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TILTROTORS FOR U.S. AND INTERNATIONAL MISSIONS

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The US Marine Corps MV-22 is in Low Rate Initial Production, and all the four Engineering and Manufacturing Development aircraft are past the middle of their flight test program at the Naval Air Test Center at Patuxent River, Maryland. The next major program steps are the Operational Test and Evaluation flights in 1999 and Milestone III in 2000 which prepares the program for full rate production. It is now time to look beyond the baseline programs: 360 MV-22s for the USMC, 50 CV-22s for the USAF Special Forces Command and 48 HV-22s for USN Combat Search and Rescue and Fleet Support, to other uses and users in need of a sophisticated turboprop multi-purpose aircraft that flies at speeds greater than 300 knots and can take off and land vertically.

During the V-22 development program that started in 1982, Bell Boeing has studied a whole range of missions for the US and other Allied Nation's Departments of Defense. There are over 30 identified missions that can be performed with the V-22, ranging from simple transport missions to electronics-dominated ASW/AEW/EW missions. The 6 x 6 x 24-foot cabin can easily accommodate the avionics and mission fits for tactical use. The aircraft has a high level of survivability and can perform these missions in hostile areas not readily penetrable by conventional helicopters.

In this paper we will describe some of the mission/equipment studies that have been performed to date. Bell Boeing also feels that there are new and exciting missions that go beyond the presently recognized ones. These will be discovered and developed by the next generation of aviators when they become familiar with the revolutionary capabilities of the tiltrotor.

Introduction

The V-22 Osprey tiltrotor is a unique rotorcraft in that it can hover efficiently like a conventional helicopter and fly at speeds greater than 300 knots with the efficiency and comfort of a turboprop airplane. Developed by the Bell Boeing team for the U.S. Marines (MV-22), USAF Special Operations Command (CV-22), and US Navy (HV-22), six aircraft (tail numbers 1 through 6) were designed, built and flight tested for almost 1200 flight hours during the Full Scale Development (FSD) phase. The development program is currently in the Engineering and Manufacturing Development (EMD) stage. Four new aircraft (tail numbers 7 through 10) have been built on production tooling. These aircraft are now at the Naval Air Warfare Test Center in Patuxent River, Maryland. The overall development program plan is presented in Figure 1. EMD testing will clear all of the structural features of the airframe and the basic USMC fit of avionics and will be completed in 1999. The development of the SOF V-22 with increased avionics and internal fuel is under contract and testing will use 2 of the EMD MV-22s with CV-22 changes. The Navy Combat Search and Rescue (CSAR) HV-22 aircraft will follow the CV-22.

The MV-22 is also in Low Rate Initial Production now and deliveries start in 1999. Projected production quantities are 360 for the USMC; 50 for SOCOM; and 48 for the Navy. Production quantities per year in the early 2000s will be in the order of 30 to 40 aircraft.

Although the tiltrotor concept was studied in the 30's and experimental aircraft were built in the 50's and 70's, there were two enabling technologies that matured in the 80's and made a viable production design possible. They were fly-by-wire (FBW) all-digital flight control systems, and composites technology for primary structure. The FBW control system allowed an automatically re-configurable control system for all modes of flight and made it easy to design the wing stow system at an acceptable weight.

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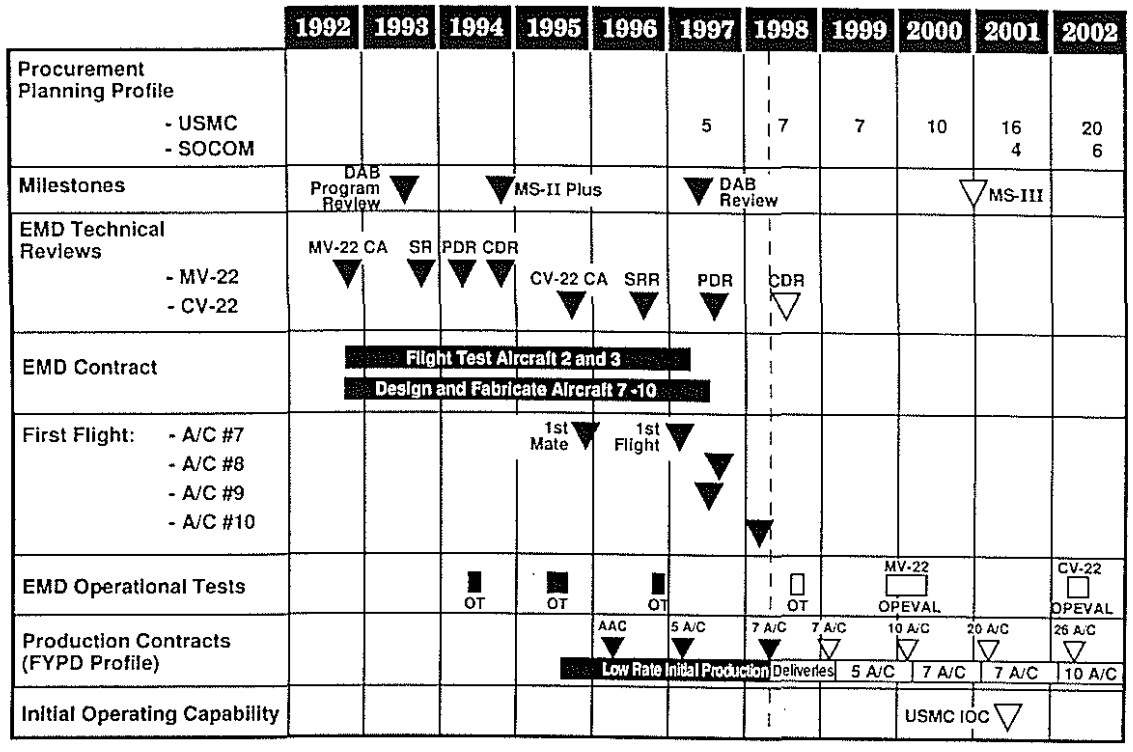

Figure 1. V-22 Osprey EMD / LRIP Schedule

Composites technology provided the choice of materials for optimum design of the structure to meet dynamic characteristics, strength, cost and weight.

Some of the salient design features of the V-22 are shown in Figure 2. The V-22 carries a crew of two to four and has seats for 24 passengers. There are 2 pilot seats and a jump seat in the cockpit and 25 seats

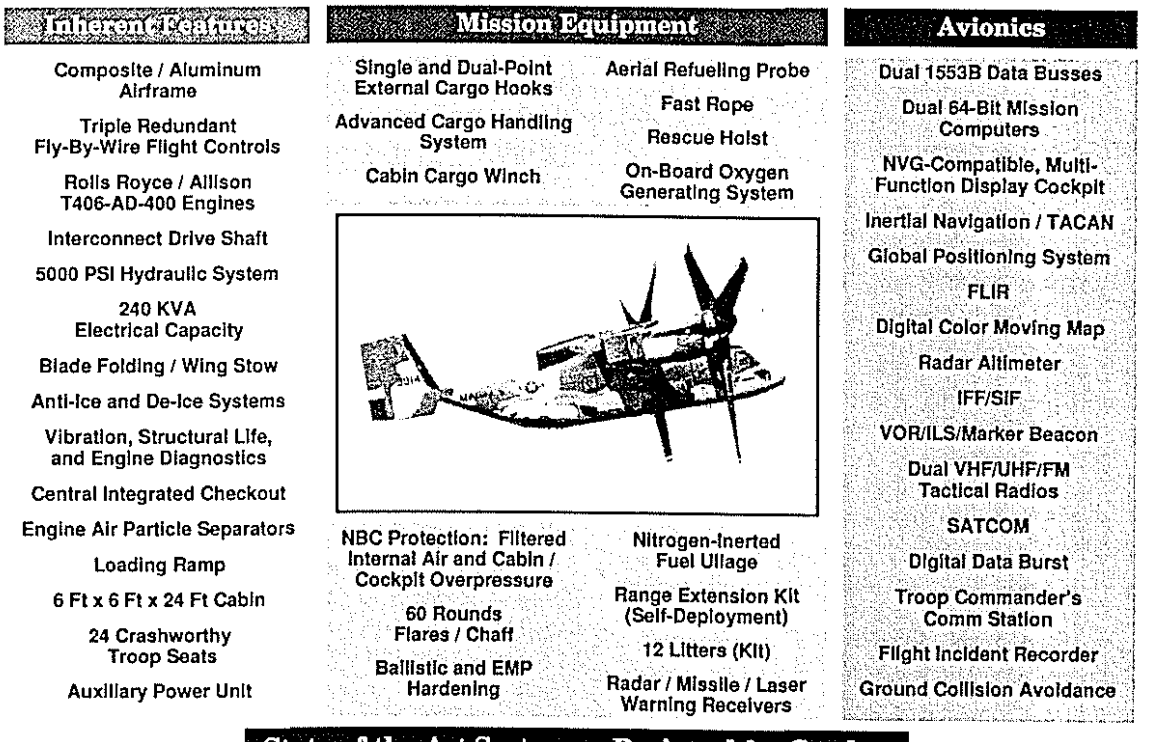

Figure 2. V-22 Multi-Mission Features

in the cabin. Flexibility is added by the ability to carry external cargo up to 15,000 pounds on tandem hooks with individual capacities of 10,000 pounds, and internal payloads of up to 20,000 pounds. An aft ramp, roller rail system and built-in winch allows rapid loading/unloading of internal cargo. The rotor blades fold and the wing rotates in 90 seconds for stowage aboard ship. The V-22 is capable of all-weather instrument flight, day or night, and continuous operation in known moderate icing conditions, and at weights up to 60,500 pounds for self-deployment. The V-22 structure uses the latest in composite materials and manufacturing processes. A synergistic combination of precision-machined aluminum, fiber-placed graphite, and titanium has allowed a significant weight reduction, as shown in Figure 3, and a 23% cost reduction in the EMD V-22 when compared to the FSD aircraft. The Night Vision Goggle-compatible cockpit includes conventional controls and digital avionics displayed on four Multi-Function Displays (MFD) and one Control Display Unit/Engine Indicating and Caution Advisory System (DCU/EICAS).

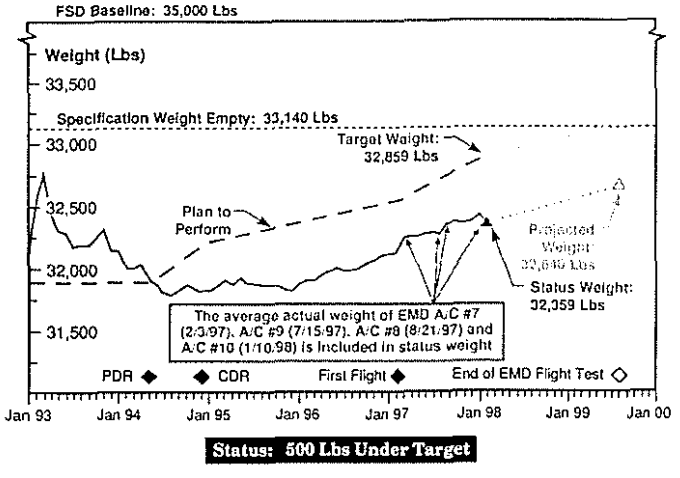

Figure 3. Weight Empty History

Aircraft and Manufacturing Design Processes

Past experience indicates 80% of a product's life-cycle cost is determined by decisions made during the first 20% of the product design cycle, a fact which encouraged Bell Boeing to adopt a new approach to designing the production V-22 which would ensure that robust decisions were made during the crucial early stages of design.

Concurrent Product Definition (CPD) includes near simultaneous design, analysis, and planning by engineering, manufacturing, logistics support and the customer in a team, called an Integrated Product Team (IPT).

Over 80 IPTs consisting of all engineering, tooling, manufacturing, customer, supportability and subcontract disciplines, worked simultaneously on each part of the aircraft to ensure a balanced design. They had the authority and responsibility (including budget) for their portion of the product. At the major system level, Analysis and Integration teams (Segment A&Is) ensured consistent application of requirements by the teams with allocation and mediation of requirements across interfaces. Typical parameters that were allocated to the IPT's were weight, drag, reliability, maintainability, design-to-cost, life-cycle cost, subsystem cost, etc. Above the Segment A&Is, the Air Vehicle A&I ensured overall consistency and adjudicated conflicts. The multiple customers for the V-22 aircraft are an integral part of the A&Is and IPTs.

The tool that facilitates all IPT activities is the graphics-based CATIA software. It provides a single-source, computer-generated, three-dimensional definition of the total product and its individual parts. As illustrated in Figure 4, CATIA facilitates the cross-talk among all functional disciplines from preliminary design to product support.

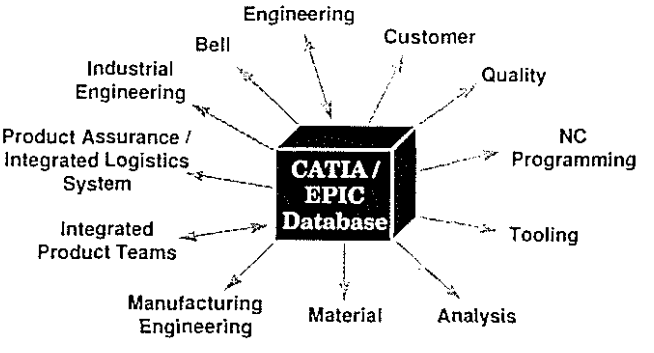

Figure 4. CATIA / IPT Processes

CATIA allows the creation of three-dimensional models such as the landing gear bay shown in Figure 5 (very similar to virtual reality) that permit engin-

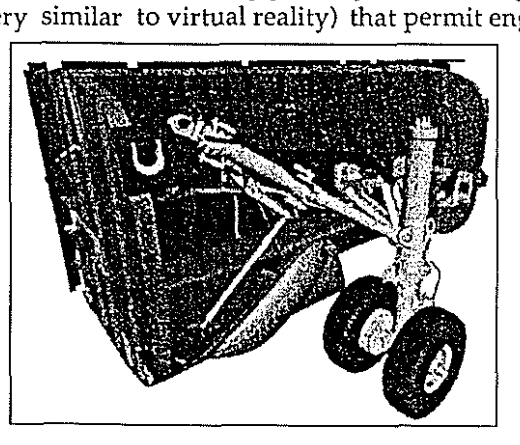

Figure 5. Landing Gear Solid

eers to assess designs early and eliminate the building of expensive hardware mockups. The elimination of hardware mockups (difficult to maintain in the latest configuration) saved 150,000 man-hours on the V-22 EMD program. Parts are then Digitally Pre-Assembled (DPA) to catch design errors now, when changes are least expensive, prior to fabrication.

Using CPD, IPTs, DPA, and VALISYS lowers cost and increases product quality. These benefits are validated early in the product development process and disseminated to the IPTs if corrective action is required. The result has been increased quality because individual parts are designed with producibility and ease of assembly considered from the beginning; this, in turn, permits proper manufacturing tolerances and decreased variation so parts fit correctly the first and every time. As an example, the three sections that comprise the V-22 airframe were successfully mated in a half hour (excluding fastening). In FSD this process took several days.

Manufacturing Process Advances

Advanced machines, utilizing the CATIA database, robotically manufacture large, one-piece composite sections and high-speed machine single- piece frames from aluminum billets for the V-22. These systems allow engineers to eliminate literally hundreds of parts and dedicated tooling. Four important systems being used are optical lay-up template, trim and drill cell, advanced technology assembly, fiber placement and high-speed aluminum machining. The advantages are discussed in Figure 6.

Technology	Description	Advantage
Optical Lay-Up Template	Laser-based ply-locating system CATIA driven	Most physical templates eliminated
Trim and Drill Cell	Universal holding fixture with CATIA driven trim and drill functions	Eliminates trim and drill templates and inspects the part
Advanced Technology Assembly	Precisely located parts in adjoining parts for assembly. CATIA driven.	Reduces non-recurring tooling for assembly
Fiber Tow Placement	Automated lay-up of composite materials for complex parts. CATIA driven	Significantly reduces cost (> 50%)
Aluminum Frame High Speed Machining	Machining one-piece aluminum frames/ stiffeners. CATIA driven	Parts count reduced 40X; fasteners 258X; tool count 23X; cost 62%; weight 18%

Figure 6. Manufacturing Process Improvements

Rejection Reports

As a visual summary of the concepts discussed earlier, Figure 7 shows that Rejection Reports, a metric of the problems encountered in the manufacture and assembly phase, have been reduced by 60% from FSD to EMD and have been further reduced by 80% from EMD to LRIP, for a total reduction of 92%.

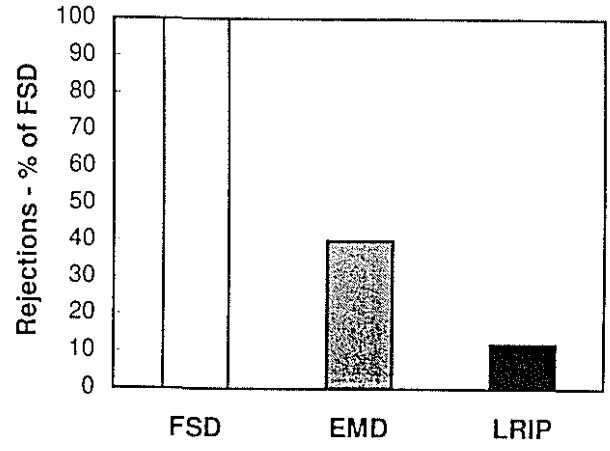

Figure 7. V-22 Rejection Reports - FSD to EMD to LRIP

This means less scrap, less rework, less handling of parts, less shortages, less out of sequence installs, and translates directly into less unit cost in production.

Supportability

Finally, the V-22 has an advanced, state-of-the-art, on-board check-out/condition monitoring and diagnostics capability. The V-22's monitoring system is setting new standards in diagnostics and will be a major contributor to the V-22's low cost of ownership by facilitating the on-condition maintenance concept. Two key systems, the Centrally Integrated Checkout and the Vibration, Structural Life, and Engine Diagnostics systems, provide fault detection, fault isolation, and continuously monitor aircraft health and usage. Figure 8 illustrates numerous other features provided in the V-22 for high reliability and ease of maintenance.

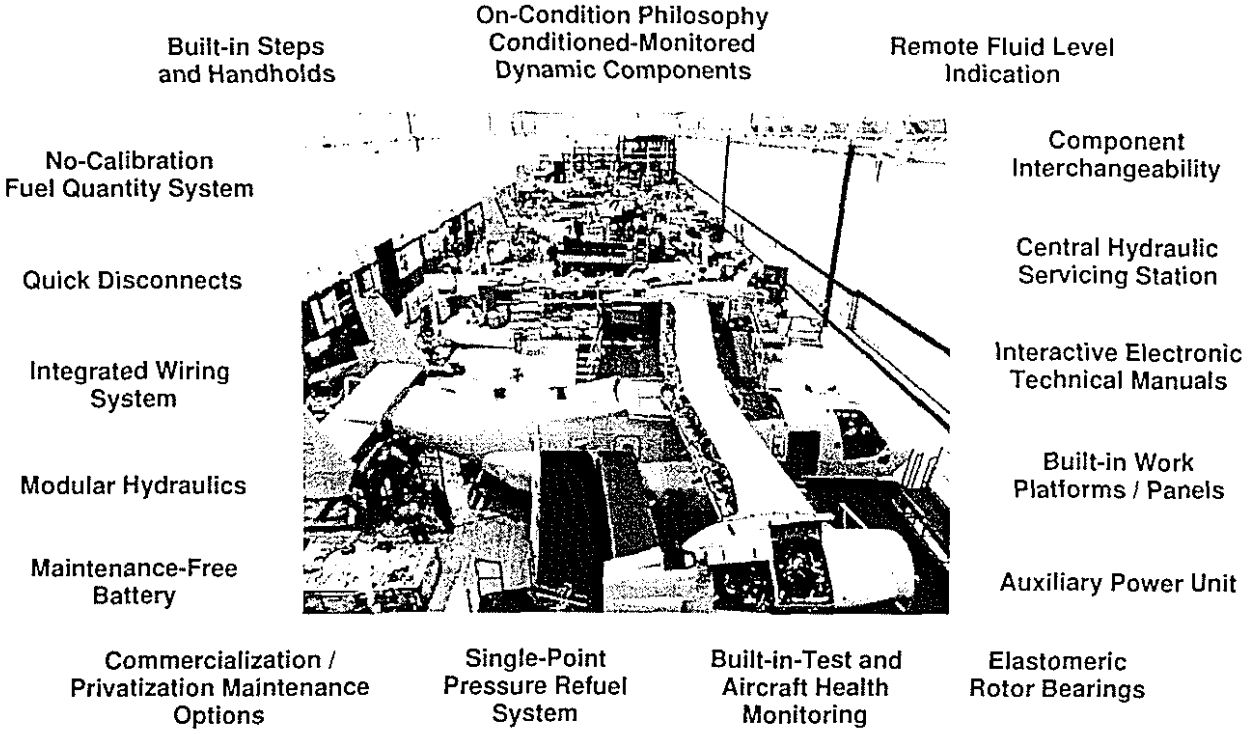

Figure 8. Supportability Features

Prime Mission Performance

The V-22 was designed from its inception as a highly flexible, multi-purpose aircraft. The US Department of Defense (DOD) has identified over 32 mission for the V-22. It has also been the winner in over seventeen different mission effectiveness studies by the US Government, Bell Boeing, and independent analysis companies. Some of these missions are shown in Figure 9. The V-22 meets or exceeds all mission requirements. In addition, the independent variables used in the compliance calculation all have built-in buffers to ensure that the required Key Performance Parameters (KPP's) are met at the end of EMD in 1999.

USMC MV-22

For the Marine Corps, the Osprey's speed and range provide an expanded battle-space that complicates the enemy's ability to defend their territory. Figure 10 shows the increased combat reach the Marines will have while making an amphibious assault, relative to the capability of the present Marine assault medium-lift aircraft, the CH-46. The range capability of the Osprey permits the amphibious fleet to use the sea as operational maneuver space. This increased capability allows greater standoff distance for the amphibious fleet, thus avoiding coastal minefields and missile defenses. It also enhances the element of surprise by providing a capability for feint and deception.

- **JROC has validated V-22 as a multi-mission platform and verified the key performance parameters**
- **Additional high-priority missions:**
  - Search and Rescue
  - Tactical Surveillance
  - Airborne Early Warning
  - Anti-Submarine Warfare
  - Medical Evacuation
  - Aerial and Ground Refueling
  - Executive Transport
  - Combat Rescue
- **V-22 offers simultaneous search *and* rescue**

Figure 9. Expanded Mission Capability

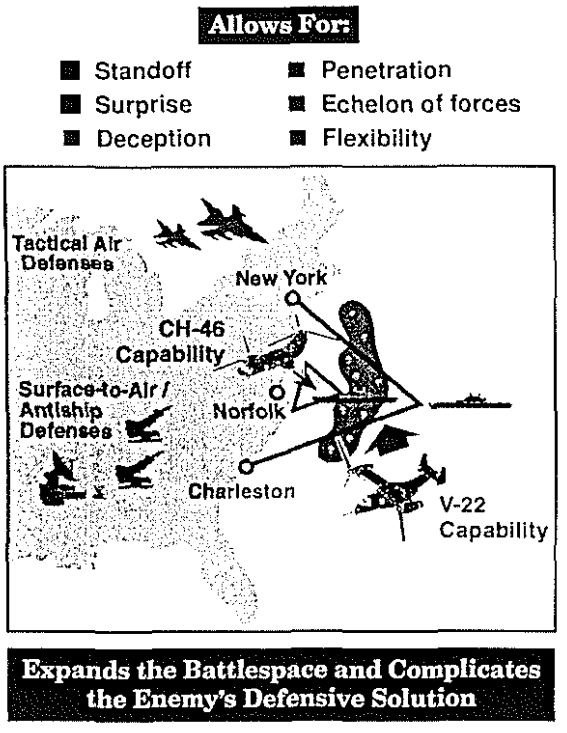

Figure 10. Enhanced Reach in War

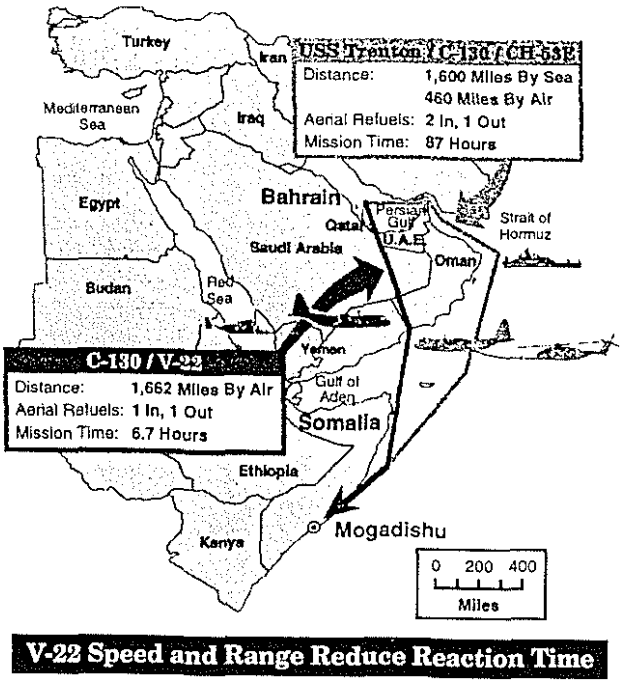

Figure 11. Operation Eastern Exit - Comparing Helicopter and V-22

USAF SOF CV-22

Special Operations Forces (SOF) require high-speed, long-range, V/STOL aircraft capable of penetrating hostile areas. The SOF V-22 is capable of covert penetration of medium to high threat environments in low visibility, while employing self-defensive avionics and secure, anti-jam, redundant communications. The SOF V-22's inherent long-range and self-deployment ability maximizes mission security and minimizes logistics cost. It has an unrefueled combat range sufficient to satisfy current military needs and carries a built-in refueling boom for range extension. The SOF V-22 has the necessary speed to complete most operations within one period of darkness and can operate from air capable ships without reconfiguration or modification.

V-22's Mission Performance Capabilities

Figure 11 portrays the potential advantages of using the V-22 in the initial stage of "Operation Eastern Exit", the evacuation of 61 Americans and several foreign Ambassadors from the US Embassy in Mogadishu, Somalia. The actual evacuation by CH-53Es, carried to waters off Somalia by the USS Trenton (LPD-14) from its anchorage off Oman, took 87 hours and included three aerial refuelings per helicopter. With the V-22, the same mission could have been flown directly from Oman using two aerial refuelings with a total mission time of less than seven hours.

Similarly, in an April 1980 attempt to rescue US embassy personnel in Iran, a 33 hour mission could have been performed by the V-22 in less than 7 hours without the attendant problems of refueling at Desert One.

Combat Search and Rescue

Combat Search and Rescue variants of the V-22 have been studied for the US Navy, the USAF, and for International Governments. Typical SAR missions often require extended range and speed combined with extended time-on-station to perform the necessary search and often, hover pickup. The ability to combine speed, range, and time-on-station with the ability to hover and recover victims in a hostile environment (V-22 incorporates a very robust survivability capability), means the SAR V-22 can provide a great improvement over the current necessity for combining fixed-wing aircraft for search and helicopters for pickup. VTOL capability also allows the aircraft to deliver the rescued people directly to an aid station or a hospital thereby bypassing transfers and attendant time delays. A rescue hoist (Figure 12) and litter kit (Figure 13) were designed into the aircraft from inception. The hoist in the right-hand entry door pivots into the aircraft when not in use. Hoist operation and limited aircraft control is available to the hoist operator in the cabin doorway upon pilot concurrence and command.

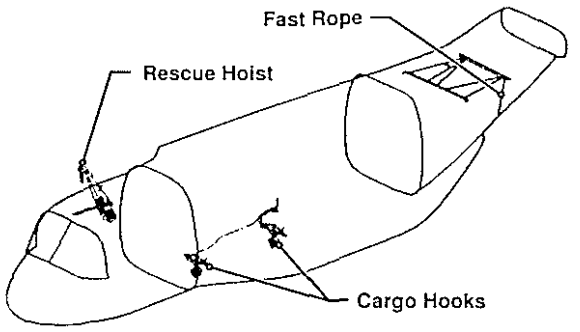

Figure 12. External Load Handling Equipment

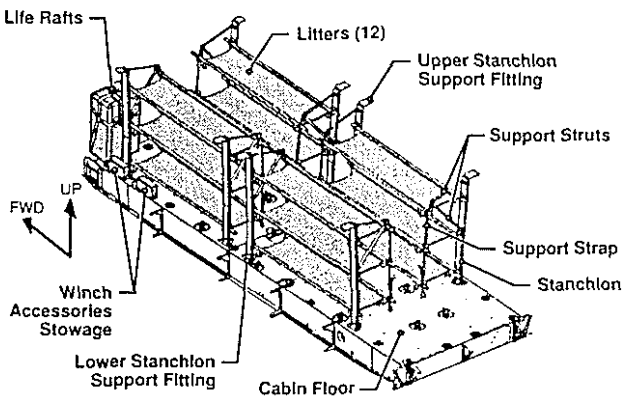

Figure 13. Cabin Litter Configuration

A recent study conducted by the US consulting firm ANSER and Britain's Defense Evaluation and Research Agency (DERA) concluded that the V-22 tiltrotor is "significantly more effective" than present rescue helicopters in conducting search and rescue even under the most limiting assumptions. They found that:

- V-22 is anywhere from 3 to 7 times more effective
- The more difficult the rescue environment, the greater the advantage of the V-22
- V-22's greater survivability is a key variable in CSAR effectiveness. V-22 is 2 to 10 times more effective
- V-22, because of it's range capability, eliminated the need for over 100 aerial refuels that the helicopters needed
- V-22s did not need any aerial refuels in hostile areas
- As a comparison, one scenario required 8 helicopters and 11 MC-130 tankers versus only 4 V-22s and no tankers
- V-22's capabilities also reduced the need for other support equipment, personnel and strategic airlift to conduct CSAR missions

Domestic / Civilian SAR

In addition to combat SAR, the V-22 is very well suited for civilian and non-military government SAR uses. Bell Boeing has designed several internal arrangements for civilian SAR with full integral fuel of 13,850 pounds (full wing and sponson fuel) and with an additional 615 gallon cabin tank for a total of 18,270 pounds of fuel for extended range and time on station. The V-22 is designed with standard kits to use HIFR (Hover In Flight Refuel) capability from ships with no landing decks. A refuel boom kit is also provided so that fuel can be obtained from any aerial tanker (Figure 14) equipped with a hose and drogue system. Figure 15 shows typical search times versus radius for the aircraft with integral fuel of 13,850 pounds. With a cabin tank, and refueling from ships or an aerial tanker, search time/pickup time is only limited by crew endurance.

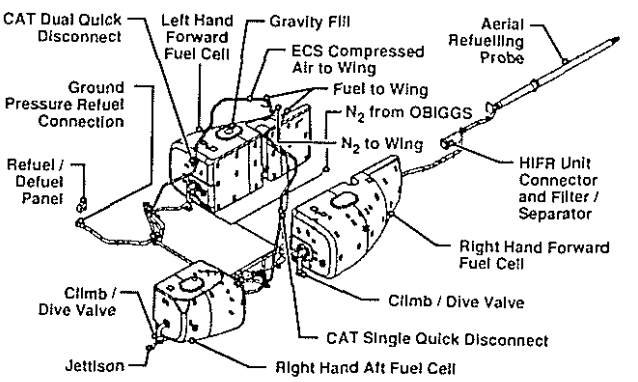

Figure 14. Aerial Refueling Boom

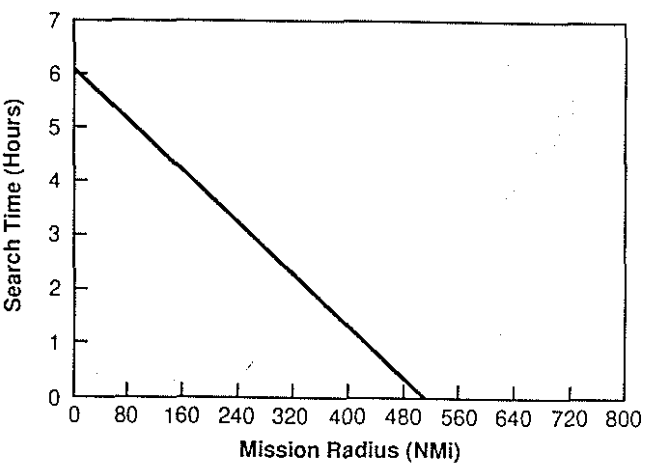

Figure 15. Typical Search and Rescue Mission

An illustration of the SAR capability of the V-22 is shown in Figure 16. Flying from bases in France, the V-22 could perform SAR missions covering all of France and the surrounding seas.

Figure 16. V-22 Search and Rescue Capability From France

A notional example of the inherent capabilities of the V-22 in performing long range SAR missions is shown in Figure 17. During the Vendee Globe Race in January 1997, two of the yachts foundered approximately 1300 nautical miles south of Australia. A combination of P-3C Orion aircraft for search and a destroyer with a helicopter for pickup were used by the Australian Forces. The total rescue operation time from emergency beacon activation to return to port with the survivors was in the order of 8 days (200 hours). The same operation could be performed in the order of 8 hours with a V-22 and an aerial tanker. Cost of the operation for the Australian Forces was reputed to be $4M to $8M by the popular press. The cost of the V-22/refuel tanker would have been one sixtieth of the search aircraft/ship/ helicopter operation.

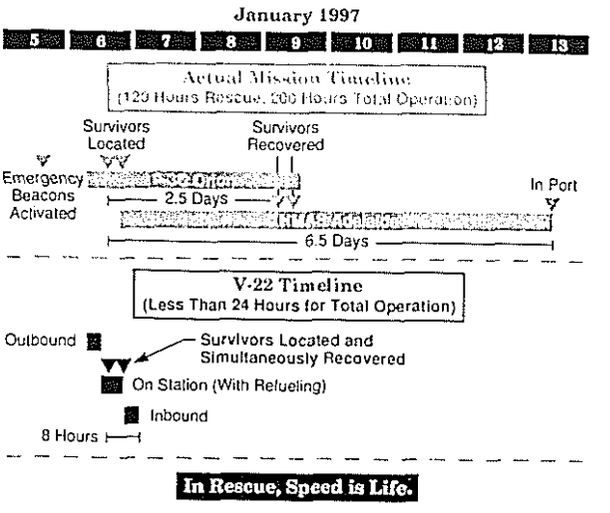

Figure 17. Vendee Globe Race Rescue

Future Mission Development

Common Features

While the V-22 has been designed for specific U.S. military missions, it can readily be reconfigured to meet a variety of needs. This flexibility of use is the principal reason the V-22 will be highly attractive to military operators worldwide. The following sections describe the currently envisioned variant configurations using available equipment. Of course, operators are free to select their own unique equipment and suppliers.

The most significant common feature of all V-22 variant configurations is its ability to combine long-range, high-speed cruise with the ability to takeoff or land in small and/or unprepared sites. Its flight envelope is fully compatible with existing helicopter and fixed-wing assets (Figure 18), thereby affording a very high degree of utility for different mission scenarios.

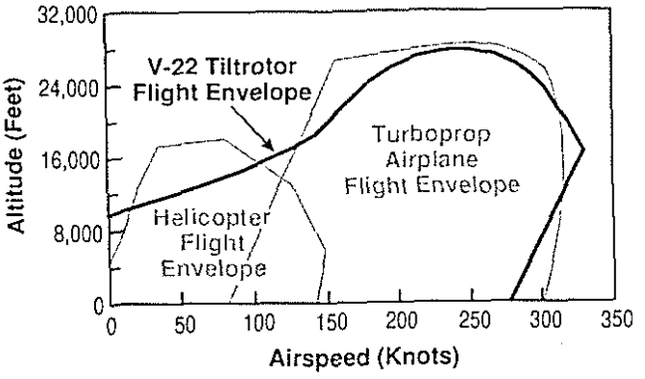

Figure 18. V-22 Flight Envelope

The V-22 can accommodate a wide array of available and customer-specified cabin and avionics equipment within the standard cargo handling and electrical systems. The use of a MIL-STD-1553 databus architecture means that new systems and technologies can be easily accepted with minimal cost to integrate.

Anti-Submarine Warfare (ASW)

As a V/STOL ASW aircraft, the V-22 (Figure 19) is capable of operating from the decks of destroyer-sized warships and air-capable fleet auxiliary ships.

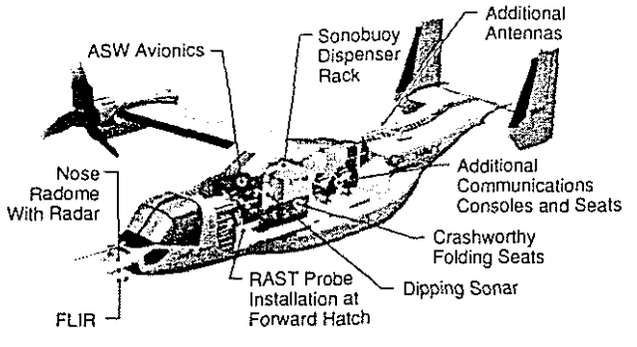

Figure 19. Anti-Submarine Warfare V-22

The ASW V-22 can combine the sonobuoy processing capability of the S-3B with the dipping sonar capability of the SH-60F ASW helicopter. The aircraft's hover capability, high speed, and long mission radius enable it to conduct independent ASW operations over a much greater area than conventional helicopters. The V-22 can incorporate a digital data link system to exchange real-time tactical information with surface ships, ASW helicopters, and other aircraft.

Airborne Early Warning, Electronic Warfare, Electronic Intelligence, and Command and Control

An airborne surveillance and control variant of the V-22 (Figure 20) can be designed to combine a V/STOL aircraft with a modern, multi-mode phased array radar system. Bell Boeing has worked closely with the Swedish aerospace company Ericsson to develop an installation of the ERIEYE radar.

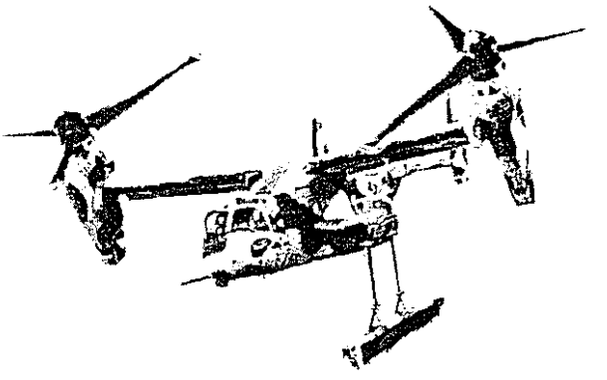

Figure 20. V-22 Airborne Early Warning

The speed and maneuverability of the V-22 improves surveillance range and response time along sea lanes, island chains, and coastlines. When launched from a ship, the V-22 can reach and search an assigned area hours ahead of the flotilla.

An electronic warfare variant can be fielded using a unique standoff jamming system designed by Boeing's ARGO Systems Division. The electronic warfare variant could provide both low and high frequency radar jammers as well as a communications jamming capability. These active systems are mounted in a pod that is similar in size and shape to that of the ERIEYE radar discussed above. An electronic intelligence system can be developed based on this same pod fitted with receiver modules. This configuration could include a roll-on/roll-off van with up to six operator stations.

Because of its inherent capability to operate from unimproved sites near ground troop commanders and its excellent range and time-on-station capabilities, the V-22 is a useful platform for command and control operations. As shown in Figure 21, the V-22 can easily accommodate onboard operator consoles that use removable, hatch-mounted antennae.

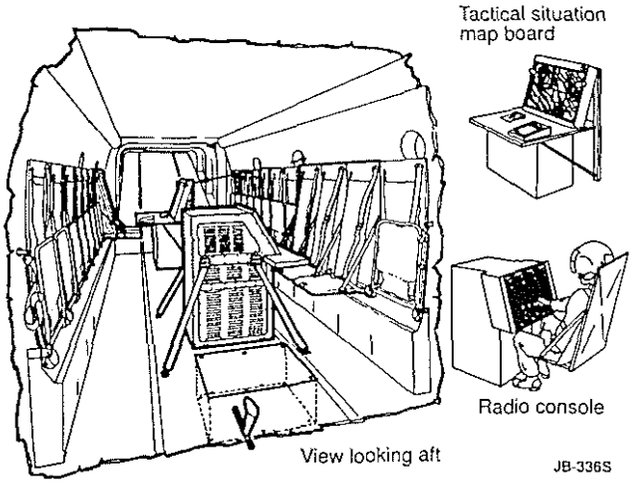

Figure 21. V-22 Command and Control Cabin

Aerial Tanker

Because the V-22 can operate over a wide range of cruise speeds, has a large cabin, and ample useful load; it can easily accommodate an aerial refueling kit and is well-suited as a refueler to many different types of aircraft, helicopters or fixed-wing, at speeds up to 275 knots. The kit, shown in Figure 22, enables the V-22 to supply any probe-equipped aircraft up to 13,000 lbs of fuel at a distance of 250 nm from the V-22's base.

The aerial refueling kit uses the same fuel supply system already incorporated for V-22 self-deployment. The kit is integrated with the baseline V-22 fuel system and allows nearly all on-board fuel to be given away. Using this kit, V-22s can perform a dual role, refueling themselves for long range missions, thus reducing a force's dependence on fixed-wing refueler aircraft. The V-22 Aerial Refueler could deliver fuel to a Forward Area Refueling Point (FARP) to refuel helicopters not equipped with probes and ground vehicles.

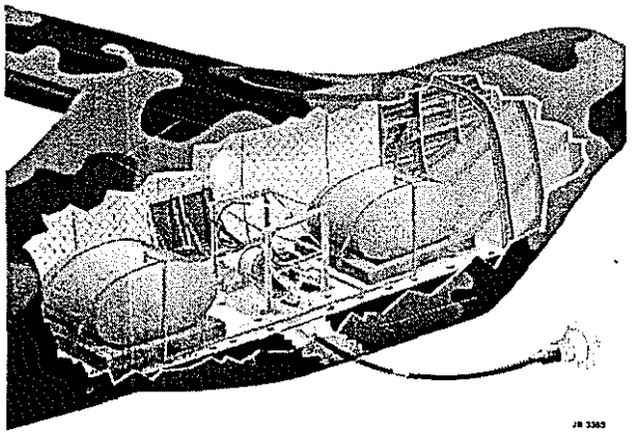

Figure 22. V-22 Aerial Tanker

Armed

The V-22 is a troop and cargo transport that will, by its mission, enter hostile areas. For maximum survivability, it can be fitted with a multi-barrel, 0.50-caliber, nose-mounted, turreted Gatling gun and a ramp-mounted machine gun. Sidewinder (AIM-9) and Stinger (FIM-92A) installations have been investigated to provide a full suite of self-defensive weaponry for the V-22 (Figure 23).

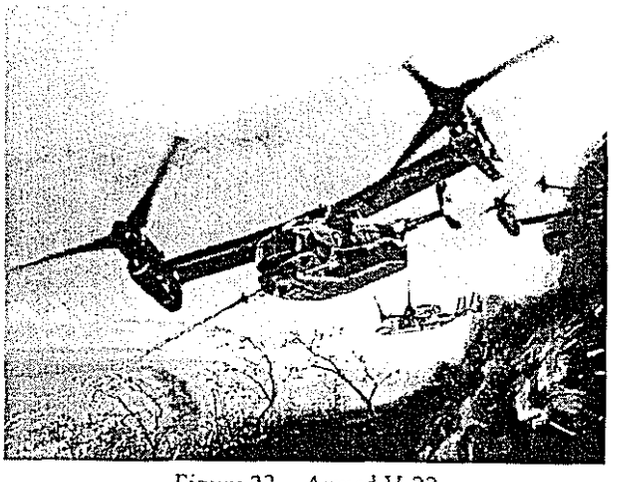

Figure 23. Armed V-22

Executive

Layouts have been evaluated to provide executive style seating for up to 14 with a crew of three. Figure 24 presents an interior cabin view.

Figure 24. V-22 Executive Interior Layout

Concluding Remarks

Tiltrotors are an extremely capable and uniquely versatile aircraft that have ushered in, or utilized, many new and exciting technologies. These include innovative design and manufacturing processes and features and systems directly applicable to a large variety of missions. The V-22 team is looking forward to the MV, CV, HV and other exciting derivatives reaching their operational units. We expect that the aircraft will be equally useful to U.S. friends and allies in war and peace.