G					
041	B	Internal Payload, Cargo Space - Space must be sufficient to allow for the safe transport of small boats (T).	G					
042	B	Internal Payload, Cargo Space - Space must be sufficient to allow for the safe transport of 12 litters (T).	G					
043	B	Internal Payload, Internal Loading - Loading capability must provide configurations flexibility and support rapid reconfiguration of the cargo area. Routine configuration changes required to convert from one mission to the next must be achievable in field and shipboard environments by organizational level maintenance personnel.	G					Cargo rollers redesigned in A/C 19 and subsequent. VALIDATE IN OT-IIIA
044	C	Internal Payload, Internal Loading - Cabin reconfiguration timing from deployment to employment and/or employment to deployment configuration with one internal auxiliary fuel tank for installation/removal (to include operational checkout and servicing/defueling) will not be greater than 2 hours (T), 4 hours for two internal tanks (O).	G					CV IOT&E
045	B	Internal Payload, Internal Loading - Must incorporate a cargo winch to aid in cargo on-loading/off-loading (T).	G					
047	B	External Payload - The aircraft must provide single and dual point external load capability (T).	Y					NIGHT EXTERNALS RESTRICTED. LPIA RADALT UNDER INVESTIGATION.

CURRENT STATUS
G Full Capability Exists or Threshold Met
Y Limited Capability Exists
R No Capability or Threshold Not Met

STATUS ARROW
↑ Ahead of Recovery Plan
→ Recovery Plan on Schedule or Not Required
↓ Behind Recovery Plan

PROJECTION OF STATUS FOR LOT PRODUCTION
G Complete or Meets Production Lot with Low Risk
Y Current Plan Meets Production Lot with Low or Medium Risk
R Current Plan Does Not Meet Production Lot
N/A CV Specific Requirement to Be Tested in CV OT-IIH

JORD Requirements

Num	(M)V (C)V (B)oth	Requirement	Current Status G/Y/R	Status Lot 5 G/Y/R	Status Lot 6 G/Y/R	Status Lot 7 G/Y/R	Status Lot 8 G/Y/R	Comments
048	B	External Payload - The aircraft must provide selectable automatic, and electrical load release options from the cockpit and crew stations (T).	G					
049	B	External Payload - The aircraft must provide a manual emergency load release option from the cabin area as well as a center fuselage belly portal for inflight access to the external cargo hook(s) and load observation (T).	G					
050	B	Self-Deployment Capability - The aircraft must have a self-deployment range greater than or equal to 2100 nm with one refueling (T)/2100 nm with no refueling (O) on a tropical day. Fuel capacity must permit arrival over destination with enough usable fuel remaining to increase the total planned flight time between refueling points by the greater of 10% or 20 minutes at Best Endurance Velocity (Vbe) at 10,000 ft MSL. Crew fatigue considerations dictate that the 2100 nm leg be flown in 12 hours or less (T)/8 hours (O/USMC).	G					
051	B	Avionics - A redundant and fully integrated avionics suite is required (T).	G					
052	B	Avionics - The avionics suite must automatically control avionics systems to minimize crew workload, particularly at night, in low-level, adverse weather, and increased threat environments, and allow for graceful degradation of navigation capability.	G					CV IOT&E
053	C	Avionics - The Control Display Unit must allow ability to manipulate multifunction displays (T/USSOCOM/P3I).				G		P3I, BLOCK 10 INCORPORATION
054	B	Avionics - Avionics displays will be Night Vision Device (NVD) compatible and allow two pilot independent operations.	G					
055	B	Avionics - Electromagnetic compatibility and frequency spectrum assignments must be compatible with air strike packages and shipboard operations (T).	G					

JORD Requirements

Num	(M)V (C)V (B)oth	Requirement	Current Status G/Y/R	Status Lot 5 G/Y/R	Status Lot 6 G/Y/R	Status Lot 7 G/Y/R	Status Lot 8 G/Y/R	Comments
056	C	Mission Computer - The Mission Computer must integrate the radar (USSOCOM only).	G					CV IOT&E
057	B	Mission Computer - The mission computer must integrate Infrared Sensor System (ISS) and other navigation equipment to provide sensor update capability to the navigation system in use (T).	G					VALIDATE IN OT-IIIA
058	B	Mission Computer - The mission computer must be able to hold and process at least 200 Navigation Reference Points (NRP) (T).	G					
059	B	Mission Computer - The mission computer must be able to work in conjunction with the Digital Map (DM) to store, continuously update, and display DM threat intervisibility based on altitude (T).	G					
060	C	Mission Computer - The system must retain mission data using an internal backup power source for a minimum of 15 minutes (T)/30 minutes (O).	R					NO FEASIBLE CHANGE, PMA RECOMMENDS ORD CHANGE
063	B	Flight Control Computers - The aircraft must incorporate triply redundant flight control computers (T).	G					
064	B	Flight Control Computers - The aircraft must provide the aircraft pilot in command the capability to override nacelle position inputs from the copilot from either	G					
065	B	Flight Control Computer - The aircraft must provide the ability for either pilot to obtain maximum reserve power from the engines during critical phases of flight (T). To the maximum extent possible, aircraft controllability will not be limited during reserve power operations (T/P3I).	R					ECP IN-HOUSE BUT NOT YET FUNDED, TRADE STUDY INITIATED FOR CV UNIQUE CONCERNS
067	B	A Standard Digital Flight Data Recorder (SDFDR) capable of removal/replacement without special tools is required (T).	G					
068	B	Data Storage System (DSS) - A DSS with removable and portable nonvolatile solid state data storage medium (cartridge, disk, etc.) is required (T).	G					

Num	(M)V (C)V (B)oth	Requirement	Current Status G/Y/R	Status Lot 5 G/Y/R	Status Lot 6 G/Y/R	Status Lot 7 G/Y/R	Status Lot 8 G/Y/R	Comments
069	B	Data Storage System (DSS) - The DSS must allow the uploading, storing, and downloading of data between the aircraft's onboard integrated avionics system and computerized ground support systems (T).	G					
070	B	Data Storage System (DSS) - The DSS must allow the segregated downloading of classified and unclassified data and provide the capability to destroy classified information with minimal crew actions required (T).	G					
072	B	Data Storage System (DSS) - The DSS must interface with the appropriate service-unique mission planning system (T). Single point entry of mission planning and cryptographic data is desired (O).	G					
073	M	Data Storage System (DSS) - There must be an identified medium to accommodate the downloading of maintenance data in 15 minutes or less (T) to support maintenance debriefings, allow the rapid sorting and correlation of data points, and provide effective guidance for maintenance personnel (T). The unit/medium used to accept and process maintenance data must be compatible as a front end load to the Naval Aviation Logistic Command Management Information System (NALCOMIS) (T).	Y					SOFTWARE CHANGE INWORK TO MAKE MORE USER FREINDLY
074	C	Data Storage System (DSS) - There must be an identified medium to accommodate the downloading of maintenance data in 15 minutes or less (T) to support maintenance debriefings, allow the rapid sorting and correlation of data points, and provide effective guidance to maintenance personnel (T). The unit/medium used to accept and process maintenance data must be compatible as a front end load to the USAF Core Automated Maintenance System (CAMS), and the future Integrated Maintenance System (IMDS) (T).	Y					SOFTWARE CHANGE INWORK TO MAKE MORE USER FREINDLY
076	B	Automatic Flight Control System - An AFCS capable of altitude, airspeed, and heading hold is required (T).	G					

JORD Requirements

Num	(M)V (C)V (B)oth	Requirement	Current Status G/Y/R	Status Lot 5 G/Y/R	Status Lot 6 G/Y/R	Status Lot 7 G/Y/R	Status Lot 8 G/Y/R	Comments
077	C	Automatic Flight Control System - The ability to make a flight director coupled approach is required (T). The coupled approach shall provide automatic precision hover with vertical hold capability adjustable from 5-4900 ft Above Ground Level (AGL) (T/P3I).	R	R	G			JASS 2.7 WILL CORRECT
079	C	Joint Survivor Avionics - The survivor avionics must be capable of providing survivor identification and location and must be capable of handling multiple survivors simultaneously (T).	G					CV IOT&E
080	B	Communications - The aircraft is required to provide a simultaneous use, highly reliable, jam resistant, long range, secure voice and digital data burst communications capability (T). Communications must optimize interoperability and commonality with other DoD and civil systems (T).	Y					SEE INDIVIDUAL COMMENTS ON REQUIREMENTS 81 THROUGH 96 (JOINT POINT PAPER TO EXPLAIN COMMUNICATION ISSUES)
081	B	Communications - Communications are required to be effective at ranges varying from within a formation to Over-the-Horizon (OTH) (T).	Y					LIMITED OVER THE HORIZON CAPABILITY. CV IS CURRENTLY GREEN. PR 03 FUNDING REQUEST FOR LOT 9 MV INCORPORATION
083	B	Communications - Aircraft communications capabilities must include: UHF, VHF AM/FM and Satellite Communications (SATCOM) (T).	G					LIMITED SATCOM CAPABILITY.
085	B	Communication, Secure Voice and Data Communications - All UHF SATCOM voice and data communications will be narrow band secure voice and data capable in accordance with Joint Staff directive MCM-105-94 of 31 August 1994 to ensure joint interoperability with all existing and planned UHF SATCOM radios (T).	R					CV IS CURRENTLY GREEN. PR 03 FUNDING REQUEST FOR LOT 9 MV INCORPORATION
086	B	Communication, Secure Voice and Data Communications - All voice and data communications will be secure capable (T).	G					DOT&E WILL VERIFY WITH MOTT

JORD Requirements

Num	(M)V (C)V (B)oth	Requirement	Current Status G/Y/R	Status Lot 5 G/Y/R	Status Lot 6 G/Y/R	Status Lot 7 G/Y/R	Status Lot 8 G/Y/R	Comments
087	C	Communication - All UHF SATCOM radios will be both 5 and 25 khz Demand Assigned Multiple Access Capable (DAMA) to ensure joint interoperability with all existing and planned DoD UHF SATCOM radios (T/USSOCOM). The radio will be certified by Joint Interoperability Test Center to ensure DAMA Compliance.	G					CV IOT&E
088	M	Communication - All UHF SATCOM radios will be both 5 and 25 khz Demand Assigned Multiple Access Capable (DAMA) to ensure joint interoperability with all existing and planned DoD UHF SATCOM radios (T/USMC/P3I). The radio will be certified by Joint Interoperability Test Center to ensure DAMA Compliance.						P3I (PR 03 FUNDING REQUEST FOR LOT 9 MV INCORPORATION)
090	B	Communication - The aircraft must have an intercom (T).	G					
091	C	Communication - In addition to the cyclic and communications cord in the cockpit, a "hands off" (foot and voice) activated intercommunications capability will be provided for each of the three cockpit crew members (T/USSOCOM/P3I).	Y					P3I (FE STATION HAS NO FOOT SWITCH PMA RECOMMENDING ORD CHANGE)
092	B	Communications, Troop Commanders Station - provide a dedicated antenna jack compatible with a man-portable VHF (FM) radio and access to the aircraft's radios in the troop/cargo compartment (T).	G					
096	C	Communications, Troop Commander's Station - The troop commander's station provides a dedicated Troop Commander SATCOM antenna jack (T/USSOCOM/P3I)				G		BLOCK 10 INCORPORATION
098	B	Identification Friend or Foe (IFF)/Selectively Improved Flagging (SIF) - The IFF/SIF has Mode IV capability (T).	G					VALIDATE OT-IIIA
100	C	Identification Friend or Foe (IFF)/Selectively Improved Flagging (SIF) - The IFF/SIF is Mode S level 3 compatible with foreign and domestic navigation and identification systems is required (T/USSOCOM). (T)	G					CV IOT&E

JORD Requirements

Num	(M)V (C)V (B)oth	Requirement	Current Status G/Y/R	Status Lot 5 G/Y/R	Status Lot 6 G/Y/R	Status Lot 7 G/Y/R	Status Lot 8 G/Y/R	Comments
102	M	Identification Friend or Foe (IFF)/Selectively Improved Flagging (SIF) - DON-standard IFF capability (T).	G					VALIDATE OT-IIIA
103	C	Communications, Multi-mission Advanced Tactical Terminal (MATT) - The aircraft must include a MATT or feasible follow-on capability (T).	G					CV IOT&E
104	B	Communications, Global Navigation System - Global Air Traffic Management System (GATM) capability to meet air transport category requirements for domestic and foreign air traffic management operations is required (T/P3I)						P3I CV BLOCK 20 INCORPORATION. PR 03 FUNDING REQUEST FOR MV INCORPORATION, CURRENT PROJECTED STATUS - GREEN.
107	B	Mission Planning System - The aircraft design must include a mission planning capability which, at a minimum, integrates imagery, weather information, digital map, and communications functions (T).	Y					IMPROVEMENTS WILL BE VALIDATED IN OT-IIIA
108	B	Mission Planning System - The capability to modify/update mission data while airborne is required (T).	G					
110	B	Navigation - The navigation subsystem must incorporate redundant sources of precise location data (T).	G					
111	B	Navigation - Aircraft navigation capabilities include Global Positioning System (GPS).	G					
112	B	Navigation - Aircraft navigation capabilities include Inertial Navigation System (INS).	Y					INS CAPABILITY PROVIDED. HANDSET ALIGNMENT WILL BE VALIDATED IN OT-IIIA
113	B	Navigation - Aircraft navigation capabilities include Very High Frequency Omni-directional Range (VOR).	G					
114	B	Navigation - Aircraft navigation capabilities include Instrument Landing System (ILS).	G					
115	B	Navigation - Aircraft navigation capabilities include Tactical Air Navigation (TACAN).	G					

CURRENT STATUS
G Full Capability Exists or Threshold Met
Y Limited Capability Exists
R No Capability or Threshold Not Met

STATUS ARROW
↑ Ahead of Recovery Plan
→ Recovery Plan on Schedule or Not Required
↓ Behind Recovery Plan

PROJECTION OF STATUS FOR LOT PRODUCTION
G Complete or Meets Production Lot with Low Risk
Y Current Plan Meets Production Lot with Low or Medium Risk
R Current Plan Does Not Meet Production Lot
N/A CV Specific Requirement to Be Tested in CV OT-IIH

Num	(M)V (C)V (B)oth	Requirement	Current Status G/Y/R	Status Lot 5 G/Y/R	Status Lot 6 G/Y/R	Status Lot 7 G/Y/R	Status Lot 8 G/Y/R	Comments
116	M	Navigation - The aircraft must navigate to within GPS accuracy with a maximum error accumulation of 0.8 nm/hour (T). This performance must not be degraded by hostile jamming or deceptive countermeasures.	G					
117	C	Navigation - The aircraft must navigate a tactical profile to the full combat radius of the aircraft and locate a landing zone within two times the rotor diameter (T)/one times the rotor diameter (O), at night, in 1/4 mile visibility, from 100 ft AGL.	G					CV IOT&E
118	C	Navigation - The aircraft must demonstrate a 200 nm extended over-water navigation segment wherein the navigational accuracy of the aircraft must locate a landing zone within two times the rotor diameter (T)/one times the rotor diameter (O), in 1/4 mile visibility, at night, from 100 ft AGL.	G					CV IOT&E
119	C	Navigation - The aircraft must navigate the appropriate profile to a first-pass, coupled approach to a hover over the landing zone with no reliance on visual/sensor position updates by the crew during the flight (T). The same capability is required with the failure of one navigation subsystem given periodic visual/sensor position updates by the crew.	R	G				CV FOT&E
120	C	Navigation - The navigation system must provide groundspeed based on time-on-target calculation to a target waypoint to within plus or minus 10 seconds. Time-on-target calculation to the waypoint must be calculated and displayed independent of the flight plan steering (T).	G					CV IOT&E
121	B	Digital Map (DM) - A DM capable of presenting a plan view using Defense Mapping Agency (DMA), Digital Terrain Elevation Data (DTED), aeronautical charts, and photos (T).	G					

JORD Requirements

Num	(M)V (C)V (B)oth	Requirement	Current Status G/Y/R	Status Lot 5 G/Y/R	Status Lot 6 G/Y/R	Status Lot 7 G/Y/R	Status Lot 8 G/Y/R	Comments
123	B	Digital Map (DM) - DM must include zoom capability in all scales, countour lines, elevation color banding, cultural features, sun shading, and EOB and flight plan overlays (T).	G					
124	B	Digital Map (DM) - DM must be integrated with the mission computer to provide unslaved manual navigation selection which updates the selected navigation program and provides an autotrack capability to any selected NRP (T).	G					
125	C	Digital Map (DM) - The DM must interface with CONSTANT SOURCE and MATT or feasible follow-on capability; be able to receive, store, and recall updated terrain anomalies identified by other terrain sensors not identified in DTED; and be capable of receiving and displaying threat intervisibilities regardless of aircraft altitude (T).	G					CV IOT&E
126	C	Digital Map (DM) - The DM must be compatible with SOF unique mission planning system and the Air Force Mission Support System (AFMSS) (T).	G					CV IOT&E
127	C	Multi-Mode Radar (MMR) - The MMR must be integrated to allow the aircraft to conduct Terrain Following/Terrain Avoidance (TF/TA) flight operations 300 ft (T)/100 ft (O),day and night, in VMC and IMC including adverse weather conditions without the loss of terrain following capability(T).	G					CV IOT&E
128	C	Multi-Mode Radar (MMR) - With one engine inoperative (OEI), TF/TA command must reflect accurate TF/TA capability (T/P3I).				Y		P3I BLOCK 10 TF/TA COMMANDS WILL SUPPORT OEI, TF/TA PERFORMANCE WILL BE SIGNIFICANTLY DEGRADED
129	C	Multi-Mode Radar (MMR) - The MMR must have capabilities for TF/TA, ground mapping, weather detection, beacon mode, obstacle warning, and multifunction operation over multiple frequencies (T).	G					CV IOT&E

CURRENT STATUS
G Full Capability Exists or Threshold Met
Y Limited Capability Exists
R No Capability or Threshold Not Met

STATUS ARROW
↑ Ahead of Recovery Plan
→ Recovery Plan on Schedule or Not Required
↓ Behind Recovery Plan

PROJECTION OF STATUS FOR LOT PRODUCTION
G Complete or Meets Production Lot with Low Risk
Y Current Plan Meets Production Lot with Low or Medium Risk
R Current Plan Does Not Meet Production Lot
N/A CV Specific Requirement to Be Tested in CV OT-IIH

JORD Requirements

Num	(M)V (C)V (B)oth	Requirement	Current Status G/Y/R	Status Lot 5 G/Y/R	Status Lot 6 G/Y/R	Status Lot 7 G/Y/R	Status Lot 8 G/Y/R	Comments
131	B	Infrared Sensor System (ISS) - An ISS with contrast tracking (thermal reference), geo reference autotrack capability compatible with mission requirements, and four modes of stabilization (Flight Path Vector (FPV); Fix (Search, Fixed-Point Tracking and Update/Store); Hover; and Unslaved is required (T).	Y					ISS DOES NOT HAVE CONTRAST TRACKING. REQUIRES NEW FLIR, UNFUNDED
132	B	Infrared Sensor System (ISS) - The ISS must be integrated with the mission computer for navigational update capability in the unslaved mode and be able to autotrack to a navigational reference point in the slaved mode (T).	G					
133	C	Infrared Sensor System (ISS) - The capability to record ISS data (including symbology (T)) and voice (O) on a standard "off-the-shelf" camcorder is required (T).	G					CV IOT&E
134	M	Night Vision Goggle Head-up Display (NVG HUD/Helmet Mounted Display (HMD) - An integrated NVG HUD is required (T).	G					
136	B	Radar Altimeter - A radar altimeter incorporating audio low warning is required(T).	G					
137	C	Radar Altimeter - A Low Probability of Detection/Low Probability of Intercept (LPD/LPI) capability is required (T).	R					LPIA TESTING CURRENTLY PLANNED AS PART OF MV FOT&E.
138	B	Ground Collision Avoidance and Warning System (GCAWS)/Enhanced Ground Proximity Warning System (EGPWS) - A GCAWS with voice warning is required (T). The voice warning feature must be capable of being disabled by the aircrew in the cockpit for low-level flight operations (T).	R	R	G			JASS 2.7 INCORPORATION
140	B	External Lighting - A Landing Light for use with or without NVGs is required (T).	G					
141	B	External Lighting - Hover Lights for use with or without NVGs are required (T).	G					

JORD Requirements

Num	(M)V (C)V (B)oth	Requirement	Current Status G/Y/R	Status Lot 5 G/Y/R	Status Lot 6 G/Y/R	Status Lot 7 G/Y/R	Status Lot 8 G/Y/R	Comments
142	B	External Lighting - Position Lights for use with or without NVGs is required (T).	Y					POSITION LIGHTS NOT NVG COMPATABLE, PMA RECOMMENDS ORD REVIEW .
143	B	External Lighting - Anti-collision Lights for use with or without NVGs are required (T).	G					
144	B	External Lighting - Aerial Refueling Lights for use with or without NVGs are required (T).	G					
145	B	External Lighting - Formation Lights for use with or without NVGs are required (T).	Y					ECP FOR DUAL MODE OPERATIONS AND TO INCREASE LIGHT SIZE
146	B	External Lighting - Blade Tip Lights for use with or without NVGs are required (T).	G					
147	B	External Lighting - Search Lights, controllable by either pilot, and capable of providing visible and dimmable IR illumination for use with or without NVGs are required (T).	Y					IR searchlight not dimmable. PMA RECOMMENDS REQUIREMENT REVIEW
148	B	External Lighting - Probe Lights, controllable by either pilot, and capable of providing visible and dimmable IR illumination for use with or without NVGs are required (T).	G					
150	C	External Lighting - Covert external lighting is required (T).	G					CV IOT&E
151	B	Internal Lighting - Internal lighting for cabin, cockpit, and exits capable of normal and emergency illumination is required (T).	G					
152	B	Internal Lighting - Internal lighting must be NVG compatible, self-contained, automatic, and permanently installed (T).	G					
153	B	Internal Lighting - Emergency lighting must not require aircraft power for operation in emergency conditions and must be capable of being manually secured after activation (T).	G					

JORD Requirements

Num	(M)V (C)V (B)oth	Requirement	Current Status G/Y/R	Status Lot 5 G/Y/R	Status Lot 6 G/Y/R	Status Lot 7 G/Y/R	Status Lot 8 G/Y/R	Comments
154	M	Ballistic Tolerance - The aircraft must be resistant to flight critical damage imposed by hits in vital areas by 12.7 millimeters (mm) (T)/14.5 mm (O) Armor Piercing Incendiary (API) projectiles at 90 percent of their respective muzzle velocities. Greater levels of ballistic hardening/tolerance are desired and should be incorporated if achievable without significant aircraft performance or cost penalties.	G					ECP is in work to address issues with wheel well fire suppression.
155	B	Seating - Crashworthy seats are required for all crew members and passengers in the cargo area (T).	G					
156	B	Fuel Tanks - Permanently installed crashworthy fuel tanks must be self-sealing (lower one third) (T)/self-sealing entire tank (O) and nitrogen inerted (T).	G					
157	B	Fuel Tanks - Internally carried crashworthy cabin auxiliary fuel tanks must be nitrogen inerted (T) and self-sealing (T/USSOCOM)(O/USMC) to allow aircraft to deploy directly to a target area.				G		CV IOT&E LOWER 1/3 IS SELF-SEALING
158	B	Flotation - The aircraft must be capable of remaining afloat and upright, with engines secured, for two hours in Sea State 4 (International Code for State of Sea Scale) after a controlled ditching (T).	G					DEMONSTRATED THROUGH MODELING AND SIMULATION
161	B	Crash Position Indicator (CPI) - A CPI capable of being installed and removed without special tools by one person is required (T).	G					DOT&E WILL VERIFY WITH MOTT
163	B	Fueling/Defueling - The aircraft must include accommodations for both permanently installed internal tanks, and removable auxiliary tanks. Installation must be simple and easily accomplished in field and shipboard environments by organizational level maintenance personnel (T).	G					CV IOT&E

CURRENT STATUS

G Full Capability Exists or Threshold Met
Y Limited Capability Exists
R No Capability or Threshold Not Met

STATUS ARROW

↑ Ahead of Recovery Plan
→ Recovery Plan on Schedule or Not Required
↓ Behind Recovery Plan

PROJECTION OF STATUS FOR LOT PRODUCTION

G Complete or Meets Production Lot with Low Risk
Y Current Plan Meets Production Lot with Low or Medium Risk
R Current Plan Does Not Meet Production Lot
N/A CV Specific Requirement to Be Tested in CV OT-IIH

Num	(M)V (C)V (B)oth	Requirement	Current Status G/Y/R	Status Lot 5 G/Y/R	Status Lot 6 G/Y/R	Status Lot 7 G/Y/R	Status Lot 8 G/Y/R	Comments
164	B	Aerial Refueling - An aerial refueling receiver capability compatible with current USMC and USAF tanker assets utilizing probes and high, low, or variable speed drogues is required (T).	Y					M/KC-130 CLEARED AIRPLANE MODE ONLY. TEST PLANNED TO CLEAR C-130J AND KC135. KC-10 HOSE WHIP ISSUES PREVENT FURTHER TESTING AT PRESENT AND VSD IN DEVELOPMENT BY USAF.
165	C	Aerial Refueling - The capability to aerial refuel with one engine inoperative from a K/MC-130 tanker is required (T).	R					REQUIRES OEI TEST UTILIZING VSD. VSD IS STILL UNDER DEVELOPMENT BY USAF.
167	B	Ground Refueling - A single-point pressure refueling system, capable of operating with or without engines running, and a gravity refueling capability are required (T).	G					
168	B	Defueling - An integral pressure defueling capability is required (T).	G					
169	B	Fuel Dumping - The capability to dump/jettison fuel at 800 pounds per minute (T) is required/1000 pounds per minute is desired (O).	G					VALIDATE IN OT-IIIA
170	B	Fuel Purge System - The capability to purge all nonessential fuel lines after refueling or transferring fuel between tanks (T).	G					
171	B	Shipboard Compatibility - Full shipboard compatibility with air capable ships is required (T).	G					SHIPBOARD DYNAMIC INTERFACE TESTING ONGOING, AND WILL CONTINUE FOR THE LIFE OF THE AIRCRAFT. FOT&E WILL CLEAR REMAINING LHA/LHD SPOTS AND NIGHT STO.
172	B	Shipboard Compatibility - A blade fold/wing stow system allowing both automatic and manual (backup mode) fold/stow in winds up to 45 knots from any direction (T).	G					
173	B	Shipboard Compatibility - The capability to engage and disengage proprotors in windspeeds up to 45 knots	G					
174	B	Shipboard Compatibility - the capability to sustain winds up to 60 knots from any direction without damage to the aircraft once folded, stowed, and tied	G					

Num	(M)V (C)V (B)oth	Requirement	Current Status G/Y/R	Status Lot 5 G/Y/R	Status Lot 6 G/Y/R	Status Lot 7 G/Y/R	Status Lot 8 G/Y/R	Comments
175	B	Shipboard Compatibility - The capability to launch and recover from a maximum deck displacement of +-3 deg pitch and +-8 deg roll displacement from 0 deg centerline (T).	G					
176	M	Shipboard Compatibility - The capability to stow below deck on aircraft carriers, LHA, and LHD class amphibious assault ships (T).	G					
177	C	Shipboard Compatibility - The capability to stow below deck on aircraft carriers, LHA, and LHD class amphibious assault ships (T) without removing the aerial refueling probe (T).	R	R	G			RETRACTABLE REFUEL PROBE WILL ALLOW USE ON ALL ELEVATORS
178	B	Shipboard Compatibility - The aircraft must be resistant to the corrosive effects of the maritime environment and allow for freshwater wash of the airframe and engines (T).	G					SINGLE POINT ENGINE RINSE WILL BE VALIDATED IN MV FOT&E
179	B	Shipboard Compatibility - The capability to embark and operate 24 (T)/30 (O) aircraft from an LHA or LHD size ship with six JMVX-capable spots available for use.	G					DEMONSTRATED THROUGH MODELING AND SIMULATION, WILL ADDRESS ISSUES IN FOT&E
180	B	Cabin Restraining Devices - Cabin cargo loading tie-down fittings shall be accessible and compatible for attachment of aircrew personnel restraining devices (gunner's belt) are required.	G					
181	M	Reliability, Mission Reliability (MR) - MR must be at least 85% for a three hour mission (T).	G					
182	C	Reliability, Weapon System Reliability (WSR) - WSR must be greater than or equal to 0.77 is required (T)/greater than or equal to 0.84 is desired (O) for a four hour mission. This scenario assumes 100 percent of the missions will be flown at night as discussed in mission description.	Y					CV IOT&E .71 TO .84 BASED ON MV DATA EXTRAPOLATED TO CV CONFIGURATION
183	B	Reliability, Availability/Mission Capable (MC) Rate – An MC rate greater than or equal to 82% is required (T)/greater than or equal to 87% is desired (O).						DOT&E VIEWS STATUS AS RED. PMA VIEWS STATUS AS YELLOW (RM&A POINT PAPERS WILL BE PROVIDED)

JORD Requirements

Num	(M)V (C)V (B)oth	Requirement	Current Status G/Y/R	Status Lot 5 G/Y/R	Status Lot 6 G/Y/R	Status Lot 7 G/Y/R	Status Lot 8 G/Y/R	Comments
185	M	Maintainability, Scheduled/Preventive Maintenance - Ten hours continuous flight operation without exceeding scheduled/preventative maintenance inspection items is required (T)/12 hours continuous flight operation is desired (O).	G					
187	B	Maintainability, Mean Time Between Failure (MTBF) – An MTBF of at least 1.4 hours is required (T)/at least 2.0 hours is desired (O).	R	R	G			PLAN AVAILABLE FOR REVIEW
188	C	Maintainability, Mean Repair Time-Operational Mission Failure (MRTomf) - An MRTomf of 7 hours or less is required (T)/5 hours or less is desired (O).	G					CV IOT&E
189	M	Maintainability, Mean Repair Time (Abort)(MRTa) - An MRTa of 4.8 hours or less is required (T).	Y					VALIDATE IN OT-IIIA (MAIN OPEVAL PROBLEM CORRECTED)
190	B	Maintainability, Integrated Diagnostics - A 100 percent integrated diagnostics capability using automated, semi-automated, and manual diagnostics resources is required.	Y					SOFTWARE UPGRADES WILL BE VALIDATED IN OT-IIIA
192	B	Maintainability, Integrated Diagnostics - The aircraft shall achieve a Built-in-Test (BIT) Fault Detection (FD) rate of 70% (T)/85% (O).	G					
193	B	Maintainability, Integrated Diagnostics - The aircraft shall achieve a Built-in-Test (BIT) Fault Isolation (FI) rate of 70% (T)/85% (O).	G					
194	B	Maintainability, Integrated Diagnostics - The aircraft shall achieve a Built-in-Test (BIT) Fault Alarm (FA) rate of 25% (T)/15% (O).	R	R	G			JASS 2.7 WILL CORRECT
195	B	Mobilization and Surge Requirements - The aircraft must be capable of arriving at a staging base within 72 hours of initial mobilization notification and launching within 12 hours of arrival at the staging base (T).	G					

CURRENT STATUS
G Full Capability Exists or Threshold Met
Y Limited Capability Exists
R No Capability or Threshold Not Met

STATUS ARROW
↑ Ahead of Recovery Plan
→ Recovery Plan on Schedule or Not Required
↓ Behind Recovery Plan

PROJECTION OF STATUS FOR LOT PRODUCTION
G Complete or Meets Production Lot with Low Risk
Y Current Plan Meets Production Lot with Low or Medium Risk
R Current Plan Does Not Meet Production Lot
N/A CV Specific Requirement to Be Tested in CV OT-IIH

Num	(M)V (C)V (B)oth	Requirement	Current Status G/Y/R	Status Lot 5 G/Y/R	Status Lot 6 G/Y/R	Status Lot 7 G/Y/R	Status Lot 8 G/Y/R	Comments
196	B	Combat Support Requirements - The aircraft must provide ease of access for inspection and facilitate the rapid repair/replacement of aircraft components in the field.	Y					
197	B	Combat Support Requirements - A rapid repair of minor battle damage capability by Organizational Maintenance Activity (OMA) personnel is required (T). Battle damage assessment and repair procedures will be incorporated into the Interactive Electronics Technical Manuals (IETMs).	Y					UNREPAIRED DAMAGE LIMITS (UDL) FOR ALL CRITICAL COMPONENTS ARE FUNDED AND IN DEVELOPMENT. CONCURRENTLY, SPONSON DEPOT LEVEL REPAIR PROCEDURES ARE FUNDED AND IN DEVELOPMENT. FUNDING FOR DEVELOPMENT OF COMPOSITE DYNAMIC COMPONENT REPAIR PROCEDURES IS A PR03 ISSUE AND EXPECTED TO BE COMPLETE IN FY07
198	B	Combat Support Requirements - Rapid mission turn-around (refuel only) is required to be completed by no more than two qualified 15 minutes or less (T)/10 minutes or less (O).	G					
199	B	Service Life - A minimum aircraft service life of 20 years is required (T)/30 years is desired (O).	G					
200	B	Defensive Electronic Countermeasures (DECM) - An integrated DECM capability is required to support the detection, evasion, and/or countering of threat anti-air and air-to-air weapons systems. USSOCOM DECM requirements are detailed in a classified document.	G					
201	B	Defensive Electronic Countermeasures (DECM) - DECM capabilities will include passive IR suppression (T).	G					
202	B	Defensive Electronic Countermeasures (DECM) - DECM capabilities will include radar warning (T).	G					
203	B	Defensive Electronic Countermeasures (DECM) - DECM capabilities will include laser warning (T/P3I)	G					MV IS GREEN. P3I FOR CV BLOCK 10 INCORPORATION.

JORD Requirements

Num	(M)V (C)V (B)oth	Requirement	Current Status G/Y/R	Status Lot 5 G/Y/R	Status Lot 6 G/Y/R	Status Lot 7 G/Y/R	Status Lot 8 G/Y/R	Comments
204	B	Defensive Electronic Countermeasures (DECM) - DECM capabilities will include missile approach warnings (T).	G					(MV and CV lots 5,6) AAR-47 operational and tests completed in EMD. DIRCM will replace AAR-47 in lot 7 for CV.
205	B	Defensive Electronic Countermeasures (DECM) - DECM capabilities will include state of the art countermeasures, to include automatic and manual dispensing of expendables (T).	G					(MV) ALE-47 operational and tested in EMD. (CV) Testing is ongoing.ECP IN WORK TO ADD A FORWARD BUCKET TO INCREASE NUMBER OF EXPENDABLES
206	B	Defensive Electronic Countermeasures (DECM) - DECM capabilities will include switches for chaff and flare expendables located on the flight controls and at the scanner/observer stations in the cargo compartment, crew door, and cargo ramp (T).	Y					MV Chaff and flare switches are only located on the flight controls. CV IS CURRENTLY GREEN
208	C	Defensive Electronic Countermeasures (DECM) - DECM capabilities will include radio frequency jamming (T).	G					CV IOT&E
210	C	Defensive Electronic Countermeasures (DECM) - DECM capabilities will include a follow-on infrared jamming capability (T/P3I).				G		P3I BLOCK 10 INCORPORATION
212	B	Defensive Weapons - A mission configurable, selectable rate of fire, Night Vision Device (NVD) compatible weapon system is required (T). Space and power for USSOCOM requirements must be preserved (T).	R	R	R	R	G	Proposal recieved from Bell-Boeing and funded in FY-01
215	B	Nuclear, biological, and Chemical (NBC) Survivability - Electronic pulse hardening for survivability of flight critical components is required (T).	G					DEMONSTRATED WITH COMPONENT LEVEL TESTING
216	B	Nuclear, biological, and Chemical (NBC) Survivability - Fuselage and cockpit design must restrict the entry of contaminant agents into the aircraft's interior and must support the isolation/protection of the primary flight crew during ground operations (T).	Y					Overpressurization of aircraft not achievable, MOPP gear is required. PMA RECOMMENDS REVIEW OF REQUIREMENT

CURRENT STATUS
G Full Capability Exists or Threshold Met
Y Limited Capability Exists
R No Capability or Threshold Not Met

STATUS ARROW
↑ Ahead of Recovery Plan
→ Recovery Plan on Schedule or Not Required
↓ Behind Recovery Plan

PROJECTION OF STATUS FOR LOT PRODUCTION
G Complete or Meets Production Lot with Low Risk
Y Current Plan Meets Production Lot with Low or Medium Risk
R Current Plan Does Not Meet Production Lot
N/A CV Specific Requirement to Be Tested in CV OT-IIH

JORD Requirements

Num	(M)V (C)V (B)oth	Requirement	Current Status G/Y/R	Status Lot 5 G/Y/R	Status Lot 6 G/Y/R	Status Lot 7 G/Y/R	Status Lot 8 G/Y/R	Comments
217	B	Nuclear, biological, and Chemical (NBC) Survivability - Aircraft external and internal surfaces must be resistant to the adherence or effects of contaminants and be designed to facilitate rapid post-mission decontamination (T).	Y					COST EFFECTIVE SOLUTION NOT ACHIEVABLE WITH CURRENT TECHNOLOGY
218	B	Nuclear, biological, and Chemical (NBC) Survivability - All aircrew stations are required to be compatible with aircrew body armor and NBC protective garments and masks (T). All future modifications to the aircraft should be compatible with the Service's NBC ensemble (T).	G					
220	B	Environmental Control Unit (ECU) - A self-contained ECU capable of maintaining a suitable crew and cabin occupant comfort level throughout the operating environment is required (T).	Y					ECS UPGRADE CURRENTLY FUNDED
221	B	Oxygen System - An aircrew oxygen receptacle must be provided at each of the seven aircrew/scanner/observer stations (T).	G					
222	B	Oxygen System - The oxygen system must be self-contained, must not rely on external support for liquid oxygen, and must support the oxygen requirements for a crew of four from any four of the seven oxygen receptacles throughout the altitude range of the aircraft (T).	Y					ABOVE 18,000 FT REQUIRES SUPPLEMENTAL OXYGEN
223	B	Magnetic Heading Indicator - An easily readable, NVG compatible aircraft magnetic heading indicator in the troop/cargo compartment is required (T).	G					
224	B	Personnel Hoist - A variable speed (0 to 225 feet per minute) personnel hoist with at least 235 feet of useable cable is required (T).	R					HOIST NOT INSTALLED. CURRENT HOIST REQUIRES ADDITION OF CLUTCH. CAN EITHER ADD CLUTCH OR INTEGRATE CLUTCHED COTS HOIST. INVESTIGATING ALTERNATE LOCATION FOR HOISTING (UNFUNDED)

Num	(M)V (C)V (B)oth	Requirement	Current Status G/Y/R	Status Lot 5 G/Y/R	Status Lot 6 G/Y/R	Status Lot 7 G/Y/R	Status Lot 8 G/Y/R	Comments
225	B	Personnel Hoist - Hoist capacity must be at least 600 lb/272 kg up and down (T).	R					HOIST NOT INSTALLED. CURRENT HOIST REQUIRES ADDITION OF CLUTCH. CAN EITHER ADD CLUTCH OR INTEGRATE CLUTCHED COTS HOIST. INVESTIGATING ALTERNATE LOCATION FOR HOISTING (UNFUNDED)
226	M	Personnel Hoist - The hoist must have the capability to be operated by a non-flying crewman from the cabin door/cabin area (T). Operation by either pilot from the cockpit is desired (O).	G					CONTROL PROVISIONS IN PLACE
227	C	Personnel Hoist - The hoist must have the capability to be operated by a non-flying crewman from the cabin door/cabin area and simultaneously be controlled from the cockpit (T).				G		P3I BLOCK 10 INCORPORATION
228	B	Aerial Delivery Provisions - Provisions for aerial delivery (airdrop) of personnel and various types of loads are required (T). Airdrops will be both static-line and free fall parachuting for personnel; static-line parachuting and free fall (no chute) for equipment. The cargo ramp will be the primary exit for airdrop, but the ability to airdrop personnel and equipment bundles from the cabin door is also desired (O).	G					ALL AERIAL DELIVERY CAPABILITIES WILL BE VALIDATED IN OT-IIIA EXCEPT AIRDROPS FROM THE CABIN DOOR
229	B	Aerial Delivery Provisions - The ability to airdrop from the ramp two, simultaneous, six-man sticks of parachutists or jumpers.	Y					Physical dimensions of ramp do not allow simultaneous six man sticks. Twelve jumpers serially can be accomplished.
230	B	Aerial Delivery Provisions - The ability to airdrop from the ramp up to four 500 lb/227 kg, sequentially-loaded, A-7 or A-21 containerized delivery system bundles.	G					
231	B	Aerial Delivery Provisions - The ability to airdrop from the ramp small vehicles and palletized equipment.	G					Palletized equipment demonstrated. No vehicles.
232	B	Fast Rope - The aircraft must provide the capability to employ two Fast Ropes off the ramp and one out the cabin door to quickly deploy personnel in a hover (T).	Y					No FASTROPE operations from cabin door. (PMA RECOMMENDS JORD CHANGE FOR ALTERNATE LOCATION)

Num	*(M)V (C)V (B)oth*	*Requirement*	*Current Status G/Y/R*	*Status Lot 5 G/Y/R*	*Status Lot 6 G/Y/R*	*Status Lot 7 G/Y/R*	*Status Lot 8 G/Y/R*	*Comments*
233	C	Fast Rope/Rope Ladders - The requirement to employ the Fast Rope Insertion and Extraction System (FRIES) through both the ramp and cabin door is required (T).	Y					No FASTROPE ops from cabin door. (PMA RECOMMENDS JORD CHANGE FOR ALTERNATE LOCATION)
234	C	Fast Rope/Rope Ladders - The requirement to employ Stabilized Extraction Rigging (STABO) through both the ramp and cabin door is required (T).	Y					STABO operations conducted through cargo hook doors. (PMA RECOMMENDS JORD CHANGE FOR ALTERNATE LOCATION)
235	C	Fast Rope/Rope Ladders - The requirement to employ rope ladders through both the ramp and cabin door is required (T).	R					No certified rope ladder available or planned. (PMA RECOMMENDS JORD CHANGE)
237	B	Rough Terrain Operations - The aircraft must be capable of routine rough terrain VTOL operations without damage to the aircraft or components as a result of normal procedures.	G					
238	B	Safety - Airframe and component design and operation must be IAW existing standards to ensure the safety and health of aircrews and maintenance personnel.	G					LACK OF HANDHOLDS IN CABIN AREA.
239	B	Safety - Explosive devices incorporated into the weapon system design must be certified under the Hazards of Electro-magnetic Radiation to Ordnance (HERO) program (T).	G					
241	B	Combat Identification - The aircraft must provide an overall, general knowledge of the tactical battlespace, including the location of friendly, neutral, and enemy forces as wall as the plan of action for battle	R					JTIDS REQUIRED

Num	(M)V (C)V (B)oth	Requirement	Current Status G/Y/R	Status Lot 5 G/Y/R	Status Lot 6 G/Y/R	Status Lot 7 G/Y/R	Status Lot 8 G/Y/R	Comments
242	B	Combat Identification - The aircraft is interoperable with existing avionics systems, integrated with head-up display screen (O), interoperable with friendly and allied systems, highly jam resistant, and causes no degradation of other operating systems. Sensors are highly jam and spoof resistant, interoperable with existing weapons systems, compatible with planned/existing communications structure, highly accurate, stand-alone operations, interoperable with planned/existing position location identification (PLI) systems, and interoperable with joint/allied systems.	Y					PR 03 FUNDING REQUEST FOR LOT 9 MV INCORPORATION, UPGRADED GPS RECEIVER
245	B	Support Equipment (SE) - Organizational and Intermediate level SE is required to be of modular design for two person maneuvering (without the aid of additional motorized material handling equipment) and transportable as internal cargo aboard the aircraft for strategic and tactical mobility (T).	G					REQUIRES PGSE FOR VEHICLES (SHORING)
246	B	Support Equipment (SE) - SE must be operable and maintainable under all environmental conditions expected of the aircraft.	G					
247	B	Support Equipment (SE) - Automated test equipment (ATE) should be of modular design with each module weighing no more than 150 pounds (T)/120 pounds (O) and be operable and maintainable in all environmental conditions expected of the aircraft.	G					
248	B	Support Equipment (SE) - Peculiar SE must be kept to a minimum.	G					
249	B	Support Equipment (SE) - Organizational SE must be available prior to first aircraft delivery and must interface with the aircraft Built-In-Test/Built-In-Test Equipment (BIT/BITE) to the maximum extent possible.	G					PMA RATING, DOT&E DID NOT EVALUATE

JORD Requirements

Num	(M)V (C)V (B)oth	Requirement	Current Status G/Y/R	Status Lot 5 G/Y/R	Status Lot 6 G/Y/R	Status Lot 7 G/Y/R	Status Lot 8 G/Y/R	Comments
250	B	Support Equipment (SE) - Intermediate level Automated Test Equipment (ATE) must be used to the maximum extent possible. ATE, test program sets, and adapters must be able to detect 100% of all supported Weapons Replaceable Assembly (WRA) faults.	G					PMA RATING, DOT&E DID NOT EVALUATE
251	B	Support Equipment (SE) - Intermediate level Automated Test Equipment (ATE), must be able to isolate 100% of all detected faults to three Shop Replaceable Assemblies (SRA), 95% to two SRAs, and 90% to one SRA (T).	G					PMA RATING, DOT&E DID NOT EVALUATE
252	B	Integrated Logistics Support (ILS) - Navy and Air Force policy on ILS shall be followed. An appropriately tailored MIL-STD-1388 LSA shall be initiated and performed concurrently with RDT&E. Organic support at Initial Operational Capability (IOC) shall at a minimum, consist of a complete set of logistic resources required for organizational and shipboard maintenance of the system (T).	G					PMA RATING, DOT&E DID NOT EVALUATE
253	B	Manpower Constraints - The aircraft shall not require unique service skill levels.	G					
254	M	Manpower Constraints - The aircraft shall utilize integrated Military Occupational Specialty (MOS) codes.	G					
255	C	Manpower Constraints - The aircraft shall utilize Air Force Specialty Codes(AFSC).	G					
256	M	Manpower Constraints, USMC Aircrew - USMC pilot and enlisted aircrew (crewchiefs/aerial observers) manpower requirements and crew-to-seat ratios must not exceed those currently dedicated to CH-46E and CH-53D medium lift squadrons. A capability for full system flight operations with a minimum crew of two pilots and one crew chief is required (T).	G					

CURRENT STATUS
G Full Capability Exists or Threshold Met
Y Limited Capability Exists
R No Capability or Threshold Not Met

STATUS ARROW
↑ Ahead of Recovery Plan
→ Recovery Plan on Schedule or Not Required
↓ Behind Recovery Plan

PROJECTION OF STATUS FOR LOT PRODUCTION
G Complete or Meets Production Lot with Low Risk
Y Current Plan Meets Production Lot with Low or Medium Risk
R Current Plan Does Not Meet Production Lot
N/A CV Specific Requirement to Be Tested in CV OT-IIH

JORD Requirements

Num	*(M)V (C)V (B)oth*	*Requirement*	*Current Status G/Y/R*	*Status Lot 5 G/Y/R*	*Status Lot 6 G/Y/R*	*Status Lot 7 G/Y/R*	*Status Lot 8 G/Y/R*	*Comments*
257	C	Manpower Constraints, USSOCOM Aircrew - SOF pilot and enlisted aircrew manpower requirements must not exceed those currently dedicated to the MH-53J weapon system. A capability for full system flight operations with a crew of two pilots and two Flight Engineers (FE), on FE in the cockpit jump seat as an integral cockpit crew member and one FE in the cabin is required (T). A crew ratio of 1.5:1 at IOC and building to 2.0:1 at FOC is required (T).	G					CV IOT&E
258	M	Manpower Constraints, USMC Maintenance Personnel - Direct Maintenance Spaces Per Aircraft (DMS/A) must not exceed current levels dedicated to CH-46E and CH-53D medium lift squadrons.						DOT&E VIEWS AS YELLOW. PMA VIEWS AS GREEN (COVERED IN RM&A POINT PAPER)
259	C	Manpower Constraints, USSOCOM Maintenance Personnel - Direct Maintenance Spaces Per Aircraft (DMS/A) must be <=20.5 people per aircraft (T)/<=13.33 people per aircraft (O).	G					CV IOT&E
260	M	Training - The training concepts, devices, training agencies, and equipment requirements will be developed in consort with USSOCOM requirements and promulgated in the JTP, and TDRD. Appropriate computer courseware (hardware and software), flight trainers, instrument trainers, weapons systems trainers, maintenance trainers, and publications will be	G					VALIDATE IN FOT&E
261	C	Training - An integrated, ground based training system support aircrew and maintenance training, formal school curricula, and combat mission refresher training is required.	G					CV IOT&E

CURRENT STATUS
G Full Capability Exists or Threshold Met
Y Limited Capability Exists
R No Capability or Threshold Not Met

STATUS ARROW
↑ Ahead of Recovery Plan
→ Recovery Plan on Schedule or Not Required
↓ Behind Recovery Plan

PROJECTION OF STATUS FOR LOT PRODUCTION
G Complete or Meets Production Lot with Low Risk
Y Current Plan Meets Production Lot with Low or Medium Risk
R Current Plan Does Not Meet Production Lot
N/A CV Specific Requirement to Be Tested in CV OT-IIH

JORD Requirements

Num	(M)V (C)V (B)oth	Requirement	Current Status G/Y/R	Status Lot 5 G/Y/R	Status Lot 6 G/Y/R	Status Lot 7 G/Y/R	Status Lot 8 G/Y/R	Comments
262	C	Training - A total training system that maximizes the integration of curriculum, training media, courseware, stand up instruction, facilities, management support, support equipment and the aircraft is required. Resources and provisions must be provided to accommodate training for all personnel who will operate, support, and maintain the aircraft throughout it's life cycle (T).	G					CV IOT&E
263	C	Training - Concurrency of training devices (TD) through the life cycle of the aircraft is required (T). All TDs should be reconfigurable in a simple, complete manner to rapidly accommodate engineering change proposals (ECP), operational flight programs (OFP), design enhancements, and aircraft modifications. Applicable ECPs and OFPs must be written to Include TDs. This includes the capability to incorporate changes required to bring the CV-22 up to a full JORD compliant configuration (T).	G					CV IOT&E
264	B	Logistics Considerations - A task oriented, Integrated Electronic Technical Manual (IETM) system (Level 4) is required at the Organizational and Intermediate maintenance levels (T).	Y					SOFTWARE UPGRADES IN WORK. SYSTEM VALIDATION IN OT-IIIB
265	B	Logistics Considerations - Computer Aided Acquisition and Logistics Support (CALS) for technical data is required as specified in OPNAVINST 3120.5, AFI 21-104, and DoD MIL-HDBK-59 (T).	G					PMA RATING, DOT&E DID NOT EVALUATE
266	B	Command, Control, Communications, Computers, and Intelligence - Interoperability with existing (T) and planned (O/P3I) DoD systems is required (T) and with allied service systems is desired (O).	G					A JOINT PMA-DOT&E POINT PAPER ADDRESSING INTEROPERABILITY/COMMUNICATION ISSUES
267	B	Command, Control, Communications, Computers, and Intelligence - A DoD approved High Order Language (HOL) must be used for all newly developed software (T).	G					

JORD Requirements

Num	(M)V (C)V (B)oth	Requirement	Current Status G/Y/R	Status Lot 5 G/Y/R	Status Lot 6 G/Y/R	Status Lot 7 G/Y/R	Status Lot 8 G/Y/R	Comments
268	B	Command, Control, Communications, Computers, and Intelligence - Interface with existing and planned information sources to receive and process intelligence, flight planning, and support data in near	R					CV IS CURRENTLY GREEN WITH "MATT". PR03 ISSUE REQUESTING DATA LINK FOR MV
269	B	Command, Control, Communications, Computers, and Intelligence - Provide an override function to allow incorporation of local updates (T).	G					
270	B	Command, Control, Communications, Computers, and Intelligence - Support entry, time stamping, access retrieval, modification, and deletion of data as well as frequency keying and zeroizing capability (T).	G					
271	B	Command, Control, Communications, Computers, and Intelligence - Be able to input to a standard DSS or to interface directly with the aircraft avionics system.	G					
272	B	Transportation - The aircraft is required to be self-deployable to all theaters of operations.	G					
273	B	Transportation - For intra-theater movements, all required supplies and SE must be V-22 transportable.	G					
274	B	Transportation - For inter-theater movements, all required supplies and SE must be C-141/C-17/C-130 transportable (T).	G					
275	C	Transportation - The capability to transport required SE, supplies/spare parts, munitions (7 day supply), and support personnel with personal gear) for 3 aircraft for a 30 days deployment in no more than 5 C-141 equivalent sorties is required (T) and no more than 3 C-141 equivalent sorties is desired (O).	G					CV IOT&E
276	B	Basing - The aircraft will utilize existing bases and facilities in place at time of fielding. Additionally, the aircraft will be required to operate from air capable ships, fully supported forward main bases, and austere foreward operating bases.	G					

CURRENT STATUS
G Full Capability Exists or Threshold Met
Y Limited Capability Exists
R No Capability or Threshold Not Met

STATUS ARROW
↑ Ahead of Recovery Plan
→ Recovery Plan on Schedule or Not Required
↓ Behind Recovery Plan

PROJECTION OF STATUS FOR LOT PRODUCTION
G Complete or Meets Production Lot with Low Risk
Y Current Plan Meets Production Lot with Low or Medium Risk
R Current Plan Does Not Meet Production Lot
N/A CV Specific Requirement to Be Tested in CV OT-IIH

Num	(M)V (C)V (B)oth	Requirement	Current Status G/Y/R	Status Lot 5 G/Y/R	Status Lot 6 G/Y/R	Status Lot 7 G/Y/R	Status Lot 8 G/Y/R	Comments
277	B	Interoperability with Joint Service, and Allied Systems - The aircraft must comply with applicable provisions contained in the DoD Joint Technical Architecture (JTA) to include DII COE compliance.	G					JITC CERTIFICATION IN WORK
278	B	Energy Standardization and Efficiency Needs - The aircraft must operate with JP-5 and JP-8 fuel as well as their civilian and NATO equivalents (T).	G					
279	B	Geographical Information and Services (GI&S) - The navigation system must support joint interoperability by allowing navigation with respect to all datum. Standard GI&S products form the National Imagery and Mapping Agency (NIMA) should be used to support digitized moving map and navigational technologies (T). The navigation system must also have the capability to translate all ingested datums to the DoD standard WGS-84.	Y					VALIDATE IN OT-IIIA
280	M	Key Performance Parameter (KPP) - Cruise Speed 240 kts (T)/270 kts (O).	G					
281	C	Key Performance Parameter (KPP) - Cruise Speed 230 kts (T)/250 kts (O).	G					CV IOT&E
282	C	Key Performance Parameter (KPP) - Mission Radius (Long Range Special Ops) 500 nm (T)/750 nm (O).	G					CV IOT&E
283	B	Key Performance Parameter (KPP) - Mission Radius (Pre Assault Raid) 200 nm X 1 (T)/(O)	G					
284	M	Key Performance Parameter (KPP) - Mission Radius (Sea Trooplift) 50 nm X 2 (T)/110 nm X 2 (O).	G					
285	M	Key Performance Parameter (KPP) - Mission Radius (Sea External) 50 nm X 1 (T)/110 nm X 1 (O).	G					
286	M	Key Performance Parameter (KPP) - Mission Radius (Land Trooplift) 200 nm X 1 (T)/(O).	G					
287	M	Key Performance Parameter (KPP) - Mission Radius (Land External) 50 nm X 1 (T)/110 nm X 1 (O).	G					

Num	(M)V (C)V (B)oth	Requirement	Current Status G/Y/R	Status Lot 5 G/Y/R	Status Lot 6 G/Y/R	Status Lot 7 G/Y/R	Status Lot 8 G/Y/R	Comments
288	B	Key Performance Parameter (KPP) - Self-Deployment range 2100 nm with 1 refuel (T)/2100 nm with O refuel (O).	G					
289	M	Key Performance Parameter (KPP) - Payload (troopseating) 24 (T)/(O).	G					
290	C	Key Performance Parameter (KPP) - Payload (Troop seating) 18 (T)/24 (O).	G					CV IOT&E
291	M	Key Performance Parameter (KPP) - Payload (External Lift) 10,000 lb (4536 kg) (T)/15,000 lb (6804 kg) (O).	G					
292	B	Key Performance Parameter (KPP) - V/STOL Capable (T)/(O).	G					
293	B	Key Performance Parameter (KPP) - Shipboard Compatible (T)/(O).	G					
294	B	Key Performance Parameter (KPP) - Aerial Refuel Capable (T)/(O).	G					
295	M	Key Performance Parameter (KPP) - Survivability 12.7 mm @ 90% VEL (T)/14.5 mm @ 90% VEL (O).	G					
296	C	Key Performance Parameter (KPP) - Operational Environment 300 ft TF/TA, Day/Night, VMC/IMC (T)/100 ft TF/TA, Day/Night, VMC/IMC (O).	G					CV IOT&E
297	C	Key Performance Parameter (KPP) - Precision Navigation - Locate LZ within 2X Rotor Diameter @ Max Combat Radius (T)/Locate LZ within 1X Rotor Diameter @ Max Combat Radius (O).	G					CV IOT&E
298	C	Key Performance Parameter (KPP) - Weapons System Reliability - >=0.77 (T)/>=0.84 (O).	G					CV IOT&E

CURRENT STATUS
G Full Capability Exists or Threshold Met
Y Limited Capability Exists
R No Capability or Threshold Not Met

STATUS ARROW
↑ Ahead of Recovery Plan
→ Recovery Plan on Schedule or Not Required
↓ Behind Recovery Plan

PROJECTION OF STATUS FOR LOT PRODUCTION
G Complete or Meets Production Lot with Low Risk
Y Current Plan Meets Production Lot with Low or Medium Risk
R Current Plan Does Not Meet Production Lot
N/A CV Specific Requirement to Be Tested in CV OT-IIH

JORD Requirements

Num	(M)V (C)V (B)oth	Requirement	Current Status G/Y/R	Status Lot 5 G/Y/R	Status Lot 6 G/Y/R	Status Lot 7 G/Y/R	Status Lot 8 G/Y/R	Comments
299	M	Amphibious Pre-Assault/Raid Operations - Execute a vertical takeoff with a minimum of 18 (T)/24 (O) combat equipped Marines or an internally carried vehicle with a crew of three combat equipped Marines, from an air capable ship and Hover Out of Ground Effect (HOGE) at sea level/103°F/39.44°C in no wind conditions at 95% engine Takeoff Rated Power (TRP). Transition to forward flight and transit at best cruise airspeed at or below 500 feet AGL for 200 nautical miles (nm) to a confined area landing zone at 3000 feet Mean Sea Level (MSL)/91.5oF/33.05°C. Transition to and HOGE at 95% engine TRP, in no wind conditions, execute a vertical landing and discharge the payload. Then execute a vertical takeoff, transition to forward flight, clearing a 50 foot obstacle within 100 feet horizontally, and transit at best cruise airspeed at or below 500 feet AGL for 200nm to return to the ship and land. The flight profile must be completed without refueling, and must include sufficient fuel to loiter in the vicinity of the CAL for 30 minutes after delivery of the payload. The loiter fuel requirement is in addition to the OPNAVINST 3710.7 reserve fuel requirement.	G					

Num	(M)V (C)V (B)oth	Requirement	Current Status G/Y/R	Status Lot 5 G/Y/R	Status Lot 6 G/Y/R	Status Lot 7 G/Y/R	Status Lot 8 G/Y/R	Comments
300	M	Amphibious Troop Lift - Execute a vertical takeoff, with 24 combat equipped Marines or an internally carried vehicle with a crew of three combat equipped Marines, from an air capable ship and HOGE at sea level/103oF/39.44°C in no wind conditions at 95% engine TRP. Then transition to forward flight and climb to and loiter at or below 1000 feet AGL for 40 minutes. Next, transit at best cruise airspeed at or below 500 feet AGL for 50nm (T)/110nm (O) to a confined area landing zone at 3000 feet MSL/91.5oF/33.05°C. Transition to and HOGE at 95% engine TRP, in no wind conditions, and execute a vertical landing and discharge the payload. Then execute a vertical takeoff, transition to forward flight, clearing a 50 foot obstacle within 100 feet horizontally, climb to and transit at or below 500 feet AGL for 50nm (T)/110nm (O) to return to the ship, loiter 15 minutes, and then land. Repeat preceding mission flight profile, excepting the initial 40 minute loiter, without refueling.	G					
301	M	Amphibious External Lift - Execute a 10,000 lb/4536 kg external cargo payload pick-up from an air capable ship at sea level/103oF/39.44°C and HOGE, in no wind conditions, at 95% engine TRP. Then transition to forward flight and transit at optimum airspeed at or below 500 feet AGL for 50nm (T)/110nm (O) to a confined area landing zone at 3000 feet MSL/91.5oF/33.05°C. Transition to and HOGE at 95% engine TRP, in no wind conditions, for five minutes and release the payload. Then transition to forward flight, clearing a 50 foot obstacle within 100 feet horizontally, and transit at best cruise airspeed at or below 500 feet AGL for 50nm (T)/110nm (O) to return to the ship, loiter 15 minutes, and land prior to first refueling.	G					

Num	(M)V (C)V (B)oth	Requirement	Current Status G/Y/R	Status Lot 5 G/Y/R	Status Lot 6 G/Y/R	Status Lot 7 G/Y/R	Status Lot 8 G/Y/R	Comments
302	M	Land Assault Troop Lift. Execute a vertical takeoff, with 24 combat equipped Marines or an internally carried vehicle with a crew of three combat equipped Marines, from a confined area landing zone and HOGE at 3000 feet MSL/91.5oF/33.05°C, in no wind conditions, at 95% engine TRP. Transition to forward flight, clearing a 50 foot vertical obstacle within 100 feet horizontally. Climb to and transit at or below 500 feet AGL at best cruise airspeed for 200nm to another confined area landing zone at 3000 feet MSL/91.5oF/33.05°C. Transition to and HOGE at 95% engine TRP, in no wind conditions, and execute a vertical landing and discharge payload. Then execute a vertical takeoff, transition to forward flight, clearing a 50 foot vertical obstacle within 100 feet horizontally, climb to and transit at or below 500 feet AGL at best cruise airspeed for 200nm to the point of origin. Transition to a HOGE and execute a vertical landing. This mission flight profile must be done without refueling.	G					
303	M	Land Assault External Lift - Execute a 10,000 lb/4536 kg external cargo payload pick-up from a confined area landing zone at 3000 feet MSL/91.5oF/33.05°C and HOGE, in no wind conditions, at 95% engine TRP. Transition to forward flight, clearing a 50 foot vertical obstacle within 100 feet horizontally. Climb to and transit at or below 500 feet AGL at optimum airspeed for 50nm (T)/110nm (O) to another confined area landing zone at 3000 feet MSL/91.5oF/33.05°C. Transition to and HOGE at 95% engine TRP, in no wind conditions, for five minutes and release payload. Then transition to forward flight, clearing a 50 foot vertical obstacle within 100 feet horizontally, and transit at or below 500 feet AGL at best cruise airspeed for 50nm (T)/110nm (O) to point of origin. Transition to a HOGE and execute a vertical landing. This mission flight profile must be done without refueling.	G					

Num	(M)V (C)V (B)oth	Requirement	Current Status G/Y/R	Status Lot 5 G/Y/R	Status Lot 6 G/Y/R	Status Lot 7 G/Y/R	Status Lot 8 G/Y/R	Comments
304	C	Long Range Special Operations - The JMVX must be capable of transporting 18 mission equipped troops (4770 lb/2,272 kg) (Threshold)/24 troops (6,360 lb/2,885 kg) (Objective) 500 nm (Threshold)/750 nm (Objective), off-load the troops from a 70 foot HOGE in 1 minute, and return 500 nm (Threshold)/750 nm (Objective). The transition from HOGE to forward flight must clear a 50 foot obstacle within 100 feet horizontally. The aircraft must be capable of flying this mission under Tropical Day conditions except for the takeoff and landing which shall be performed at sea level, 88°F/32°C, and the mid-point hover which shall be at 3,900 feet, 82°F/28°C. Outbound cruise shall be restricted to no greater than 10,000 feet pressure altitude (PA). The final 250 nautical miles prior to the mid-point shall be flown in the terrain following/terrain avoidance mode starting at 300 feet PA and increasing 144 feet PA per 10 nautical miles flown. The first 250 nautical miles of the return flight shall also be flown in the terrain following/terrain avoidance mode starting at 3,900 feet and decreasing 144 feet per 10 nautical miles flown. Cruise portions of the mission shall be flown at constant airspeeds. Fuel capacity must permit arrival over destination with enough usable fuel to increase the total planned flight time between refueling points by 10 percent or 20 minutes at Best Endurance Velocity (VBE) at 10,000 feet MSL, whichever is greater.	G					CV IOT&E

CURRENT STATUS
G Full Capability Exists or Threshold Met
Y Limited Capability Exists
R No Capability or Threshold Not Met

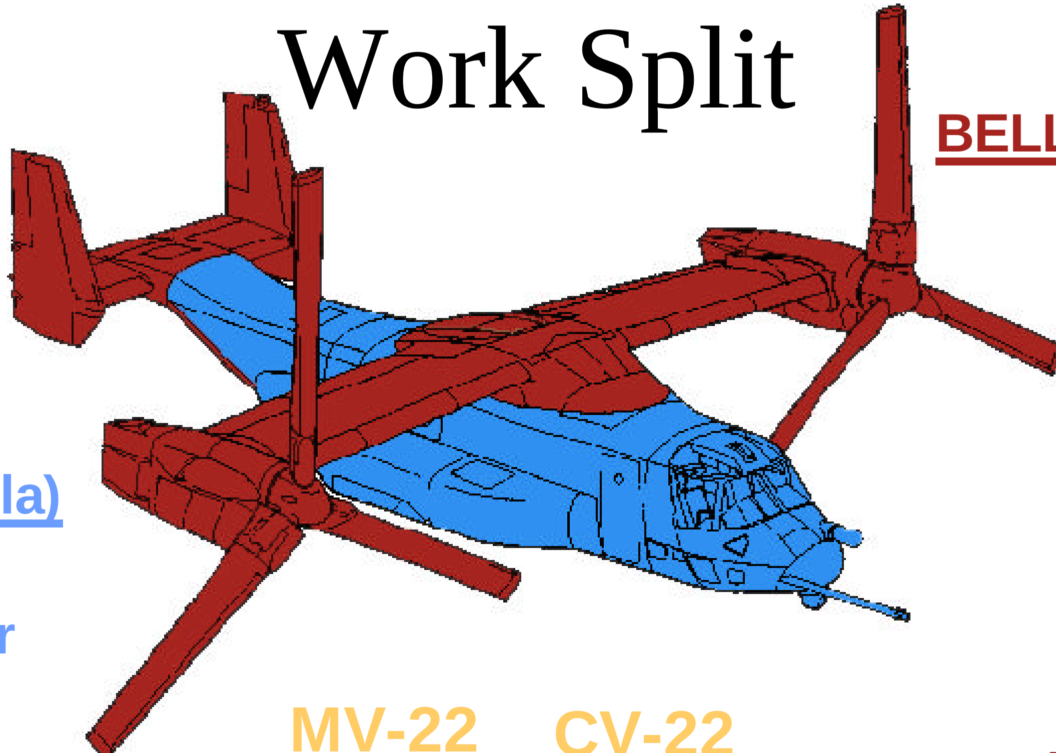
STATUS ARROW
↑ Ahead of Recovery Plan
→ Recovery Plan on Schedule or Not Required
↓ Behind Recovery Plan

PROJECTION OF STATUS FOR LOT PRODUCTION
G Complete or Meets Production Lot with Low Risk
Y Current Plan Meets Production Lot with Low or Medium Risk
R Current Plan Does Not Meet Production Lot
N/A CV Specific Requirement to Be Tested in CV OT-IIH

APPENDIX G

BELL-BOEING TEAM WORK SPLIT

Bell-Boeing Team
Work Split



BOEING (Phila)
- Fuselage
- Landing Gear
- Avionics
- Electrical & Hydraulic
- Performance
- Flying Qualities
- Development Flight Test

MV-22 **CV-22**

BELL (Arlington, Tx)
- Wing
- Wing Fairing
- Nacelles
- Propulsion
- Rotors
- Dynamics
- Empennage
- Ramp
- Final Assembly
- Flight Operations
- Delivery
- Electronic Warfare Systems

Final Assembly BELL (Amarillo, Tx)

APPENDIX H

GLOSSARY

Acronym	Definition
A/C	Aircraft
ACM	Air Combat Maneuvering
AGL	Above Ground Level
AMEGS	Aviation Maintenance Event Ground Station
AoA	Angle of Attack
BFWS	Blade Fold/Wing Stow
BIT	Built-In-Test
CAI	Computer Aided Instruction
CAL	Confined Area Landing
CAS	Calibrated Air Speed
COEA	Cost & Operational Effectiveness Analysis
CPI	Cost Performance Index
DCMA	Defense Contracts Management Agency
DSS	Data Storage Set
DT	Development Testing
EI	Engineering Investigation
EMD	Engineering & Manufacturing Development
FA	False Alarm
FADEC	Full Authority Digital Engine Control
FCC	Flight Control Computer
FD	Fault Detection
FFS	Full Flight Simulator
FI	Fault Isolation
FLIR	Forward Looking Infra-Red
FLOT	Forward Line of Own Troops
FMC	Full Mission Capable
FOC	Full Operational Capability
FOD	Foreign Object Debris
FOT&E	Follow On Test & Evaluation

FPI	Fixed Price Incentive
FRS	Fleet Replacement Squadron
FSD	Full Scale Development
GSE	Ground Support Equipment
HAZREP	Hazard Report
HIGE	Hover In Ground Effect
HMD	Helmet Mounted Display
HMR	Hazardous Material Report
HOGE	Hover Out of Ground Effect
HROD	High Rate Of Decent
HUD	Head-Up Display
ICDS	Inter-Connected Drive Shaft
ICW	Interactive Courseware
IETM	Interactive Electronic Technical Manual
ILS	Integrated Logistics Support
ILSP	Integrated Logistics Support Plan
IMC	Instrument Meteorological Conditions
IMI	Interactive Multi-media Instruction
IOC	Initial Operational Capability
IOT&E	Initial Operational Test & Evaluation
IPT	Integrated Project Team
ITT	Integrated Test Team
JASS	JMVX Applications System Software
JORD	Joint Operational Requirements Document
KPP	Key Performance Parameter
LATT	Low Altitude Terrain Tactics
LFT&E	Live Fire Test & Evaluation
LHA	Amphibious Assault Ship, TARAWA Class
LHD	Amphibious Assault Ship, WASP class
LRIP	Low Rate Initial Production
LSA	Logistics Support Analysis
LSAR	Logistics Support Analysis Report
LZ	Landing Zone
MAF	Maintenance Action Form
MAGTF	Marine Air Ground Task Force
MC	Mission Capable
MCAS	Marine Corps Air Station

MEU(SOC)	Marine Expeditionary Unit (Special Operations Capable)
MFD	Multi-Functional Display
MFHBA	Mean Flight Hours Between Abort
MFHBF	Mean Flight Hours Between Failure
MFHBUM	Mean Flight Hours Between Unscheduled Maintenance
MMH/FH	Maintenance Man-Hours/Flight Hour
MOUT	Military Operations in Urban Terrain
MR	Mission Reliability
MRTa	Mean Repair Time after Abort
MTAT	Mean Turn Around Time
MTBF	Mean Time Between Failure
NALCOMIS	Naval Aviation Logistics Command Management Information System
NAMTS	Naval Aviation Maintenance Trainer Suite
NATOPS	Naval Air Training and Operating Procedures Standardization
NAWC	Naval Air Warfare Center
NBC	Nuclear, Biological & Chemical
NOE	Nap-Of-the-Earth
OEI	One Engine Inoperative
OFT	Operational Flight Trainer
OGE	Out of Ground Effect
OMF	Operational Mission Failure
OMFTS	Operational Maneuver From The Sea
OPEVAL	Operational Evaluation
ORD	Operational Requirements Document
PAA	Primary Aircraft Authorized
PEDD	Portable Electronic Display Device
PEO	Program Executive Officer
PIO	Pilot Induced Oscillation
PRGB	Prop-Rotor Gear Box
PTT	Part Task Trainer
QA	Quality Assurance
QMS	Quality Management System
RFI	Ready For Issue
RM&A	Reliability, Maintainability & Availability
S/A	Situational Awareness
SAR	Safety Action Records
SAR	Search And Rescue

SAR	Selected Acquisition Report
SME	Subject Matter Expert
SOF	Special Operations Force
SPI	Schedule Performance Index
SPIE	Special Personnel Insertion & Extraction
STO	Short Take Off
TACAN	Tactical Air Navigation
TAS	True Air Speed
TCL	Thrust Control Lever
TF/TA	Terrain Following/Terrain Avoidance
TOA	Total Obligation Authority
TOC	Total Ownership Cost
USSOCOM	US Special Operations Command
VLATT	V-22 Low Altitude Terrain Tactics
VMC	Visual Meteorological Conditions
VMS	Vehicle Management System
VRS	Vortex Ring State
VSLED	Vibration, Structural Life, and Engine Diagnostic system
VTOL	Vertical Take Off & Landing
WSR	Weapon System Reliability