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V-22 DEVELOPMENT STATUS

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Abstract

This paper summarizes the status of the V-22 Engineering and Manufacturing Development program, emphasizing the status of the Integrated Product Teams and resulting aircraft design-to-cost and weight status. It discusses the V-22 overall design constraints, digital electronic flight controls, benefits of automated composite construction and hot isostatic processed titanium castings, the integrated wiring system, multi-mission and supportability features designed into the V-22. Status of risk reduction flight testing of aircraft #2 and #3 is also presented.

1. Introduction

The V-22 Engineering and Manufacturing Development (EMD) program was awarded to Bell Helicopter Textron, Inc. and The Boeing Company, Defense & Space Group, Helicopters Division (Bell-Boeing) in October 1992. The EMD contract continues and completes the development work begun under the original V-22 Full Scale Development (FSD) contract, which was terminated upon commencement of EMD. The EMD program has already provided the U.S. Navy with significant improvements in aircraft performance and affordability while remaining solidly on schedule. EMD consists of the design, fabrication and flight testing of four new production representative aircraft. Concurrently, flying qualities and performance flight testing continues on two FSD aircraft in order to further expand the V-22's operating envelope and reduce risk in the EMD design. Figure 1 depicts the EMD program schedule and shows planned production contracts and aircraft deliveries.

Military service designations for the new V-22 aircraft are the MV-22 for the U.S. Marine Corps version (and baseline aircraft for the family), CV-22 for the U.S. Special Operations Command variant, and HV-22 for the U.S. Navy version. The Marine Corps intends to produce 425 MV-22s for the amphibious assault mission to replace its aging fleet of CH-46 helicopters. USSOCOM will integrate 50 CV-22s into its mix of aircraft to provide an enhancement of long range infiltration / exfiltration capabilities. The Navy's 48 HV-22s will provide a significant improvement in combat search and rescue capability. See Figure 2. Although not shown on Figure 1, production of the HV-22 is anticipated to commence in 2005.

2. Integrated Product Teams (IPTs)

The V-22 Program incorporated an IPT approach initiating with design work to garner the benefits which accrue from concurrent engineering. Each IPT operates as a miniature, self-contained program having ownership of a specific product and the authority to manage all aspects of its develop-

V-22 Joint Program Schedule

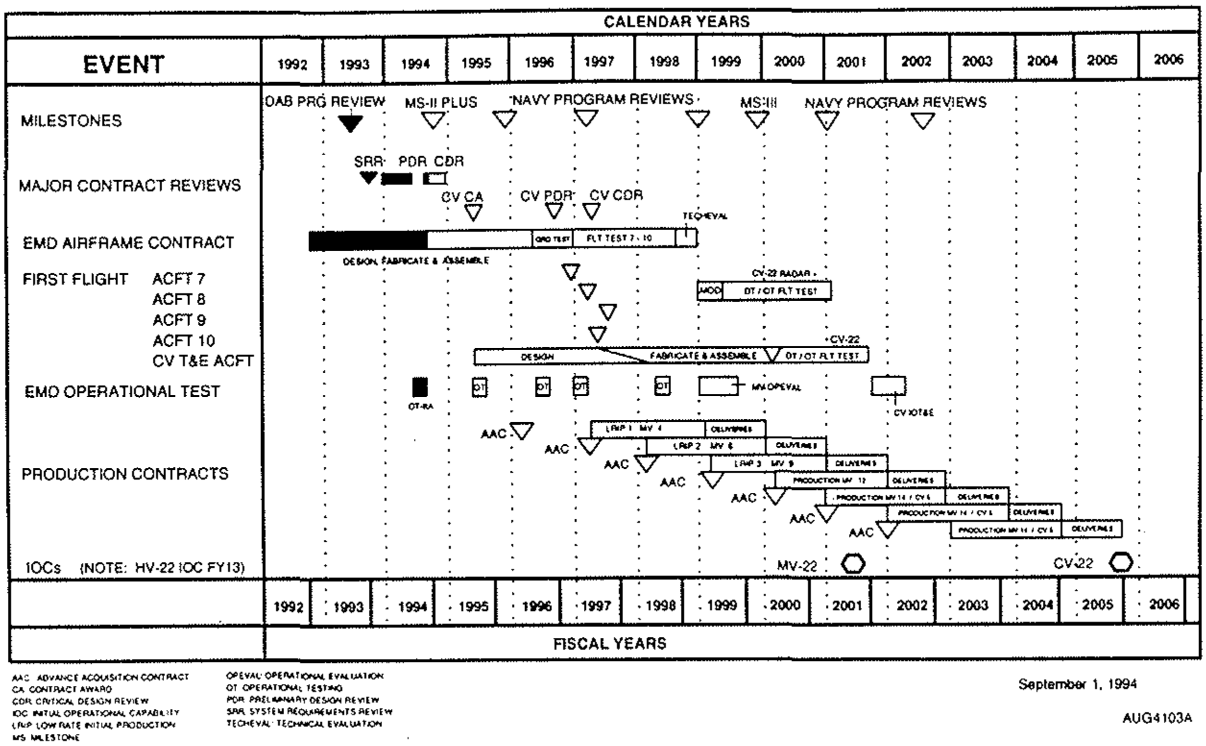
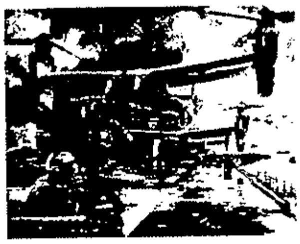


Figure 1

V-22 Joint Service Operational Requirements

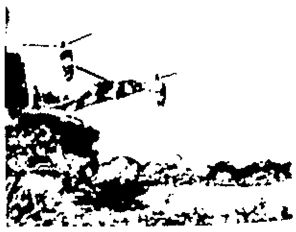


U.S. MARINE CORPS
425 MV-22B

- COMBAT ASSAULT
- ASSAULT SUPPORT

U.S. AIR FORCE
50 CV-22

- LONG RAMGE SPECIAL OPEREATIONS



U.S. NAVY
48 HV-22

- SPECIAL WARFARE
- FLEET LOGISTICS SUPPORT

Figure 2

ment. The IPT is composed of members of the various functional organizations within Bell-Boeing and the Navy. The V-22 program presently has 72 IPTs at Bell and Boeing focused on meeting the needs of the services while reducing cost and enhancing quality. The air vehicle integration and aircraft global issues are managed and directed by a combined Bell-Boeing and NAVAIR team from the V-22 Program Office. See figures 3 through 5.

3. Design-To-Cost (DTC)

Bell-Boeing began EMD by initiating affordability trade studies and soliciting Cost Improvement Proposals (CIPs) to generate ideas for cost reduction. Many of these proposals have been incorporated into the EMD configuration. The combination of affordability trade studies and an effective DTC program have yielded a steady reduction in recurring production costs. See Figure 6. As shown in Figure 6, the

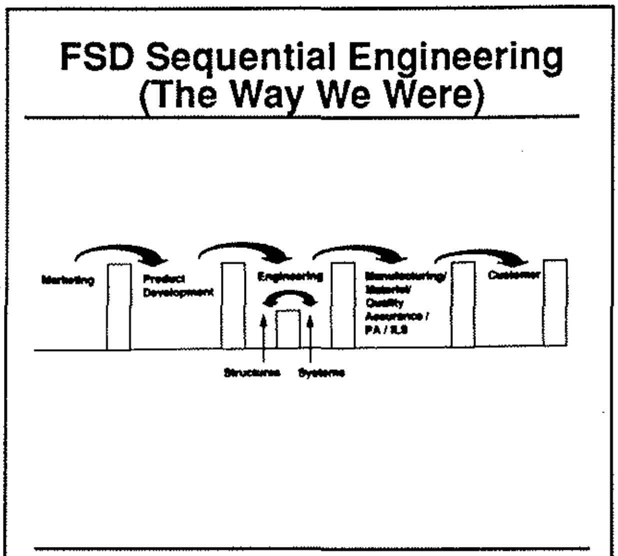


Figure 3

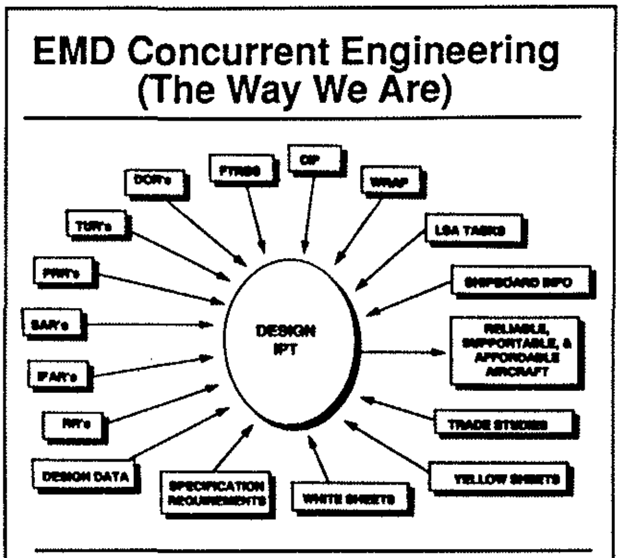


Figure 4

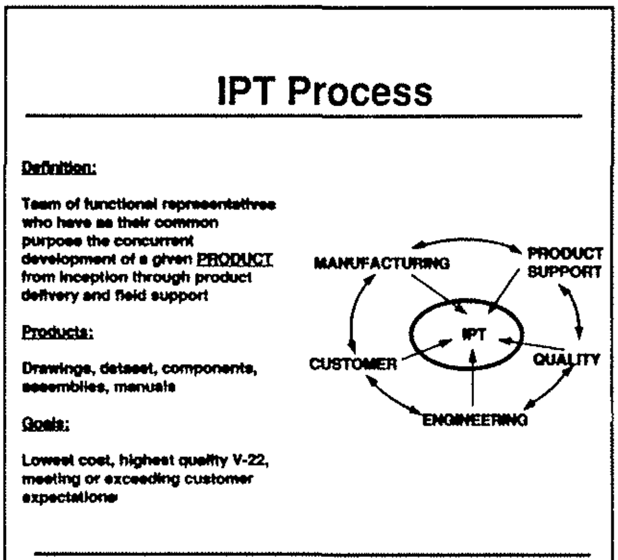


Figure 5

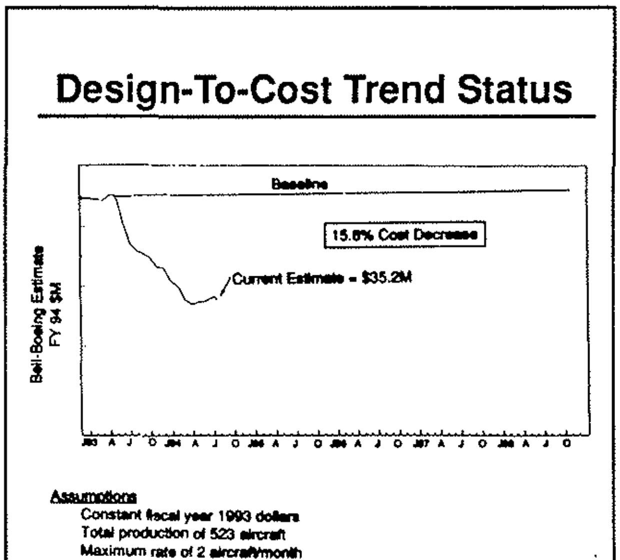


Figure 6

recurring flyaway cost has been reduced by 16%. This reduction in recurring cost has been achieved in consonance with a net reduction in operating and support costs. Consequently, reduction of near-term production cost has not been achieved at the expense of increasing life cycle cost (LCC).

DTC is an acquisition management technique integral to the systems engineering process that encompasses all elements of recurring flyaway cost. The joint Navy/Bell-Boeing DTC plan documents the resources, tools, and processes being used to minimize V-22 LCC; to report progress against cost targets; and to initiate actions whenever cost targets are breached. A target for recurring flyaway cost has been developed and allocated to each Integrated Product Team (IPT). Variances to the target are managed by DTC personnel assigned to each team. The DTC plan encourages active involvement and participation among contractor personnel, subcontractors and the Government.

The IPTs will continue to use DTC to incorporate as many cost saving ideas into the EMD configuration as possible. However, due to development cost and schedule constraints, some improvements will be postponed until production. They may fall into the category of Value Engineering Change Proposals (VECPs) or a Preplanned Product Improvement (P^3I) block upgrade. Bell-Boeing will continue to report recurring flyaway cost as it evolves for the EMD aircraft. To preclude the loss of any attractive cost saving ideas, the program team will attempt to capture them through a V-22 production initiatives (VPI) effort.

4. Weight Control

Bell-Boeing's EMD proposal included design changes that reduced aircraft weight empty from 35, 332 pounds (end of FSD weight) to 33,140 pounds (end of EMD weight). The major weight reduction areas have been: (1) Fuselage -1,162 pounds, (2) Empennage and vibration suppression system -397 pounds, (3) Wing and nacelle -896 pounds, (4) Integrated wiring system -523 pounds, (5) Drive and rotor systems -190 pounds, and (6) Avionics and other subsystems -425 pounds.

Based on a specification weight of 33,140 pounds, a target of 31,890 pounds was set with allocations to each IPT. The 1,250 pound difference from target weight to specification weight is comprised of 650 pounds (2.0%) margin for growth during design and manufacturing and 600 pounds (1.8%) margin from first flight to the end of the EMD contract.

Figure 7 shows the progress the IPT(s) have made meeting their assigned weight targets. The V-22 weight empty at the end of July 1994 was 31,784 pounds, 122 pounds below Bell-Boeing's target for this phase. As can be seen, the weight trend has been continuing down but will tend to flatten as design drawings are released. It should be noted that a more conserva-

MV-22 Weight Empty Profile
Weight Status 14

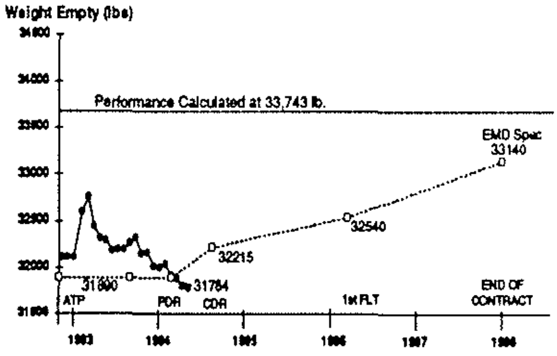


Figure 7

tive value for weight empty (33,743 pounds) has been used for all performance calculations shown later.

5. Overall Design

Meeting the constraints imposed by shipboard compatibility has established such important design parameters as rotor diameter, wing span, landing gear footprint, empennage height, and nacelle length. A cross section of a Navy amphibious assault ship, LHA (Figure 8), illustrates these constraints. Shipboard spotting factors and elevator size also dictated the blade fold / wing stow complexity. To minimize the space occupied when folded, the width across the main landing gear, the horizontal stabilizer span, and the nacelle length are approximately the same. Once the overall configuration was set, new technologies were applied which included: (1) digital electronic flight controls, (2) automated composite construction, (3) hot isostatic process (HIP) titantium castings, and (4) an integrated wiring system. Some of these new technologies will be discussed below.

6. Digital Electronic Flight Controls

The V-22's digital electronic flight control system (EFCS) allows the Vehicle Management System (VMS) to be tailored to optimize handling qualities throughout all tiltrotor flight regimes: helicopter, conversion, and airplane modes. Combined with the electronically controlled, 5000 psi hydraulic actuating system, fly-by-wire allows scheduling and mixing of both

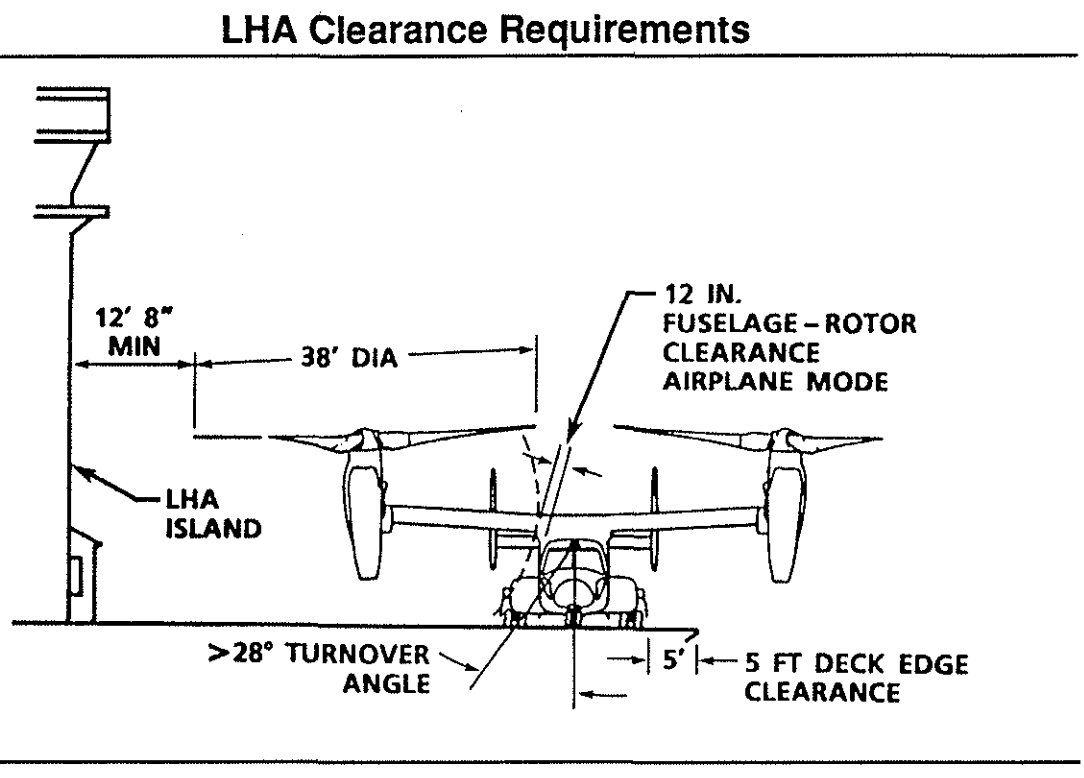


Figure 8

helicopter and airplane controls with minimal weight penalty. Additionally, automatic flight envelope protection is provided, including engine/rotor torque limiting, structural load alleviation, and conversion corridor protection. Flight safety reliability is the primary driver for the VMS, whose architecture is based on a robust EFCS design proven in 25 years of ground and flight testing.

Flight critical functionality is partitioned to provide protection between critical and non-critical functions and to minimize critical hardware and software failures. In-line fault monitoring provides 100% detection of critical failures. Finally, the occurrence of failures is accepted and embedded recovery routines protect against processing lock-up. A "third fail inhibit" insures that no fault will cause the third and final system of a triply redundant digital EFCS to be shut off (if the other two have previously failed). Figures 9 and 10 depict key characteristics of the V-22 VMS.

Vehicle Management System

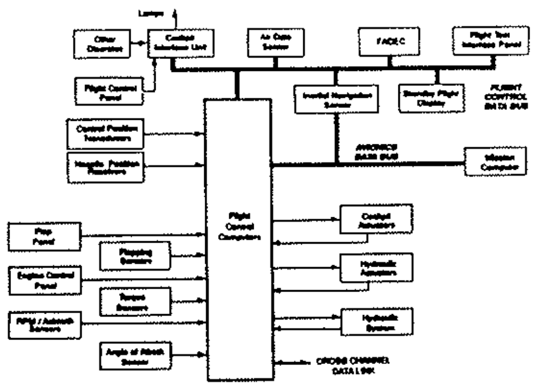


Figure 9

VMS Design Features

Digital Fly-By-Wire
- Triplex-Dual Architecture
- Interchannel Communication
- Minimal Unique I/O

Functionally Partitioned

Cockpit Controls
- Conventional Cockpit Control Sticks With Electrical Position Sensors
- Variable Force/Feel Electro-Mechanical Actuators

Jam Resistant Hydraulic Actuators

Redundant Power Sources - Electrical / Hydraulic
- 5000 PSI System

Strategic Component Installation
- Inherent Ballistic Protection

Integrated Diagnostic Approach

Figure 10

6. Automated Composite Construction

Composite materials give the designers precise control over the stiffness of primary structure, allowing them to place the aeroelastic stability limits well outside of the operating envelope and to avoid resonance that could lead to unacceptable vibration levels and fatigue loads. Structures that use composite materials have a high resistance to fatigue, will not corrode, and weigh less than equivalent metal structures, making them particularly suited to a Navy tactical aircraft such as the V-22.

The incorporation of a new composite manufacturing technology (fiber placement) into the V-22 has provided two major benefits: (1) recurring cost reduction, and (2) improved quality through process repeatability. The aft fuselage is shown in figure 11 being produced on the fiber placement machine at Boeing Helicopters. This specimen is presently being sectioned to confirm its predicted structural properties and manufacturing processes. This design resulted in a recurring cost savings of $364,000. The redesigned proprotor grip development specimen, shown in figure 12, yielded a recurring cost savings of $89,000 per aircraft.

Aft Fuselage

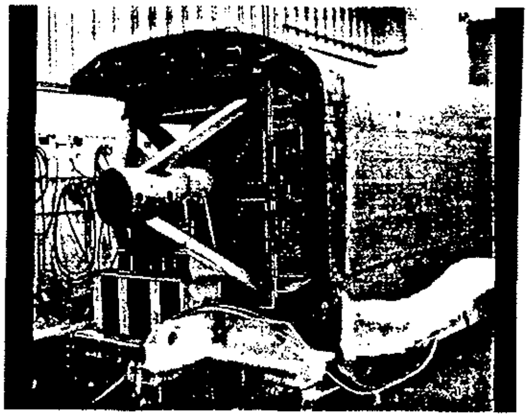


Figure 11

Proprotor Grip

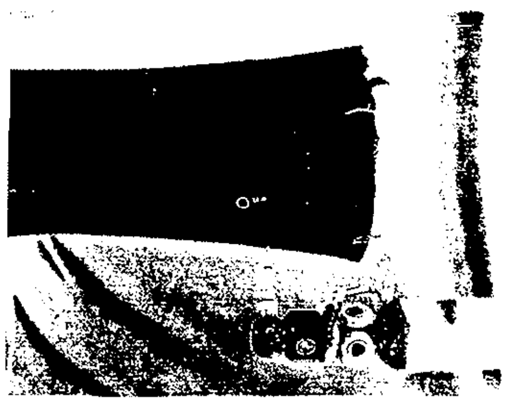


Figure 12

Transmission Adapter

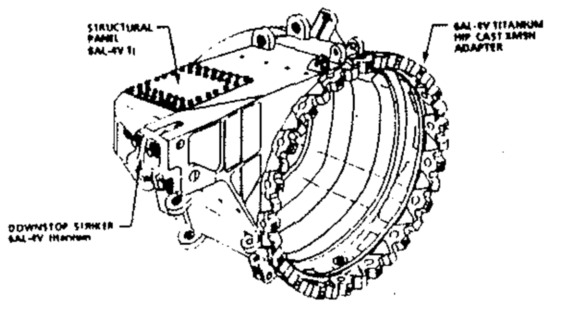


Figure 13

7. Hot Isostatic Process (HIP) Titanium Castings

The transmission adapter, which transfers thrust loads from the rotor to the airframe, offered great potential for cost and weight reduction and fatigue life improvement in EMD. After several trade studies, it was concluded that the best approach was to use a HIP titanium casting with machined interfaces (figure 13) in lieu of the multi-piece machined and bolted forgings used in FSD. The HIP cast transmission adapter has resulted in a weight and recurring cost savings of 162 pounds and $63,000 per aircraft. This component is presently being developed by Howmet of Norfolk, VA, and Bell Helicopter Textron.

8. Integrated Wiring System (IWS)

The IWS was a a refinement of a Navy initiated trade study to determine the benefits of various wiring concepts. IWS was selected for the basic wiring architecture to improve supportability while reducing weight and cost. Implementation of IWS permits squadron level repair and replacement (with removable harnesses) thus decreasing repair time. IWS also improves the accuracy of repair and further reduces the requirement for depot level rewiring during each aircraft's service life.

IWS uses an organized wiring concept to protect critical wires from hostile signals by shielding with non-critical wires. See Figure 14. This concept, along with the addition of junction boxes, eliminates the "spider" harnesses commonly used on existing aircraft. See Figure 15. IWS has resulted in a weight and cost savings of 523 pounds and $316,300 per aircraft.

9. Multi-Mission Features

The V-22 has been designed with multi-mission features in the baseline MV-22 (Marine Corps) that allow the CV-22 (USSOCOM) and HV-22B (Navy) to meet their requirements with a single joint service airframe. Some of the features inherent in the V-22 are described in Figures 16 and 17. Not shown, but important to the military suitability of the V-22, are the many redundant systems and other features to enhance its ballistic survivability and its design for operation in a chemically, biologically, or radioactively contaminated environment. Chief among the latter features are a slight over-pressure of the troop compartment and cockpit to inhibit entry of contaminates into occupied areas of the aircraft. The EMD program has allowed refinements in the design which U.S. fighting forces will appreciate as enhancements of the aircraft's war fighting capability. The V-22's high speed performance compares favorably with conventional turboprop aircraft, although its high maneuver performance exceeds that of most transports. Using conservative values of 29.4 ft^2 (Figure 18) and 33,743 pounds for drag and weight, respectively, it can be shown that the V-22 easily meets the requirements for the Marine Corps and USSOCOM missions. (See Figure 19.) Strategically and tactically, the two performance enhancements that the V-22 delivers over conventional helicopters are speed and range. Recalling that the area (A) of operational effectiveness increases with the square of range (R), A=PR2, the impact of the V-22's speed and range advantage is shown in figures 20 through 23.

10. Supportability

Supportability has been designed into the V-22 from the ground up. Real concurrent engineering, which considers design engineering, manufacturing, human factors engineering (HFE, for both aircrew and maintainer), reliability and supportability, has been achieved in EMD through customer participation in IPTs and through logistics support analyses (LSAs). An effective design-for-maintainer (DFM) program

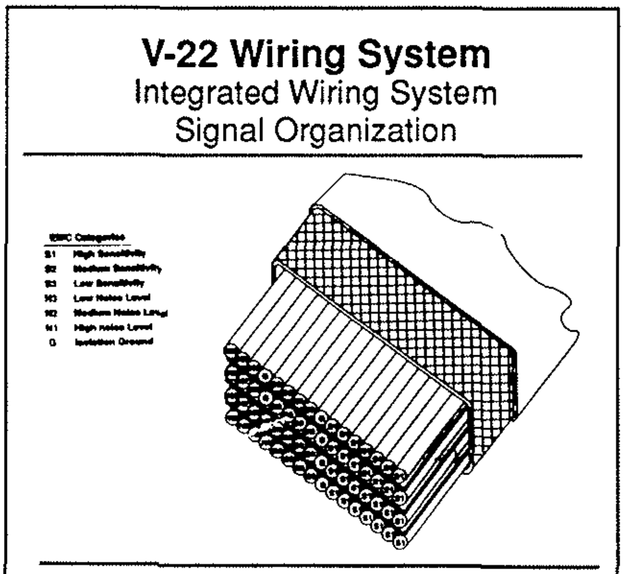


Figure 14

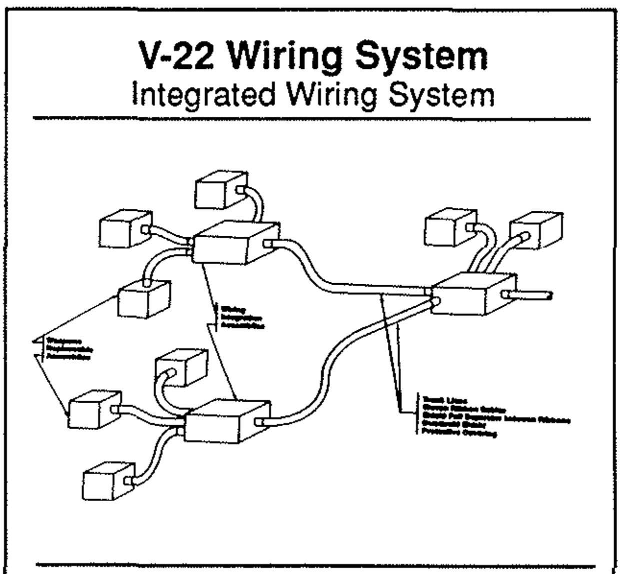


Figure 15

V-22 Multimission Features

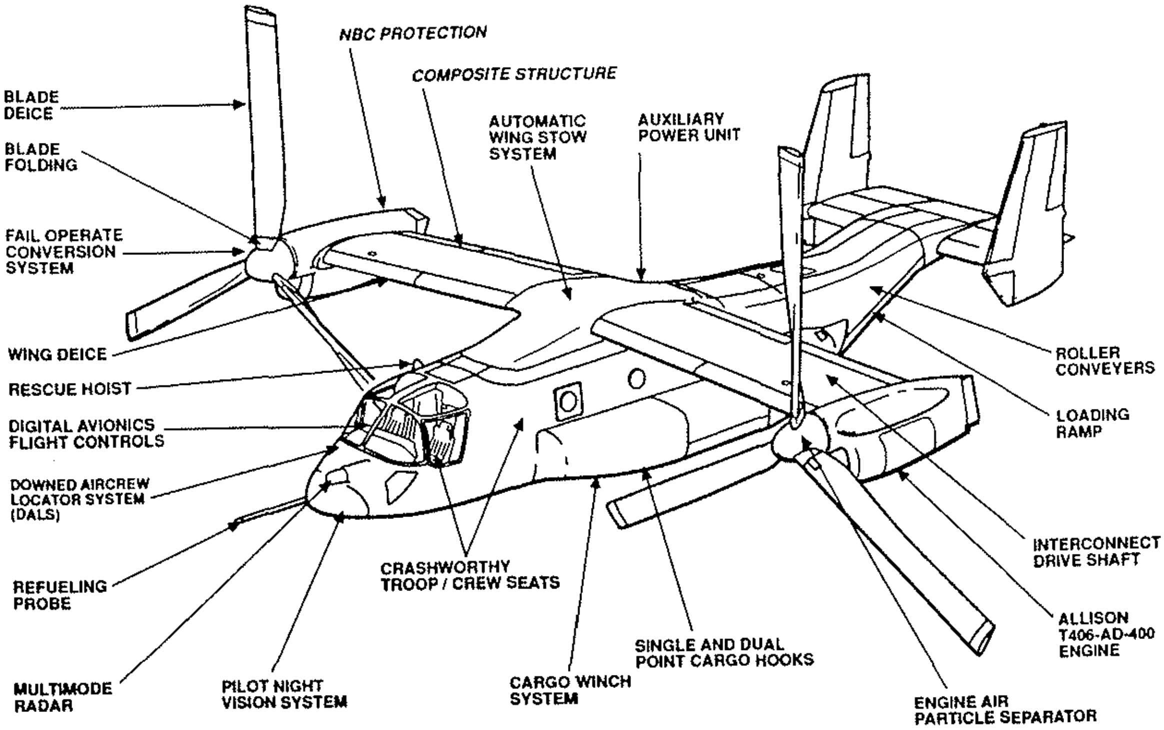


Figure 16

Survivability Configuration

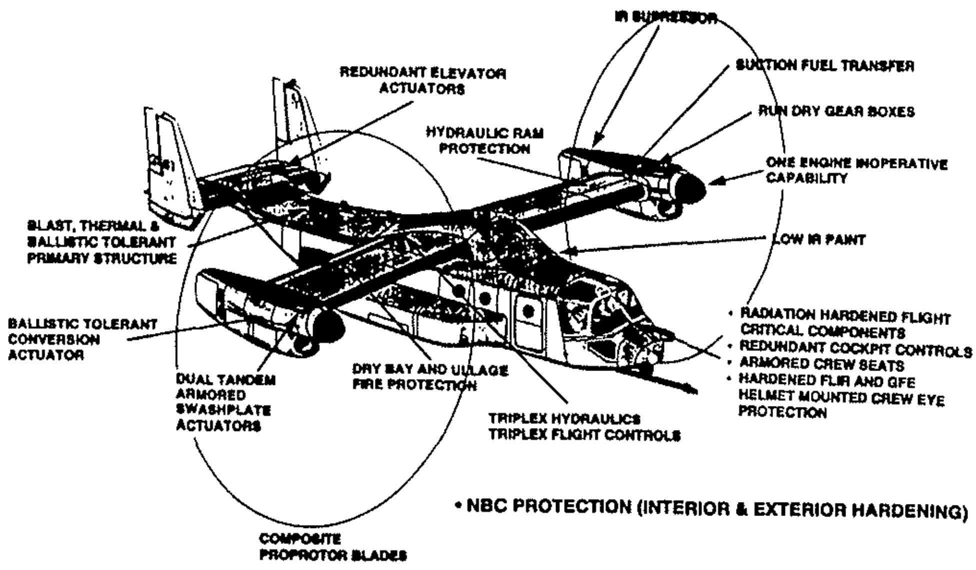


Figure 17

Minimum Drag Level

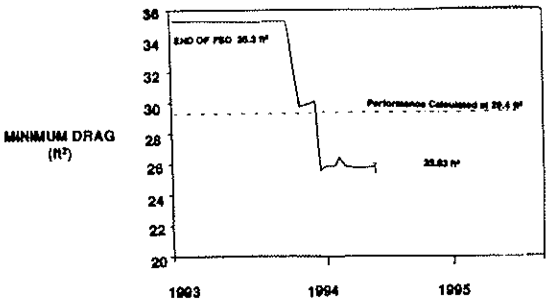


Figure 18

Mission Performance

MISSION	REQUIREMENT PAYLOAD / RADIUS (LBS / NM)	CURRENT ESTIMATE (NM)
AMPHIBIOUS ASSAULT / TROOPS	6,420/50 (x2)	50 (x2)
AMPHIBIOUS ASSAULT / EXT LIFT	10,000/50	100
LAND ASSAULT / TROOPS	6,420/200	267
LAND ASSAULT / EXT LIFT	10,000/50	71
AMPHIBIOUS PRE-ASSAULT RAID	4,960/200	212
LOSUF	4,770/500	496
	RANGE (NM)	
MV-22 SELF DEPLOYMENT (W/ AERIAL REFUEL)	2,100	2,522
CV-22 SELF DEPLOYMENT (W/ AERIAL REFUEL)	2,100	2,543

ASSUMPTIONS
[illegible]

Figure 19

The V-22 Is More Capable Than Helicopters

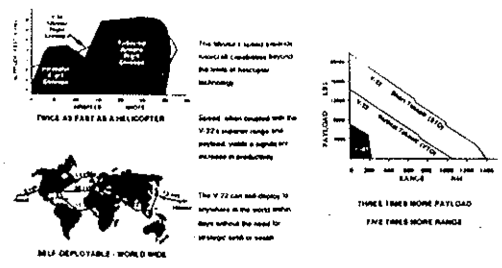


Figure 20

The Benefits of Speed and Range

MISSION	SPEED / RANGE BENEFIT
Amphibious Assault	• Deeper power projection "From the Sea" • Allows greater fleet stand-off distance for protection from mines and anti-ship missiles • Faster combat power buildup ashore • Lower attrition - fewer casualties
Land Warfare	• Enhanced maneuver warfare capability - Greater exploitation of threat weaknesses - Expanded radius of action - Faster reaction time
CSAR / TRAP	• Increased probability of rescue
Special Operations	• Increased operational security • Greater operational flexibility
MedEvac	• Reduced casualty mortality - "The Golden Hour"
Self-Deployment	• Reduced reliance on overseas basing • More rapid force closure • Reduced reliance on strategic lift

Figure 21

V-22 Potential Operation Desert Shield

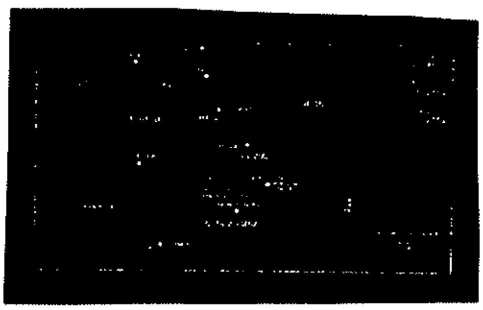


Figure 22

HV-22 Combat Radius Comparison

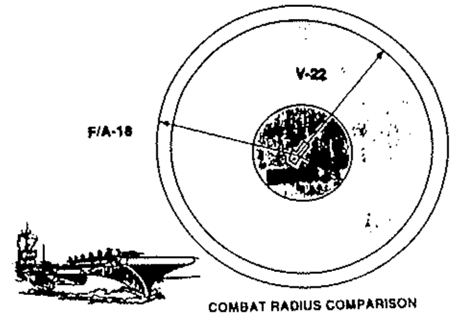


Figure 23

fine tunes the design prior to drawing release for maintainability and accessibility and makes the V-22 a "maintenance friendly" aircraft. Figure 24 depicts how the V-22 is being prepared for fleet introduction.

V-22 Supportability / Fleet Introducton

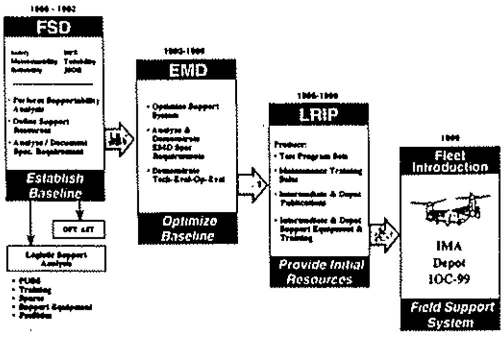


Figure 24

The requirement for scheduled depot level maintenance (SDLM), or periodic overhaul, has been reduced through the use of composite construction and an "on condition" component removal philosophy. "On condition" maintenance is implemented through the V-22's health monitoring system (HMS). HMS makes use of the cockpit management system; the vibration, structural life, and engine diagnostics (VSLED) maintenance data recording system; and applies a central, integrated check-out philosophy. HMS, combined with extensive built-in test systems and high reliability, reduces the need for between-flight inspections and will result in high mission availability.

11. Integrated Flight Testing

As a special case IPT, a flight test Integrated Test Team (ITT) has been formed to consolidate contractor and government development testing (DT). The ITT is composed of Bell-Boeing and government personnel working as a unified team to meet both contractor and government flight test objectives. As a result, schedule inefficiencies have been reduced and dedicated government DT periods have been eliminated. Safety has been enhanced and recurring training requirements have been reduced because the government and contractor are no longer transferring the aircraft back and forth. By combining government and Bell-Boeing pilots and engineers into one test team, the total number of both has been reduced. Also, joint government / contractor flight testing has allowed the development of one common, shared flight test database. Single siting of the ITT at NAS Patuxent River, MD, has allowed further resource pooling and safety enhancement through improved communication and reduced personnel travel. Figures 25 through 26 summarize flight test achievements and show test schedules for the risk reduction test aircraft (#2 and #3) and the follow-on EMD flight test aircraft (#7 through #10). Particularly worthy of note is that an independent operational test team, which evaluated the FSD aircraft, concluded that the V-22 is potentially operationally effective and potentially operationally suitable for its intended missions.

V-22 Flight Test Accomplishments (as of 11 August 1994)

- 251 KNOTS AT 10,000 FEET
- 310 KNOT 30 DEGREE DIVE
- 21,500 FEET ALTITUDE
- FORMATION FLYING
- FLIR EVALUATIONS
- SEA TRIALS, USS WASP
- 3.1 g
- GROSS WEIGHTS: 37,000 TO 51,150 POUNDS
- 4,000 POUND SLING LOAD TO 175 KNOTS
- 1,200 MILE CROSS-COUNTRY FLIGHTS
- NIGHT AND SIMULATED IFR OPERATIONS
- CLIMATIC LABORATORY TESTING
- ICING FLIGHT TESTING
- OT-IIA COMPLETED

921 FLIGHT HOURS IN 787 FLIGHTS

Figure 25

V-22 EMD Program Schedule

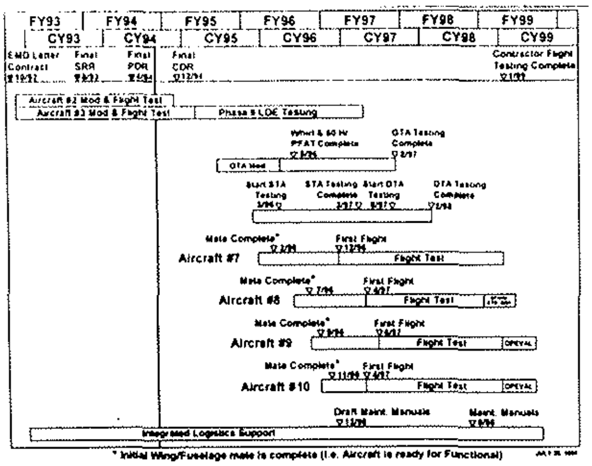


Figure 26