
V-22 Osprey Program

Report on Operational and Live Fire Test and Evaluation



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Executive Summary

This is the second DOT&E combined operational and live fire test and evaluation report on the V-22 Osprey. Following two crashes in 2000, the Navy restructured the V-22 program. New, improved aircraft capabilities were to incorporate changes in block upgrades. The Block A aircraft is intended for use in a training unit; this configuration incorporates modifications to address recommendations from the two mishap investigations and DOT&E's earlier report. Some capabilities were re-designated as threshold requirements for future MV-22 Block B aircraft. MV-22 Block B will be the first configuration procured for deployment and will undergo additional testing.

Similar aircraft performance is expected of the MV-22 Block B and CV-22 airframe. The CV-22 will have additional equipment for special operations missions and will be evaluated in future CV-22 operational testing scheduled for 2006 and 2008.

Test Adequacy

Operational testing was adequate to determine the effectiveness, suitability, survivability, and safety of the V-22. Previous live fire test and evaluation adequately addressed vulnerabilities to ballistic threats; no additional live fire testing was conducted in this test phase. Operational testing occurred in multiple locations using MV-22 Block A production aircraft. Commander, Operational Test and Evaluation Force, using a dedicated tiltrotor operational test squadron, conducted the V-22 OPEVAL Phase II called OT-IIG. VMX-22, the Marine Corps' V-22 test squadron, accomplished the operational testing with an eight-aircraft detachment with representative military and contractor manning equivalent to two thirds of a typical flight squadron. VMX-22 conducted the operational test in accordance with the DOT&E-approved V-22 Test and Evaluation Master Plan and the OT-IIG Test Plan.

Operational Effectiveness

OT-IIG demonstrated that the MV-22 Block A is operationally effective in low and medium threat environments.¹ The MV-22 Block A aircraft satisfied all key performance parameters as VMX-22 flew scenarios for the following mission areas:

¹ Low threat includes sporadic small arms fire from random locations (maximum caliber 7.62 mm/.30 cal), and automatic weapons (assault rifles). Medium threat includes those threats, plus larger caliber weapons (.50 cal/12.5 mm and 23 mm, but not AAA) adapted for anti-aircraft fire, more sophisticated aiming devices, and legacy MANPADS (SA-7 and variants).

- Ship-to-objective maneuver.
- Sustained operations ashore.
- Tactical recovery of aircraft and personnel.
- Self-deployment.
- Amphibious evacuation.

Performance of the Block A aircraft will be the baseline for future effectiveness evaluations of follow-on V-22 variants.

Enhancing Features. During operational testing, the V-22 system demonstrated significant mission advantages when compared to the medium-lift helicopters that it will replace. The V-22 advantages include:

- Extended range with high speeds and larger payloads for greater operational reach and reduced response times.
- Self-deployment capability for reduced strategic lift requirements.
- Advanced mission management systems and situational awareness equipment for precision navigation, increased battlefield situational awareness, and reduced aircrew workload providing greater tactical flexibility for commanders.

Follow-On Test Requirements. Some system performance shortfalls remain. Follow-on system upgrades and testing should include:

- Personnel hoist.
- Defensive weapons system.
- Weather radar.

Resolved Areas of Concern from Previous Operational Testing. The program resolved four areas of concern that DOT&E reported from the first operational test phase, including the safety problems associated with the two crashes in 2000:

1. Vortex Ring State. The Vortex Ring State (VRS) envelope for the V-22 is now well defined and avoidable. During OT-IIG, VMX-22 aircrews accomplished all operational missions while remaining outside the VRS-susceptible envelope and pilots are trained regarding its dangers.

2. Flight Control Software Reliability. Comprehensive evaluation in simulation laboratories verified the integrity of the flight control hardware and software prior to the MV-22 returning to flight in May 2002.

3. Hydraulic Line Routing. The V-22 program conducted a thorough review, redesign, and re-routing of hydraulic lines. Over 5,000 flight hours with the new design provide confidence that the current hydraulic system is safe to operate.

4. Impact of Downwash on Operations. Flight and ground operations demonstrated that revised tactics, techniques, and procedures allow safe operations in downwash. VMX-22 routinely operated in remote terrain and unprepared areas. There was limited testing at night in severe brownout conditions. Air and ground crews demonstrated satisfactory external load hookup and transporting operations.

Operational Suitability

OT-IIG demonstrated that the MV-22 Block A is operationally suitable. The aircraft demonstrated improvement in the suitability metrics and satisfied thresholds for:

- Mean flight hours between aborts (25 hrs. vs. >17 hrs. required).
- Mean flight hours between failures (1.4 hrs. vs. >0.9 hrs. required).
- Maintenance man-hours per flight hour (7.2 hrs. vs. <20 hrs. required).
- Mission capable rate (78-88 percent vs. 82 percent required at 60,000 hrs. total fleet time).

The MV-22 did not meet the threshold for mean repair time for aborts, but this deficiency did not impact the overall operational suitability of the aircraft, as abort-causing failures accounted for only 5 percent of the overall maintenance workload.

Shipboard testing on USS Bataan (LHD 5) verified improvements in the aircraft's operating envelope and the blade-fold wing-stow system. The MV-22 is compatible with flight and hangar deck operations. Deck heating and shipboard power compatibility deficiencies were discovered during operational testing.

The MV-22 satisfied its top-level information exchange requirements. During mission-representative flights, VMX-22 pilots were able to plan and re-create missions before and after flight, maintain in-flight situational awareness and communications with other service platforms and data links, and use navigation aids and required Identification, Friend-or-Foe transponder modes. Planned corrections to the avionics system for the Single Channel Ground and Airborne Radio System (SINCGARS) will be evaluated in follow-on testing.

The following human factors and safety items remain:

- The congested cabin and cumbersome seat belts may increase the debarkation time for the 24 combat-loaded Marines, and pose a safety risk during combat or emergency evacuations. The Navy plans to install and test new seats and restraints as part of the Block B upgrade.
- The restricted field of view to the left from the cabin limits the ability of the crew chief to keep a safe lookout.
- The environmental control system does not cool the cabin adequately in hot weather.

- Emergency landing after the sudden failure of both engines in the Conversion/Vertical Take-Off and Landing modes below 1,600 feet altitude are not likely to be survivable. The likelihood of sudden, dual-engine failure is remote, but possible. The V-22 cannot autorotate to a safe landing.

Survivability

Live fire test and evaluation results, and Phase I and II operational testing indicate that the MV-22 Block A is a survivable aircraft in low and medium threat environments. The basic design and speed, range, and altitude performance of the V-22 reduce its overall susceptibility as compared to legacy transport helicopters. Ballistic vulnerability testing demonstrated that the V-22 is capable of withstanding impacts by expected threat projectiles. Live fire test results led directly to several vulnerability reduction improvements.

The integrated defensive electronic countermeasures system provides an adequate capability for detecting radio frequency and laser energy directed at the aircraft. There are major deficiencies in spatial coverage and threat displays that should be addressed. The quantity and placement of the countermeasure expendables are not sufficient for multiple threat encounters on long missions.

The MV-22 Block A aircraft does not have a defensive weapon. This is a Block B requirement.

During the susceptibility testing versus ground threats, pilots noted that the current flight restrictions on aircraft maneuvering in airplane mode (roll and pitch attitude) restricted the aircraft's ability while performing defensive maneuvers. While developing tactics, current bank angle and pitch attitude limitations may prove insufficient to counter threat systems. The maneuvering envelope of the aircraft should be expanded as necessary through follow-on developmental testing.

Analysis of the aircraft design and infrared emission sources indicates that the V-22 exhibits a decreased susceptibility to man portable air defense systems compared to legacy transport conventional helicopters. This decrease in susceptibility comes from the design feature that places most of the infrared emission at the end of the nacelles, which are displaced from both the engines and fuselage.

Recommendations

Operational Effectiveness

- Assess V-22 survivability in realistic tactical approaches to landing zones in high-threat areas during follow-on testing and tactics development.

- Training, which is critical for this hybrid aircraft, should emphasize:
 - Aerial refueling at night and in turbulence.
 - Landing techniques in severe brownout conditions.
 - High-tempo operations, particularly aboard ship.
- Resolve remaining deficiencies in Joint Mission Planning System (JMPS) version 5.2.
- Pursue a radar altimeter that allows the V-22 to carry dual-hook external loads at night.
- Pursue flight testing to define V-22 performance in extreme environmental conditions.
- Install and test an effective personnel hoist.
- Consider installing a weather radar in the MV-22.

Operational Suitability

- Implement planned upgrades to seats and harnesses.
- Implement logistics support plans to support deploying MV-22 squadrons.

Survivability

- Develop appropriate tactics for coordination with helicopter and fixed-wing fire support aircraft.
- Equip the flare and chaff dispensing system with sufficient capacity for multiple threat encounters on long missions.
- Install and test a defensive weapon (planned for Block B aircraft).
- Correct the deficiencies in the defensive electronics countermeasures system.
- Consider adding active fire suppression systems to the wheel well and under floor dry bays.
- Determine the effectiveness of the engine bay fire extinguishing system against actual threat-induced fires.
- Devise/improve cabin wall battle damage repair methods and procedures. Damage to this wall can make the aircraft unavailable for an extensive period.



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Section 1

Mission and System Description

Mission

The V-22 Osprey is a multi-mission tiltrotor aircraft. The program sought to achieve a common air vehicle (with common logistics) for use by each Service. The air vehicles for Marine Corps and Air Force missions are nearly identical, with common subsystems and military components sustainable by each Service's logistics system. The Marine Corps will replace current medium-lift helicopters (CH-46E and CH-53D) with the MV-22 variant. The CV-22 variant will supplement the Air Force Special Operations MC-130 aircraft. While the two basic aircraft are the same, the CV-22 carries additional mission-specific equipment.

The MV-22 will be the only medium-lift assault support aircraft for the Marine Corps. It is designed to provide the speed, endurance, radius of action, payload, and survivability required for the following missions:

- Ship-to-objective maneuver.
- Sustained operations ashore.
- Tactical recovery of aircraft and personnel.
- Self-deployment.
- Amphibious evacuation.

MV-22 squadrons are to deploy and operate from air-capable ships (LHD, LHA, and LPD-17 classes) in support of training, contingency, combat, and non-combat operations. The aircraft are designed to provide greater operational reach for deployed Marine Air-Ground Task Force elements than legacy transport helicopters.

System Description

The V-22 Osprey is a tiltrotor aircraft capable of vertical and short takeoffs and landings and conventional wing-borne flight. The tiltrotor design allows the aircraft to fly in a larger envelope than any previous assault support aircraft. The V-22 is capable of worldwide self-deployment and air-to-air refueling. The two Rolls-Royce AE 1107c turboshaft engines housed in the nacelles are derived from the proven T56-A engine. An interconnecting cross-shaft allows either engine to power both rotors. The aircraft design incorporates an automatic blade-fold wing-stow system for shipboard operations.

The aircraft has three modes of operation (Figure I-1) defined by the proprotor's incidence (called the nacelle angle) on the aircraft:

- A vertical takeoff and landing mode defined as flight with the nacelle angle above 85 degrees (the V-22 can take off and land vertically with only one engine operable).

- Conversion mode defined as flight with the nacelle angle between zero and 85 degrees.
- Airplane mode, defined as flight with the nacelle angle at zero degrees (the V-22 cannot take off or land in airplane mode).



MV-22 in Vertical Takeoff and Landing Mode



MV-22 in Conversion Mode



MV-22 in Airplane Mode

Figure I-1. V-22 Flight Modes

All V-22 aircraft have the following subsystems:

- Three fully redundant flight control system computers.
- Two fully redundant mission computers and a flight incident recorder.
- Tactical Aid to Navigation (TACAN) system.
- Very high frequency omni-directional range (VOR)/instrument landing system (ILS).
- Global Positioning System (GPS) receiver.
- Radar altimeter.
- Three redundant inertial navigation systems.

- A night vision device (NVD)-compatible cockpit management subsystem consisting of four multi-function displays, two control keyboards, an engine instrumentation/crew alerting system display, a flight director, and standby flight display instrumentation.
- Two remote communication frequency indicators/selectors.
- A communications suite consisting of an Identification, Friend-or-Foe (IFF) set and two secure voice ultra high frequency (UHF)/very high frequency (VHF) radios (one with satellite communication capability).
- Situational awareness and navigation aids, including digital map system, night vision device-compatible heads up display, and a forward-looking infrared camera display.
- A vibration, structural life, engine diagnostic (VSLED) system providing a data collection, storage, and onboard analysis capability for the aircraft propulsion system and its associated support structure.
- The basic design includes features that reduce susceptibility to hostile fire:
 - Engine infrared suppressors.
 - Low acoustic signature proprotor blades.
 - Electronic combat suite.
- Design features that reduce system-level vulnerability include:
 - Ballistically tolerant drive train.
 - Crew seat armor.
 - Fuel tank ullage inerting systems.
 - Redundant flight control hydraulic systems.
 - Landing gear and crew seats designed to absorb energy in crash landings.

The MV-22-unique electronic warfare suite consists of:

- An integrated radar warning receiver.
- A missile warning system.
- A laser warning system.
- A countermeasures dispensing system.

The CV-22 variant includes:

- A multi-mode radar for terrain-following and terrain-avoidance capabilities.
- A multi-mission advanced tactical terminal.
- A suite of integrated radio frequency countermeasures.

- Directed infrared countermeasures.

The Live Fire Test and Evaluation (LFT&E) program led to several improvements to the production design:

- Wing structure that increases hydrodynamic ram tolerance.
- Sponson that increases hydrodynamic ram tolerance.
- Jam-proof flight control actuators.
- Crash-resistant self-sealing fuel tanks.
- Automatic fire extinguishing system in mid-wing gearbox dry bay.
- Re-designed fuel tanks adjacent to wheel well to reduce likelihood of fire.

Section 2

Test Adequacy

The operational and live fire tests were adequate to determine the effectiveness, suitability, survivability, and safety of the V-22. Operational testing was conducted in accordance with DOT&E approved plans.

Live Fire Test Program

The V-22 Live Fire Testing and Evaluation (LFT&E) program was completed in 2000. LFT&E was adequate to assess the vulnerability of the V-22, with minor limitations noted. Live fire tests included: 7.62 mm armor-piercing incendiary (API), 12.7 mm API, 14.5 mm API, 23 mm API and high-explosive incendiary (HEI), and 30 mm HEI. The program conducted 60 separate ballistic test series with 592 shots in all.

Developmental Testing Prior to the Operational Evaluation Phase II

The program conducted developmental testing to verify correction of deficiencies identified during prior OT&E and subsequent reviews. Before the determination of readiness for OT-IIG, the program performed 730 test flights with 1,433.1 flight hours between May 29, 2002, and December 31, 2004.

Operational Assessment (OT-IIF)

From May 18 through July 9, 2004, VMX-22 conducted an operational assessment (OT-IIF). The purpose of this test was to assess the impact of Block A modifications to previous effectiveness and suitability determinations, identify risk areas for OT-IIG, and support continued development.

Austere Landing Deployment

During September 2004, VMX-22 deployed six aircraft to Nellis Air Force Base, Nevada, to conduct flight operations into austere landing sites. The test team conducted flight operations in five separate landing zones challenging pilots with varying levels of reduced visibility (from light to severe) caused by blowing sand and dust generated by aircraft downwash.

Operational Evaluation Phase II (OT-IIG)

VMX-22 conducted OT-IIG from March 28 to June 18, 2005, using eight MV-22 Block A aircraft. The primary test locations were:

- Marine Corps Air Station New River, North Carolina.
- Mountain Warfare Training Center Bridgeport, California.
- Nellis Air Force Base, Nevada with operations to several western United States test ranges in California, Nevada, Arizona, New Mexico, and Texas.
- USS Bataan (LHD-5) in the western Atlantic with flight operations to North Carolina, Virginia, and Mississippi.

VMX-22 flew 751.7 flight hours during 204 events in the three-month OT-IIG period. In addition to missions defined in the test plan, VMX-22 flew flights in support of developmental testing objectives, validation and refinement of the tactics guide, advanced training, and fleet support missions. The flight hours and events include functional check flights, which are required after significant maintenance activities. Nearly half of the total flights conducted in the three-month period (89 out of 204 events) were realistic end-to-end operational missions. The remaining flights, although not necessarily flown in a representative mission profile, provided useful data in assessing operational effectiveness and suitability parameters.

VMX-22 manning for the test team was adapted from the United States Marine Corps Table of Organization for a 12-aircraft MV-22 squadron to assign representative manning for the eight-aircraft detachment that was used in the operational evaluation. This manning included flight crews, maintainers, administrative personnel, and Marine Aviation Logistics Squadron personnel. A fleet support team (FST) also augmented the VMX-22. The FST is a government entity that works directly for the program office and provides supplemental system contractors and logistical and engineering support for all Navy and Marine fleet squadrons.

Test Limitations

Night Operations. VMX-22 conducted less operational testing at night than originally planned. Pilots wore night vision goggles for 6 percent of the total test time. Although the test plan included 29 mission profiles (131 flight hours) at night, they only accomplished 12 (33 flight hours). Twelve additional night flights (or 14 hours) were flown for training and proficiency.

Night flights were also shorter than planned, particularly during the shipboard phase where most of the shortfall in night flying occurred. Two primary reasons caused this shortfall:

- *Pilot Currency.* For two months immediately before the start of the operational evaluation, proprotor gearbox problems significantly curtailed flight operations. As a result, VMX-22 could not completely qualify the expected number of aircrew to conduct night operations aboard the ship.
- *Ship Availability.* VMX-22 originally planned the shipboard test period for 21 days. Due to USS Bataan schedule, shipboard testing was limited to 10 days. VMX-22 could not conduct all of the planned shipboard training. This resulted in a decrease in the number of qualified crews to conduct operationally realistic missions at night.

The limited number of flight hours at night reduced the basis for evaluating night shipboard capability and crew fatigue issues.

Brownout Conditions. VMX-22 did not encounter landings under conditions with severe visibility degradation during OT-IIG. While the pilots frequently sought such

conditions in desert locations known for extreme blowing sand and dust, an unusually wet spring resulted in a large amount of vegetation that prevented severe brownouts during landing attempts. During the six-plane deployment to Nellis AFB following OT-IIF, the test team demonstrated the ability to operate in light to moderate visibility degradation and, with lower certainty, to operate in highly degraded visibility conditions.

Shipboard Flight and Hangar Deck Congestion. The number of aircraft operating on the USS Bataan during OT-IIG (other than MV-22) was slightly more than half of the aircraft projected for a Marine Expeditionary Unit operation in 2015. With more aircraft expected on board, there will be an adverse effect upon flight deck operations. Fully congested flight and hangar decks should be evaluated aboard LHA, LHD, LPD-17, and LHA (R) classes of ships during future deployment preparations.

Immature Logistics Support System. The logistics support system that provides new and repaired parts and assemblies to repair failures will not be ready until 2007. The interim support plan in place is satisfactory, but it is not fully fleet representative.

Opposed Landings. The only opposing forces in OT-IIG were the various anti-aircraft gun and missile systems at Naval Air Warfare Center-Weapons Division, China Lake during limited electronic combat testing there. This resulted in the inability to assess the effectiveness of tactical maneuvering approaches in a high-threat environment.

Conclusions

OT-IIG and live fire testing provides an adequate basis to determine the effectiveness, suitability, survivability, and safety of the V-22. The test aircraft used in OT-IIG were Block A production aircraft. None of the limitations, separately or in combination, precludes these determinations.

Recommendations

Future testing should include more night flights, particularly those of longer duration, and should evaluate the training needed for, and the execution of, night aerial refueling.

DOT&E recommends that fully congested flight and hangar decks be evaluated aboard LHA, LHD, LPD-17, and LHA (R) classes of ships during future deployment preparations.

Section 3

Operational Effectiveness

This section discusses the demonstrated capability of a unit equipped with MV-22 aircraft to accomplish operational missions. The assessment begins with mission planning and is followed by a discussion of the five mission types used to evaluate operational effectiveness. The section ends with an examination of aircraft performance, defensive maneuvering capabilities of the aircraft, enhanced features of the V-22, and a discussion of areas of concern from previous operational testing.

Mission Planning

The MV-22 mission planning system is designed to integrate various aeronautical charts and flight information files (weather, communications, threat data, and aircraft performance) and then transfer that data via data cartridge to the aircraft. The aircraft mission avionics is designed to allow the pilots to modify or update mission planning data while airborne, and to transfer the modified data back to the mission planning system for post-flight analysis.

VMX-22 aircrews used the JMPS version 5.2 during OT-IIG. The combination of the mission planning and the cockpit management systems enhanced the pilots' ability to employ the aircraft when compared to legacy transport helicopters. JMPS version 5.2 did not have all the functionality of previous mission planning software versions, such as the ability to reconstruct mission data.

Improvements that would increase the speed of entries made in the cockpit (i.e., route changes and ambient condition updates), reduce heads-down time, and improve crew coordination are warranted. Specifically, JMPS version 5.2 needs improvement in the following areas:

- Data entry is too cumbersome for proper planning and data transfer module loading when planning under a time constraint.
- Data entry, including: a five-character limit for waypoint names, manipulating waypoints within routes, depiction of mission control measures, verification of the proper loading of mission data, and limited available map-loading memory.

For OT-IIG, the pilots worked around these deficiencies. Correction of these deficiencies will reduce the time required for mission planning and increase the effectiveness of mission planning products.

Ship-to-Objective Maneuver

The longer range and faster speed of the MV-22 are key elements of the overall ship-to-objective maneuver operational concept. With the MV-22, the Marine Air-Ground Task Force will not be limited to amphibious landings to establish a beachhead, and will be able to deliver forces to locations well inland.

VMX-22 planned to conduct tactically representative ship-to-objective maneuver missions on two occasions from USS Bataan – once during the day and once at night. Actual execution of the ship-to-objective maneuver mission was limited to a single day mission. The planned night mission did not occur due to a lack of aircrews with current night training qualifications and limited availability of the ship. For the day mission, two aircraft flew an amphibious troop-lift profile as a section. Another two aircraft flew amphibious external-cargo lift profiles, and one aircraft flew as a command and communications relay aircraft. The fifth aircraft also accomplished the amphibious delivery profile.

For the amphibious troop-lift profile, two MV-22 aircraft made two round trips between USS Bataan and a landing zone ashore, in excess of 50 nautical miles (nm), without refueling. Twenty-four combat-equipped Marines embarked on a single aircraft on each wave, delivering 48 Marines to the landing zone (Figure III-1).



Figure III-1. Marines in a Landing Zone

For the external-lift profile, two MV-22 aircraft carried a 6,250 lb water trailer and a 7,200 lb operational combat vehicle (Figure III-2) to a landing zone in excess of 85 nm, returned to the ship, picked up the helicopter support team, and delivered them to the same landing zone.

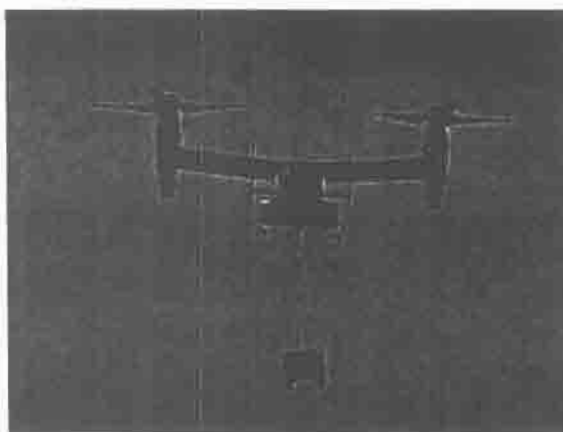


Figure III-2. MV-22 Carrying a Combat Vehicle

This test event demonstrated the ability of a unit equipped with the MV-22 to conduct the critical ship-to-objective maneuver mission. It would take twice as many CH-46 aircraft, or twice as long, to deliver only the personnel portion of the mission. The CH-46 cannot carry the external load as carried by the MV-22 in the test. Heavy lift CH-53E helicopters would have been required in addition to the CH-46 aircraft.

Sustained Operations Ashore

While ashore, the Marine Air-Ground Task Force will remain a general purpose force capable of executing a series of precise, focused combat and combat-support actions. In this capacity, the Marine Air-Ground Task Force intends to use the MV-22 to conduct long-range combat assault support during sustained operations ashore.

VMX-22 conducted three missions representative of sustained operations ashore. These consisted of a three-aircraft day rehearsal, a five-aircraft day mission, and a three-aircraft night mission. For the day mission, two aircraft conducted the land assault troop-lift profile, two aircraft conducted the land assault external-lift profile (key performance parameter), and the fifth aircraft provided a communications relay. That mission included two AH-1W Cobras and two AV-8B Harriers as part of a support package. For the night mission, one aircraft conducted the troop lift, one aircraft conducted the external lift, and one aircraft provided communications relay.

For all of these missions, the MV-22s flew from Nellis Air Force Base to Twenty-Nine Palms where they refueled and picked up troops or external combat loads. During the day mission, the two aircraft flying the troop-lift profiles each carried 24 combat-equipped Marines. The aircraft flew a low-level route of 200 nm to an unprepared landing zone at an altitude of approximately 3,000 feet. After discharging the force of Marines, the aircraft continued on the return portion of the low-level route as prescribed in the operational requirements document. These aircraft retraced the 200 nm route, refueled, returned to the landing zone, picked up the troops, and returned them to their base. The aircraft then returned to Nellis Air Force Base. The aircraft flying the external-load profiles carried a 6,250 lb water trailer (on a single point hook) and a 7,200 lb combat vehicle (on a dual point hook).

VMX-22 repeated the troop lift mission at night with a single aircraft using ballast instead of live troops. Because of continuing pilot night training requirements, no passengers were allowed on this flight. A single aircraft flew the external-lift profile carrying the water trailer. This was the only night external-lift profile during the operational evaluation. The MV-22 cannot use the forward cargo hook during night external missions because it interferes with the radar altimeter, which is required equipment for night flying. This reduces the flexibility of the aircraft and precludes the transport of loads requiring dual hook suspension during night operations. CH-53 helicopters have a similar restriction.

The MV-22 demonstrated its capability to conduct day and night missions representative of sustained operations ashore, although the night demonstration was

limited to two individual aircraft, plus the communications relay aircraft. Additional aircraft participation during the night missions would have increased squadron pilot workload and would have provided additional insights into the capabilities and/or limitations of the aircraft when operated at night in operationally realistic scenarios.

Tactical Recovery of Aircraft and Personnel (TRAP)

Tactical recovery of aircraft and personnel (TRAP) missions entail the rescue or extraction of downed aircraft and/or personnel and equipment, aircraft sanitization, and provision of advanced trauma life support in a benign or hostile environment. The Marine Corps intends to use the MV-22 for the rapid transport of personnel and equipment to support these types of operations.

On two occasions during the operational testing, VMX-22 conducted representative TRAP missions, a three-ship day mission and a two-ship night mission. The test plan called for five aircraft in each of these missions: two aircraft for the recovery team, two aircraft for the troop-lift profile (using a ballast weight of 4,760 lbs in lieu of 24 combat-equipped Marines), and a fifth radio communications relay aircraft.¹ Two aircraft aborted the day mission because of mechanical failures. The mission was conducted with two aircraft, plus the communications relay aircraft. The test team had previously scaled back the night mission to three aircraft, of which one aborted.

VMX-22 successfully executed the TRAP missions within the scope of aircraft and environments available for each mission. The MV-22 aircraft were able to land, load simulated survivors, and return. The range, speed, and payload capabilities of the aircraft allowed the mission to be conducted faster, and with fewer assets, than a similar mission conducted with CH-46 helicopters. Some recovery missions could require extraction of downed personnel in locations in which it is not possible for the recovery aircraft to land. The MV-22 Block A is not equipped with a hoist, and the only method for recovery of personnel is through the use of special personnel insertion and extraction (SPIE) equipment. The MV-22 will be equipped with a personnel hoist as part of the planned Block B upgrade and testing.

Self-Deployment

The Marine Corps expects the MV-22 aircraft to conduct extended-range self-deployment operations using either aerial refueling (Figure III-3) or internal auxiliary fuel tanks without aerial refueling. The operational requirement is for the MV-22 aircraft to be capable of self-deploying 2,100 nm with one refueling.

¹ An engine oil leak in a non-test aircraft at New River, which resulted in an emergency landing, prompted the test director to remove the ballast as a precaution against similar problems.



Figure III-3. The V-22 Aerial Refuels from a KC-130 Tanker

VMX-22 self deployed all eight operational test aircraft from their home base at New River, North Carolina to both Bridgeport, California and Nellis AFB, Nevada.² Six of these aircraft deployed more than 1,600 miles in a single day, a distance not achievable by CH-46 helicopters operating under similar crew day constraints (aircrews are limited to a maximum number of hours of duty and flying per period of time). Two aircraft flew nonstop from New River to Nellis using aerial refueling, a capability the CH-46 does not have.³

The speed and range of the MV-22 allowed the deploying aircraft to divert in flight to avoid known areas of inclement weather. The aircraft deploying to Bridgeport altered both altitude and route to reduce the impact of severe headwinds without increasing the number of fuel stops. CH-46s could not have accomplished such routing changes without increasing the number of fuel stops.

In addition to these deployments, a non-test aircraft modified with the planned Block B mission auxiliary tanks and wing auxiliary tanks demonstrated that the MV-22 can take off fully fueled, use all of the fuel in the auxiliary tanks, and then aerial refuel to refill all tanks. Performance calculations indicate that a MV-22 configured with mission and wing auxiliary tanks could achieve a range near 2,660 nm – exceeding the 2,100 nm requirement - with one aerial refueling.

While the MV-22 demonstrated that it meets the requirement for self-deployment, operational testing also highlighted the importance of having a weather radar. With a tanker available as a pathfinder, the MV-22 does not need a weather radar capability. However, a weather radar could be critical to complete the 2,100 nm mission. The

² Two aircraft deployed from New River to Bridgeport, six aircraft deployed from New River to Nellis, and eight aircraft deployed from Nellis to New River.

³ Three aircraft also planned to return from Nellis to New River non-stop. Each of these aircraft aerial refueled twice before the tanker experienced mechanical difficulties and departed.

CV-22 will be fielded with a weather radar. The operational requirement identifies radar with a weather capability as a threshold requirement for the MV-22 Block C.

Amphibious Evacuation Mission

The Marine Corps intends to use the MV-22 to provide long-range assault support for air evacuation operations in which noncombatants are evacuated to safe havens during war, civil unrest, or natural disaster.

VMX-22 conducted two representative amphibious evacuation missions, one during the day and one at night. For both missions, two aircraft flew the amphibious pre-assault raid profile, which is a key performance parameter. The two aircraft departed USS Bataan as a section, flew to Blackstone Army Airfield, Virginia, and returned. This mission exceeded 200 nm with a 30-minute loiter at the ship before landing. One aircraft carried 4,400 lbs of ballast while the other carried 2,200 lbs, representing the weights of a recovery force and evacuated noncombatants.

These missions demonstrated that the MV-22 effectively supports the amphibious evacuation mission. The airspeed and payload of the aircraft would reduce the time required to conduct any evacuation. The airborne endurance of the aircraft allows longer loiter times than a legacy transport helicopter.

Eagle Claw Iran Hostage Evacuation

VMX-22 attempted two re-enactments of the 1980 Eagle Claw mission in which a Joint Task Force attempted to rescue American hostages held in Iran. In the first mission, four MV-22 aircraft planned to fly 600 nm and return within eight hours with one aerial refueling each way. The second mission used only two aircraft, operating from USS Bataan at sea. Neither mission was completely successful. Aerial refueling in extreme turbulence at the only low altitudes authorized by the Federal Aviation Administration (FAA) that day, and limited tanker availability prevented completion of an end-to-end Eagle Claw mission during a single period of darkness. These problems would be mitigated in an actual combat environment where altitude restrictions do not apply and extra tanker resources would be available. The testing did confirm that the V-22 could fly this mission profile during a single period of darkness. The Eagle Claw mission could not be executed in this time period by any other helicopter in the U. S. inventory.

VMX-22 pilots recommended numerous training improvements as a result of their experiences during aerial refueling operations. Manned flight simulators are limited in ability to replicate extremely turbulent refueling conditions. More actual aerial refueling training may be needed before a pilot becomes proficient to conduct aerial refueling in turbulent conditions. Aerial refueling requirements within the Training and Readiness Manual should be reviewed. Increased requirements for V-22 aerial refueling proficiency training will increase the need for aerial tanker support.

Aircraft Performance

During OT-IIG, the MV-22 Block A accomplished all required mission profiles. Table III-1 summarizes the MV-22 Block A performance demonstrated during the operational testing, and the Block A and Block B performance projections for the required environmental and aircraft weight requirements.

Table III-1. MV-22 Block A Performance Results

Profile	Demonstrated Performance	Block A Projection	Block B Projection	Required Threshold
Amphibious Pre-Assault/Raid (KPP)	230 nm	247 nm	247 nm	200 nm
Land Assault External Lift (KPP)	69 nm 9,980 lb (Lightweight Howitzer)	63 nm 10,000 lb	29 nm 10,000 lb	50 nm 10,000 lb
Amphibious External Lift	89 nm 6,900 lb Vehicle	115 nm 10,000 lb	40 nm 10,000 lb	50 nm 10,000 lb
Amphibious Troop Lift	53 nm x 2 trips	120 nm x 2 trips	122 nm x 2 trips	50 nm x 2 trips
Land Assault Troop Lift	210 nm and return	279 nm and return	228 nm and return	200 nm and return
Self-Deploy (KPP)	Extrapolated to 2,660 nm with one refuel using Block B auxiliary fuel tanks	N/A	2,400 nm with one refuel	2,100 nm with one refuel
Cruise Airspeed (KPP)	255 kts	255 kts	250 kts	240 knots
Troop Seating (KPP)	24 Combat-loaded Marines	24 Combat-loaded Marines	24 Combat-loaded Marines	24 Combat-loaded Marines

Demonstrated performance results are not identical to required weights and environmental conditions. The observed performance was extrapolated with flight handbook data and the aircraft performance model for comparison with the operational requirements. Block B's predicted drop in performance is attributable to increased aircraft weight.

Flight conditions (aircraft weight, temperature, altitude, etc.) did not exactly match those conditions specified in the operational requirements document. In order to compare the tested Block A and the projected Block B performances to the threshold requirements, the demonstrated results were adjusted with numerical calculations using performance charts in the flight manual for the required environmental conditions and mission weights.

Projections indicate that Block A aircraft will meet all performance thresholds and Block B will meet all performance thresholds except the Land Assault External-Lift and Amphibious External-Lift missions (key performance parameters). The predicted shortfall could be mitigated by lower aircraft weight, lower operating altitude, or lower temperatures.

Defensive Maneuvering

The MV-22 in its aircraft mode has a reduced acoustic signature when compared to a legacy transport helicopter. Therefore, in the airplane mode, the MV-22 is close by before it can be heard.

An enhancing feature of the MV-22 is its ability to delay the conversion from airplane mode until very late in the approach. This capability permits the MV-22 to maximize airspeed, and therefore minimize exposure time when landing in hostile zones.

Accordingly, the normal tactical approaches used by the pilots in execution of missions during testing involved a high-speed, level approach in airplane mode, converting to helicopter mode at about one mile from the landing zone, and then landing. VMX-22 used three other tactical approaches that involved approaching the landing zone from different directions and executing 90 or 180 degree turns prior to landing.

The concept of operations for medium-lift aircraft, such as the MV-22 carrying Marines, is not to intentionally use these assets in a known high-threat environment. But a medium-threat, or even a low-threat environment, can change suddenly to a high-threat because enemy movements are not always known.

— In high-threat environments, a tactical approach with tight turns while maintaining minimum altitude is the standard legacy transport helicopter tactic. A review of the onboard data recordings collected during OT-IIG indicates that the MV-22 generally did not employ rapid tight turns while the nacelle angle was greater than 60 degrees. The preferred V-22 tactic is to use the rapid deceleration capability of the tiltrotor to minimize ingress time. This reduced time allows the V-22 the use of the element of surprise to deny threats in the terminal area the opportunity to engage. Further testing and tactics development is needed to expand the maneuvering flight envelope as much as possible, and to determine whether there is operational utility in the use of more extreme helicopter-style maneuvering in a high-threat environment.

Enhancing Features

By being able to convert to the conventional aircraft flight regime, the V-22 offers advantages over existing rotary-wing aircraft in mission range, speed of flight, and payload. In the planning and execution of missions, the improved range, speed, and payload can be interchanged and used to provide improved tactical flexibility. For example, the increased range of the MV-22 (as compared to the CH-46) enables the execution of amphibious assaults at extended range. This extended range provides reduced exposure of the amphibious ship-to-shore threats, and increases the number of locations that might be used as landing zones. In raids or other expeditionary operations, the MV-22 will be able to launch at a greater distance, employing its increased speed to transit to the objective area well before a similar operation using legacy transport helicopters. Excellent situational awareness and flexible in-flight mission planning capabilities allow multiple V-22s to fly separately via different routes and arrive at the objective simultaneously.

The self-deployment capability of the MV-22 Block B will reduce strategic lift required to support inter-theater movement of aircraft and personnel. If tanker support is available, long-distance inter-theater movement of assets will be possible.

The advanced mission management and situational awareness systems integrated into the MV-22 aircraft provide increased tactical flexibility for in-flight re-planning, precise navigation, and a reduction in aircrew workload.

Aboard ship, two unique capabilities of the MV-22 allow for increased flexibility and reduced deck-cycle times. The ability to self-taxi on deck allows for the expeditious repositioning of aircraft for refueling and loading passengers, freeing deck spots for other aircraft such as the AV-8B. The ability to conduct rolling takeoffs allows for a faster start and launch of more aircraft than is possible with traditional deck spotting of helicopters.

Resolved Areas of Concern from Previous Operational Testing

DOT&E's 2000 test report and the report of the V-22 Blue Ribbon Panel, established in response to the mishaps in 2000, identified several areas of concern. The following is a discussion of the resolution of those issues and recommendations for future testing or tactics development. The areas of concern identified include:

1. Vortex Ring State.
2. Flight Control Software Reliability.
3. Hydraulic Line Routing.
4. Impact of Downwash on Operations.
 - a. Landing in austere environments.
 - b. Deploying and recovering personnel while hovering.

- c. Impact on external loads.
- d. Reduced load capacity in cold weather.

1. Vortex Ring State. After initial operational testing in 2000 (OT-IIIE), DOT&E highlighted concerns regarding the ability to conduct required missions while avoiding VRS, which was the cause of the mishap in April 2000.

VRS is a condition that is characteristic of all rotary-wing aircraft. When descending at a high-rate with low-forward speed the rotor can become enveloped in its own downwash, which can result in a substantial loss of lift. Since the V-22 rotors are aligned in a side-by-side configuration, should one rotor enter VRS and lose more lift than the other rotor, a sudden roll can result, which quickly couples into a nose-down pitch.

In order to investigate VRS, the V-22 program ran flight tests in the high-rate of descent (HROD) regime. The HROD flight test program was unprecedented in rotary-wing history. It deliberately explored the flight conditions where VRS might be encountered, explored pilot actions to recover safely from the onset of VRS, and developed a warning system to alert the pilot during high rates of descent near the VRS boundary. The HROD test program was adequate to provide confidence that the V-22 VRS characteristics, operational limitations, and consequences are now well understood. A cockpit alarm has been installed to warn the pilot if the aircraft is in danger of entering this VRS-susceptible envelope. In addition, rapid recovery has been demonstrated by rotating the nacelles forward at the first sign of entering VRS.

During OT-IIIG, the aircrews were able to accomplish all missions within the flight restrictions ensuring that the aircraft remains out of the VRS-susceptible envelope. In addition, pilots have undergone extensive training regarding the dangers of approaching the VRS-susceptible envelope.

2. Flight Control Software Reliability. The V-22 program established an engineering and test program to ensure that the flight control system responds correctly in both planned and emergency circumstances. In addition to design reviews, the V-22 manufacturer integrated three simulation laboratories. This triple tie-in lab allowed a pilot in a realistic cockpit simulator to fly mission profiles and perform emergency procedures using actual flight control system hardware and software. This hardware and software translated pilot inputs to control surfaces via actual V-22 hydraulic and mechanical hardware-in-the-loop components. The program conducted simulations in these ground laboratories to verify the overall integrity of the flight control hardware and software prior to returning the V-22 to flight in May 2002.

3. Hydraulic Line Routing. The Blue Ribbon Panel and DOT&E expressed concern that the routing of hydraulic lines within the nacelles could lead to line chafing and rupture. The V-22 program undertook a thorough review of the hydraulic lines and implemented design changes. The new system design eliminated the use of marriage clamps that attached electrical wires or lines to hydraulic lines. The new design re-routed electrical wire bundles and established minimum line clearances in compliance with

industry standards. The program established a required hydraulic line inspection after every 35 flight hours to ensure adequate line clearances are maintained during aircraft operation and maintenance. Apart from a few minor indications observed after the first few developmental flights (which were corrected), no further chafing of hydraulic lines has been observed. More than 5,000 flight hours with the MV-22 Block A provide confidence that the current hydraulic line configuration is safe for operation.

4. Impact of Downwash on Operations. As a result of earlier phases of operational testing, DOT&E raised concerns regarding the potential of the V-22 proprotor downwash interfering with operations below or close by the aircraft, including troop embarkation and debarkation, hooking-up to external loads, and fastroping. The program conducted test flights in which the velocity and direction of the downwash were mapped using calibrated instrumentation. The mapping of these parameters showed that there were areas to the front and rear of the hovering aircraft in which the outflow from the V-22 was less severe. This led to procedures for allowing the safe conduct of external load hookup by a support team, as well as various means of egress from the V-22. The following paragraphs describe the status of known downwash effects on landings in austere environments, deploying and recovering personnel, and carrying external cargo:

- a. **Austere environments.** Flight and ground operations demonstrated that the refinement of tactics, techniques, and procedures mitigates risks associated with operations affected by downwash. For example, VMX-22 conducted operations to remote landing zones, including a variety of unprepared surfaces, in various terrains, including mountainous zones up to 6,400 feet altitude. VMX-22 demonstrated that the V-22 is capable of operating safely and routinely from unprepared landing zones consisting of grassy fields with some loose dirt (Figure III-4). In more severely degraded environments, such as in brownout conditions, the immediate area affected by downwash is large.

V-22 aircrews are developing tactics, techniques, and procedures for such brownout conditions, but at a cost of potentially increasing the time required to execute an approach and landing. In a high-threat environment, this could have adverse operational consequences. Improved flight information and displays, and the near-level landing attitude of the aircraft increase the crew's confidence in these procedures. The test squadron reported 140 landings in austere environments, including two section landings (two aircraft in formation) in moderate dust conditions. At least 30 of these austere landings (including two at night) were in zones with severely reduced visibility (Figure III-5). Approximately 25 percent of the landings in severe brownout conditions resulted in unintended wave-offs.

A significant feature is the ability of the aircraft to use the automatic flight control system to assist with the highly demanding tasks needed to hover in degraded visibility. While this coupled-hover approach increases exposure time somewhat during a tactical landing, pilots reported that it helped significantly in conducting

the landing in degraded visibility, making landings in these conditions easier than with legacy transport helicopters.

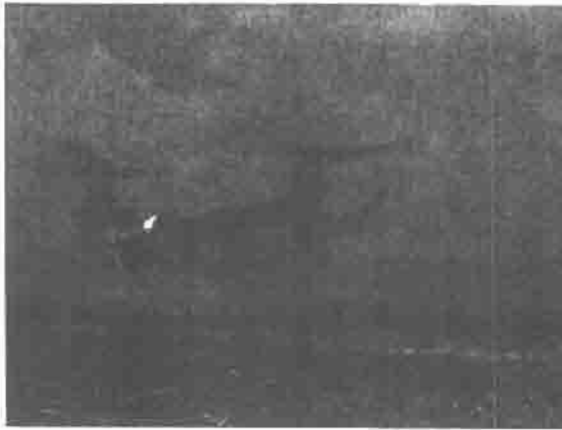


Figure III-4. Landing in an Austere Landing Zone

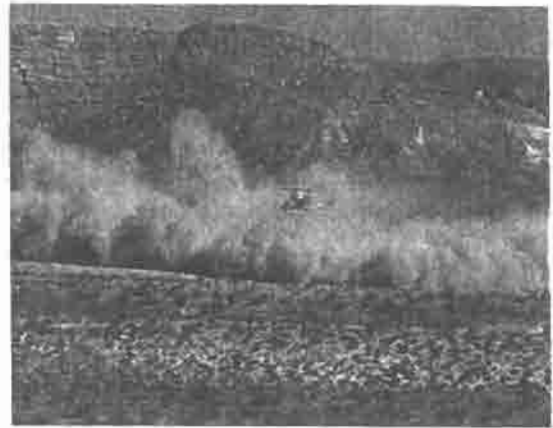


Figure III-5. V-22 Landing in Severely Reduced Visibility

- b. **Deploying and recovering personnel while hovering.** VMX-22 conducted both fastrope (Figure III-6) and special insertion and extraction (SPIE) rig deployment and recovery (Figure III-7) during OT-IIG.



Figure III-6. Marines Conducting Fastrope

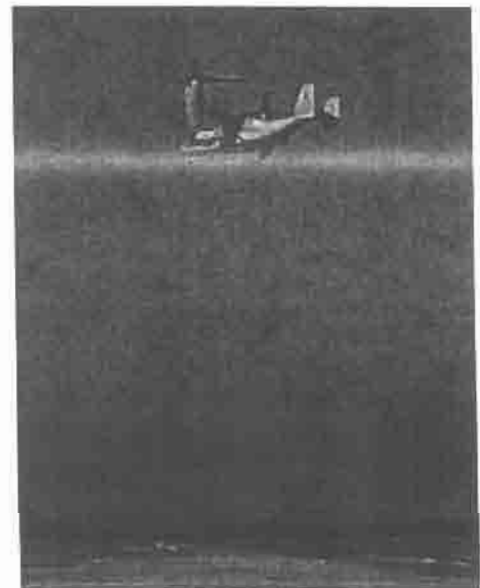


Figure III-7. Special Insertion and Extraction Rig

For the fastrope insertions, one-rope deployments were conducted from the ramp. Multiple pick-up and deployments with the SPIE rig were conducted from the aft cargo door during day testing. The aircrews reported that the aircraft was exceptionally stable in the required high-hover profiles at various nacelle settings. The ropers reported that downwash under the rotor arc was manageable and

consistent with that of the CH-53E. They also reported that platform stability during the approach and hover was better than other aircraft they had experienced.

- c. **Impact on external loads.** VMX-22 conducted successful external-load operations throughout the testing phase. VMX-22 continues to clear various additional loads as part of their tactics development. The aircrews have demonstrated that proper load rigging can be attained by building on experience from other aircraft. During OT-IIG, external loads were carried in two land assault missions (including one night mission) and in two day amphibious assault missions. The loads were a water trailer (about 6,520 lbs) with a single point hook (Figure III-8) and a combat vehicle (about 7,200 lbs) with a dual point hook (Figure III-2).



Figure III-8. MV-22 Hooking Up to a Water Trailer

In a separate demonstration prior to OT-IIG, the MV-22 carried a 9,980 lb lightweight towed howitzer (Figure III-9) with a dual hook configuration. The earlier concerns with downwash have significantly decreased. The remaining concern with downwash is associated with night landings under conditions of severe brownout, which should be addressed in follow-on tactics development.



Figure III-9. MV-22 Lifts a Lightweight Towed Howitzer

- d. **Reduced load capacity in cold weather.** The concerns noted during the initial operational evaluation were largely due to the flight handbook charts showing engine torque only. The new MV-22 handbook includes charts showing the maximum hover gross weight versus outside air temperature. This is no longer an issue.

Remaining Areas of Concern from Previous Operational Testing

Future block upgrades of the MV-22 and planned OT&E will address performance of:

- Personnel hoist.
- Defensive weapons system.
- Weather radar.
- Revised training, tactics, techniques, and procedures.

Conclusions

Operational testing has demonstrated that the MV-22 Block A is operationally effective in medium-lift assault support missions in low and medium threat environments. VMX-22 accomplished all required missions within the test limitations encountered. The MV-22 Block A aircraft satisfied all the range, speed, and payload performance parameters in actual test-day conditions. Analysis indicates that, under the exact conditions of the requirements document, the range for the MV-22 Block B carrying a 10,000 lb. external load will fall approximately 42 percent short. The operational impact is that users will have to compensate by carrying lighter loads or accepting less range.

Extensive system maturation and testing resolved or reduced the concerns identified in previous operational testing. The V-22 program should examine the remaining uncertainties in system performance during follow-on testing and tactics development.

Recommendations

- Assess V-22 survivability in realistic tactical approaches to landing zones in high-threat areas during follow-on testing and tactics development.
- Training which is critical for this hybrid aircraft, should emphasize:
 - Aerial refueling at night and in turbulence.
 - Landing techniques in severe brownout conditions.
 - High-tempo operations, particularly aboard ship.
- Resolve deficiencies in JMPS version 5.2.
- Pursue a radar altimeter that allows the V-22 to carry dual-hook external loads at night.
- Pursue flight testing to define V-22 performance in extreme environmental conditions.
- Install and test an effective personnel hoist.
- Consider installing a weather radar in the MV-22.

Section 4

Operational Suitability

OT-IIG demonstrated that the MV-22 Block A is operationally suitable. In March 2005, the program made several hardware and software changes to all MV-22 Block A aircraft, including those used in OT-IIG. These changes include the Vehicle Management System, the Joint Multi-Mission Vertical Lift Aircraft Applications System Software, the Interactive Electronic Technical Manual System, and proprotor gearbox components. These changes resulted in an improvement in the operational suitability of the MV-22. Data collected after March 2005 (on both OT and other test squadron aircraft) confirm that the MV-22 meets all but one of the requirements established for operational suitability.

This evaluation of operational suitability focuses on the primary metrics of reliability, maintainability, and availability. This section presents suitability metrics that support each of these areas and compares performance to established thresholds. Other issues discussed in this section include shipboard compatibility, interoperability, human factors, and safety.

Data Collection

The primary source of information for our assessment of operational suitability of the MV-22 Block A is the data collected from the eight operational test aircraft during OT-IIG. Between first flight on October 28, 2003, and completion of OT-IIG on June 18, 2005, the test squadron flew more than 4,000 hours using the eight OT-IIG aircraft and 16 additional squadron aircraft. VMX-22 flew the non-OT aircraft primarily for training and aircrew proficiency. The flight profiles in these non-test flights did not fully represent operational mission profiles or durations, yet the flights do provide additional data that increases confidence in the operational suitability of the overall aircraft fleet. Throughout this report, the operational test and non-test aircraft data will be presented separately so that differences, if any, can be observed. Table IV-1 summarizes the suitability results from OT-IIG. Data from OT-IIIE is presented for comparison.

Table IV-I. Suitability Metrics

Parameter*	OT-IIE November 2, 1999 – July 21, 2000	OT-IIG March 28, 2005 – June 18, 2005		Threshold
	OT aircraft (4)	OT aircraft (8)	Non-OT aircraft (16)	
MFHBA	13.9 hours	25 hours	19.4 hours	>17 hours
MFHBF _{log}	0.6 hours	1.4 hours	1.3 hours	≥ 0.9 hours
MMH/FH	25.3 hours	7.2 hours	11.0 hours	≤ 20 hours
MRT _k	5.6 hours	6.7 hours	6.2 hours	<4.8 hours
Fault Detection	92%	93%	n/a	>70%
Fault Isolation	87%	84%	n/a	>70%
MFHBFA	n/a	1.6 hours	n/a	≥1.4 hours

* Acronyms defined in the following text.

VMX-22 recorded all suitability data in accordance with normal operational procedures. Maintenance personnel entered the data into the Naval Aviation Logistics Command Management Information System-Optimized, the fleet data collection system. Additional screening of the operational evaluation data took place in accordance with the DOT&E-approved test plan. Throughout the review and scoring processes, DOT&E had access to all maintenance action forms. DOT&E is confident that all reporting, review, and scoring of maintenance actions were handled appropriately in accordance with the DOT&E-approved test plan.

Reliability

The two key measures of reliability for the MV-22 are mean flight hours between aborts (MFHBA) and mean flight hours between failures (logistics) (MFHBF_{log}). The MFHBA and MFHBF_{log} demonstrated in OT-IIG provide sound evidence of the reliability maturation of the MV-22 aircraft.

The threshold requirement for MFHBA for the Block A aircraft is 17 hours or greater, and the MV-22 achieved 25 hours. The MV-22 aircraft accumulated 751.6 flight hours while experiencing 30 mission aborts, either on the ground or in flight during the operational evaluation.

The threshold requirement for MFHBF_{log} for the Block A aircraft is greater than or equal to 0.9 hours and the MV-22 achieved 1.4 hours. The objective requirement at system maturity (60,000 MV-22 flight hours) is for an MFHBF_{log} greater than or equal to 1.2 hours. The MV-22 experienced 552 failures in the 751.6 flight hours for a MFHBF_{log}

of 1.4 hours. The system not only satisfied the current threshold of 0.9 hours, it also exceeded the objective at maturity of 1.2 hours.

Maintainability

MMH/FH and MRT_A

Two key measures of maintainability are the ratio of direct maintenance man-hours per flight hour (MMH/FH) and mean repair time for aborts (MRT_A). These two parameters indicate how hard the maintenance department will have to work to support mission readiness, and how quickly aircraft with serious failures can be repaired.

The threshold requirement for the Block A aircraft is that the MMH/FH be 20 hours or less. The objective requirement for Block A is 11 hours or less. The MV-22 accumulated approximately 5,430 man-hours of direct maintenance during the 751.6 flight hours of operational evaluation, resulting in a ratio of 7.2 maintenance man-hours per flight hour, thus achieving both the threshold and objective requirements.

Periodic inspections included in the maintenance man-hours that can require substantial time to complete. The MV-22 maintenance concept requires a phase maintenance inspection every 210 flight hours. During the operational evaluation, the maintenance team conducted one of these phase inspections, but statistically, three phase inspections normally would have occurred in the 751.6 flight hour deployment. The man-hours required by VMX-22 to conduct this phase inspection on the MV-22 Block A aircraft was approximately 120. Accordingly, if three phase inspections were conducted, rather than the one, approximately 240 additional maintenance man-hours would have been needed. This would have very little effect on the overall MMH/FH, increasing from 7.2 to about 7.5. Therefore, the observation of MMH/FH is robust.

The mean repair time for aborts (MRT_A) measures the hours required to return a non-mission capable aircraft back to a condition in which it is capable of conducting an assigned mission. VMX-22 calculated this metric by adding all the clock-hours used to resolve all grounding failures associated with each abort. The MRT_A threshold requirement for the Block A aircraft is 4.8 hours or less. There were 30 mission aborts during the operational evaluation and the total clock time to repair those aborts and other grounding failures was 270.4 hours. The total elapsed time allowing for concurrent maintenance of the grounding failures was 199.7 hours. The resulting MRT_A value is 9.0 hours. In practice, the actual maintenance actions to repair such failures are conducted concurrently. Using the start time to the end time of each of the maintenance actions for each abort lowers the calculated value of the MRT_A to 6.7 hours.

The presence of a small number of long-duration repairs increases the mean values, however calculated. For this type of distribution, the median value is a more representative number. The MRT_A (using either total clock time or total elapsed time) was 2.0 hours. For an operational commander or maintenance officer, this type of metric is far more meaningful.

For comparison, typical Air Force maintainability metrics include 2-hour, 4-hour, and 8-hour fix rates. As indicated by the median value for the MV-22, 50 percent of aborts were repaired in 2 hours, 67 percent of aborts were repaired in 4 hours, and 70-73 percent of aborts were repaired in 8 hours.

Although MRT_A is greater than the threshold using either method, these results did not have a significant operational impact on the mission capable rate. Maintenance aborts accounted for only 5 percent of the maintenance man-hours during the test while fixing all downing failures accounted for about 26 percent of the expended maintenance time. Repair actions for failures that take the aircraft out of flight-ready status (i.e., downing failures) must be repaired as soon as possible to maintain squadron readiness for missions. Repair of non-downing failures can be deferred to a time when maintenance workload permits lower-priority repairs. The rate of downing failures and the time to repair them have a much greater impact on the mission capable rate than simply the repair time for aborts. The maintenance team spent the largest fraction of their time on non-failures. Non-failure maintenance actions include preventative maintenance such as changing filters and adding lubricants, and investigation of reported failures that could not be duplicated.

Diagnostics

Three key measures of the MV-22's diagnostics capabilities are fault detection, fault isolation, and mean flight hours between false alarms (MFHBFA). VMX-22 collected data on the MV-22 diagnostics capabilities throughout OT-IIG and found that all three metrics satisfied threshold requirements. Table IV-1 contains the results for the diagnostics metrics.

The results show that the diagnostics system provided accurate built-in test fault detection and fault isolation capabilities. This likely contributed to the decrease in maintenance man-hours per flight hour between OT-IIE and OT-IIG.

During OT-IIE in 2000, the Aviation Maintenance Event Ground Station was difficult to use due to repetitive indications of failures that in actuality were normal flight parameters that experienced maintainers were able to differentiate. In practice, maintainers relied on pilot debriefs and inspections to detect and isolate true failures quickly. During OT-IIG, the Aviation Maintenance Event Ground Station allowed the maintainers to detect and isolate faults routinely, thus experiencing a low false alarm rate.

Aircraft Operational Availability

The primary measure of aircraft operational availability is the mission capable (MC) rate. This rate is the percent of time that the aircraft is capable of performing at least one of its missions. The operational requirements document states that a threshold MC rate of 82 percent should be achieved at system maturity (60,000 total aircraft flight hours). Since the MV-22 fleet accumulated only approximately 6,000 flight hours by the end of the operational evaluation phase, the test and evaluation master plan directed that

evaluation of the MC rate be based on scored data, calculated metrics, and the operational judgment of the evaluator.

The point estimate observed during the operational evaluation was 78 percent. Point estimates are subject to large fluctuations when the period of observation is short, as in OT-IIG. By using an alternative method involving an analytical model, DOT&E estimated the mature MC rate of the MV-22 to be 88 percent. The true MC rate at 60,000 hours will likely be between 78 and 88 percent. The high fraction of successfully completed flight events during OT-IIG is further evidence supporting the estimated MV-22 MC rate. The MV-22 successfully completed 157 of 182 attempted flights, or 86 percent.

Logistics Supportability

The MV-22 was logistically supportable throughout the operational evaluation. However, configuration control of aircraft and spare parts merits attention. In the near future there will be a mixed population, including MV-22 Block A aircraft, Block B aircraft, and potentially Block A aircraft modified to various degrees with Block B capabilities. A close working relationship between each squadron and the MV-22 configuration manager will be required to avoid undue delays caused by erroneous spare parts orders.

Supply Support

A complete assessment of the logistics support system is not possible because of the immaturity of that system. This was a known limitation. The interim support plan in place is satisfactory, but it is not fully fleet representative. A mature logistics support system, capable of supporting fielded aircraft, is expected to be in place by the planned material support date in 2007.

Support Equipment

VMX-22 was able to maintain the MV-22 with common hand tools and special tools. Generic ground support equipment common to the fleet, such as electric generators and hydraulic pumps, is capable of supporting MV-22 maintenance and flight operations. VMX-22 must overcome minor shortfalls with MV-22 peculiar support equipment, but the alternatives are satisfactory for interim use.

Component Repair

Intermediate-level maintenance provided by the Marine Aviation Logistics Squadron requires further definition and refinement. The individual component repair list classifies over 500 of more than 590 items as "Repair Not Authorized at the I-Level." Those items have to be returned to depot-level repair facilities when they fail. The low degree of repair authorization at the intermediate level increases the turnaround time for aircraft repairs and increases the number of spares required.

Shipboard Compatibility

During the deployment aboard USS Bataan, eight MV-22s conducted operations in conjunction with two CH-53Es, two AH-1Ws, two SH-60s, and two AV-8Bs. This section discusses the compatibility of the MV-22 in operations with other aircraft, as well as with the ship's flight deck and maintenance hangar.

Deck Operations

Multiple MV-22 aircraft conducted carrier landing qualification trials during both day and night (utilizing night vision goggles). CH-53E, AH-1W, and SH-60 aircraft also participated in the deck cycles. The MV-22s conducted landings and take-offs forward and aft of the CH-53E and SH-60 and aft of the AH-1W. Additionally, the CH-53E conducted landings and take-offs forward and aft of an MV-22. VMX-22 conducted mixed-aircraft flight operations without incident throughout the duration of the shipboard test period. SH-60 and AH-1W light helicopters experienced downwash significant enough to cause the tail or rotor to waver. To the ship's flight deck personnel and air boss, flight operations integrating all three types of aircraft appeared to be no different from integrated flight operations with existing helicopters.

Flight deck personnel stated that the nose wheel steering capability of the MV-22 enhanced maneuvering about the flight deck. Due to a lack of nose wheel steering, legacy helicopters do not self-taxi on the flight deck. Repositioning legacy helicopters on the flight deck requires that they be shut down and that tow tractors move the aircraft about the flight deck. The MV-22's self-taxi capability enhances flight deck configuration management.

The blade-fold wing-stow system proved that it could reliably fold the blades, stow the wing, and then spread the aircraft. MV-22s performed 49 automatic cycles of the blade-fold wing-stow system in winds up to 25 knots without incident.

Flight deck personnel experienced little difficulty moving the MV-22 with blades folded and wings stowed (Figure IV-1) using tow tractors. The fixed refueling probe on the Block A aircraft required a 20-foot tow bar in order to move aircraft about the flight deck. The 20-foot tow bar necessitates greater separation between parked aircraft in order to provide adequate clearance when positioning an aircraft between two others. In spite of the increased separation requirement, the aircraft handlers showed that they could fit 24 V-22s on an amphibious ship of the LHA/LHD classes as required. MV-22 Block B aircraft will deploy with a retractable refueling probe possibly allowing the use of a shorter tow bar, which would make maneuvering of towed aircraft somewhat easier.

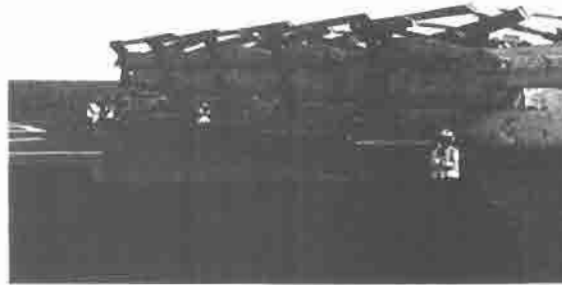


Figure IV-1. Ospreys parked on USS Bataan.

Deck Heating

Flight deck personnel noticed buckling of the flight deck underneath the right engine after the MV-22 had been idling for 20 minutes or more at full power. Figures IV-2 and IV-3 show the area of the deck affected by this engine heating and the amount of deck buckling that resulted. The deck appeared to return to its original state as the deck cooled over a period of one to two hours. During earlier developmental testing, the integrated test team observed similar deck effects during operations aboard USS Iwo Jima (LHD 7) and USS Wasp (LHD 1).

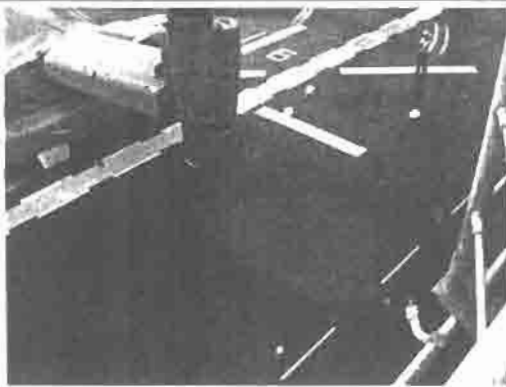


Figure IV-2. Area Affected by Deck Heating

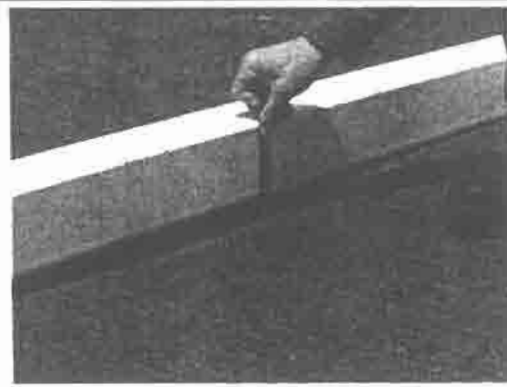


Figure IV-3. Deck Warping

The appropriate Navy engineers responsible for the LHA and LHD ships are examining this deck heating phenomenon. USS Bataan engineers performed a non-destructive inspection of the affected deck plates and adjacent welds and determined that there was no short-term damage from the heating. VMX-22, in conjunction with the program office and the amphibious ship community, should continue to develop operational procedures to mitigate the effects of exhaust striking the flight deck.

Shipboard Maintenance

The total number of aircraft onboard the ship during OT-IIG represent about half the number of aircraft that would be present in an actual Marine Expeditionary Unit. Greater numbers of aircraft and spare parts could affect the timeliness of the movement of aircraft to and from the flight deck, as well as placement of the aircraft in the hangar (Figure IV-4).

Two problems affected shipboard maintenance operations. First, the LHD hangar deck height allows only a single MV-22 with the wing flight-ready and nacelles vertical. This "high hat" area is 18 inches too narrow to spread the proprotor blades. Therefore, any maintenance actions requiring the proprotors to be spread must be conducted on the flight deck. Such maintenance will not be possible during flight operations and periods of inclement weather.

Second, deck-edge electrical power on the USS Bataan cannot provide the proper electrical power for MV-22 avionics systems. The MV-22 requires 115 (+/-2) volts, while the ship's deck-edge power supplies 118 volts. As a result, maintainers must rely on a mobile generator or the aircraft's own auxiliary power unit for troubleshooting. This will increase the wear on the auxiliary power system, thus shortening its life.

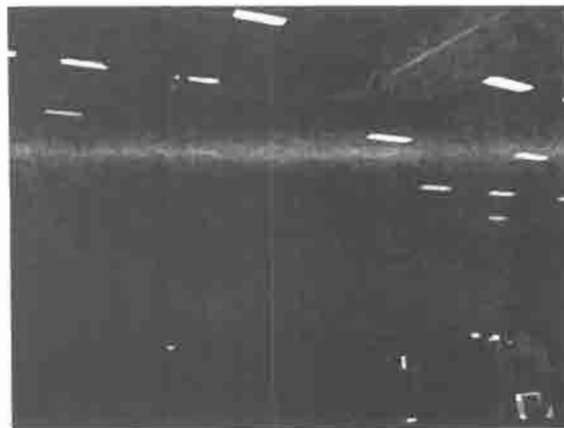


Figure IV-4. Osprey in the Hangar Deck of USS Bataan

Corrosion Environment

VMX-22 inspected two of the test aircraft prior to and after the ship deployment in order to assess the corrosive effects of the shipboard operating environment. The inspection team did not find any significant corrosion. During the shipboard testing, the MV-22 demonstrated compatibility with standard aircraft wash procedures. VMX-22 maintenance teams performed engine washes after flight operations in accordance with the Navy's corrosion control procedures. Additionally, the maintenance team washed all aircraft as required aboard the ship. No problems were noted.

Interoperability

Interoperability with existing DoD communications systems is a threshold requirement for the MV-22 Block A. Enhanced interoperability via Demand Assigned Multiple Access satellite communications for Block B and added data links for Block C are planned.

For the Block A configuration, the operational requirements specify critical voice information exchange requirements (IERS). With exception of the use of Single Channel Ground and Airborne Radio System (SINCGARS) in the anti-jam mode, the operational evaluation confirmed that MV-22 Block A meets its critical IERS. During several operational missions, the MV-22 acted as a high-altitude command and control platform supporting multiple MV-22s flying low-altitude profiles. The high aircraft provided coordination with range controllers and communications between mission elements. The relay feature of the ARC-210 radio enables the aircraft flying at low altitudes to transmit via the command and control platform to a range controller more than 80 miles away.

Use of the SINCGARS radio with user ID numbers greater than 399 causes the mission computer to cycle continuously, blanking out flight displays. Consequently, SINCGARS was not effective during the evaluation, and further attempts to use this system interfered with mission accomplishment. The contractor identified a fix to this problem, which is planned for incorporation in the next version of the aircraft avionics software. Future testing will verify the efficacy of the SINCGARS software patch.

Human Factors

VMX-22 examined man-machine interfaces during this operational evaluation. Crew surveys indicated that cockpit controls and interfaces, lighting, crew coordination, and maintenance accessibility were satisfactory. The cockpit interface is superior to current assault support aircraft. A new layout on the multifunction display now incorporates a larger, more distinct vertical velocity indicator. There is also a new cockpit door, and it is problem-free and easy to operate. The door also incorporates a jump seat for the flight engineer.

Based on crew surveys and data collected during OT-IIG, the following issues were identified:

1. Situational Awareness and Crew Coordination.
2. Passenger Seating and Egress.
3. Environmental Control and Comfort.

1. Situational Awareness and Crew Coordination. Previous operational testing noted poor crew coordination and reduced situational awareness for aircrew in the cabin area. Software upgrades now allow crew chiefs in the cabin to hear most aircraft system audible alerts, increasing their situational awareness. The crew chiefs still criticize the poor outside field of view from the back of the aircraft. The left side upper cabin window is very small. The size does not allow the crew chief sufficient visibility to scan for

traffic and airborne or ground threats, as well as keep situational awareness on the left side of the aircraft in both airplane and conversion mode. In VTOL mode, the crew chief is able to open the top part of the crew door, providing ample visibility on the right, but left-side visibility remains very poor. This is a problem when performing confined-area landings when the crew chief assists the pilots in assuring clearance from trees and obstacles.

2. Passenger Seating and Egress. The MV-22 demonstrated that it is capable of carrying 24 combat loaded Marines (Figure IV-5). This is a key performance parameter. The combat gear packs cannot be stored under the seats because the energy-attenuating design of the seats requires that they be free to collapse. Therefore, combat packs must be stored on the laps of the Marines or in front of the troop seats, blocking the aisle. Congestion in the cabin may impede an emergency or combat egress. Troop surveys indicated that the combination of the cramped cabin conditions, equipment on their laps, and an uncomfortable seat design (seat pan is too short) caused their legs to fall asleep during flight. The cramped conditions also prevented them from shifting positions to relieve pressure on their legs.

Troop surveys also indicated that the seatbelt design is not adequate. The seat belt is too small and hard to manipulate while wearing gloves; it is hard to recover when it falls between seats, and the over-the-shoulder loop becomes an egress hazard when not secured. The congested cabin and seat belt issues may increase the time for embarkation and debarkation, posing a safety risk during combat or emergency evacuations.

A safer and more comfortable seat design is currently undergoing qualification testing. The V-22 program should emphasize the need to obtain the new seats for MV-22 Block B aircraft, and retrofit to Block A aircraft if feasible.



Figure IV-5. Twenty-four Marines in an MV-22

3. Environmental Control and Comfort. During OT-IIG, crews reported that the environmental control system still does not provide adequate cooling on the ground on a hot day, but that the cabin cooled off once the aircraft was in flight. Increased range and refueling capability of the V-22 make extended flights more likely. The combination of high cabin temperatures, extended flights, and seat comfort issues may affect the combat readiness of embarked troops.

Emergency Procedures

For any rotorcraft, including the V-22, the ability to save the aircraft – or at least enhance the probability of survival of its occupants – in the event of a single or dual engine failure is critical. While a V-22 has never experienced a sudden engine failure, flight test and engineering analysis indicate that the V-22 is not capable of autorotation to a safe landing.

Single Engine Failure

In either airplane or helicopter mode, the recommended procedure in the event of a single engine failure is to convert to airplane mode, proceed immediately to a suitable landing spot, convert back to helicopter mode, and land as soon as possible. Due to its high power, the ability of the V-22 to survive single-engine failures during low-altitude hovering is excellent--better than the legacy transport helicopters it replaces.

Dual Engine Failure

In the event of either a sudden dual-engine failure, or a single failure of one engine coupled with a failure of the interconnecting drive train when the nacelles are less than 60 degrees, the recommended emergency procedure is to tilt the nacelles down, attain the best glide speed, and flare to a survivable landing. To convert the nacelles from 60 to 0 degrees requires about eight seconds and the aircraft must be above ground level by at least 1,600 feet in order to complete the conversion prior to impact. Impact-attenuating seats and other survivability design features can provide protection for passengers when failure occurs below 100 feet above the ground. Pilots practice the procedure in the simulator because of unacceptable risks in flight.

Emergency landing profiles following sudden dual-engine failure with the nacelles at 60 degrees or higher are more problematic. While the likelihood of such an occurrence is mitigated by system design, a portion of assault support missions will be accomplished in this mode of flying, e.g., carrying of external loads and vertical takeoff and landings in tactical zones. Dependent on altitude, the aircraft flight manual directs conversions to airplane mode or autorotation. Insufficient flight test data is available to determine the altitude requirements based on configuration, weight, and speed to convert to airplane mode. Additional flight tests should be conducted to provide validated procedures for dual-engine failure.

Documentation

The MV-22 technical documentation consisting of the Naval Air Training and Operating Procedures Standardization (NATOPS) Manual and the Integrated Electronics Technical Manual System (IETMS) adequately supports operations and maintenance by fleet personnel. Emergency procedures require further investigation.

NATOPS Manual

The preliminary NATOPS manual and pocket checklist used during OT-IIG contained the information necessary to conduct safe MV-22 flight operations in accordance with naval aviation instructions. The manuals are generally clear and accurate, but the procedures currently in use to update the manuals were not timely. As fleet introduction of the MV-22 progresses, standard NATOPS management should be implemented.

IETMS

Although there were some discrepancies in the IETMS, the overall system was functional and adequate. This was a distinct improvement since OT-IIE. Alternate procedures are in place to correct discrepancies such as technical action requests and technical publication deficiency reports.

Other Technical Manuals

Two important technical publications were missing. Technical documentation related to structural repair procedures was not adequate. Maintainers relied upon external support and guidance from the contractor FST whenever they attempted structural repairs. Maintainers provided comments regarding the lack of technical documentation related to the electronic wiring suite. This document is under development and was not available for full evaluation during the test.

Conclusions

OT-IIG demonstrated that the MV-22 Block A is operationally suitable. VMX-22 used the aircraft at an overall utilization rate of nearly 34 flight hours per aircraft per month, exceeding the projected peacetime utilization rate of 33.3 after the material support date in FY2007. VMX-22 accomplished OT-IIG with an eight-aircraft detachment with representative military and contractor manning. The MV-22 made progress in suitability performance and satisfied thresholds for:

- Mean flight hours between aborts.
- Mean flight hours between failures.
- Maintenance man-hours per flight hour.
- Mission capable rate.

Shipboard testing demonstrated improvements in the aircraft's operating envelope and its blade-fold wing-stow system. The MV-22 is compatible with flight and hangar

deck operations. The program is reviewing deck heating and the shipboard power compatibility deficiencies.

The MV-22 demonstrated the ability to satisfy its top-level information exchange requirements. During mission representative flights, VMX-22 pilots were able to plan and execute simulated missions, maintain situational awareness and communications with outside agencies, and use navigation aids and required transponder modes. The program identified a fix to a SINCGARS radio deficiency, which will be evaluated in follow-on testing.

Two concerns remain in the areas of safety and human factors:

- Emergency landing profiles for sudden dual-engine failures in Conversion/Vertical Take-Off Landing mode below 1,600 feet above the ground are unlikely to be survivable.
- The congested cabin and seat belt issues while carrying 24 combat loaded troops may delay embarkation and debarkation, and pose an entanglement risk during combat or emergency evacuations.

Recommendations

- Implement planned upgrades to seats and harnesses.
- Implement logistics support plans to support deploying MV-22 squadrons.

Section 5

Survivability

Assessing the survivability of the V-22 requires synthesis of two kinds of test results:

- Operational test and evaluation for susceptibility to threat weapons.
- Live fire test and evaluation for vulnerability to ballistic impacts and fire.

The design of the V-22 aircraft incorporates survivability enhancements that reduce both its susceptibility and its vulnerability to combat threats compared to legacy transport helicopters. This chapter discusses the susceptibility and vulnerability of the MV-22 and its crashworthiness. For the purposes of this report, the following threat descriptions apply:

Low Threat:

- Sporadic small arms fire from random locations.
- Maximum caliber 7.62 mm / .30 cal.
- Automatic weapons (e.g., assault rifles).
- No radar or other cueing.

Medium Threat (Above, plus):

- Larger caliber weapons (.50 cal/12.5 mm and 23 mm, but not AAA)
 - Adapted for anti-aircraft fire.
 - More sophisticated aiming devices.
 - Able to traverse and elevate.
- Legacy MANPADS (SA-7 and variants).
- Radar warning, but not tracking.

Susceptibility

After OT-IIE in 2000, DOT&E determined that the MV-22 was effective in a low-threat environment, and that many aspects of the V-22's basic design offer reduced susceptibility in the conduct of the Marine Corps' medium-lift missions compared to current transport helicopters. These advantages include:

- Increased speed and range combined with low altitude flight tactics (for terrain masking) decrease opportunities for acquisition by surface-to-air threats.
- Reduced acoustic signature, especially in airplane mode, provides less audible cueing to local threats.
- Electronic warfare suite warns the pilots of imminent threats, and automatic countermeasure dispensers decrease threat effectiveness.

The increased range and speed characteristics of the V-22 reduce its susceptibility in low and medium threat environments. With effective intelligence and mission planning, pilots can use the V-22 range advantage to circumvent known threats enroute to planned landing zones. The increased flight speed of the V-22 compared to slower flying legacy transport helicopters provides less opportunity for a surface-to-air threat system to engage the V-22. The probability of any single engagement occurring is inversely proportional to ground speed. At 240 knots, a V-22 will have a 40 percent reduction in engagement probability over the same environment as a legacy transport helicopter flying at 150 knots. This is a large survivability improvement, especially against infrared-guided MANPADS, which are the primary threat to V-22.

The MV-22 carries a suite of fielded, government-furnished equipment, defensive electronic countermeasures consisting of:

- APR-39(V)2 radar signal detection system.
- AVR-2A laser detection system.
- ALE-47 countermeasure dispensing system.
- AAR-47 missile warning system.

Testing conducted during OT-IIE in 2000 included actual and surrogate threat MANPADS, anti-aircraft gun systems, and radio frequency (RF) surface-to-air missile systems. That testing demonstrated that the MV-22 was effective in a low-threat environment, but it was less effective in a high-threat environment such as an integrated air defense system. Although the defensive suite provided susceptibility reduction in multiple threat environments, performance of the missile warning system, the radar detection set, and the effectiveness of the countermeasures system needed improvement. The limited number of chaff and flare countermeasures decreased aircraft effectiveness against threats that engaged the aircraft, and false alarms detracted from aircrew situational awareness.

Susceptibility testing during OT-IIG concentrated specifically on RF and laser threats in order to examine corrections to deficiencies from earlier testing. The testing consisted of 15 dedicated sorties at the Naval Air Warfare Center-China Lake Electronic Combat Range. These sorties evaluated the radar and laser detection systems' performance in terms of spatial coverage, detection range, threat identification, warning time, and display accuracy. They also examined operation of the countermeasure dispensing system and the capability of the MV-22 to perform maneuvers to break away from tracking by the threat systems. VMX-22 intends to use the results from this single aircraft/single threat testing to plan tactics for assault support missions. The test team conducted trials versus several different short-, medium-, and long-range surface-to-air missiles and acquisition radars.

DOT&E now assesses the MV-22 as survivable against threats up to and including a medium threat environment. The elevated threat level that the MV-22 can survive is

attributable to reduced susceptibility gained from:

- Speed, altitude, and maneuvering performance of the MV-22 in airplane mode.
- Defensive electronic countermeasures installed in the MV-22.
- Design of the MV-22 which places the nacelles away from vital aircraft components.

Survivability also depends on reduced vulnerability if hit by a threat weapon, including:

- Extensive ballistic vulnerability live fire test program in which threat weapons did not succeed in disabling the aircraft.
- Consideration of the survivability features designed into the basic V-22 aircraft, including:
 - Impact-resistant structure.
 - Energy-absorbing seating for crew and passengers.
 - Redundant controls, flight computers, and propulsion systems.
 - Fire protection/extinguishing systems.

Threat Detection

The aircraft's integrated defensive electronic countermeasures system provides the ability to detect RF and laser energy directed at the aircraft. During the tests, the system detected threats at sufficient range to provide pilots and aircrew adequate reaction time to counter most threats. Threat information was displayed in a timely manner, with an accurate representation of actual threat location relative to the aircraft. There are some deficiencies:

- The APR-39(V)2 radar detector set does not provide spatial coverage required for survivability against all threats contained in the system's threat assessment report. This deficiency is not specific to the integration of the APR-39(V)2 on the MV-22. The same deficiency exists on other similarly equipped aircraft.
- A separate threat display makes it difficult to correlate displayed threat information with aircraft position presented on the cockpit map display.
- The synthetic warning voice provided by the APR-39 is unintelligible to all crew members.
- Control and monitoring of the survivability equipment is only possible from the right seat.
- The survivability equipment is not incorporated with the IETMS for post-flight troubleshooting and repair.

Cabin Visibility

Limited visibility from the cabin area prevents the crew chief from providing effective lookout against surface and airborne threats. Due to the restricted field of view, the ability of the crew chief to detect threats is less than that of legacy transport helicopter it replaces.

Countermeasures

The automatic countermeasures dispensing system successfully deployed countermeasures when stimulated by threat radars. Several aspects of the aircraft countermeasures dispensing system require improvement:

- The mission data file was constructed specifically for the threats used in this operational evaluation and was not correlated to an operationally representative mission profile.
- As noted in previous operational testing, the quantity and placement of the flare and chaff dispensers are not sufficient for all threats identified in the system threat assessment.

Defensive Weapon System

There is no defensive weapon on the MV-22 Block A aircraft. A defensive weapon is needed to suppress threats while approaching a landing zone, disembarking troops within the landing zone, and during egress from the landing zone. The program has selected the M240G 7.62 mm squad automatic weapon and intends to test and field this weapon system in the MV-22 Block B aircraft.

Vulnerability

The V-22 design includes vulnerability reduction features. Design features such as the ballistically tolerant drive train, crew seat armor, fuel tank inerting systems, and redundant flight control hydraulic systems reduce system-level vulnerability. Landing gear and crew and passenger seats absorb energy in crash landings.

Live fire test results led to implementing the following vulnerability reduction features:

- Automatic fire extinguishing system in the mid-wing gearbox dry bay.
- Re-designed wing structure to make it more tolerant to hydrodynamic ram effects.
- Re-designed sponson that increased hydrodynamic ram tolerance.
- Re-designed jam-proof flight control actuators.
- Re-designed crash resistant self-sealing fuel tanks.
- Re-designed fuel tanks adjacent to the wheel well to reduce the likelihood of fire.

Casualties and Crashworthiness

The V-22 program placed high priority on reducing those vulnerabilities that could lead to catastrophic loss of the aircraft, crew, and passengers. For example, the fuel tanks are inerted to prevent explosions and flight control actuators are jam-proof. The V-22 also incorporates a number of features to reduce crew and passenger casualties in the event of a crash or forced landing. Design qualification tests and analyses indicate these features are effective:

- Energy-attenuating seats.
- Breakaway valves that seal off fuel tanks and other fuel line stress points if ruptured during a crash.
- Energy-absorbing cargo restraints.
- Multiple emergency exits.
- Energy-absorbing structure and landing gear, designed to allow crew and passengers to survive a vertical, 24 feet-per-second sink-rate landing, provided the main landing gear is down.

Conclusions

Operational and Live Fire Test and Evaluation results indicate that the MV-22 Block A is a survivable aircraft in low and medium threat environments. The V-22 has several characteristics that reduce the overall susceptibility compared to legacy transport helicopters. Ballistic vulnerability testing demonstrated that the V-22 is capable of withstanding impacts by threat projectiles specified in the requirements and continue to function. Live fire test results led directly to the identification of the need for a number of vulnerability reduction features. The V-22 program made numerous changes during the early design process to address these features.

The integrated defensive electronic countermeasures system provides an adequate capability for detecting RF and laser energy directed at the aircraft. There are some deficiencies in spatial coverage and threat displays that require correction.

The MV-22 Block A does not have a defensive weapon. This requires escort aircraft to provide fire support against hostile forces encountered during assault support missions. Appropriate tactics for operations with escort aircraft must be developed before the first squadron deploys.

Analysis of the aircraft design and infrared emission sources indicates that a decrease in susceptibility to MANPADS is achieved by the V-22 compared to legacy transport helicopters. This decrease in susceptibility comes from the design feature that places most of the infrared emission at the end of the nacelles, which are displaced from the rotors and fuselage by a distance greater than the lethal radius of typical MANPADS threats.

The V-22 aircraft has numerous vulnerability reduction features. Additional vulnerability reduction is attainable. In November 2000, DOT&E identified several areas where further improvement is warranted. To date, the V-22 program has not incorporated any design changes to address these areas.

Recommendations

- Develop appropriate tactics for coordination with helicopter and fixed-wing fire support aircraft.
- Equip the flare and chaff dispensing system with sufficient capacity for multiple threat encounters on long missions.
- Install and test a defensive weapon (planned for Block B aircraft).
- Correct the deficiencies in the defensive electronics countermeasures system.
- Consider adding active fire suppression systems to the wheel well and under-floor dry bays.
- Determine the effectiveness of the engine bay fire extinguishing system against actual threat induced fires.
- Devise/improve cabin wall battle damage repair methods and procedures. Damage to this all can make the aircraft unavailable for an extensive period.