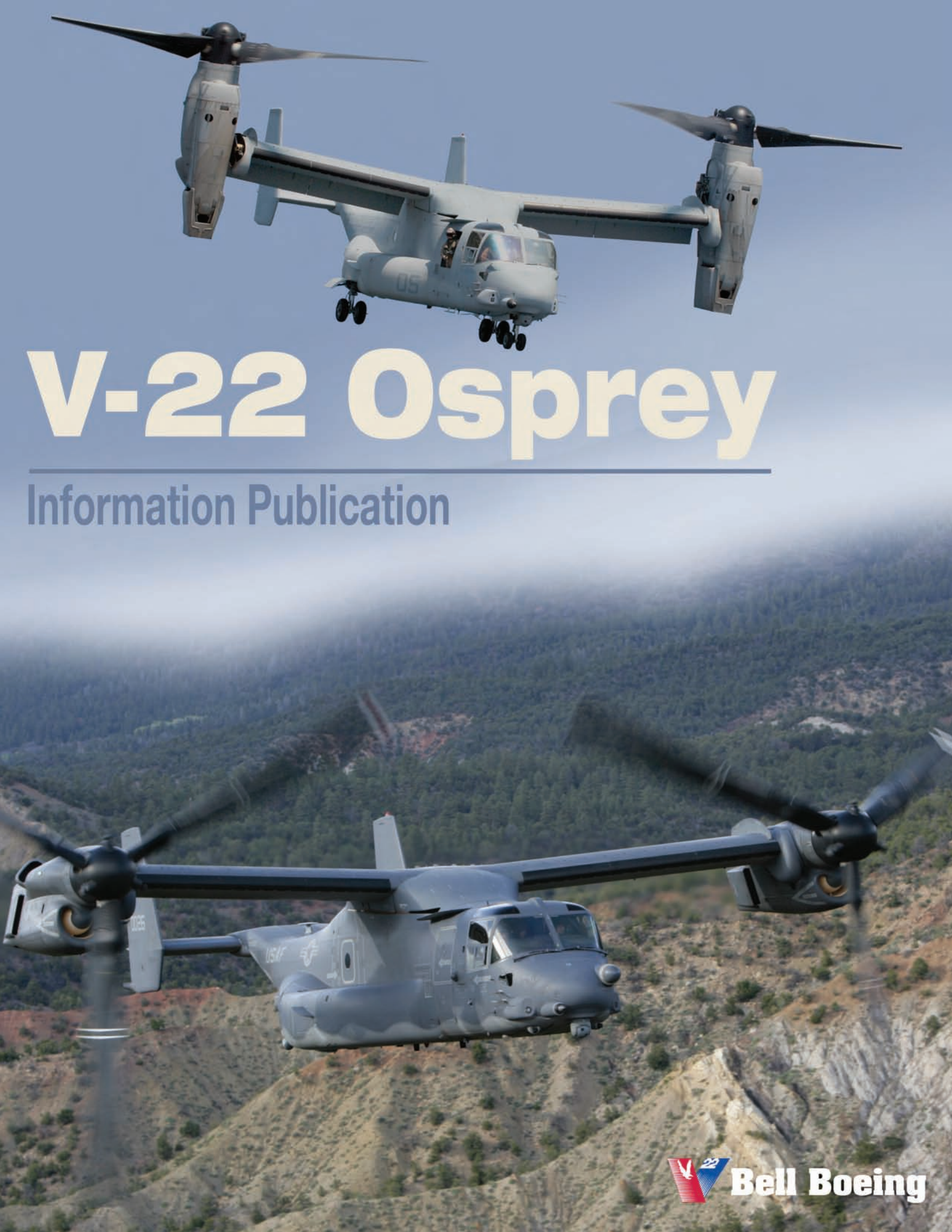

V-22 Osprey

Information Publication

Bell Boeing

V-22 Product Information
(Revision B)

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V-22 Osprey

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Availability of V-22 software source code, operating algorithms, and program maintenance documentation is subject to a separate license application.

V-22 Osprey

Sections:

1.0 Executive Summary

2.0 Aircraft Description

3.0 Integrated Logistics Support

4.0 Operating Characteristics

5.0 List of Acronyms and Abbreviations

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Preface

Dear Reader,

Aerospace history is marked by the introduction of new technologies changing forever the way we fly. The aircraft described in this publication represents such a transformational capability.

The V-22 Osprey is the first operational tiltrotor transport aircraft, blending the best elements of rotary-wing and fixed-wing performance. This issue of the ***V-22 Information Publication*** coincides with a significant achievement for the V-22 Program. The V-22 Program has delivered its 100th aircraft and is accelerating production under a multi-year contract. The aircraft is becoming a mainstay for the U.S. Marine Corps and U.S. Air Force Special Operations Command. Combat deployments are demonstrating the aircraft's capabilities. Operators are gaining an appreciation for the tremendous potential of this hybrid aircraft. These men and women are writing new operational concepts that take full advantage of the unique capabilities of the V-22.

The promise of tiltrotor technology will unfold in an increasing variety of military *and* civil variants. As you immerse yourself in this publication, I encourage you to keep in mind you are seeing ***the beginning*** of operational tiltrotor technology. The ability to leverage this unique capability is limited only by the imagination.

Gene Cunningham
Vice-President
Bell Boeing Program Office

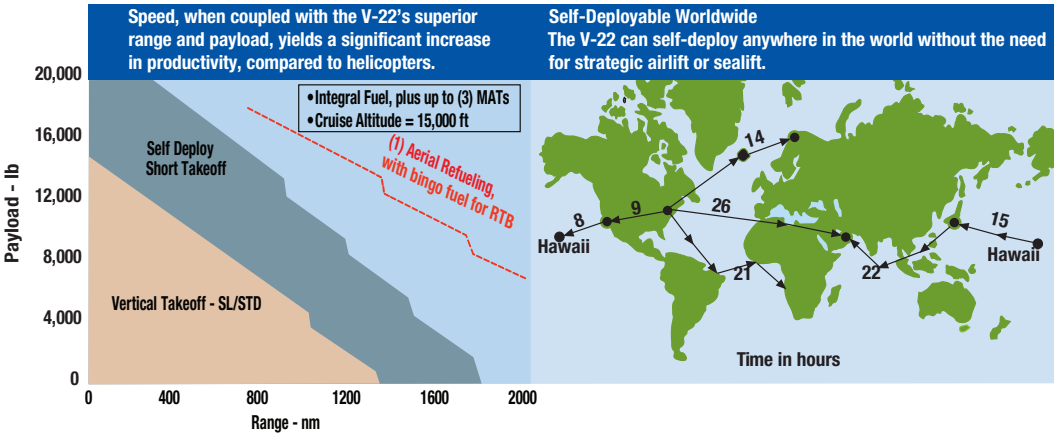
SECTION 1.0 - EXECUTIVE SUMMARY

The V-22 Osprey is the world's first production tiltrotor aircraft. Unlike any aircraft before it, the V-22 successfully blends the vertical flight capabilities of helicopters with the speed, range, altitude, and endurance of fixed-wing transports. This unique combination provides an unprecedented advantage to warfighters, allowing current missions to execute more effectively, and new missions to be accomplished that were previously unachievable on legacy platforms.

Comprehensively tested and approved for full rate production, the V-22 provides strategic agility, operational reach, and tactical flexibility - all in one survivable, transformational platform.

1.1 Introduction

The V-22 is revolutionizing military air transport with capabilities in a manner not seen since the introduction of helicopters more than 50 years ago. It has been designed to embrace the requirements for the speed of tactical fixed-wing transport aircraft and the runway independence of helicopter assault transports, with a worldwide self-deployment capability. As such, it combines Vertical Takeoff and Landing (VTOL), high altitude, and high speed with a day or night adverse-weather capability, and incorporates a series of features to improve mission success rates and survivability. The V-22 has demonstrated its ability to perform its missions and functions during thousands of hours of developmental and operational flight time.



- Sustained cruise speed: 250+ knots
- Self-deploy worldwide
- Unrefueled radius of action: 430+ nmi
- 25,000 foot service ceiling

} Fixed-wing tactical transport

- High level of ballistic tolerance
- Cockpit integrated color displays, avionics to navigate worldwide, civil and military fields
- Fold/stow and corrosion protection to meet shipboard compatibility

- Operate from amphibious ships
- Hover hot and high
- Capability for 15,000 lb external loads
- Vertical insertion/extraction

} Helicopter assault transport

1.2 Tiltrotor Background

Both Bell and Boeing have over 50 years of experience in Vertical or Short Takeoff and Landing (V/STOL) aircraft design. In 1956, Boeing began development of the world's first tiltwing aircraft the VZ-2. Its maiden flight was in 1958.

VZ-2 (1958)

Concurrently, Bell's research had focused on tilting the transmissions to achieve the conversion to conventional flight. Bell's XV-3 tiltrotor (begun in 1954), successfully achieved full conversion from helicopter to airplane mode in 1958. It continued in flight test until 1966 and further demonstrated the feasibility of tiltrotor technology.

XV-3 (1958)

Development continued in the 1960s and 1970s, with Boeing completing over 3,500 hours of wind-tunnel testing of tiltrotor models. These models included a full-scale rotor system. Based on its experience with the XV-3, Bell was awarded a NASA-U.S. Army contract in 1973 to develop two XV-15 tiltrotors.

First flight of the XV-15 occurred in 1977 with full conversion in 1979. The two XV-15s demonstrated the maturity of tiltrotor technology and were directly responsible for the birth of the Joint Services Advanced Vertical Lift Aircraft (JVX).

XV-15 (1977)

Drawing upon the strengths of their respective research efforts during the preceding 30 years, the Bell Boeing team was officially formed in April 1982. In April 1983, the U.S. Navy selected the Bell Boeing team as the prime contractor to develop the JVX aircraft – now known as the V-22 Osprey.

The V-22 was approved for full-rate production in 2005, with initial operational capability achieved in 2007. Current production requirements are for 360 for the U.S. Marine Corps, 50 for the U.S. Special Operations Command (operated by the Air Force Special Operations Command), and 48 for the U.S. Navy.

V-22 (1989)

1.3 Multiservice Production Configurations

Capitalizing on the V-22's performance, survivability, and total mission affordability, the U.S. military services have requirements for the V-22 to accomplish a variety of operations, some of which are shown below. These missions show the versatility of the V-22 in support of the Marine Corps, Special Operations Forces (SOF), and U.S. Navy operations.

U.S. Marine Corps
(360 MV-22)

- Combat Assault from ships
- Assault support

U.S. Special Operations Command (SOCOM)
(50 CV-22)

- Long-range Special Operations
- Night/Adverse Weather

U.S Navy
(48 MV-22)

- Fleet Logistic Support
- Special Warfare
- Personnel Recovery

V-22 Osprey

With V-22 full rate production approved in September 2005, the aircraft is being developed and produced for USMC and AFSOC utilizing incremental, time-phased block upgrades.

V-22 Acquisition Strategy		
MV-22		**CV-22**
• Block A Safe and Operational		• Block 0 Block B plus Multimode Radar and Suite of Integrated Radio Frequency Countermeasures (SIRFC)
• Block B Block A plus Enhanced Maintainability	**Currently in Production**	• Block 10 Block 0 plus Directed Infrared Countermeasures (DIRCM)
• Block C Block B plus Mission Enhancements and Upgrades		• Block 20 Block C plus Block 10 plus Mission Enhancements and Upgrades

MV-22 U.S. Marine Corps - Standard Configuration

V-22 Osprey

Aircraft system features

- Composite/aluminum airframe
- Triple redundant fly-by-wire flight controls
- Rolls-Royce AE1107C engines
- Interconnect drive shaft
- 5000 psi hydraulic system
- 240 kVA electrical capacity
- Blade fold/wing stow
- Anti-ice and deice systems
- Vibration, structural life, and engine diagnostics
- Engine air particle separators
- Loading ramp
- Aerial refueling probe
- 5.7’ W x 5.5’ H x 20.8’ L cabin
- Onboard oxygen and inert gas generating systems (OBOGS/OBIGGS)

Mission equipment

- Single and dual point external cargo hooks
- Advanced cargo handling system
- Fast rope
- Rescue hoist
- Paradrop static lines
- Ramp mounted defensive weapon system
- Up to (3) mission auxiliary fuel tanks

Avionics

- Dual avionics MIL-STD-1553B data busses
- Dual 64-bit mission computers
- Night Vision Goggle (NVG) compatible, multifunction displays
- Inertial navigation system (3)
- Global positioning system
- Digital map system
- SATCOM
- VOR/ILS/ marker beacon
- Radar altimeter
- FM homing system
- Dual VHF/UHF/AM/FM radios
- Digital intercommunications system
- Turreted Forward Looking Infra-Red (FLIR) system
- Identification, Friend or Foe (IFF) transponder
- Tactical Air Navigation (TACAN) system
- Troop commander’s communication station
- Flight incident recorder
- Missile/radar warning and laser detection

V-22 Osprey

CV-22 U.S. Special Operations Command

CV-22 unique equipment

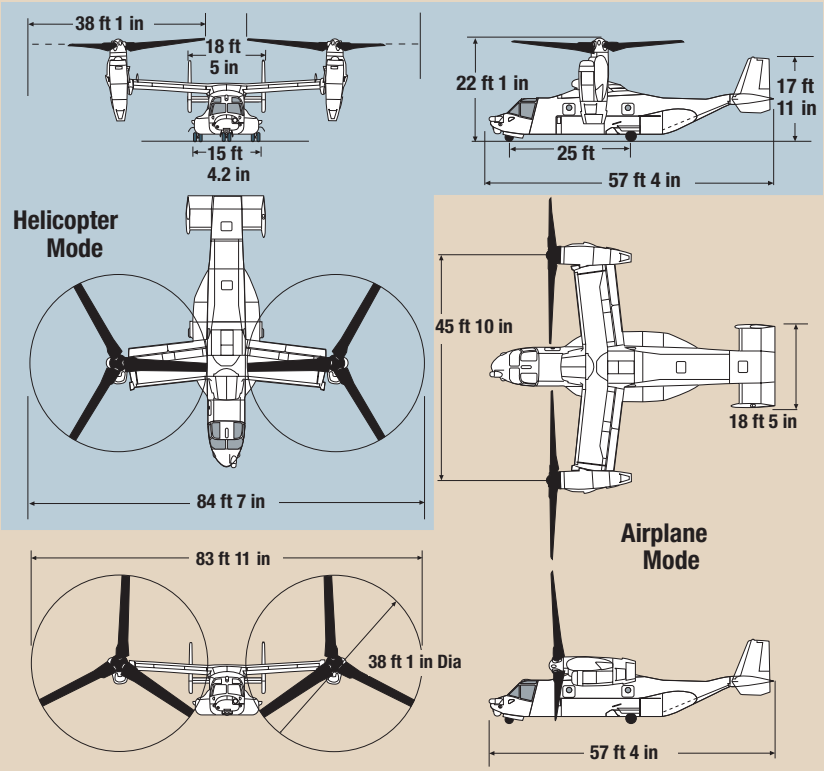
- Multimission Advanced Tactical Terminal (MATT) integrated with digital map, survivor locator equipment, and the electronic warfare suite
- Multimode Terrain Following/Terrain Avoidance (TF/TA) radar
- Advanced, integrated defensive electronic warfare suite
  - Suite of Integrated RF Countermeasures (SIRFC)
  - Directed IR Countermeasures (DIRCM)
- Additional tactical communications with embedded communication security
- Upgraded intercommunications
- Computer and digital map upgrades
- RF interference canceller system
- Flight engineer seating accommodation
- Crash position indicator

Confined Area Landings
Formation
Shipboard Operations
SPIE
Rig
Night Operations
Aerial Refueling
External Loads
Fast Rope
Over-Water Operations
Self-Defense
Operational Flexibility

1.4 V-22 Aircraft Characteristics

Performance @ 47,000 lb

Max cruise speed (MCP) Sea Level (SL), kts (km/h)	250 (463)
Service Ceiling, ISA, ft (m)	25,000 (7,620)
OEI Service Ceiling ISA, ft (m)	10,300 (3,139)
HOGE ceiling, ISA, ft (m)	5,400 (1,646)
Weights	
Takeoff, vertical, max, lb (kg)	52,600 (23,859)
Takeoff, short, max, lb (kg)	57,000 (25,855)
Takeoff, self-deploy, lb (kg)	60,500 (27,443)
Cargo hook, single, lb (kg)	10,000 (4,536)
Cargo hook, dual, lb (kg) [capability]	15,000 (6,804)
Fuel Capacity	
MV-22, gallons (liters)	1,721 (6,513)
CV-22, gallons (liters)	2,025 (7,667)
Engines	
Model	AE1107C (Rolls-Royce Liberty)
AEO VTOL normal power, shp (kW)	6,150 (4,586)
Crew	
Cockpit – crew seats	2 MV/3 CV
Cabin – crew seat/troop seats	1/24



1.5 Cost and Operational Effectiveness Studies

The V-22 represents a revolutionary change in design and versatility. It brings capabilities not found in helicopters – a leap forward in speed, range and altitude performance.

Studies and Analyses

Numerous major studies and analyses have shown that the V-22 is more cost and operationally effective than any helicopter (including compound helicopter designs), or any combination of helicopters in the medium lift assault role. Compared to a range of current and advanced helicopter designs:

- The V-22 has superior speed, range and survivability:
  - Increases the tactical options available to the operational commander
  - Dramatically reduces the risk of friendly force casualties in post-assault ground operations
- When equal lift capability aircraft fleets are considered:
  - Significantly fewer V-22s were required to accomplish the specified missions
  - Likewise, proportionately fewer support assets and personnel were required
- When equal cost aircraft fleets are considered:
  - The V-22 fleet is more effective than any of the helicopter alternatives
  - Lower through-life costs for the tiltrotor

V-22 offers best value for the money.

For example, in a recent V-22 in Global War on Terrorism (GWOT) Scenario, the disparity in required mission resources was evident. The V-22 needed about one-fourth of the resources required of conventional helicopters. Specifically, the asset requirements were:

- Three V-22s, one strategic airlift aircraft, one strategic tanker, three combat service support aircraft, and one support base

VS

- Five helicopters, seven tactical tankers, nine strategic airlift aircraft, 12 combat service support aircraft, and four support bases

Reduced complexity increases the probability of success, while decreasing requirements and total mission cost. The V-22 significantly reduces the logistical complexity to accomplish the mission.

Study	Author	Funding	Date
MV-22 Combat Effectiveness Analysis I		Bell Boeing	1987
MV-22 Combat Effectiveness Analysis II	BDM	Bell Boeing	1990
Effectiveness of Tiltrotor Support to Ground Combat	Lawrence Livermore	Bell Boeing	1991
V-22 Multimission Applications for the U.K.	DERA/TRW	Bell Boeing	1999
V-22 and the Global War on Terrorism (GWOT) - Phase I: Prevent/Retaliate	ANSER	Bell Boeing	2002
V-22 GWOT - Phase II: Respond	ANSER	Bell Boeing	2003
V-22 GWOT - Phase III: Cost and Total Force	ANSER	Bell Boeing	2003
V-22 GWOT - Phase IV: Personnel Recovery Total Force	ANSER	Bell Boeing	2005
UK V-22: To show the relevance of V-22 capabilities to current and emerging UK Defence requirements	MASS	Bell Boeing	2005
V-22 GWOT - Phase V: Relevance of V-22 Capability to Naval Applications in the GWOT	ANSER	Bell Boeing	2006
V-22 GWOT - Phase VI: V-22 Relevance to USSOCOM Current and Emerging Roles and Missions	ANSER	Bell Boeing	2007

1.6 What is a Tiltrotor?

1.6.1 Definition

A "tiltrotor" is a unique type of aircraft that has the cruise speed and efficiency to achieve the range and endurance of a turboprop airplane and can takeoff, hover, and land vertically to provide the runway independence of a conventional helicopter.

A tiltrotor has a wing with lift/propulsive proprotors at each wing tip. These proprotors are aerodynamically designed to function both as propellers and as rotors. The proprotors, along with their engines and reduction gearboxes, are mounted in the wingtip nacelles. They rotate from a horizontal position (airplane or cruise mode) to the vertical position (helicopter or hover mode).

In helicopter mode, the proprotors provide all lift and control with the required engine power being the highest when hovering. As the aircraft transitions to airplane mode, the power and thrust of the engines are reduced (as the wing takes on more of the lift). As a result, the tiltrotor can achieve a very efficient cruise performance in airplane mode. Additionally, the tiltrotor can stop the transition and fly in the conversion mode, a flight regime unique to the tiltrotor.

1.6.2 A Tiltrotor is not A Helicopter

Although a tiltrotor aircraft can hover and has excellent maneuverability and handling qualities in vertical flight like a helicopter, it has other capabilities that greatly exceed those of a helicopter. Consequently, it is misleading and inaccurate to refer to a tiltrotor as a helicopter.

A helicopter's wing is its rotor (or rotors). The rotor blades are rotated about a shaft above the aircraft. As the rotors pass through the air, they create the lift so the aircraft can remain stationary over the ground – the process is called hovering. Varying the pitch of the rotor blades (as they rotate) provides control of the helicopter. The helicopter can move vertically up and down by increasing or decreasing pitch on all rotor blades simultaneously – a process called collective pitch control.

The helicopter can control its movement over the ground by varying the pitch of individual blades, increasing or decreasing lift at selected points during blade rotation – a process called cyclic pitch control. The combination of collective and cyclic pitch-control gives the helicopter its excellent control characteristics in the hover.

The helicopter's thrust is almost always pointed upward. The helicopter achieves forward flight by tilting the plane of its blade rotation forward; thus, slightly tilting its thrust in the desired direction of flight. Tilting the thrust direction is an inefficient method for generating forward thrust. Consequently, it requires a great deal of power to achieve high speeds, while sustaining level flight. This characteristic of the helicopter, along with the high drag of its rotor system, and the problem of retreating blade stall (at higher speeds) accounts for the speed limitations of a helicopter.

The tiltrotor achieves its lift and control in hovering flight in exactly the same way as a helicopter: proprotor system lift, collective pitch-control, and cyclic pitch-control. This gives the tiltrotor its excellent hover and slow flight-handling characteristics. However, the tiltrotor can tilt its proprotors from vertical to horizontal for providing thrust while relying on its wing for lift. In this mode, the tiltrotor overcomes many of the helicopter's high speed limitations:

Some of these helicopter's limitations include:

- High rotor system drag
- Retreating blade stall
- High vibratory loads

A tiltrotor has characteristics uncommon to conventional single rotor helicopters or conventional airplanes. Of particular significance are the following:

- The counter-rotating proprotors eliminate the yawing movement due to primary lift, which drives the requirement for an anti-torque device in single rotor helicopters.
- The interconnecting driveshafts automatically deliver power to both rotors following the loss of one engine, which eliminates asymmetrical thrust during single engine operation.

1.6.3 A Tiltrotor is not A Tiltwing

In the tiltwing configuration, the aircraft's engines and propellers are rigidly mounted to the wing. The entire propulsion system and wing are tilted between the vertical and horizontal positions.

Propellers, instead of proprotors, provide the propulsion. They have no cyclic pitch-control in the vertical flight mode. Due to the concerns of wing stall (during conversion), the envelope of safe tilt angles for different airspeeds is very small. The tiltwing flies well in the airplane mode; but is inefficient at low speeds and during hover. Tiltwings avoid hovering for long periods of time due to their heavy fuel consumption.

1.6.4 A Tiltrotor is not an Airplane

An airplane's lift is produced from its wing(s). An airplane creates lift by moving its wing through the air fast enough to generate the necessary lift to overcome the aircraft's weight. An airplane uses propellers or jet engines to maintain the speed necessary to sustain flight. At low speeds the airplane wing stalls and can no longer maintain lift. The airplane's direction of flight is controlled through the use of ailerons, elevators, and rudders.

In airplane mode, the tiltrotor functions the same as a typical airplane. In forward flight, the tiltrotor is supported by the lift of its wing. Its turboshaft engines drive the proprotors in order to sustain its speed. Its controls are ailerons, elevators and rudders, and function like those of a conventional airplane. However, for low speed or hovering flight, a tiltrotor can rotate its nacelles (i.e., its thrust direction) from the horizontal to the vertical position — something no airplane can do.

Finally, a tiltrotor's proprotors are much larger than an airplane's propeller. Consequently, the proprotors can generate the same amount of thrust as an airplane at a much slower RPM. The lower tip speed of the tiltrotor makes it very quiet in cruise flight (even at high speeds) which is a significant advantage when operating in urban or high threat environments.

1.6.5 Flying a Tiltrotor

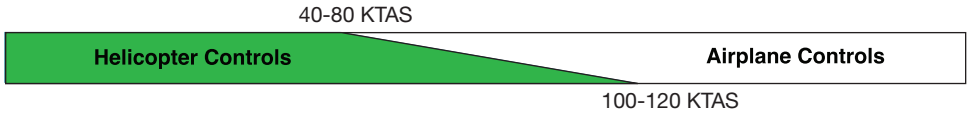
The pilot controls both flight modes with a single set of controls. The conventional airplane stick, rudder pedals, and thrust lever automatically function like a cyclic stick, yaw pedals, and collective control in a helicopter. The flight control system is designed to smoothly change the flight control functions between helicopter and fixed wing modes automatically and transparently as the aircraft speed increases or decreases during conversion from one mode to the other.

In a tiltrotor, the pilot also controls the nacelle angle. Using the nacelle control provides an additional method to accelerate forward or aft, and to control aircraft pitch attitude – it is used as complementary control with the longitudinal cyclic stick, and includes automatic conversion corridor protection control.

1.6.6 Transition and Conversion

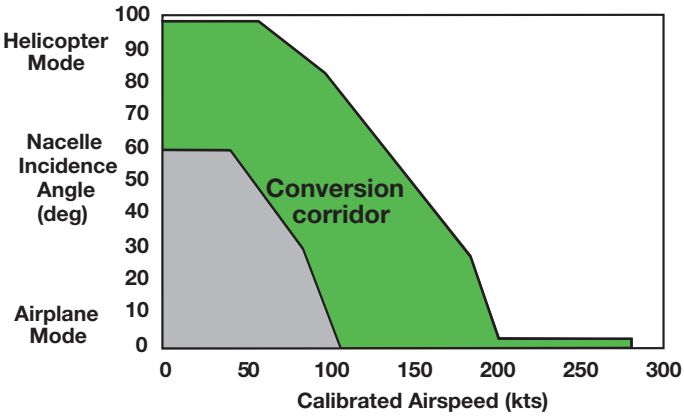
The process of rotating the nacelles between helicopter and airplane mode is called "transition", and the reverse from airplane mode to helicopter mode, "conversion". Transition and conversion procedures are simple, straightforward, and easy to accomplish. The amount and rate of nacelle tilt can be manually controlled by the pilot or can be performed automatically by the flight control system.

The V-22 can perform a complete transition from helicopter mode to airplane mode in as little as 16 seconds. Conversions and transitions can be continuous, stopped partway through, or reversed as desired. A tiltrotor can fly at any degree of nacelle tilt within the authorized conversion corridor envelope.



During vertical takeoff, the conventional helicopter controls are utilized. As the tiltrotor gains forward speed, the wing begins to produce lift and the ailerons, elevators, and rudders become more effective. Between 40 and 80 knots, the rotary-wing controls begin to be phased out by the flight control system. Once in airplane mode, the wing is fully-effective and pilot control of cyclic pitch of the proprotors is locked out.

Because the nacelle angle can be commanded separately from the primary pitch controls of rotor cyclic and tail elevator, the conversion corridor (the range of permissible airspeeds for each angle of nacelle tilt) is very wide (about 100 knots). In both accelerating and decelerating flight, this wide corridor means that a tiltrotor can have a safe and comfortable transition or conversion, offering the combined advantages of speed and maneuverability for low level flight.



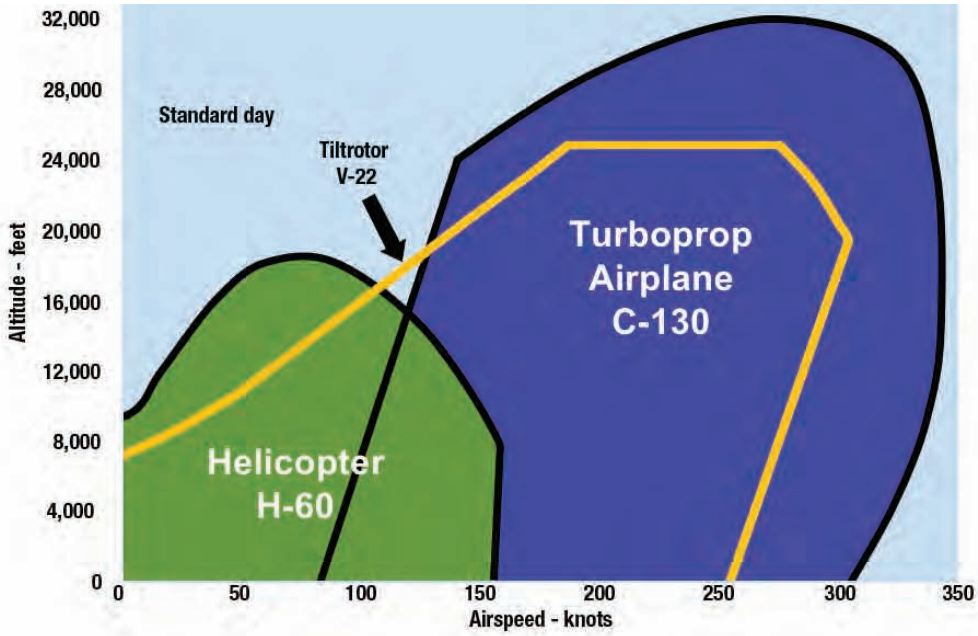
1.6.7 Flight Safety

A shaft through the wing connects the engines of a tiltrotor. Under dual-engine operations, the connecting shaft transmits very little power; but, if power from one engine is lost the shaft transfers half the power from the remaining engine to the opposite proprotor. The transfer of power is automatic, avoiding the adverse yaw which normally accompanies loss of power on one side of a multi-engine airplane. The only sensation felt in the cockpit is an overall reduction in thrust.

Although modern engines are very reliable and the probability of both engines failing on the same flight is extremely low, the tiltrotor can maintain the RPM of its proprotors while descending without power. In the unlikely event of a dual engine failure in a tiltrotor, continued safe flight to a landing is possible in either airplane or helicopter mode.

1.7 Tiltrotor Advantages

Tiltrotor technology offers the warfighter exceptional improvements in operational effectiveness coupled with significant reductions in mission costs and risk. The extensive flight envelope, vertical lift, and unrefueled range allows the warfighter to complete current missions more effectively, as well as execute entirely new mission sets. The improved productivity and reduced reliance on support systems actually reduces total mission costs, while reduced susceptibility, vulnerability, and mission complexity diminish mission risks. Some examples of these operational, economic, and risk advantages of tiltrotors are described below.



V-22 Comparative Flight Envelope

1.7.1 Operations

Transport tiltrotors, such as the V-22, are well suited to perform numerous V/STOL missions, as described in section 1.10 Multimission Capabilities. Many operational features and advantages provided by tiltrotors include:

Special Warfare

- Expanded period of darkness coverage
- Faster response times
- Adverse weather, deep penetration

Sea Control

- Expanded air, sea surface, and sub-surface area coverage
- Faster response times for Tactical Recovery of Aircraft and Personnel (TRAP), pop-up threats
- Expanded distributed naval operations enabled by long range airborne resupply

Theater Operations

- Improved combat power build-up rate
- Threat circumvention and/or standoff due to increased range and speed capability
- Organic aerial and ground refueling capability
- Airfield reconstitution service delivery
- Self-deployment capability to theater

Recovery and Civil Support

- Expanded 'Golden Hour' rescue and casualty evacuation coverage
- Faster response times to emergency situations (non-combatant evacuation operations, terrorist attack, disaster relief, weapons of mass destruction response, etc.)

Communications

- Improved airborne surveillance and control ranges
- Expanded Over The Horizon (OTH) Targeting/Surveillance, with onboard analysis and planning
- Expanded network-centric operational utility and reach-back

Intelligence

- Extended loiter time for sensor collection
- Wide area Signals Intelligence (SIGINT) collection

Transport

- Improved operational tempo
- Combined carrier/vertical onboard delivery services

Support

- Improved unrefueled mission range and response time

1.7.2 Mission Economics

There are two key ways in which tiltrotor technology measures improved economics over other vertical lift platforms: Total Ownership Costs and Total Mission Costs.

Total Ownership Costs (TOC) are a broad measurement of the cost to acquire and operate a fleet of aircraft. The near doubling of productivity of a tiltrotor, due to its speed advantage over helicopters, enables an operator to have a smaller fleet of rotorcraft (or allows for more expanded capability and service), thus saving on fleet acquisition and training costs. The combination of improved high altitude cruise efficiency and reduced vibration-induced maintenance coupled with reduced mission time required, makes the aircraft operating costs significantly lower. These factors result in overall reduced total ownership costs. This improved value is a hallmark of tiltrotors.

Total Mission Costs include allocated costs of many complementary elements, in addition to the direct operating cost of the platform itself. Tiltrotor technology greatly reduces the need for many of these support structures and systems, including, but not limited to:

- Tanker support for long range missions
- Forward Arming and Refuel Point (FARP) operations
- Maintenance and support facilities (due to fewer aircraft)

These economic advantages make it easy to demonstrate that overall, tiltrotors provide improved operational effectiveness and reduced costs, rendering a superior value proposition.

1.7.3 Mission Risk

There are many ways a tiltrotor, such as the V-22, reduces mission risk:

- Increased speed and terrain following features reduce susceptibility.
- Lower enroute acoustic signature reduces susceptibility and threat cueing.
- Extra range capability and speed allows the V-22 to circumvent threats and still arrive on target at the required time.
- Rapid transitions between helicopter and airplane modes reduce the classic helicopter terminal approach and departure timeline, and thus reduce terminal operations threat exposure.
- Improved reliability increases probability of mission success.
- Reduced mission complexity (less reliance on support aircraft, systems, and multiple staging points) improve mission probability of success.

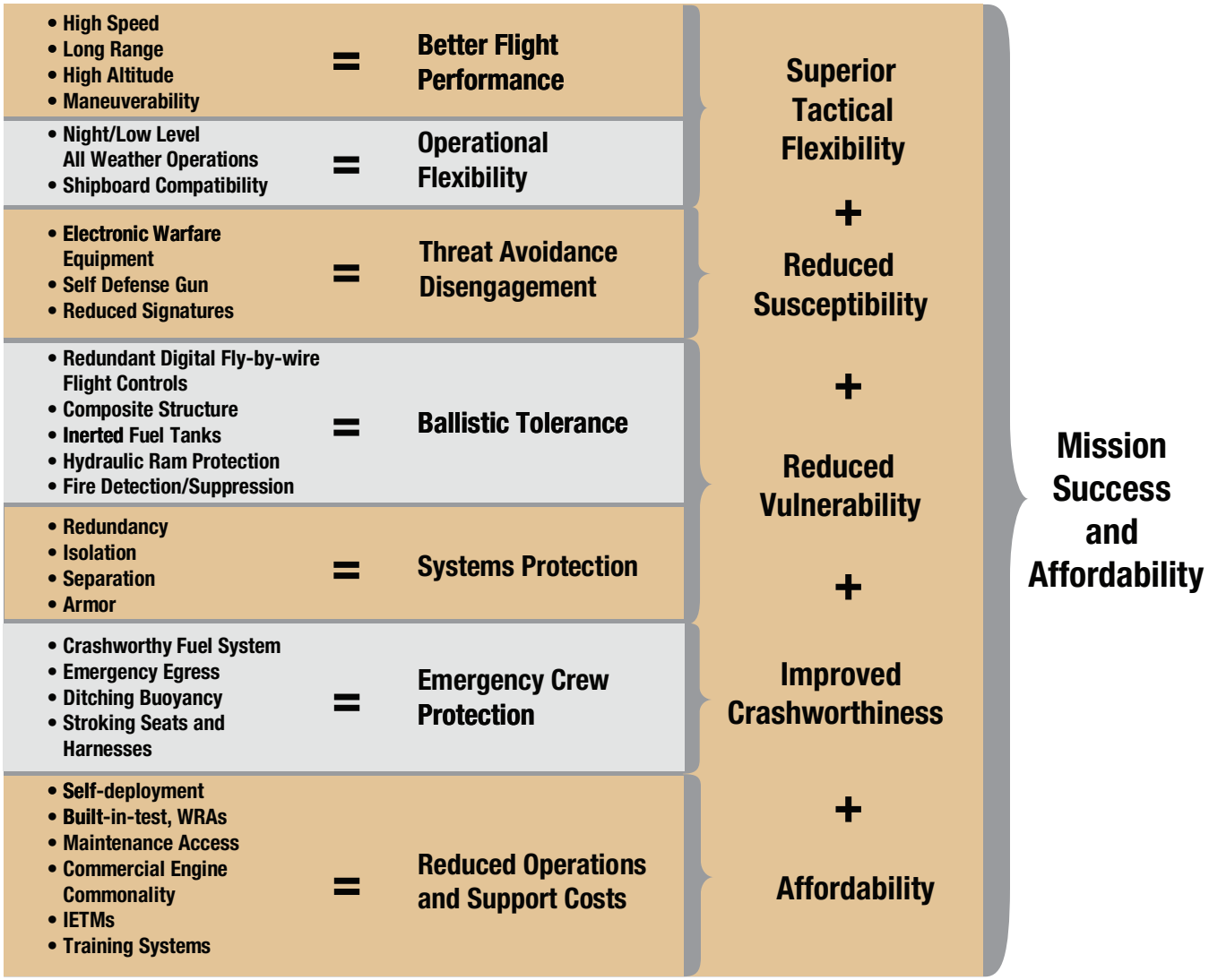
The operational advantages, reduced costs, and reduced mission risks make the tiltrotor a superior platform for practically every mission requiring vertical lift capability.

- Typical helicopter acoustic signature is Omni-directional

- V-22 acoustic signature is greatly reduced in cruise:
  - Unloaded rotor (wing lift) and 84% rotor rpm
- V-22 exposure to ground detection is much less than helicopters

1.8 V-22 Design

The V-22 is designed to a broad set of drivers to provide an affordable, effective mission capable aircraft. It combines VTOL and high-speed night/all-weather capability, while incorporating a series of advanced features to improve mission success rates, enhance survivability, and affordability. When combined with the V-22's range and payload capacity, this also means that fewer aircraft may be required to accomplish a given mission set.



Key Military Features and Design Drivers

1.8.1 Configuration Summary

The rotor system and airframe are made of advanced composite materials, fiberglass, and metal. More than 43 percent of the V-22's structural weight is fabricated from composites. The airframe structure and its seating accommodations for the passengers and crew have been systematically designed to maximize crashworthiness and safety.

Internal personnel/cargo features include:

- Crashworthy seating for 24 combat troops
- Palletized cargo
- Light-wheeled vehicles
- Up to 12 medical litters (for Block C aircraft)

These requirements defined the cabin dimensions and volume as well as the ramp design.

External cargo features include:

- External cargo up to 10,000 lb (4,536 kg) in single hook operations, and capability for 15,000 lb (6,804 kg) with dual hook operations, for loads such as netted cargo, large vehicles, or ordnance pallets.
- The dual-hook arrangement provides additional load stability for cruise at higher speeds.

The turboshaft engines are located in nacelles at each end of the wing. The engines drive two 38.1 ft (11.6 m) diameter proprotors through gearboxes, which are interconnected to provide fail-safe, one-engine inoperative (OEI) power to both rotors.

The design features include:

- State-of-the-art avionics
- Triply redundant digital fly-by-wire flight controls
- Onboard Central Integrated Checkout (CIC)
- Vibration, Structural Life, and Engine Diagnostics (VSLED) systems, which are employed to provide continuous condition monitoring of the aircraft's structure, engines, and dynamic components

The V-22 has been designed from the ground-up to be a low-maintenance aircraft. The requirements to meet tough Life Cycle Cost, Reliability and Maintainability goals has resulted in an aircraft that balances redundancy, condition monitoring, and inspection accessibility to achieve an "on-condition" maintenance concept.

The aircraft's tricycle landing gear provides for excellent ground or deck handling qualities. An aft ramp and side-cabin door facilitate troop and cargo loading and unloading.

1.8.2 Flight Crew

The standard crew consists of three personnel: a pilot and a copilot in the cockpit, and a crew chief in the cabin. A third cockpit seat is available between the two pilots. This "observer" seat may also be configured for a flight engineer.

Blade Fold Wing Stow

1.8.3 Shipboard and Ground Operations

The wing can be rotated and the proprotor blades folded and stowed automatically in winds up to 45 knots. This blade-fold/wing-stow ability accommodates deck spotting and minimizes shipboard stowage space. This compact configuration also reduces the hangar space required.

Shipboard compatibility requirements imposed design constraints on rotor disk size. The ship deck or ground-to-rotor clearances are such that personnel and most ground support equipment are not endangered by rotor strikes – a significant safety factor.

1.8.4 Flight Operations

In addition to operating as a helicopter during takeoff and when landing vertically, the V-22 can also conduct rolling takeoff and landings in a partially converted mode, which allows for higher gross weight operations.

The V-22 provides excellent air and ground taxiing capability. Nacelle tilt provides thrust control to accelerate and decelerate easily and rapidly. The aft nacelle tilt feature (7.5°) aids in stopping and backing the aircraft for precise ground handling.

V-22 Osprey

In hover and slow flight, it has the maneuverability and agility of a helicopter. Counter-rotating proprotors eliminate torque coupling. The stability of the V-22 in airplane mode compares favorably with that of a conventional twin-engine commuter type airplane. It has proven to be easy for both fixed- and rotary-wing pilots to transition to tiltrotor flight.

Mission range or endurance establishes the fuel requirement thus sizing the remainder of the physical aircraft, the engine power, and transmission ratings. The V-22 was given mission requirements for both long- and short-range operations. To most effectively perform these missions, the V-22 is available with extended range fuel system options. Additionally, in order to self-deploy at distances over 1,800 nm (3,334 km), the V-22 incorporates a retractable aerial refueling probe.

With its basic tactical fuel tanks (11,700 lb/5,307 kg capacity), the V-22 can carry its troop payload to a tactical radius of action of more than 400 nm (740 km) and return without refueling. With the use of two mission auxiliary tanks, the V-22 can extend this unrefueled tactical radius of action to more than 600 nm (1,111 km) for a team of eight troops. Finally, with the addition of a third mission auxiliary tank, the V-22 can achieve a non-refueled, zero payload ferry flight range of 1,800 nm (3,334 km). For longer-range missions, the V-22 can also be refueled in flight using its retractable refueling probe.

1.8.5 Flight Control System

The V-22 flight control system is a full-authority, triply-redundant, digital, fly-by-wire system. Its control laws are structured within a Primary Flight Control System (PFCS) and the Automated Flight Control System (AFCS). The PFCS provides the basic control functions for flight.

The AFCS is included to provide stability and control augmentation for enhanced handling qualities. The V-22 flight handling qualities are enhanced through command shaping, rotor and engine speed governing, rate feedback, and automatic flap control.

Flight on the PFCS has been demonstrated throughout the operational envelope and meets all control requirements for primary flight. Flight on the AFCS has also been demonstrated throughout the envelope and has been optimized to meet pilot needs for a wide range of missions. The fly-by-wire architecture allows the flight control systems to incorporate changes based on pilot feedback, which results in a lower pilot workload for all tasks.

The Flight Director provides uncoupled guidance commands and coupled (autopilot) engagement for several flight path, inertial navigation, and electronic navigation modes.

1.8.6 Maintenance

Under normal conditions, the V-22 can support either three-level [organizational (O), intermediate (I), and depot (D) unscheduled] or two-level (O and D) maintenance concepts. Scheduled inspection requirements have been minimized through up-front design. Some of the enabling technologies that support this philosophy include:

- Extensive use of composites
- Enhanced toughness technologies
- Central integrated checkout systems
- Integrated diagnostics systems
- Composite repair development programs

In addition, the V-22 can operate for extended periods from austere sites that lack normal maintenance support. Onboard power generation and built-in hand holds and work platforms enable field maintainers to perform all normal flight inspections without special facilities or equipment.

The V-22 was designed with maintenance and support in mind. It incorporates some marked advances in maintenance concepts and employs a substantially different scheduled maintenance philosophy. This philosophy reduces maintenance manpower requirements and lowers operating costs.

1.8.7 Growth Potential

Multirole capability is a cornerstone of the V-22 program. The V-22 has a basic configuration that supports multimission applications using standard, existing, or provisioned mission kits.

Because of its ability to fly like an airplane, the V-22 is well-suited for missions that require a substantial sensor package to be maintained at altitude (e.g., Airborne Early Warning). The V-22 can perform such missions while operating from an austere site, a short landing strip, or a ship equipped with a suitable landing pad.

Flexibility in the avionics system is also a fundamental characteristic of the V-22 design. The use of the MIL-STD-1553 databus architecture means that different units can be integrated provided they conform to V-22 command protocols. This minimizes the modifications necessary to produce service-unique configurations for special performance and/or operational needs. This flexibility has been demonstrated within the V-22 program with the transition from the baseline USMC mission configuration to that required for the U.S. Special Operation Command missions.

Additionally, the V-22 is the most thoroughly tested aircraft in history. With the Engineering and Manufacturing Development (EMD) and Production programs, Bell Boeing has a complete database of the important test parameters, including:

- Static Test Article
- Fatigue Test Article
- Drop Test Article
- Vulnerability tests
- Flight tests
- Reliability growth tests
- Comprehensive component qualification testing
- Live Fire Test And Evaluation

As mission enhancements are developed over the life of the aircraft, this data will allow effective incorporation such that weight and cost impact will be minimized, while maximizing performance and capability.

The V-22 stands ready to integrate the technology of tomorrow. It is designed for a future that will minimize the effort to adapt the aircraft in order to satisfy future mission requirements.

1.9 Affordability

Affordability, mission effectiveness, and operational flexibility are key issues facing military aircraft operators worldwide. The V-22 tiltrotor aircraft provides a cost-effective system with significantly reduced Total Ownership Cost and Total Mission Costs, while providing for improved effectiveness and flexibility. This reduction in cost stems from several V-22 features, including:

- Increased transport productivity (troops and/or cargo delivery rate) make the operating costs, when based on mission accomplishment (vs. per hour), lower than conventional helicopters.
- Increased range reduces the need for support equipment and systems such as tankers or FARPs, and permits self-deployment for most missions.
- Improved survivability reduces attrition replacement costs.
- Flexibility to fulfill both helicopter and airplane roles reduces total aircraft and facilities requirements. Crew and maintenance personnel training can be consolidated, further reducing the total training time and related costs.

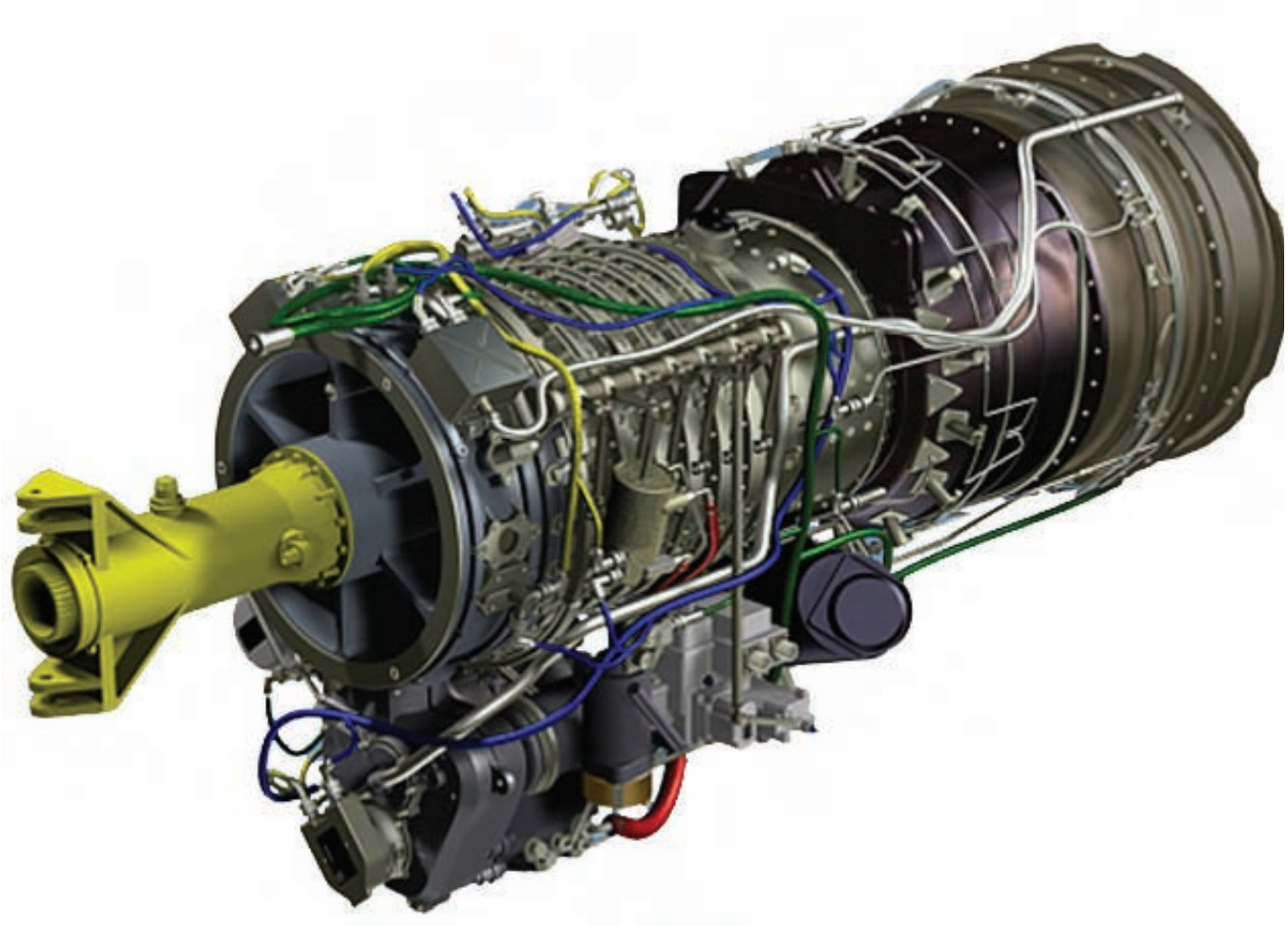
Bell Boeing is committed to continuously address affordability issues that will reduce total ownership and mission costs. Significant areas that contribute to V-22 affordability are the Cost Reduction Initiative, Common Engine Core, and maintainability design features.

1.9.1 Acquisition Cost

Bell Boeing employs an aggressive cost containment and reduction program to keep the price of the V-22 affordable. Our Cost Reduction Initiative continually investigates, and implements, component and manufacturing process improvements for the V-22. Modern manufacturing fabrication and assembly processes for both composite and metal components are utilized. These processes were demonstrated on early production prototypes and continue to be improved for production models of the V-22. Continuous improvements in these processes are reducing both man-hours and assembly time requirements. Additionally, aircraft components and systems are studied for opportunities to reduce acquisition and support costs.

1.9.2 Engine Spares Commonality

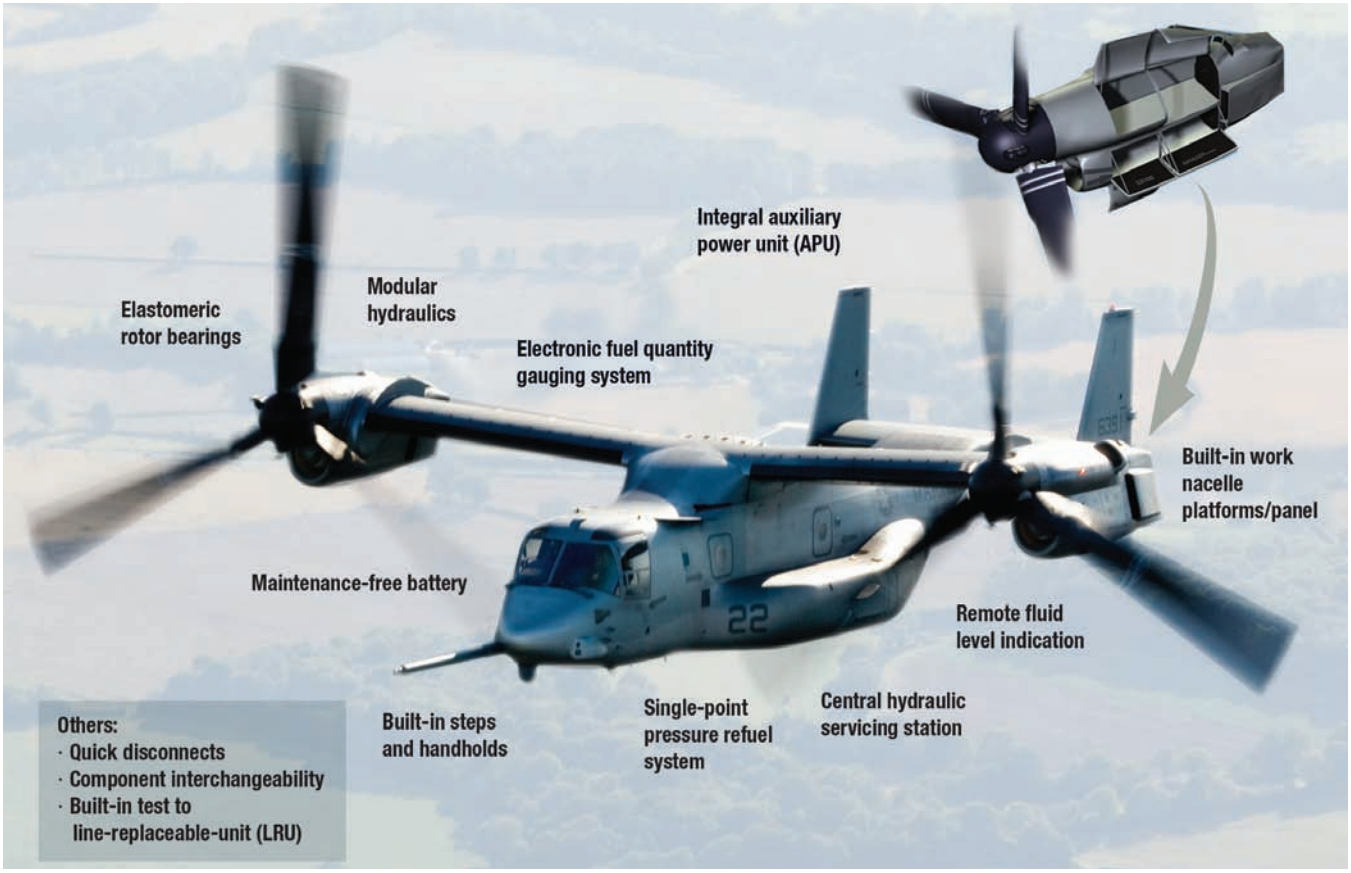
The V-22 is equipped with two Rolls Royce AE1107C engines (which is an evolution of the proven T-56 powerplant). This engine shares many parts and functions with the AE2100 series engines found on the Lockheed-Martin C-130J and SAAB 2000. The high pressure spool of the AE1107C is also common with the AE3007 series turbofan engines found on the Cessna Citation and Embraer EMB-145 aircraft. This common core approach provides the V-22 program with performance and affordability benefits from the common spare parts supply, shared lessons-learned, training, maintenance procedures, and tools.



Rolls Royce AE1107C engine

1.9.3 Maintenance

With Integrated Logistics Support as an integral part of the V-22 aircraft design and systems engineering process, the V-22 incorporates many support and maintainability features that reduce the maintenance hours per flight hour. For example, there are over 300 access panels on the V-22. These access panels and remote fluid indicators permit ready visual inspection and maintenance of all significant systems and components. From pre-flight inspection to component replacement, the ease of servicing and maintenance cost reductions are proven in operational tests.



Built-in Maintainability Features

1.10 Multimission Capabilities

The V-22 tiltrotor design can be adapted to many missions, yet to be specified by current and future customers. Bell Boeing has developed numerous design upgrades and configuration improvement concepts to suit alternate missions. Highlighted below are the most prominent of the configurations conceived to date. With the V-22's speed, range, and internal cargo capacity, it would make an excellent platform for aerial refueling, aerial surveillance, or command and control.

The V-22 is a highly-flexible multipurpose aircraft capable of performing many missions. The U.S. Government, Bell Boeing, and third party analysis have evaluated the suitability and effectiveness of V-22 variants for over 30 different missions.

Potential Mission Applications	
Special Warfare • Special Operations • Electronic Warfare **Sea Control** • Antisubmarine Warfare • Anti-Surface Ship Warfare • Mine Warfare **Theater Operations** • Assault Medium Lift • Tactical Mobility • Advanced Rotary Wing Attack • Gunship/Close Air Support • Aerial Refueling **Recovery and Civil Support** • Search and Rescue • Combat Rescue • Medical Evacuation • Joint Emergency Evacuation of Personnel • Weapons of Mass Destruction Consequence Management • Forward Air Control	**Communication** • Surface, Subsurface, Surveillance Coordination • Over-the-Horizon Targeting • Surface Combatant Airborne Tactical System **Intelligence** • Observation • Armed Reconnaissance • Airborne Early Warning-Surface Combatants • Signal Intelligence • Battle Group Surveillance-Intelligence **Transport** • Fleet Logistics • Carrier/Surface Ship On-Board Delivery • Operational Support Airlift • Mid-Air Retrieval System • Light Intra-theater Transport • National Executive Transport **Support** • Missile Site Support • Range Support

The V-22 has been designed with space, weight, and power provisions for various electronic and equipment upgrades. The two mission computers and the triple MIL-STD-1553B digital data busses afford significant growth potential for additional avionics systems or operator consoles. Under non-icing, normal conditions, the V-22 electrical system (240-kVA total from four generators) has significant power generation margin, and can provide 50 kilowatts of 'mission' power over that required for flight.

For each of these missions, the V-22's combination of high-speed flight and hover capabilities provide substantial advantages. These advantages include a large area of operation and the rapid responsiveness of a fixed-wing turboprop aircraft, while retaining a helicopter's capability to operate from confined areas. When compared against conventional aircraft (to cover a given territory or ocean zone), the V-22 aircraft requires fewer bases, aircraft, and personnel. Additionally, self-deployability, improved reliability, and reduced maintenance significantly reduce the cost of deployment for field operations.

Potential Multimission Applications
MV-22
Assault Support
CV-22
Special Operations
Combat Search and Rescue
Aerial Refueling
Command and Control
Ground Refueling
Logistics Support
MEDEVAC
Antisubmarine Warfare
Executive/VIP
Disaster Relief
Aerial Surveillance
Force Protection
Airborne Tactical Laser

SECTION 2.0 - V-22 AIRCRAFT DESCRIPTION

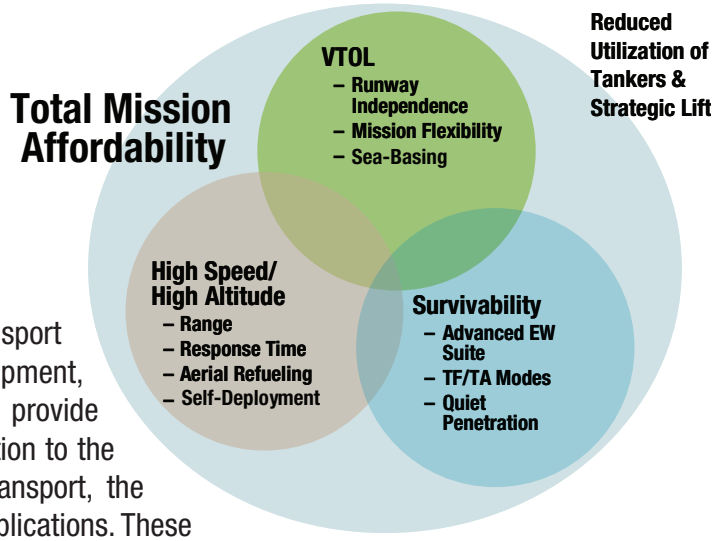
2.1 Design Environment

The V-22 aircraft is state-of-the-art in design, manufacturing and performance technology. The V-22's design represents the collection of years of prior study and the demonstration of the various technologies necessary to construct a lightweight, affordable, high-performance rotorcraft. This section describes in detail many of the key features of its design.

The V-22 has been designed using the Integrated Product Team (IPT) concept. The IPT concept was adopted as a result of lessons learned from design, production, and sustainment of numerous military and commercial aircraft programs at both Boeing and Bell.

2.2 Aircraft Operations

2.2.1 Design Drivers



Rapid response and extended mission reach, vertical/ short takeoff and landing, and survivability features are critical traits required for a mission-affordable, modern military aircraft.

These core features, along with the assault transport requirements for delivery of troops, cargo and equipment, and primary basing aboard amphibious assault ships, provide the main drivers for design of the V-22 tiltrotor. In addition to the features required in a modern medium-lift assault transport, the V-22's design was influenced by many other mission applications. These missions include: combat search and rescue, fleet logistic support, special warfare missions, long-range insertion and extraction of special operations forces teams, medical evacuations, combat assault, tactical airlift, and electronic warfare missions.

The detail requirements of these missions vary significantly, consequently the design of the V-22 aircraft is driven to provide a multimission platform, with payload, performance, and electronic equipment flexibility. For example, the mid-mission hover requirement of special operations forces mission sized the aircraft engines and rotor system. In addition, the U.S. Navy's requirement that the V-22 be able to carry an F/A-18 engine within its shipping container sized the height of the cabin.

In order to meet the various mission options that individual customers may have, the following enhancements can be added to the aircraft's basic configuration:

- **Increased Mission Radius** – To achieve an extended mission radius, the V-22 can be equipped with up to three 430-gallon mission auxiliary tanks (MATs) in the cabin, or two MATs and use of the optional aft sponson fuel tank. Total fuel for these configurations is approximately 3,000 gallons.

- **Terrain Following/Terrain Avoidance (TF/TA) Flight** - To minimize detection, the V-22 can incorporate equipment for TF/TA flight. This enhancement allows for low-altitude flight during day or night conditions – in either visual or instrument meteorological environments. The altitude capabilities are 300 feet above terrain and below.
- **Improved Self-Defense Capability** – To achieve a superior element of surprise, the V-22 can be equipped with an enhanced electronic warfare suite. This can enhance threat detection and situational awareness, countermeasures, and enroute mission planning. While this enhancement lessens the probability of aircraft detection and engagement, it can also serve to lessen the need for extensive suppression of enemy air defenses (which normally precedes any conventional deep penetration mission).
- **Increased Communications Capability** – To achieve greater communication security, the V-22 can be equipped with an enhanced communications suite. This enhancement is ideal for those missions that require additional security, low probability for adversarial interception, and incorporation of updated threat data while on mission. This suite also meets the needs of special operations missions, which must be able to communicate simultaneously with airborne C2 elements, other aircraft in the formation, and ground forces in the area of operation.

2.2.2 Basing and Deployment

Land basing for the V-22 will range from fixed air stations to austere temporary Forward-Operating-Bases (FOBs). The V-22's primary sea base will be amphibious assault ships.

2.2.2.1 Air Stations

Due to their inherent expeditionary capability, V-22 squadrons are routinely deployed forward in support of national policy. In addition to operations from amphibious assault ships, squadrons may be deployed to a variety of aviation facilities. These facilities may range from fully-functional fixed air-stations to semi-prepared areas with minimal facilities.

A main air base is a secure airfield, capable of handling all types of aircraft – up to and including theater lift assets. Support units and facilities are determined by task organization; but, normally include I-Level support with their associated mobile facility vans.

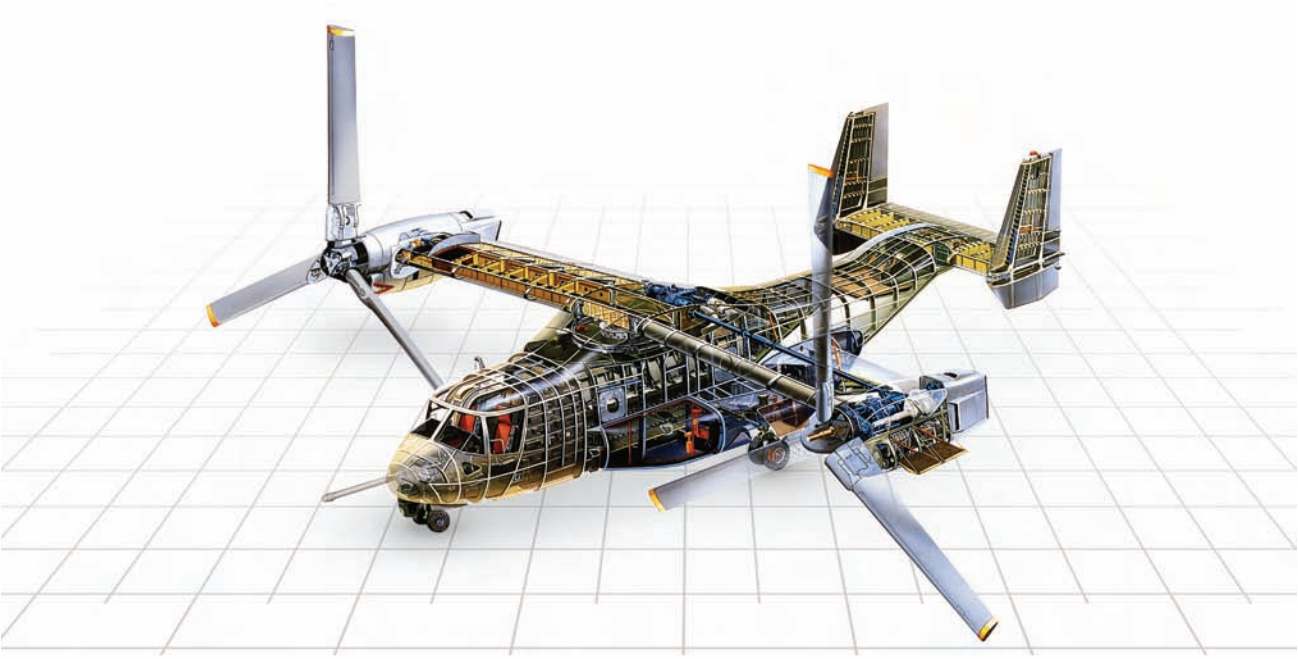
2.2.2.2 Shipboard Basing

The V-22's primary sea base will be amphibious assault and transport ships, including the U.S. Navy LHA, LHD, LHA(R), and LPD fleet. During the course of amphibious operations, the V-22 may be phased ashore in support of the commander's scheme of maneuver. The embarked maintenance personnel, equipment, and material would then be ferried ashore by aircraft or surface landing craft.

The V-22 is capable of landing on, performing shutdown/startup, and refueling operations from numerous other air-capable and amphibious aviation ships in the U.S. Navy's inventory. These ships include: aircraft carriers, amphibious warfare ships, combat logistics force ships, and several classes of cruisers.

2.3 Airframe Structure

During the past two decades, the aerospace industry has conducted extensive research and development into composite materials and its applications. The results of this research have directly benefited the V-22's structural design. Composite design and manufacturing processes have reduced cost and weight, improved reliability, and provided additional ballistic tolerance.



Structural Arrangement

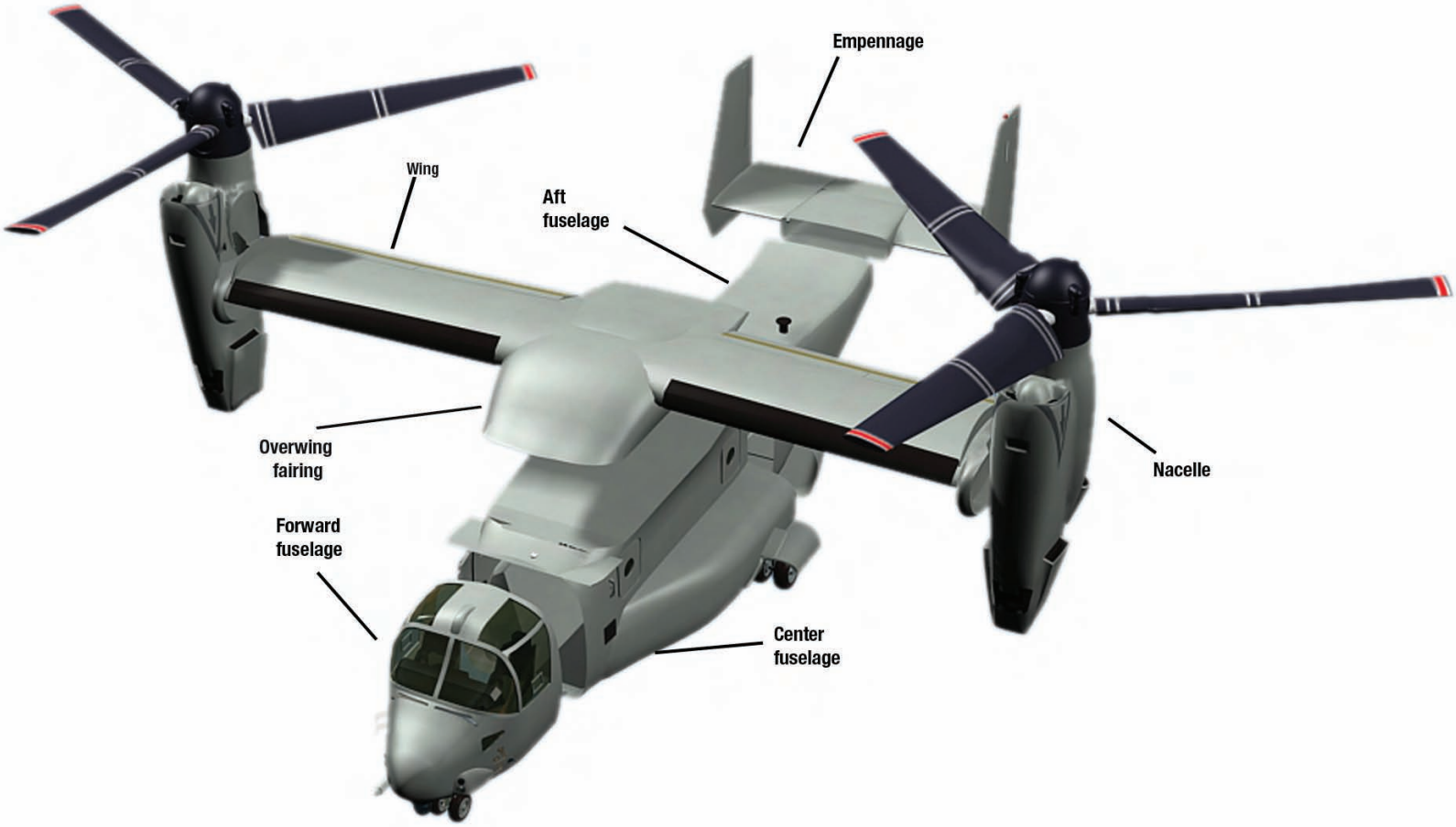
Modular construction	Large structural assemblies: forward fuselage, center fuselage, aft fuselage, ramp, empennage, wing, and nacelles
Airframe material	Aluminum major frames with graphite/epoxy (fabric and unidirectional prepregs) subframes, skins, and main landing gear doors
Airframe construction	Machined aluminum and composite frames/stiffened skins/molded longerons
Mechanical fasteners	Subassemblies and skins assembled with compatible titanium fasteners
Major honeycomb components	Cockpit and cabin floors, sponsons (fuel tanks and ECS compartment), fairings and select airframe components
Major fittings	Predominantly metal: steel, titanium, and aluminum
Transparencies	Windshield: laminated acrylic/polycarbonate Canopy and side windows: laminated hard coat/hard coat polycarbonate

Structural Features

Using composite materials means components have fewer fasteners and, as a result, fewer fatigue effects. Approximately 43 percent of the V-22's airframe structure is fabricated from composite materials (e.g., the wing, fuselage, empennage, tail assemblies, stiffeners, stringers, and caps).

The wing is made primarily of Hercules IM-6 graphite/epoxy solid laminates. These laminates are applied unidirectionally to provide optimum stiffness. The fuselage, empennage, and tail assemblies have AS4 graphite fibermaterials incorporated into their fabrication. Various airframe components (like stiffeners, stringers, and caps) are co-cured with the skin panels.

The airframe delivers the necessary stiffness and light weight needed for V/STOL, while providing a resistance to salt water and environmental corrosion. The composite airframe is fatigue resistant and damage tolerant, which increases its ballistic survivability.



Airframe Sections

2.3.1 Fuselage

The V-22 fuselage design is modular and includes redundant load paths so that continuous safe operation is possible even after the failure of a major component. The fuselage is comprised of the forward, center, and aft fuselage, and the empennage.

Fuselage Assembly Modules

Forward Fuselage Structure

2.3.1.1 Forward Fuselage

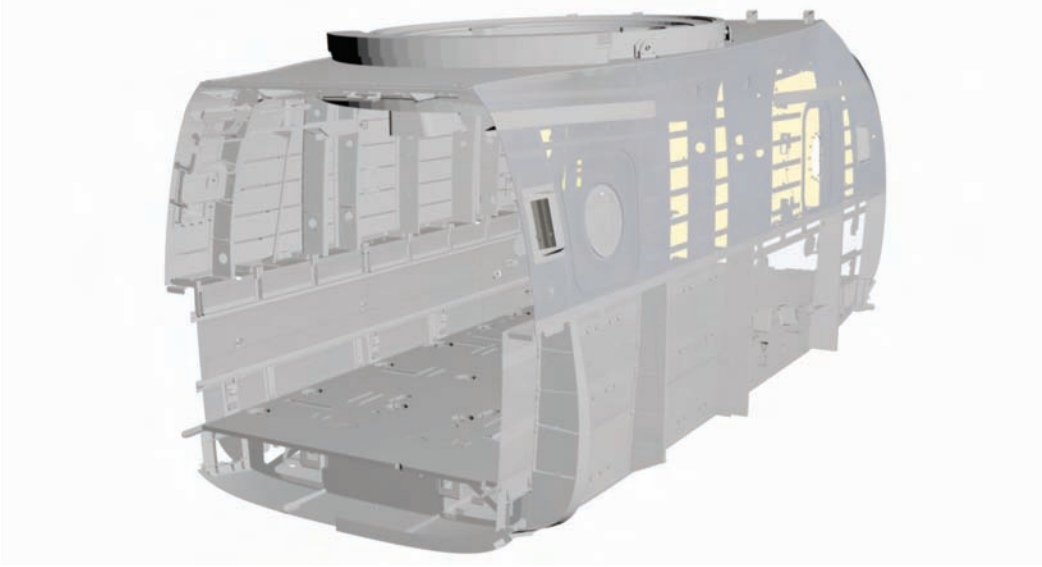
The forward fuselage design is a hybrid of graphite/epoxy and aluminum alloy construction. Aluminum is used for all of the major frames and fittings. Graphite/epoxy is generally used for the exterior skins. However, the skins around the avionics racks are aluminum to allow for better electromagnetic interference (EMI) protection. The cockpit windshield is laminated acrylic/polycarbonate and designed to withstand the impact of a 3 lb (1.36 kg) bird at 275 knots (510 km/hr).

The main entry door is located on the right side of the forward cabin and it has an upper and lower section. The upper door section rolls along tracks so that it may be stored overhead. The lower section folds down and has integral steps. The lower door is hinged and may be set in a normal open position for entry/exit.

2.3.1.2 Center Fuselage

Similar to the forward fuselage, the center fuselage is also a hybrid of graphite/epoxy composite attached to aluminum alloy frames. The internal surface is covered with a layer of E-glass to prevent corrosion between the graphite and aluminum frame structure. The external surfaces are sealed with epoxy primer and polyurethane paint. A copper mesh is integrated near the outer surface of selected areas of the exterior composite skin to provide additional lightning protection.

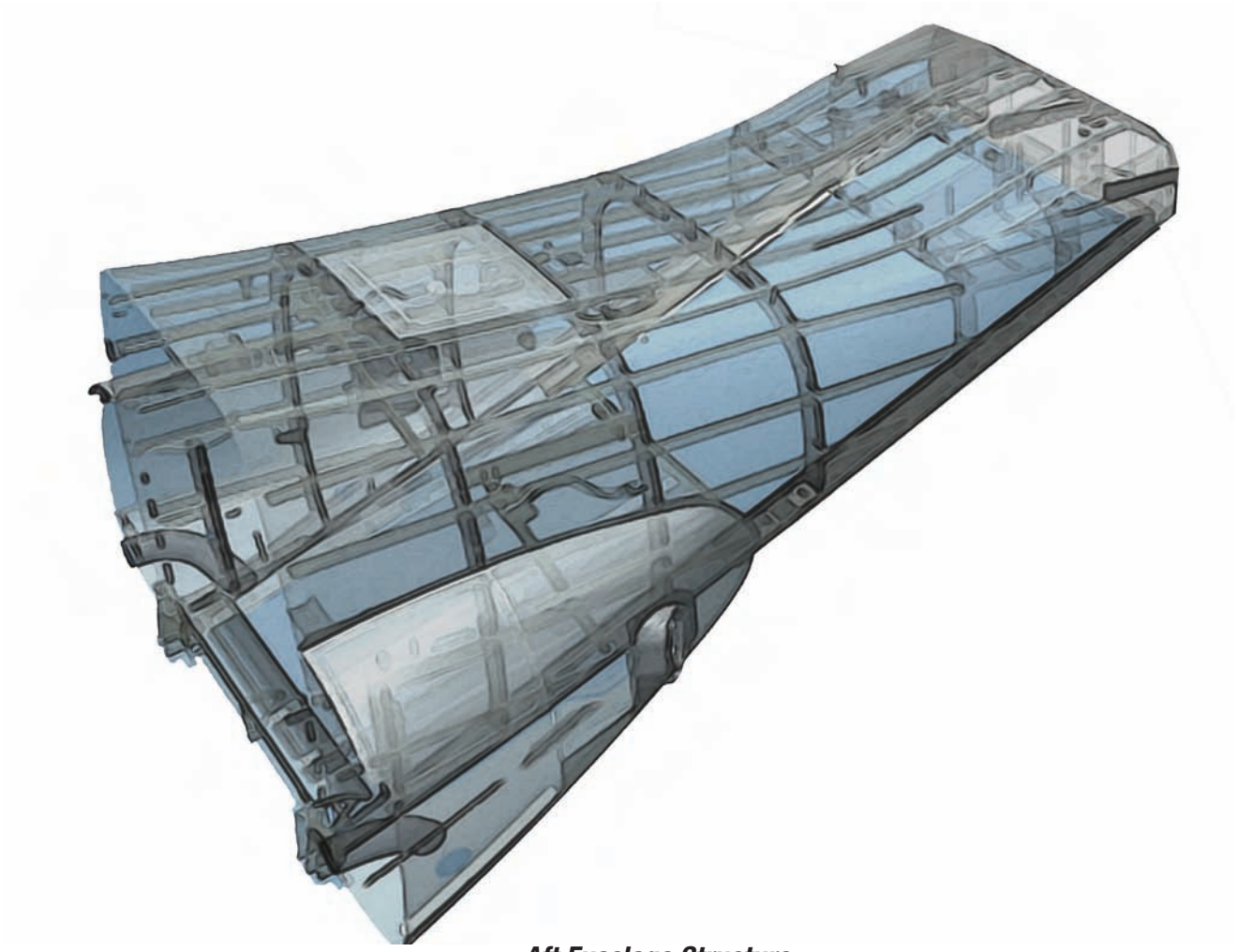
The fuselage's design allows for ease of maintenance and movement about the exterior fuselage. Exterior hand and foot holds provide easy access to the sides and top of the aircraft. Also, a reinforced, non-slip walkway extends the length of the fuselage and empennage.



Center Fuselage Structure

Attached to each side of the center fuselage is a large external sponson. The sponsons contain fuel in the forward areas, and an option for fuel in the aft right side. They also provide the stowage needed for the main landing gear, the Environmental Control Unit (ECU), and/or provide an additional area upon which external equipment can be mounted. The Ground Refuel/Defuel Panel is located aft in the left sponson; ground personnel may service the entire fuel system though this panel.

Left Sponson Structure



Aft Fuselage Structure

2.3.1.3 Aft Fuselage

The aft fuselage has an all composite skin and stringer construction. It incorporates the rear (cargo) ramp and door.

The cargo ramp and door provide a means to load and deploy troops and cargo. Operation of the ramp and door may be performed from:

- The cockpit overhead control-panel,
- The forward cabin control-station (located just aft of main cabin door),
- The ramp control-station (located on the right side of ramp), or
- An external panel (located on the aft right sponson).

The cargo ramp and door is an integrated, two-piece component. The ramp is hinged onto the lower aft-fuselage and opens downward. The door is hinged onto the upper aft-fuselage and opens upward. Both are constructed of aluminum frames and graphite epoxy skins. The ramp incorporates cargo tiedown points rated at 3,500 lb (1,588 kg) for use with traditional (unattenuated) tiedown devices. The cargo tiedown points are rated at 5,000 lb (2,268 kg) for use with load attenuated devices.

Aft Fuselage Door and Ramp

2.3.1.4 Empennage

The empennage is an H-tail configuration with graphite epoxy skin and stringers. The horizontal surface has a single elevator controlled by three actuators. Rudders are mounted in each vertical fin, and are controlled by separate, single actuators.

Empennage Structure and Components

2.3.2 Wing

The wing is a single structural composite unit. The wing is composed of a main single-cell torque-box, fixed trailing-edge, wing/fuselage attachment-fittings, flaperons, and leading edge.

Wing Structure

The wing supports a pylon/nacelle assembly at each end. Routing and access provisions for fuel, electrical, hydraulic and drive systems are integrated into its design. Access panels are provided in the lower skin of the wing torque box to permit local access and fuel cell installation. The wing is attached to the fuselage by the flexring assembly. In the standard configuration, there is one feeder fuel tank on each end of the wing, and four tanks installed between the wing ribs on each side.

The center section of the wing has no sweep or dihedral. The outboard sections have a 3.5° dihedral (wing tips up) and a 6° forward sweep. Each side of the wing has two flaperons (combined flaps/ailerons), all of which are interchangeable. Each flaperon is a single movable surface, which has a travel limit of 23.5° up to 72.5° down. In cruise flight, the flaperons function as normal ailerons – providing conventional roll control. During conversion to hovering flight, the flaperons extend downward as the nacelles tilt upward to maximize wing lift, prevent stall and minimize download. In helicopter mode, the surfaces are commanded to full down, to minimize hover download forces.

The wing has both inboard wing ribs and outboard wing ribs. The inboard wing ribs are designed with access doors to provide for the installation and maintenance of the fuel cells. The outboard ribs are designed to react the proprotor nacelle forces, to provide a pivot location for the tilting of the proprotor nacelle system, and to provide an attachment and pivot location for the tiltrotor conversion actuators.

The wing is attached to the top of the fuselage through the wing stow ring, which includes a powered system mechanism to rotate and lock the wing in the flight or stow positions. For ground or deck operations, the wing can be unlocked, rotated 90°, and re-locked in a stowed position for compact parking of the aircraft. The wing can be rotated to any intermediate position and stopped for maintenance.

Wing-Stow Mechanism

2.3.3 Overwing Fairing

An overwing fairing provides for an aerodynamically smooth cover to the mid-section. It is attached to the wing in a manner that allows it to rotate with the wing. Avionics and electrical equipment are located under the overwing fairing (on a shelf forward of the front spar). The Midwing Gearbox (MWGB), gearbox accessories, and Auxiliary Power Unit (APU) are located under the aft fairing.

Overwing Fairing Configuration

These fairings are designed to accommodate the aerodynamic forces of flight and provide support personnel with a maintenance platform. Hinged doors on the fairings allow access to the equipment located below.

2.3.4 Wing Fences and Vortex Generators

To improve airflow over the wing and fuselage, a series of vortex generators (VGs) are installed on the upper surface of the wing and mid-wing area. A wing fence is installed chord-wise across the wing approximately 37 inches (94 cm) inboard of each wing tip. The wing VGs allow lower stall speeds and increased maneuverability while reducing turbulent flow on the empennage. The wing fence contains the nacelle-wing junction vortex, at nacelle angles other than airplane, from interacting with the empennage.

2.3.5 Nacelles

The nacelles support and house the engine and drive system components, and are located at each wing tip. The discrete components housed within include: engine, transmission, transmission adapter, pylon support, conversion spindle, nacelle structure and the infrared suppressor.

The maintenance doors allows for easy access to the nacelle systems and components. Routine inspections and maintenance can be conducted with ease. Two of the outboard access doors also serve as work platforms, thus eliminating the need for additional support equipment.

Each nacelle is connected to the inboard and outboard tip ribs via the conversion spindle, down-stop striker (for airplane mode), conversion actuator and conversion actuator spindle. The transmissions are located in the upper portion of the nacelle, while the engine is located in the lower portion. These two compartments are separated by a horizontal firewall.

Nacelle Group Components

2.3.6 Landing Gear

The landing gear configuration is comprised of a fully retractable, crashworthy tricycle gear-set. The tricycle gear configuration consists of two main gear struts (located amidship), and one steerable nose gear strut located forward, below the cockpit. All three landing gear are of a cantilever shock-strut configuration. They are held in the extended and retracted position by internally locking actuators that also serve as drag struts. All three landing gear assemblies are completely enclosed within the fuselage when retracted. Ground handling, directional control, and aircraft braking are also provided by components of the landing gear system.

The hydraulically powered landing gear system is electrically controlled and monitored. The landing gear system consists of the landing gear assembly, main wheel brakes, and nose wheel steering systems. The struts are hydraulically retracted. The nose wheel retracts in an aft direction, while the main wheel gear retracts in a forward direction. Hydraulic power is supplied by the No. 3 utility system. Alternate extension power is provided by a 2800 psi (19.3 mPa) nitrogen bottle.

The design descent conditions for the landing gear are 12 ft/s (3.7 m/s) for normal operations and 24 ft/s (7.3 m/s) for a crash landing. The V-22 is capable of routine operations over field conditions consisting of rocks, sand, dust, dirt, grass, brush, snow, rain, and ice. The clearance needed for boulders/stumps is 12 in (30.5 cm) high. Landings to VTOL weight may be accomplished on a sloped terrain with a maximum slope of 12 degree up/down slope or 6 degree cross-slope.

Steerable-Nose Landing Gear

Main Landing Gear

2.3.6.1 Main Landing Gear

The main landing gear system consists of two landing gear assemblies (left and right). Each main landing gear is fully retractable and enclosed within the left and right sponsons. Each main landing gear assembly consists of: a shock strut, drag strut/actuator, landing gear door and linkage, wheel brakes, wheel/tire assemblies, weight-on-wheel switches, and down-lock/up-lock position switches. The shock strut provides damping and shock absorption of forces created during landing or ground maneuvering. The drag strut/actuator moves and holds the main landing gear either in the extend or retract position. The drag strut/actuator is attached to the shock strut, and to the frame of the aircraft. The wheel brake assemblies are multiple “floating disk” types, operated by a variable pressure, hydraulic system.

2.3.6.2 Nose Landing Gear

The steerable nose landing gear is located under the cockpit floor. The nose landing gear assembly consists of: a shock strut, drag strut/actuator, landing gear doors, wheel/tire assemblies, weight-on-wheels switches, down-lock/up-lock switches, steering and centering system, and hiking system. The shock strut and drag strut/actuator perform the same as they do in the main landing gear. Typical of Naval aircraft, the nose landing gear has a full 360 degree swivel capability. The power steering unit is mounted on the right side of the nose landing gear shock strut. The hydraulically actuated, electrically controlled power steering unit provides 75 degree left and right steering authority, and is controlled by the rudder pedals.

The power steering unit also provides nose wheel shimmy dampening during taxi, rolling takeoffs, and roll on landings. The nose wheel can be locked in the centered position to keep the nose landing gear fixed during VTOL operations. Nose gear center locking is activated through the steering control panel on the cockpit overhead console.

When the aircraft is weight off wheels, the power steering motor is used to center the nose gear prior to gear retraction.

A remote ground lock-pin actuation handle is located on the right external side of the fuselage (below the pilot's side window).

A hike valve is located on the left external side of the forward fuselage. Using an external high pressure nitrogen charge, the nose landing gear can be fully extended to raise (hike) the nose of the aircraft. This allows towbarless towing of the aircraft, significantly aiding in shipboard aircraft positioning.

2.3.6.3 Loading

The V-22 landing gear was designed for a California Bearing Ratio (CBR) of 4.0. The table below provides the landing gear loading in helicopter mode at the 1 g static condition (at aircraft empty weight).

Weight distribution	lb	kg
Main landing gear (ea)	12,337	5,595
Nose gear	9,264	4,202
Footprint area per tire	**sq in**	**sq cm**
Two mains, each	54	348
Nose wheels	18	116
Footprint pressure	**psi**	**kPa**
Main landing gear (ea)	120	827
Nose gear	270	1,860

Landing Gear Loading

2.3.6.4 Brakes

A power-assisted brake assembly is fitted to each main landing gear wheel. The wheel brake assemblies are multiple carbon-carbon "floating disk" types, operated by a variable pressure, hydraulic system. The No. 3 utility hydraulic system supplies hydraulic power to the master braking cylinders. Depressing the toe pad on the rudder pedals (pilot or copilot) activates the brakes. For brake pressure over extended periods of time, the cable-operated parking brake is to be used.

2.3.7 Crashworthiness

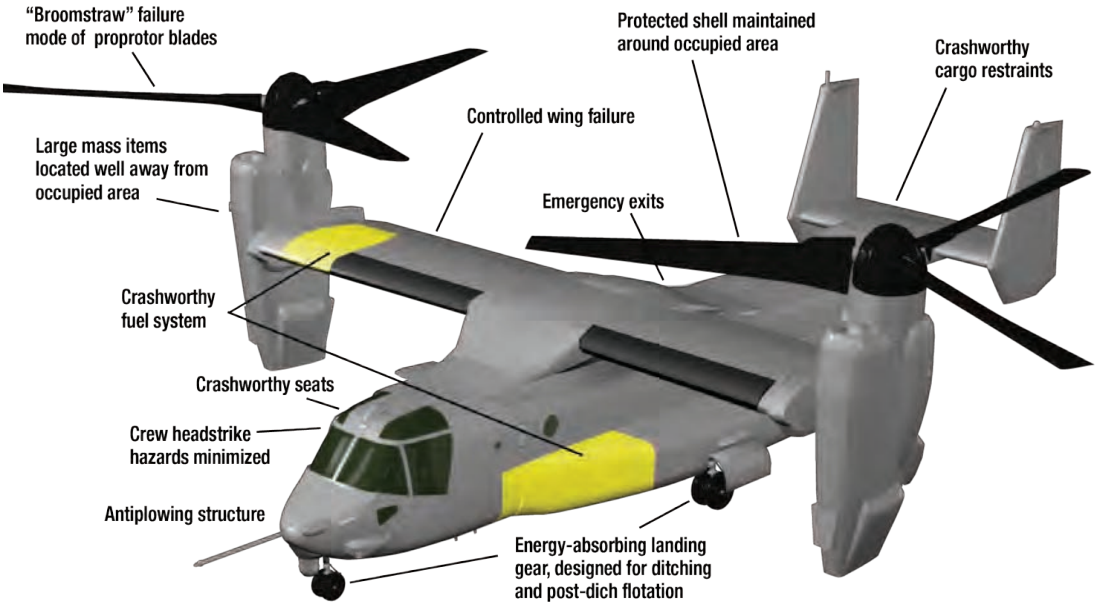
The V-22 incorporates numerous advanced and state-of-the-art crashworthiness features in the areas of structural design, load attenuation, passenger safety, payload retention, fire suppression, and emergency escape.

Items of standard crashworthiness equipment include:

- An automatic electronic and acoustic emergency locator beacons.
- A crash survivable memory unit, which provides for the recording of flight data.
- A cockpit designed to minimize head strike hazards.
- Cockpit and cabin crew seats are equipped with 5-point and 3-point restraining harnesses.

As optional equipment, Bell Boeing offers a tactical Emergency Locating Transponder (ELT). The tactical ELT has the capability of serving as a transponder for Search and Rescue Task Force (SARTF) situational awareness.

The V-22 has been designed for emergency water ditching, and subsequent flotation for emergency egress.



Crashworthiness Features

2.3.7.1 Structural Provisions

Inherent to all tiltrotor designs, the large mass items (e.g., the transmissions and engines) are located away from the occupied areas. In the event of a crash landing, the wing is designed to fail outboard of the fuselage attachment so that its mass shedding will diminish the crash's kinetic energy. Otherwise, this energy must be absorbed or dissipated by the landing gear and structure.

To reduce nose plowing in longitudinal impacts, a strong sled-like nose structure is provided with a canted anti-plow bulkhead. The forward fuselage is designed for impact forces of 4 g upward and 6 g rearward. A 24 ft/s (7.3 m/s) energy-absorbing landing gear system is provided to attenuate most of the energy in a hard landing.

The structure surrounding the occupied area is designed to be 15 percent stronger than the wing's failure load. Since normal landing loads from the wing must be carried through the cabin structure, this design provides inherent structural strength around the occupied area – in the event of a rollover or inverted impact. In a crash, the volume of the occupied cabin area decreases less than 15 percent.

Since composite strands fail individually, the rotor blades fray instead of disintegrating. This design inhibits blade shedding and allows for a progressive benign failure mode, which precludes the generation of debris in sizes that could pose a hazard to the aircraft's occupants.

All fuel is contained in crashworthy self-sealing fuel bags. All fuel lines are fitted with automatic fuel shut off valves which operate to prevent fuel leakage under crash conditions.

2.3.7.2 Passenger Safety

The cockpit and cabin seats are crashworthy and provide a vertical stroke capability to absorb energy. Each seat incorporates a restraint system to ensure the retention of a seated occupant, in the event of a crash. The cockpit environment has been carefully designed to preclude head strike hazards.

2.3.7.3 Payload Retention

Cargo restraints are designed into the V-22 structure to safely retain payloads in the event of a crash. The system has been designed so that crash induced cargo displacement should not impede egress through the emergency exits. Recessed floor tiedown fittings are intermittently provided throughout the cabin and ramp floors for flexibility in arranging appropriate payload retention devices. There are 22 fittings rated at 3,500 lb (1,588 kg) for use with traditional (unattenuated) tiedown devices (increased rating of 5,000 lb (2,268 kg) is available for use with load attenuated devices) and 18 fittings rated at 7,000 lb (3,175 kg) or 10,000 lb (4,536 kg) attenuated.

Ancillary equipment (carried within the portions of the aircraft that may be occupied), is restrained so that it cannot become dislodged during a survivable crash.

2.3.7.4 Fire Prevention

A crashworthy fuel system is used to prevent fuel spillage and post-crash fire. The system meets MIL-STD-1290 and includes suction feed, self-sealing breakaway valves, steel-overbraid high-elongation fuel-hoses, and a frangible attached vent system.

2.3.7.5 Emergency Escape

Emergency escape locations are provided in the cockpit with two pyrotechnically released (not ejected) side canopy windows for the pilot, copilot, and crew member/troop commander (seated on a fold-down crashworthy seat attached to the cockpit/cabin interconnecting door). These escape hatches may be actuated using inside and outside ejection control points.

The cabin side structure provides two pyrotechnically released panels on the cabin left side and one on the right side in the aft cabin. There is a manual emergency egress in the upper cabin entry door and an explosively-released escape hatch located overhead in the aft fuselage, which also serves as an emergency egress point. These hatches are all Class C emergency exits. The upper segment main cabin door is a Class C exit within a Class A door, which is used in the event of a jam.

All of the emergency exits permit evacuation of the flight crew within 30 seconds and all passengers within 60 seconds using half of the aircraft exits. The ramp may also be utilized for escape purposes by accessing the ramp control panel in the aft cabin, if the hydraulic systems are still functional.

The aircraft's emergency exits are shown below. The aircraft is also fitted with an Emergency Egress Lighting System (EELS).

Emergency Exit Locations

Emergency light assemblies are installed at each of the aircraft exit hatches. The assemblies are mounted on the top and sides of each of the five aircraft emergency exits. A manual arm/off switch is provided in the cockpit (on the lighting control panel) to arm the system for automatic activation with low rotor speeds.

2.3.7.6 Emergency Locating Beacons

The V-22 is designed for use with an underwater locator beacon for overwater operations, and can also be configured wih an Emergency Locater Transmitter (ELT).

- **Underwater Locator Beacon.** For emergency location assistance in the event of a forced landing at sea, a crashworthy 37.5 kHz underwater locator beacon has been incorporated into the aircraft's design. The beacon provides an audible signal with a 1- 2 mile underwater detection range in all directions for 30 days after water entry. The beacon will operate at depths of up to 20,000 ft.
- **Emergency Locator Transmitter (ELT).** For overland crash and/or emergency location assistance, an ELT system is available for the aircraft (sometimes called a Crash Position Indicator.) The standard ELT is a completely self-contained, battery-powered unit with an external aircraft antenna. The unit installation can be easily removed, if undesirable for certain missions, It is a small, lightweight, commercial ELT, FAA certified to TSO C91a, which supports an automatic beacon for use in crash events.

An upgraded ELT that includes operation with the COSPAS-SARSAT satellite system can also be incorporated into the aircraft. It would transmit a downed aircraft's Global Positioning System (GPS) position to the search and rescue command center using the COSPAS-SARSAT satellite system, and simultaneously transmit the aircraft's latitude /longitude position on the UHF Guard channel via a synthesized voice. The upgraded ELT would conform to TSO C126 (406 MHz digital.)

2.3.7.7 Ditching

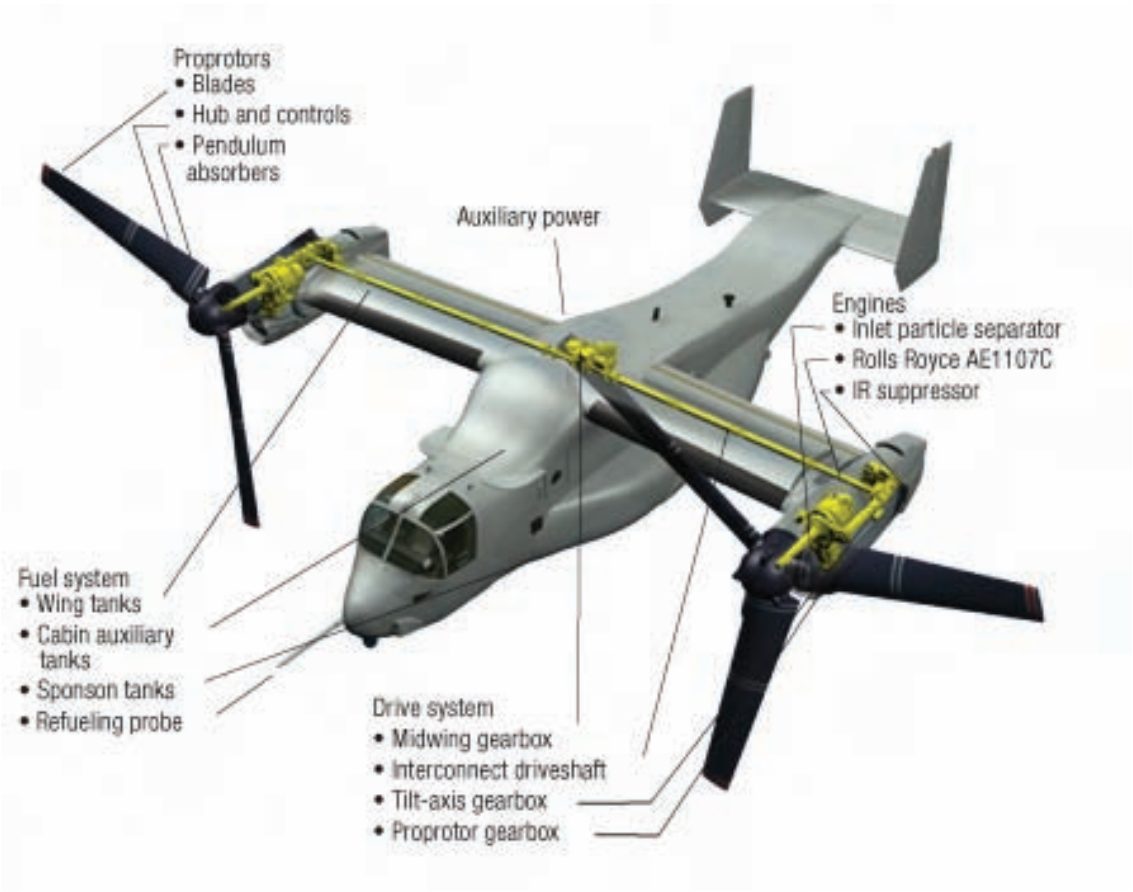
The ditching and flotation characteristics of the V-22 enhance its survivability.

Safe ditching is possible in conditions up to Sea State 2 – wave heights up to 2 ft (0.6 m) – at combined speeds up to 6 ft/s (1.8 m/s) sink and 30 knots forward. Docile ditching characteristics were demonstrated at these conditions in one-twelfth scale model tests. The tests examined all expected flare angles, all possible personnel door configurations (closed, opened, jettisoned), and landing gear both extended and retracted. The capability of the structure to withstand ditching loads was verified through analysis.

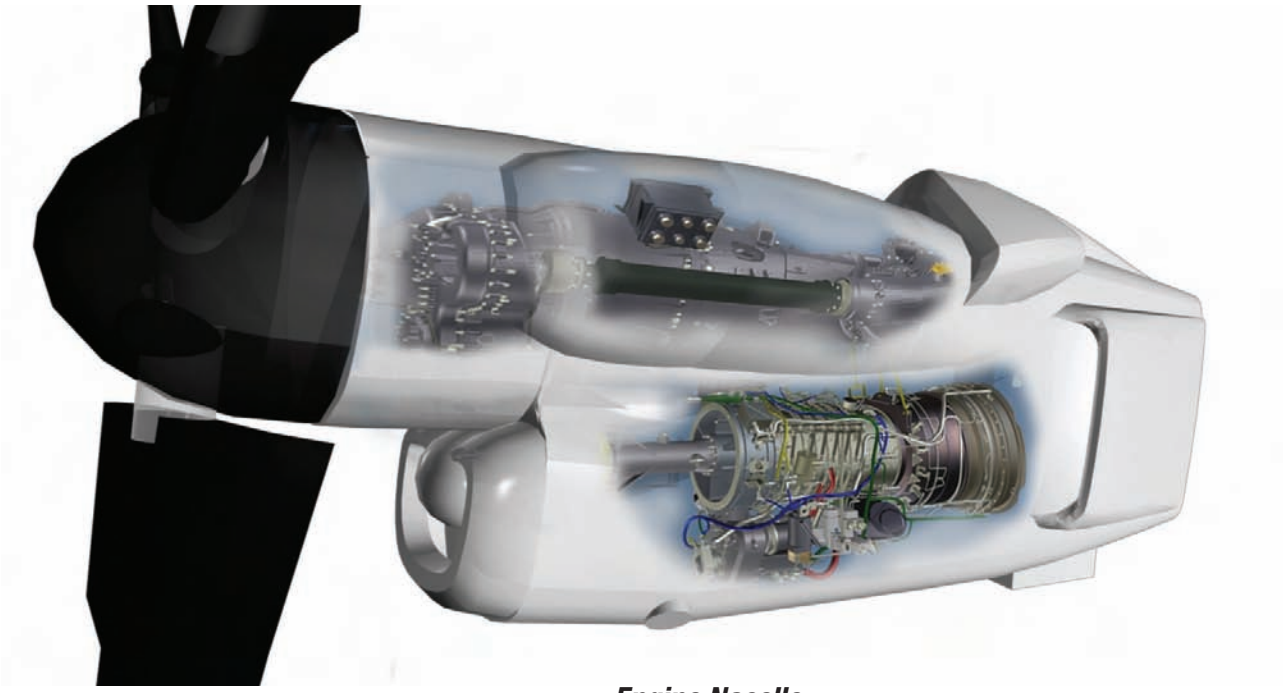
Flotation testing (also conducted with the one-twelfth scale model) demonstrated that inherent buoyancy compartments provide adequate time for emergency egress. Following a water landing, the aircraft can remain upright (with engines secured) for 10 minutes at Sea State 5 – wave heights from 8 to 12 ft (2.4 to 3.7 m) and wind speed of 28 to 40 knots. In Sea State 4, it is capable of remaining upright (with engines secured) for a two-hour period.

2.4 Propulsion System

The major components of the V-22 propulsion system are the engines, proprotors, drive system, auxiliary power unit, and fuel system, arranged as shown below.



Propulsion System Components



Engine Nacelle

2.4.1 Engines

Primary power for the aircraft is provided by two Rolls-Royce AE1107C Liberty engines. The engines, designed for low maintenance and consistent with the overall V-22 design, are located within the nacelles below the proprotor gearbox/pylon support. The compartment is formed by the forward, horizontal, and aft firewalls.

The AE1107C is based on a balanced blend of modern technology and features proven from more than 170 million hours of Rolls-Royce turboshaft/turboprop experience – in the 3,000 - 6,000 shp (2,237 - 4,474 kW) class of engines. The AE1107C is a free turbine, front drive, 6,150 shp (4,586 kW) axial-flow turboshaft engine incorporating high-efficiency components and reduced maintenance features. Its modern design offers a versatile core common to the AE 2100 turboprop and AE 3007 turbofan engines for regional, business jet, and military transport aircraft.

The AE1107C is a 6,000-shaft horsepower class, two spool, turboshaft gas turbine engine. Forward shaft power takeoff is accomplished by the mechanical coupling of a two-stage power turbine to the proprotor transmission system. The engine is equipped with an integral lubrication system that allows for vertical operations and provides regulated oil pressure, filtering, cooling, and dry sump scavenge. An accessory gearbox provides drivers for the fuel pump, starter, vent air de-oiler, and an oil pump.

The AE1107C provides the V-22 with advanced technology features that include all-axial high efficiency turbo-machinery components, only four main rotor bearings, positive sump scavenging, modular construction, and dual-independent Full-Authority Digital-Engine Controls (FADECs).

The ignition system is a dual capacitor discharge type. It provides voltage from start-up speeds throughout the operating range. It is controlled by relay command from the FADEC.

The V-22's engine inlet and exhaust losses are approximately 6 percent of its uninstalled performance. The table below provides nominal engine characteristics. Actual engine characteristics should be requested from Rolls-Royce.

Performance (Sea Level/Standard Day)				
Weight, dry	972.9 lb			441.2 kg
Power/weight ratio	6.3:1 shp/lb			10.4 kw/kg
Airflow	35.5 lb/sec			16.1 kg/sec
Pressure ratio		16.6:1		
Output shaft speed at 100%		15,000 rpm		
Fuels		JP-5/JP-8		
Oils		MIL-L-7808 or 23699		
Overall dimensions	77.9 in long			197.9 cm
	28.8 in wide			73.2 cm
	34.9 in high			88.6 cm
All attitude, continuous operations	Pitch +115, -45			Roll +/-20

	Power		Fuel consumption	
	shp	kW	lb/shp-h	kg/kW-h
Maximum Rating	6,150	4,586	0.42	0.26
OEI	6,830	5,093		

Engine Specifications

2.4.1.1 Engine Description

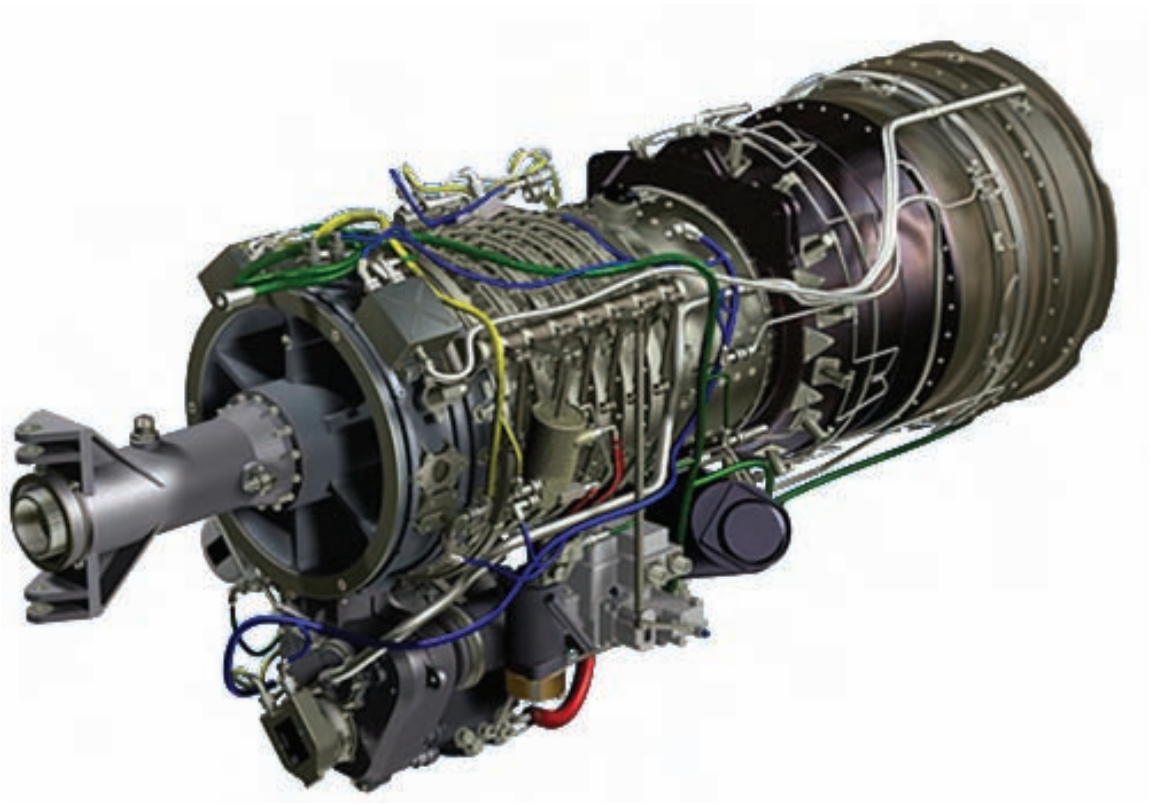
Thermodynamically, the AE1107C is capable of producing nearly 7,000 shp (5,220 kW). However, it has been "derated" for use in the V-22. The engine's maximum rating during normal operations is 6,150 shp (4,586 kW). Its emergency, OEI, rating is 6,830 shp (5,093 kW).

The engine's modular design features the following components: high-pressure compressor, diffuser/combustor, high-pressure turbine, low-pressure turbine, accessory gearbox, and electronic control system. The engine lubrication and electrical systems are self-contained.

- High-Pressure Compressor: The AE1107C compressor is a high-efficiency, long-life, 14-stage, axial flow. The design produces 16.6:1 pressure ratio at 35.5 lb/s (16.1 kg/s) airflow. It incorporates variable geometry vanes at the inlet guide vane through the fifth stage. Using variable setting vanes optimizes both starting and operating performance.
- Diffuser/Combustor: The diffuser/combustor section provides efficient airflow management from the compressor exit to the turbine inlet. The diffuser is a major structural component of the engine and connects the compressor to the turbine. Externally, the diffuser has cast lugs that serve as the rear engine mount. The combustor is an annular, effusion-cooled design with 16 air-blast fuel nozzles and two igniters. It has successfully demonstrated Rolls-Royce's stringent goals for efficiency, operability, and low emissions.
- High-Pressure Turbine: The two-stage high pressure turbine includes air-cooled first-stage vanes and blades, an uncooled second-stage vane, and solid second-stage blade. The first-

stage blade is unshrouded and incorporates an abrasive tip design. All blades and vanes are of single crystal material for enhanced durability. Brush-type inter-stage seals are used to significantly reduce the amount of coolant air required for purging turbine cavities. These seals are superior in regulating seal leakage air during transient operation.

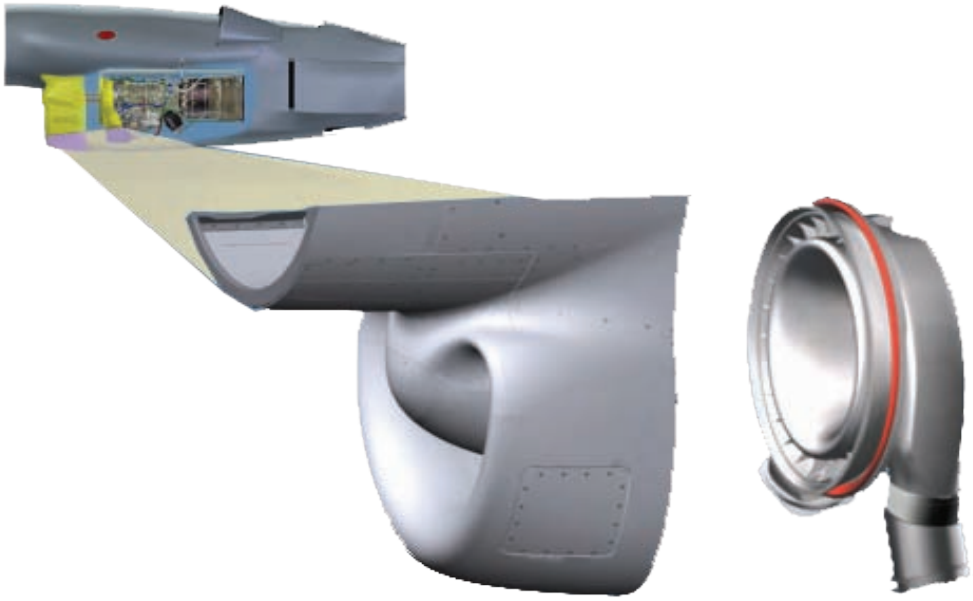
- Low-Pressure Turbine. The low-pressure turbine includes two stages of uncooled vanes and blades. The first vane accommodates features for measuring gas temperature with thermocouples located inside the vane airfoils. Both stages are shrouded. The low-pressure turbine shafting arrangement eliminates the need for any inter-shaft bearings. The forward shaft drives a torque-meter assembly that is directly coupled to the aircraft's proprotor gearbox via a gimbal mount. The torque tube housing serves as the front engine mount.



Rolls Royce AE1107C Engine

2.4.1.2 Air Induction

The V-22 engine inlet is designed using advanced computational fluid dynamic techniques to provide low losses and low inlet distortion. The inlet design satisfies the rigorous performance goals needed for maximum engine performance in both hover and cruise flight modes.



Engine Inlet Shroud

The inlet is specially designed to eliminate Foreign Object Damage (FOD) particulates from the inlet air stream. The inlet incorporates an integral, self-cleaning Engine Air-Particle Separator (EAPS) capable of removing 90 percent of particles 100 microns or larger and 75 percent of particles between 20 to 100 microns in size.

To reduce inventory, the inlets are designed with a maximum number of interchangeable parts. Parts are easily mated with the assistance of shear pins and are locked in place with panel fasteners and adjustable latches, which provide a visual indication of a secure installation.

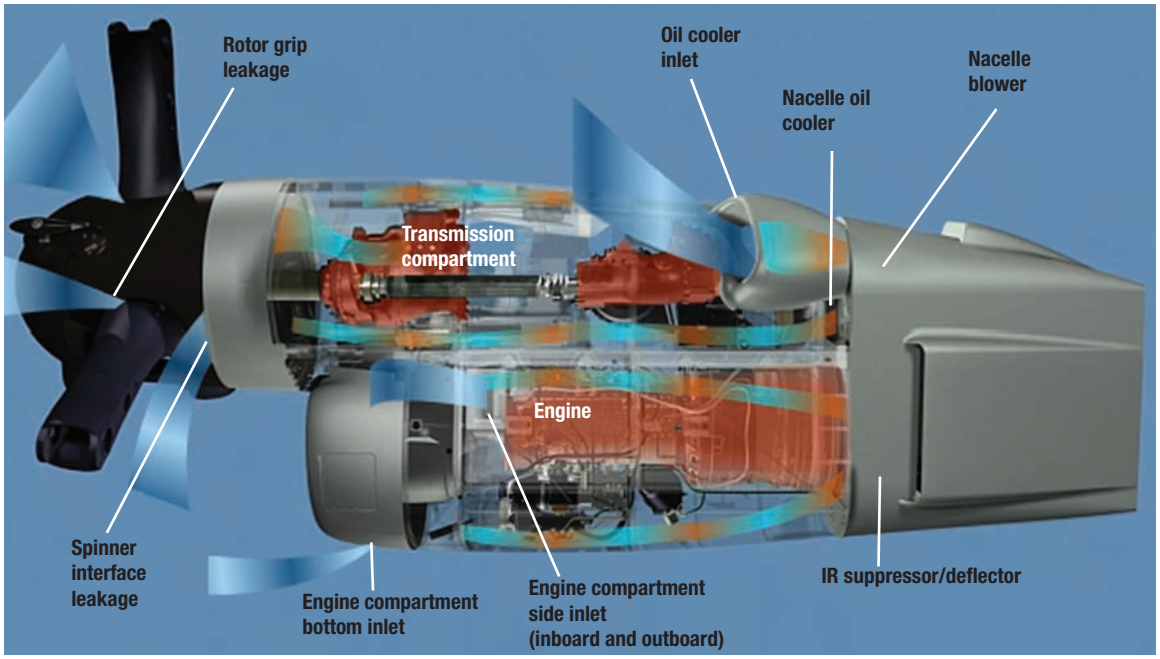
A center strut drains any trapped fluids that collect in the inlet center-body from the drive system components above. The system drains by gravity in airplane mode and with the help of scuppers in helicopter mode.

For maximum safety in icing conditions, the entire air flow path is heated, including the EAPS and drainage strut.

2.4.1.3 Exhaust and Engine Cooling

The nacelle air management system is designed to:

- Provide cooling of nacelle heat sources (engine, proprotor gearbox, tilt-axis gearbox, hydraulic system, electrical components, etc.) and lubricating fluids;
- Suppress nacelle infrared signatures; and
- Redirect engine exhaust.



Nacelle Air Management System

System components include: the shaft-driven transmission compartment blower, the nacelle heat exchanger, and the infrared suppressor (which incorporates the Coanda exhaust deflector).

The nacelle cooling system is designed to vent all the combustible vapors, maintain internal temperatures, and cool the aircraft structure, engine components, and accessories. Cooling of the upper compartment components/fluids is accomplished using heat exchangers located in the aft-end of the transmission compartment (forward of the nacelle blower). Cooling air is drawn in through a single intake forward of the heat exchanger. Flow is induced by blowers and by the negative pressures created by the IR suppressor (ejector effect).

Cooling airflow to the lower compartment is induced by the negative pressures in the engine exhaust gas flow through an ejector in the IR suppressor. This negative pressure is further enhanced by the recoverable ram air-pressure in forward flight. Air is brought in through three inlets in the lower compartment panels. Inlet positions were selected to provide uniform flows while operating, as well as adequate venting during post-shutdown – with the nacelles in the (vertical) helicopter mode.

Deflectors are installed on each nacelle to redirect exhaust gases clear of personnel, airframe structure, and accessory intakes during ground operations. Engine bleed air is ducted to two nozzles mounted on the side walls of the exhaust duct. The inboard nozzle injects air outboard across the exhaust path. The outboard nozzle uses the Coanda effect to also draw air outboard, away from the aircraft. This outboard flow is further entrained by an external slot structure directly outboard. Depending on flow conditions, the deflector can turn the engine exhaust up to 40º outboard.

2.4.1.4 Thrust/Power Management System

The Thrust/Power Management System (TPMS) couples the Flight Control System (FCS) and the engine control system. Each engine is controlled by either of two FADECs. The selected FADEC is in command; however, the standby FADEC makes concurrent control logic calculations and is ready to instantaneously assume command via FADEC-in-control-handoff due to self-diagnostic malfunction or pilot command through the select switch. The remaining unit provides system redundancy. The commands from the FADEC to provide required engine power are accomplished by controlling engine compressor geometry and fuel flow. The fuel flow follows the FADEC schedules by a stepper motor metering unit and compressor inlet variable geometry is changed with fuel pressure supplied by a fuel pump.

The FCS sends a Power Demand Signal (PDS) to the FADEC. The PDS emanates from the pilots Thrust Control Lever (TCL). Under normal flight conditions the PDS is scheduled to provide torque limiting up to the transmission ratings. For One Engine Inoperative (OEI), the PDS will command the FADEC to provide maximum allowable power from the remaining engine. This is equivalent to 107.5% engine torque and approximately 65% rotor torque.

2.4.1.5 Electronic Control System

The engine control system consists of:

- Dual-redundant full-authority digital engine controls (FADEC),
- An integrated fuel pump and metering unit, and
- Redundant sensors and actuators.

The system provides:

- Closed-loop control of fuel flow and compressor variable geometry,
- Automatic control of ignition, and
- Manual control of engine anti-ice.

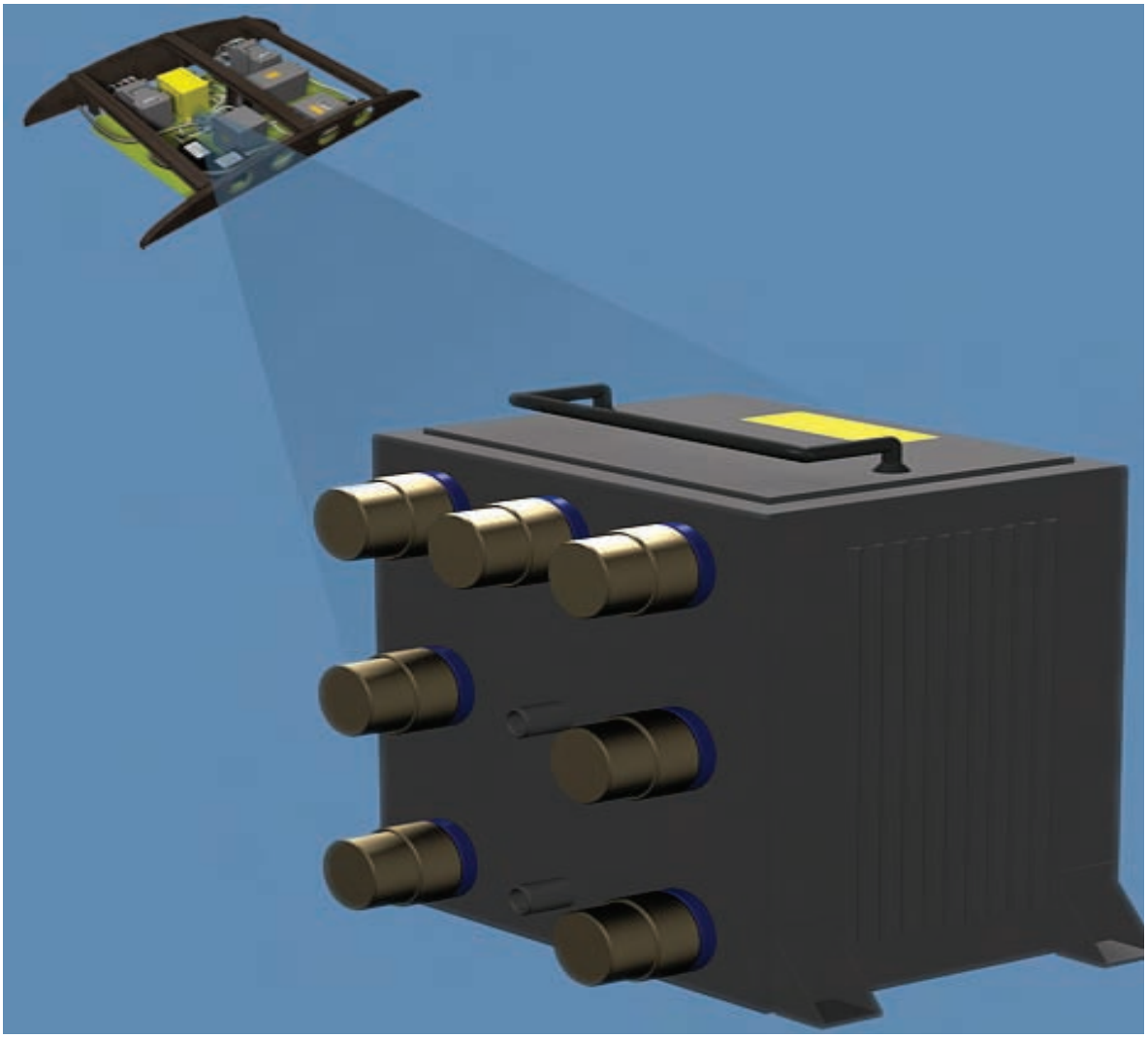
The system also incorporates extensive levels of fault detection capability, which are used to manage any system failures. The FADECs receive electrical power from an engine-mounted permanent-magnet alternator with backup power from the aircraft. The FADEC interface with the aircraft is via a MIL-STD-1553B data bus.

2.4.1.6 Engine Monitoring System

The Engine Monitoring System (EMS) is a part of the VSLED airborne unit that provides both engine and aircraft systems operational monitoring. The VSLED airborne unit interfaces directly with the aircraft mission computers and contributes functionally to the Central Integrated Checkout (CIC).

The on-board EMS provides a continuous assessment of engine operation to include:

- Limit exceedance and Line Replaceable Unit (LRU) fault detection,
- Engine performance evaluation, and
- Component life usage measurement.



VSLED Airborne Unit

To perform these functions, engine sensor inputs (oil pressure, temperature and level; compressor discharge temperature and pressure; engine vibration, and engine ignition system parameters) are monitored in addition to the engine FADEC parameters (rotor speed, measured gas temperature, torque, faults, etc.) made available by the mission computers. The resultant data storage provided by the on-board EMS is transferred via a removable cartridge for subsequent ground based processing by the Aircraft Maintenance Event Ground Station (AMEGS). This system provides the basis for an on-condition maintenance program.

2.4.1.7 Maintenance Features

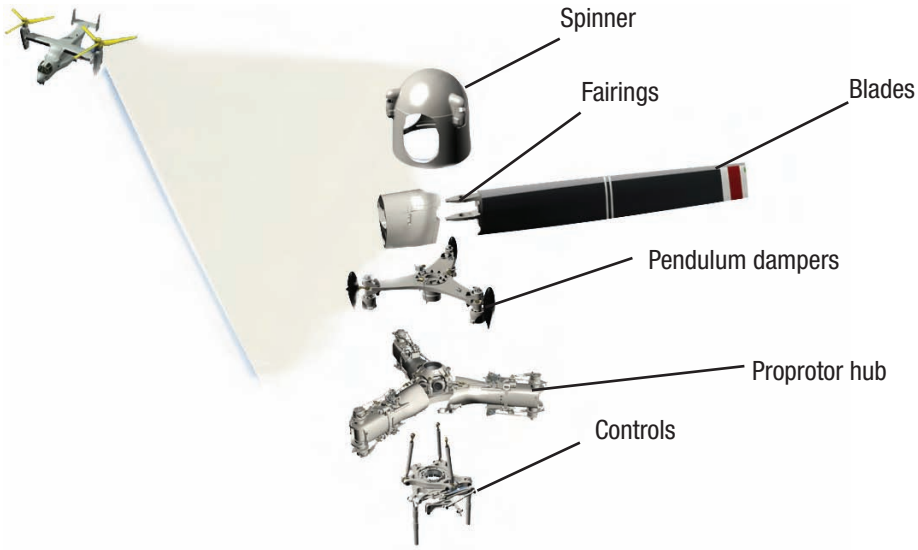
The maintainability characteristics designed into the AE1107C allow it to meet aggressive readiness goals and to reduce operating cost. Several design features provide for ease of maintenance. Some examples include:

- System component mounting with “V” band clamps.
- Plumbing connections of different sizes to reduce maintenance error.
- Quick-disconnect electrical connections.
- Oil filters that are easily accessible from the bottom of the engine.
- Identical pressure and scavenge oil filter elements.
- Self-locking nuts (in place of “Safety Wiring”) for quicker and safer maintenance and less risk of engine FOD.
- Multiple magnetic plugs to fault-isolate debris by engine section.
- Borescope ports for access to each compressor stage, the combustor, and the turbine.
- Access for radioisotope inspection.
- The engine gas generator may be rotated with common hand tools.
- Engine diagnostics and trending reduce corrective maintenance effort and improve availability.
- Automated engine life management based on actual component usage.
- Modular construction.
- Standard lubrication fluids.

2.4.2 Proprotors

The V-22 is equipped with two counter-rotating, 3-bladed proprotors. The proprotor system is a semi-rigid, underslung, gimbaled rotor system. The rotor hub provides flapping and feathering motions, and transmits blade forces to the aircraft structure.

The rotors have cyclic and collective pitch for aircraft control. A constant speed drive-coupling transmits torque from the mast to the rotor yoke. The coupling also provides flapping freedom and transmits rotor thrust forces. Pitch change bearings transmit centrifugal and blade bending forces, and accommodate pitch change motions.

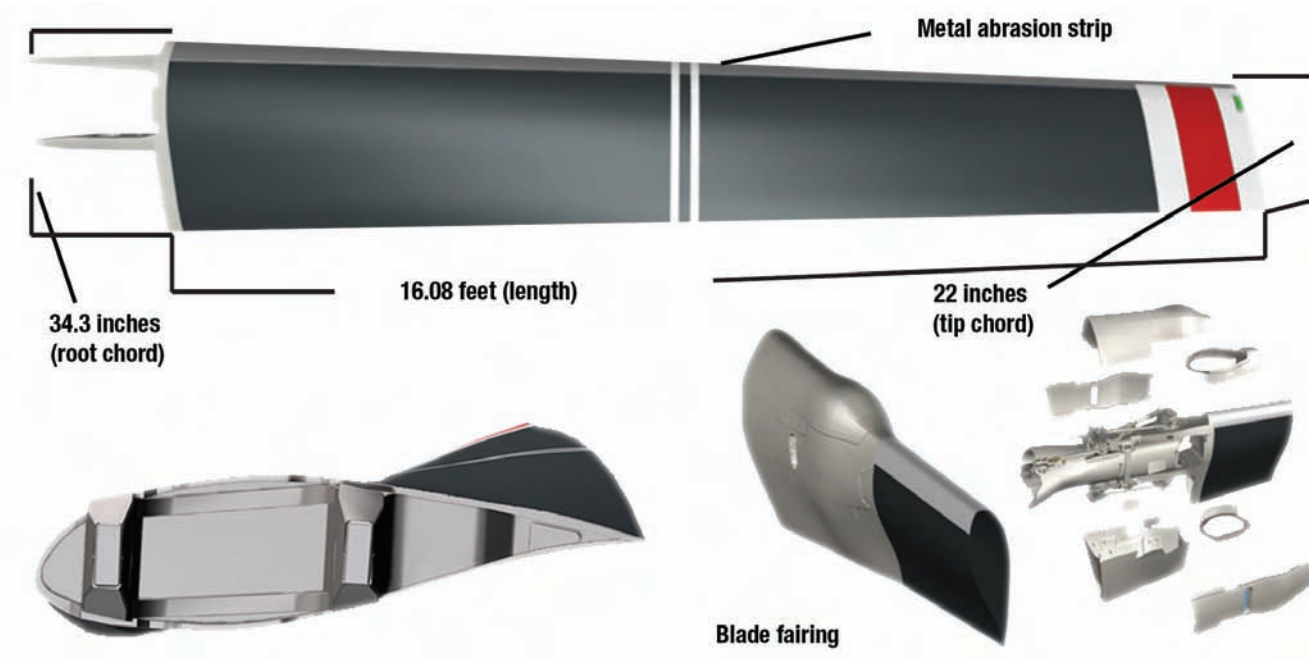


Proprotor Components

2.4.2.1 Proprotor Blades

The proprotor blades are constructed primarily of composite materials. A metallic, leading edge abrasion strip is provided to protect the spar from erosion. A deice blanket is bonded between the abrasion strip and the spar. Each proprotor blade weighs 191 lb (86.6 kg) and has a 42° twist from root to tip.

The blades are attached to the hub yoke by grip assemblies, which transmit all blade forces (shear, centrifugal force, lead/lag/coning) to the hub. The assembly allows feathering movement of the blades for changing the blade angle of attack.

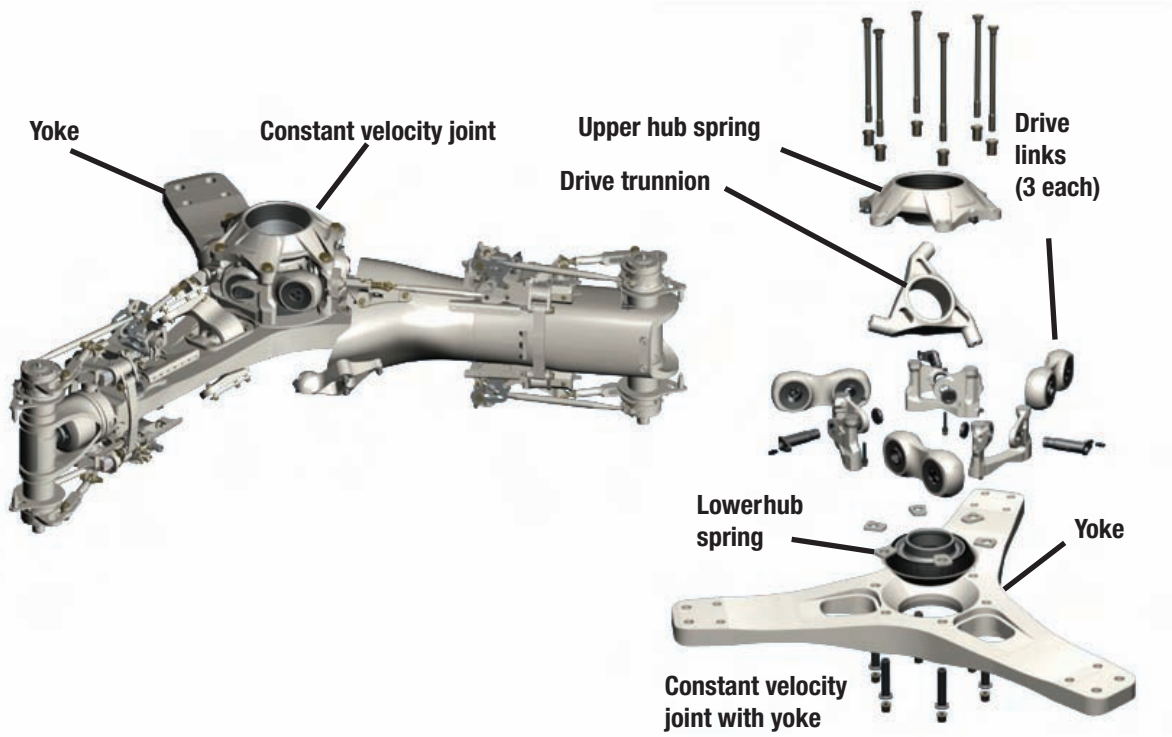


Proprotor Blades

2.4.2.2 Proprotor Hub

The proprotor hub assembly transmits the drive torque to the proprotor system at a uniform rotational velocity. It is constructed primarily of composite material with elastomeric bearings that require no lubrication. The proprotor hub assembly is attached to the splined proprotor mast/shaft. An aerodynamic spinner protects the hub assembly.

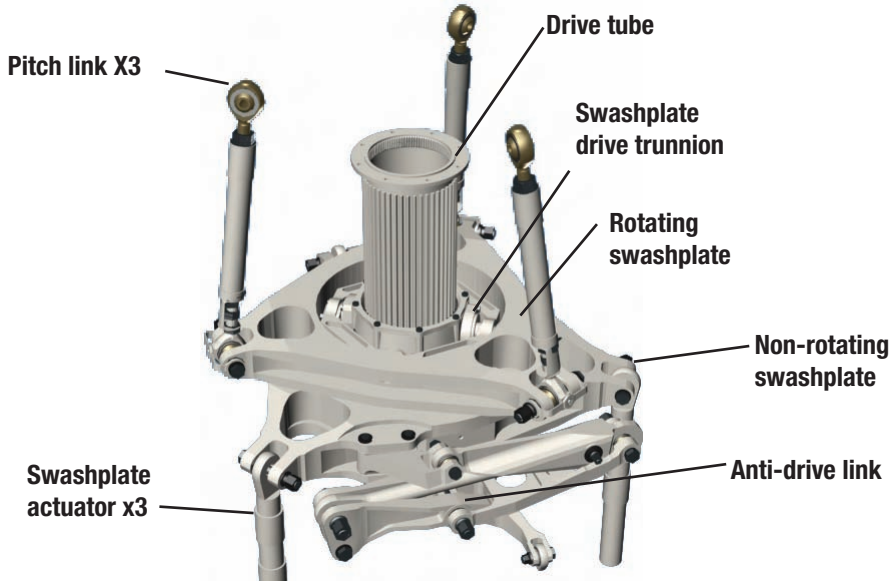
A blade fold mechanism is attached to the blade grip just inboard of the main attachment for the blade. The hub is made largely of composite materials for reduced weight and improved damage tolerance. Metal parts are corrosion-resistant.



Proprotor Hub Components

2.4.2.3 Proprotor Controls

The proprotor system responds to cyclic, directional, and thrust lever inputs in helicopter and conversion modes. It provides thrust inputs alone in airplane mode. Rotating controls transmit motion from the nonrotating hydraulic actuators to the rotor blades.



The proprotor controls consist of a swashplate, swashplate drive, and pitch links. The controls are of metallic construction, primarily aluminum. Except for the rotating swashplate, the control system bearings require no lubrication.

The swashplate consists of a rotating and a nonrotating ring. The swashplate rotating ring is driven by a sliding spline and attached to the mast through a gimbal drive. Attaching linkage to the proprotor gearbox case prevents rotation of the fixed ring.

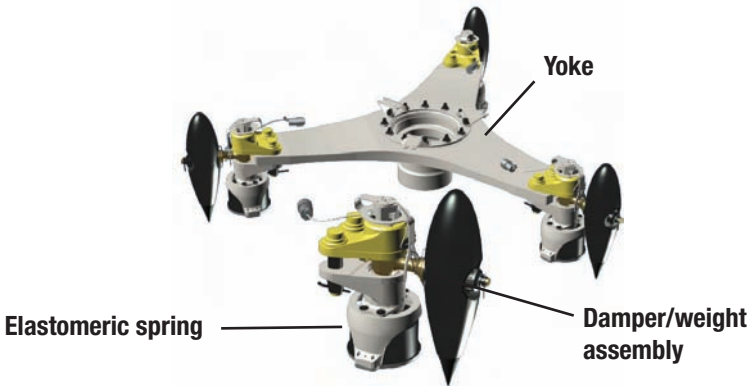
2.4.2.4 Rotor Brake

The rotor brake is installed on the midwing gearbox (MWGB). It is an electrically controlled, hydraulically operated unit. A two-position rotor-brake handle, located on the engine control panel in the cockpit, controls the rotor brake.

The rotor brake is designed to provide normal stops with engines off, from rotor speeds of 40% of nominal rpm to full stop in 12 seconds. In the event of an emergency, the rotor brake can stop the rotors from 100% of nominal rpm in 20 seconds. Mechanical interlocks prevent application of the rotor brake unless both engine control levers are in the OFF position. When the brake is applied, the engine control levers are limited from movement past the CRANK position.

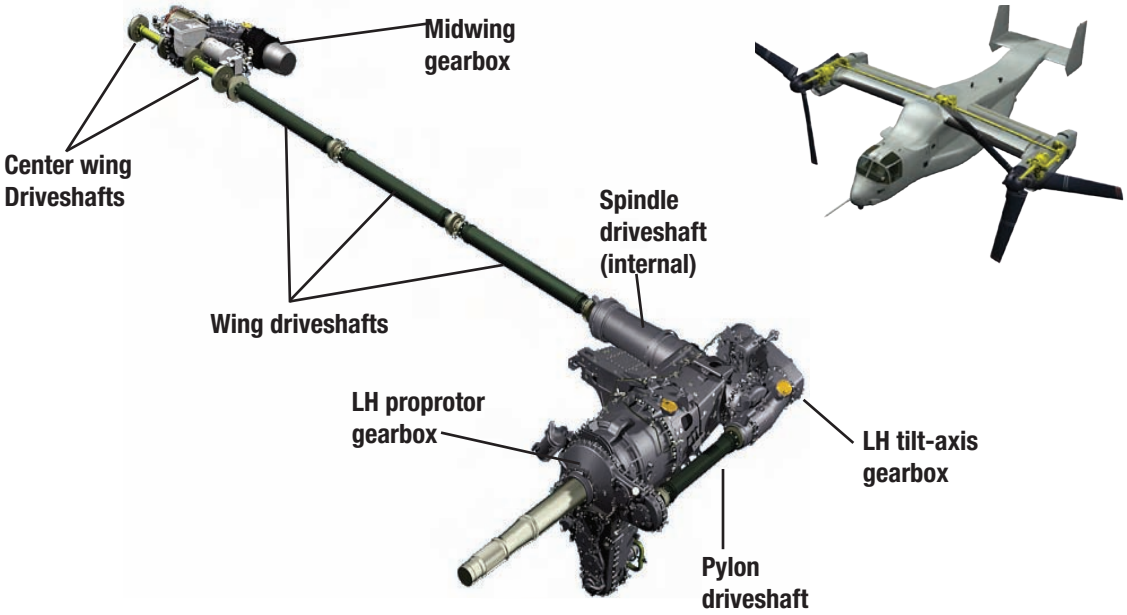
2.4.2.5 Pendulum Dampers and Absorbers

Vibration reduction is enhanced by the installation of pendulum absorbers on the proprotor hubs to counter rotor system vibratory loads. There are three pendulum damper/absorbers mounted in the spinner on each proprotor hub.



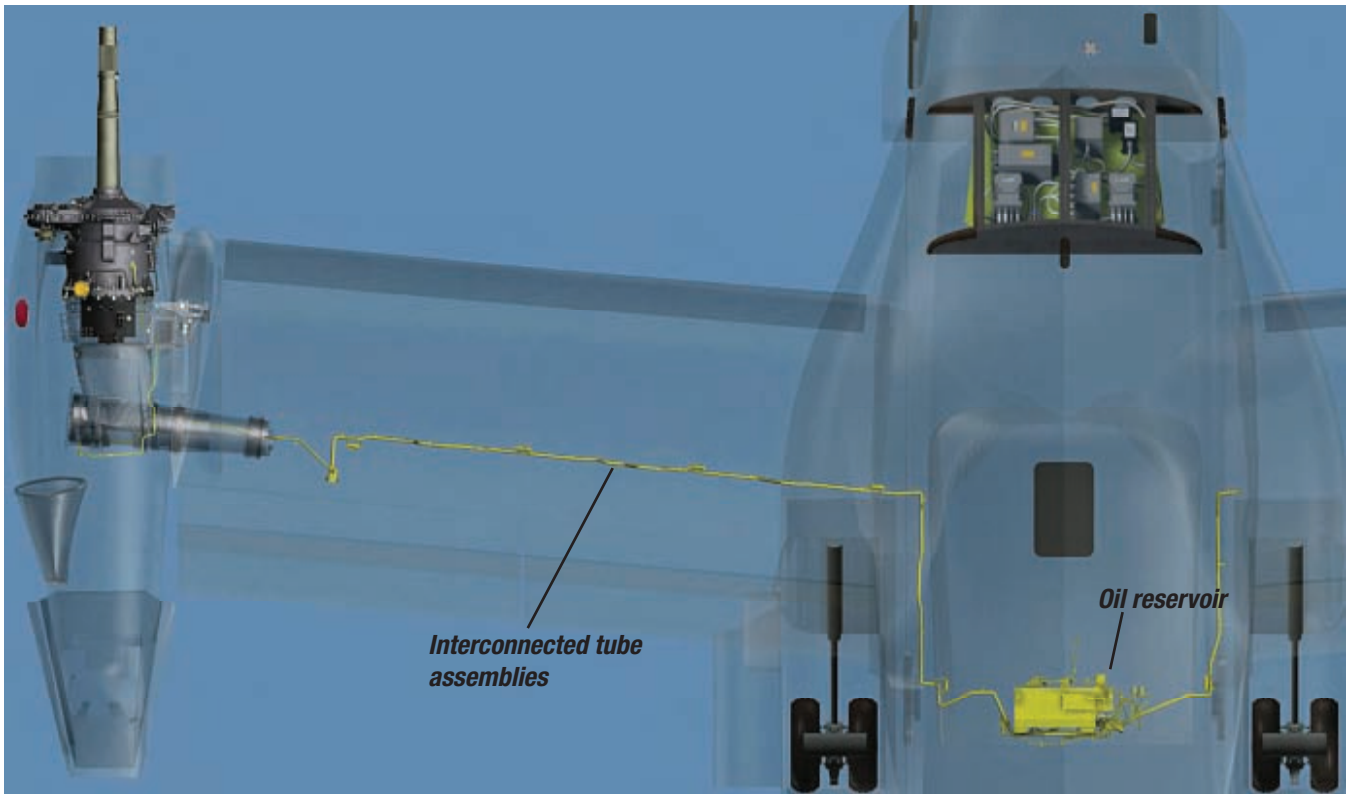
2.4.3 Drive System

The V-22 drive system consists of transmissions, interconnecting shafts, and associated couplings and supports. The drive system transmits torque from the engines to the proprotors and to the gearbox mounted accessories. Additionally, the drive system provides rotor synchronization and power distribution from both engines, or from a single engine.



Drive System Components

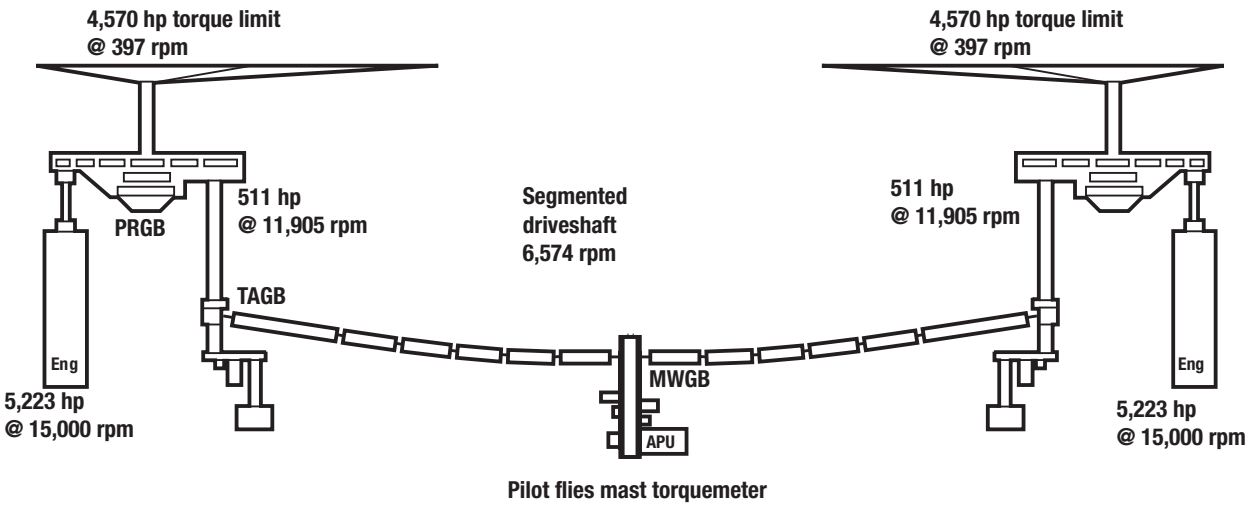
The engines and engine transmissions are enclosed in nacelles. The nacelles are attached to conversion spindles. The conversion spindles are rotated between vertical and horizontal positions using double ball-screw actuators. A triple-redundant hydraulic system and triple-redundant hydraulic motors drive the actuators.



Emergency Lubrication System

The driveshaft system assemblies include low maintenance, lubrication free, flexible couplings. These couplings have been designed with an on-condition removal criteria. The transmissions have an emergency lubrication system, which provides 30 minutes of flight at cruise power following the loss of primary lubrication.

Under normal twin engine operations, only a small amount of power is transferred through the interconnect driveshaft to drive components on the MWGB. This design condition is shown schematically in the following figure.

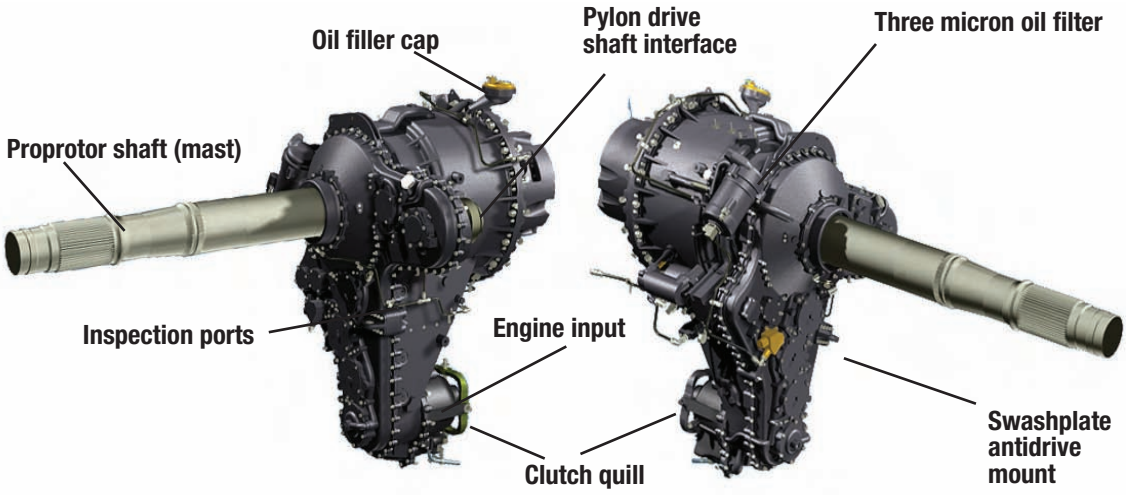


Normal Operation Drive System Design Condition

During single engine operations, power is distributed from the remaining engine to both proprotors through the interconnect driveshaft.

2.4.3.1 Proprotor Gearbox

The proprotor gearbox (PRGB) provides power transfer from the engines to the proprotor shaft and to the nacelle-mounted drive shafting. It also provides a speed reduction through three gear stages from the normal engine output of 15,000 rpm to the proprotor shaft speed of 397 rpm. The PRGB provides the forward mounting of the engine.

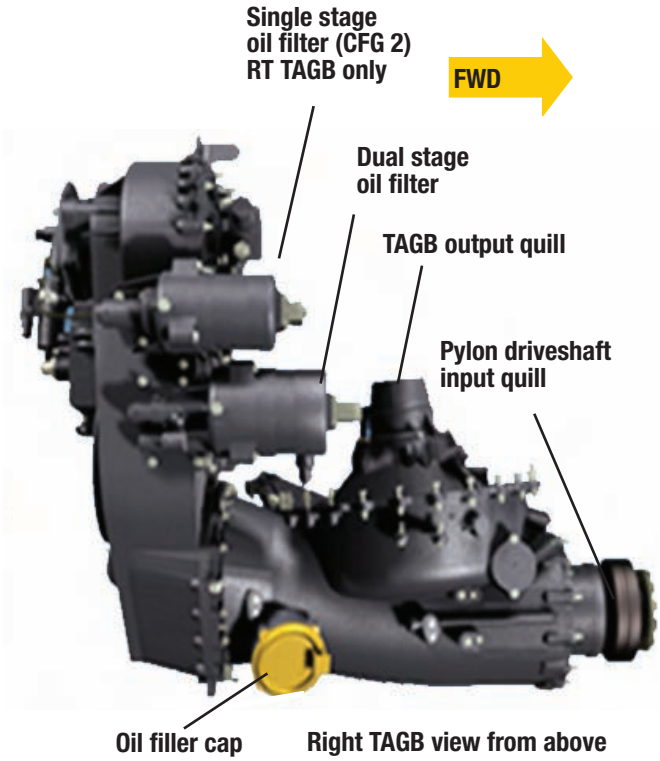


Proprotor Gearbox

An overrunning clutch transmits engine-torque during normal operation. It permits overrunning during single engine operation, autorotation, or if the engine speeds are not matched. An extra idler gear in the left PRGB first-stage gear-train provides counterclockwise rotation of the left proprotor.

2.4.3.2 Tilt-Axis Gearbox

The tilt-axis gearbox (TAGB) consists of a bevel section assembly and an accessory section assembly. It is mounted on the outboard end of the pylon-support spindle structure, located in the nacelles. These gearboxes interconnect the wing cross shafting with the nacelle shafting.

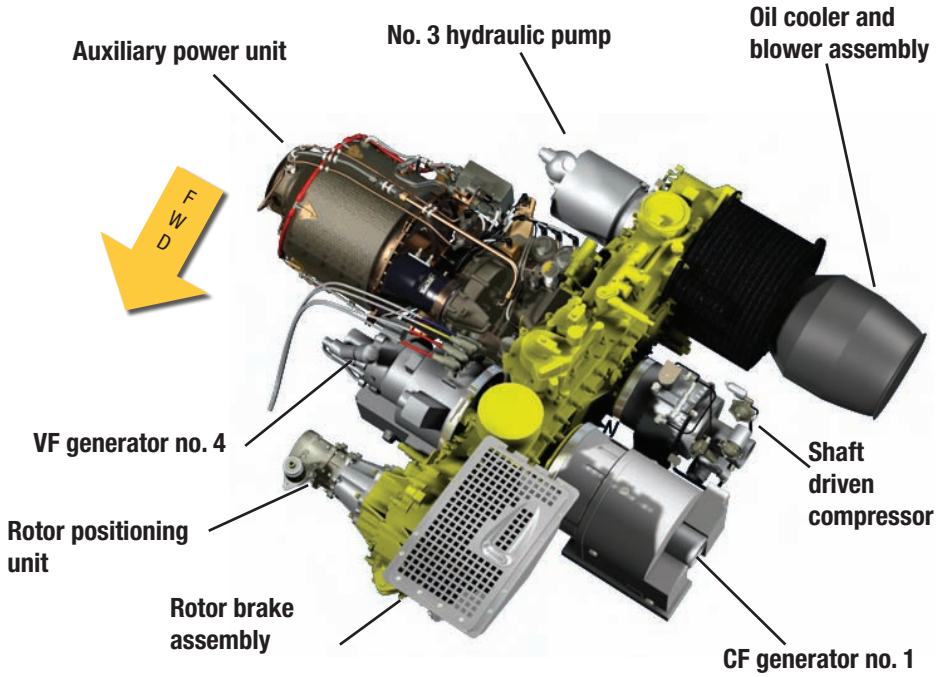


Tilt-Axis Gearbox

The bevel section consists of the main housing, a bevel pinion quill assembly, and a spiral bevel gear assembly. The accessory section mounts on the bevel section assembly, which contains seven simply supported spur gears that drive the various accessories.

2.4.3.3 Midwing Gearbox

The midwing gearbox (MWGB) is located in the fuselage and is geared to the interconnecting driveshaft. The gearbox is fitted with the speed sensors, lube pump, dipstick, drain port, and a sight glass. It also provides a mounting location for several accesories. Input power to the accessories may come from the interconnecting driveshaft or the auxiliary power unit (APU). An overunning clutch is provided on both the APU and interconnecting shaft. This allows the APU to drive the accessories with the engines off and to automatically disengage as the rotors reach 84% speed and the interconnecting shafts take over.



Midwing Gearbox (MWGB)

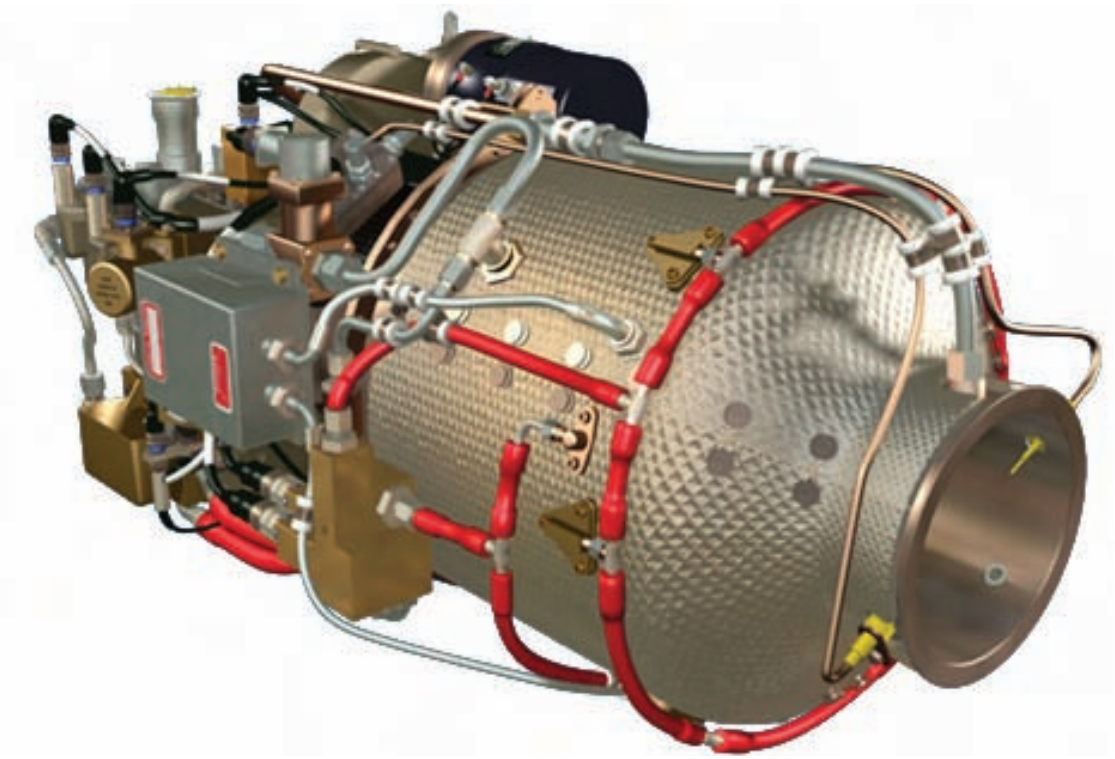
The APU clutch (disengaged for starting the APU) is a multiple-disc type and is hydraulically actuated by the APU lube system. The gearbox is the primary mount point for the APU. The APU is cantilevered from the gearbox by a mount flange on the APU forward face. There is an additional strut support between the rear of the APU and the aft wing spar.

The MWGB drives a number of system accessories (e.g., electrical generators) and drives the Shaft Driven Compressor (SDC) that is used as a part of the aircraft Environmental Control System (ECS).

2.4.3.4 Interconnecting Driveshaft (ICDS)

The interconnecting driveshaft (ICDS), shown previously, is positioned aft of the rear wing spar and is geared to the TAGB and MWGB. Under normal operations, the driveshaft carries a minimum amount of power to the MWGB accessories. During single-engine operations, it is designed to transmit power to both proprotors from the remaining engine.

2.4.4 Auxiliary Power



Auxiliary Power Unit (APU)

The auxiliary power unit (APU) is mounted on the MWGB. Through the MWGB, the APU drives constant frequency generator No. 1, hydraulic pump No. 3, and the Shaft Driven Compressor (SDC). These supply electrical, hydraulic, and pneumatic power for ground checkout, main engine starting, and proprotor fold/wing stow. The APU also drives the MWGB oil pump and oil cooler blower.

The APU is composed of a power section, speed reduction gearbox with an integral clutch, lubrication system, fuel system, air intake system, exhaust system, and controls. The APU is rated at 225 shaft horsepower on a sea level 125°F (52°C) day.

The power section is a single-shaft (constant speed device) consisting of a compressor, combustion section, and turbine. Containment features are provided for compressor or turbine rotor blade containment.

The APU lubrication system is a self-contained integral system that provides cooling and lubrication. The internal system includes a reservoir, pressure pump, full flow filter, and pressure-regulating valve.

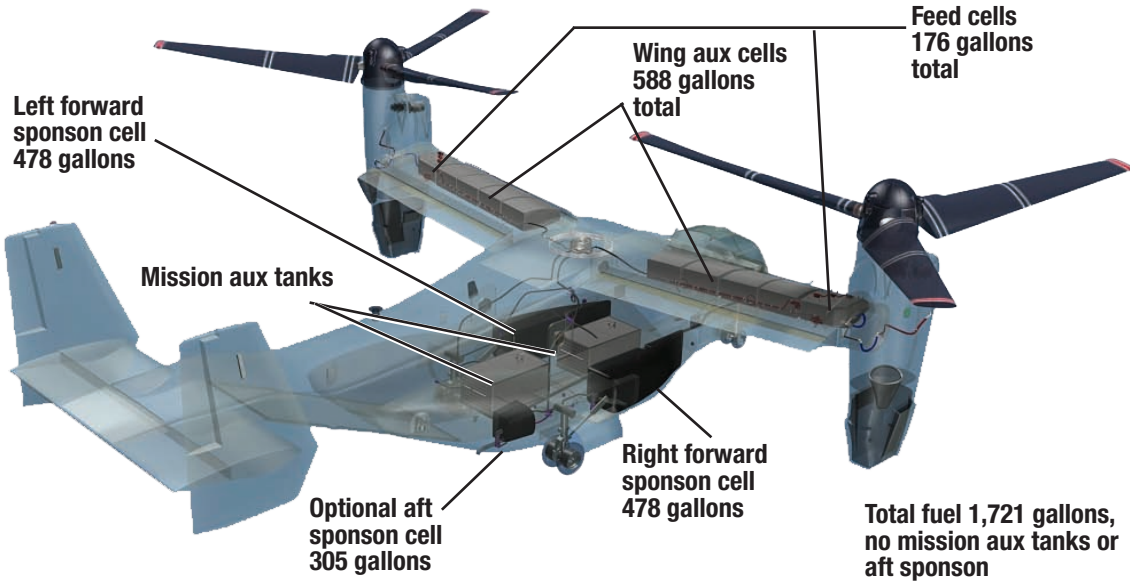
The APU fuel system is composed primarily of the fuel control and fuel nozzles. The system is compatible with aircraft fuels. In conjunction with the electronic control unit, it provides an automatic fault shutdown. To provide an environment more compatible with electronic equipment, the electronic control unit is mounted outside the APU compartment.

The APU starter is DC electric and is provided as part of the APU build-up. Fuel is supplied from the right-wing feed tank to the APU.

APU Starter Control

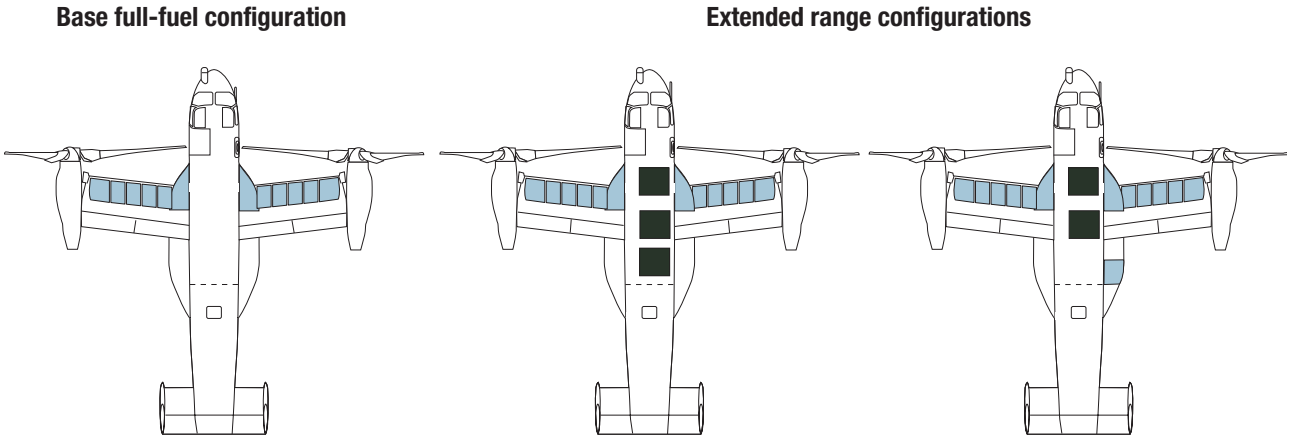
2.4.5 Fuel Management

The fuel system is integrated into the wing and fuselage systems. The basic configuration consists of twelve tanks: an engine feed tank located in the outboard section of each wing, four auxiliary tanks located in each wing, and sponson tanks located in the left and right forward sponsons. An optional tank is available in the aft right sponson.



Basic Fuel Configuration

For extended range operations, up to three Mission Auxiliary Tanks (MATs) can be used in the cabin, or two MATs in the cabin and the optional aft sponson tank. Electrical, plumbing, and vent connections are provided for the installation of up to three internal cabin tanks.



The V-22 can self-deploy anywhere in the world in less than two days. Thus, the need for additional strategic lift assets is eliminated. It can be configured for self-deployment in less than six hours and may be directly deployed into combat zones.

A Rapid Ground Refuel (RGR) kit provides for Forward Area Refueling Point (FARP) to ground refuel helicopters, ground vehicles, and other V-22s. This refueling capability further reduces the need for strategic assets.

The fuel distribution system consists of the engine feed system and the APU feed system. The left and right feed tanks supply engine fuel. Fuel is supplied to the APU from the right feed tank. All other tanks transfer fuel to the feed tanks. Fuel can be cross-fed between the feed tanks. Fuel transfer operations are automatic, although the pilot can control some functions.

The fuselage fuel system provides pressure refueling from a sponson-mounted pressure refueling adapter. Gravity refueling is done from a port on the left forward sponson. Auxiliary fuel can be provided in the right sponson and in the cabin (using the mission auxiliary tanks for long-range missions). The following is a summary of the V-22 fuel system capacities.

Configuration	Maximum Number of Tank	Usable Fuel per Tank		Fuel Weight per Tank	
		(gal)	(liters)	(lb)	(kg)
Wing feed tanks	2	88	334	600	272
Fwd sponson	2	478	1,809	3,250	1,474
Wing tanks	8	74	278	500	227
Total - Standard	All Tanks	1,721	6,513	11,700	5,307
Mission auxiliary tanks	up to 3	430	1,628	2,924	1,326
Right aft sponson	1	305	1,155	2,075	941

Fuel System Capacities (JP-5)

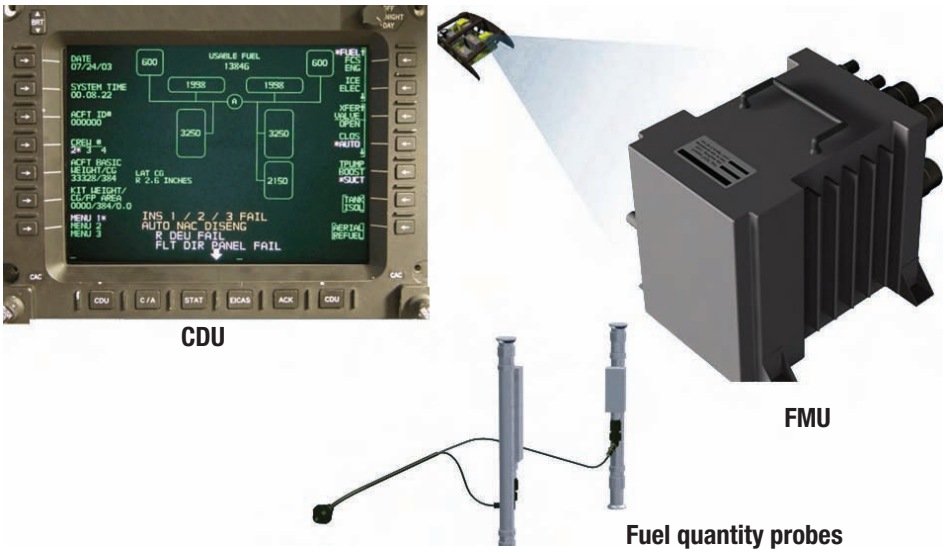
2.4.5.1 Fuel Management Control

Two microprocessor-based Fuel Management Units (FMU) automatically control the operation of the fuel system. These units interface with the Cockpit Management System (CMS) for system condition advisory and pilot-selected mode input. They interface with the ground pressure fueling-panel for ground pressure and gravity fueling operations. They also send system failure information to the aircraft maintenance computer.

2.4.5.2 Fuel Quantity Gauging System

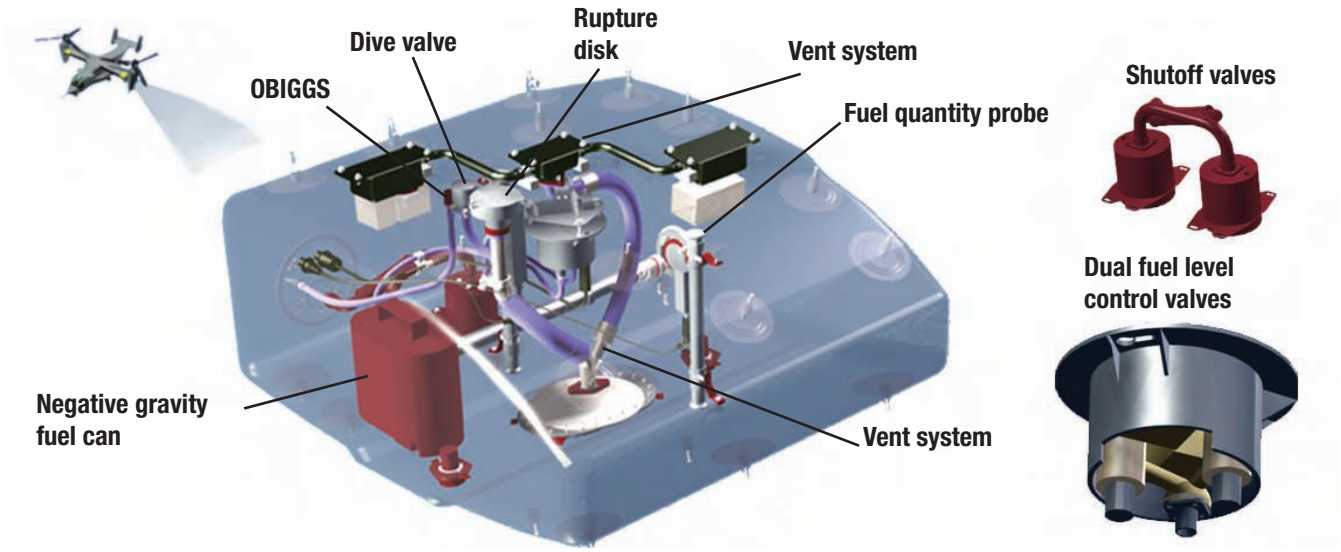
The fuel system uses a DC-type fuel gauge. The Fuel Management Unit (FMU) supplies excitation current for the capacitance tank units and tank-unit signal conditioning. Installation of the tank units incorporates features to enhance crash resistance.

Point sensors in the feed tanks provide low-level fuel-quantity indication and overfill detection. A low fuel warning-signal is generated, if either feed tank empties to less than 84 gallons (318 liters). If fuel flow indications to the Fuel Management Unit fail, the FMU will continue to estimate fuel consumption (using a worst-case fuel-flow condition).



2.4.5.3 Engine Feed System

The engine feed system consists of a feed canister with a negative-g capability, self-sealing breakaway valves, and engine-driven suction pumps. In normal operation, the primary engine pump draws fuel from the feed tank. A pendulum fuel pickup ensures uninterrupted flow during maneuver-induced negative-g conditions. The pressure switches detect system operation. An engine-mounted flow meter generates fuel flow information. In the event of an engine fire, the motor-operated shutoff valve (with position indication) shuts-off the fuel flow to an engine.



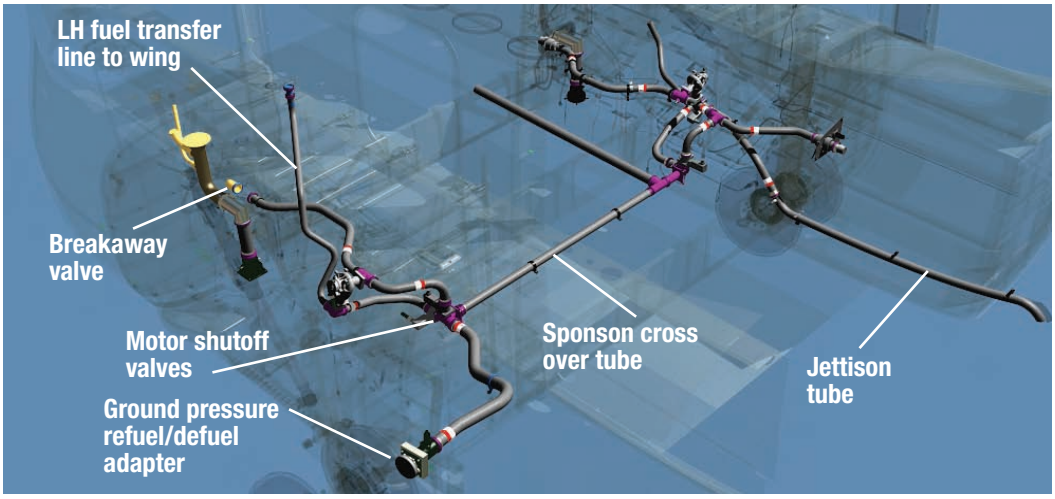
Feed Cell

2.4.5.4 APU Feed System

The fuel pump (in the APU) draws fuel from the right-hand feed tank. The fuel is drawn through a system of hoses, aluminum tubing, and a shutoff valve.

2.4.5.5 Fuel Transfer System

A multifunction transfer system transfers fuel from the sponson to the feed tanks. The system allows for gravity fueling, pressure fueling/defueling, and fuel jettison. A series of aluminum tubes and flexible hoses connects each sponson tank with its respective feed tank. Self-sealing breakaway valves are located at each line-to-tank connection. A suction transfer pump is located adjacent to each feed tank. A transfer boost pump is mounted adjacent to each sponson tank.



Fuel Transfer System

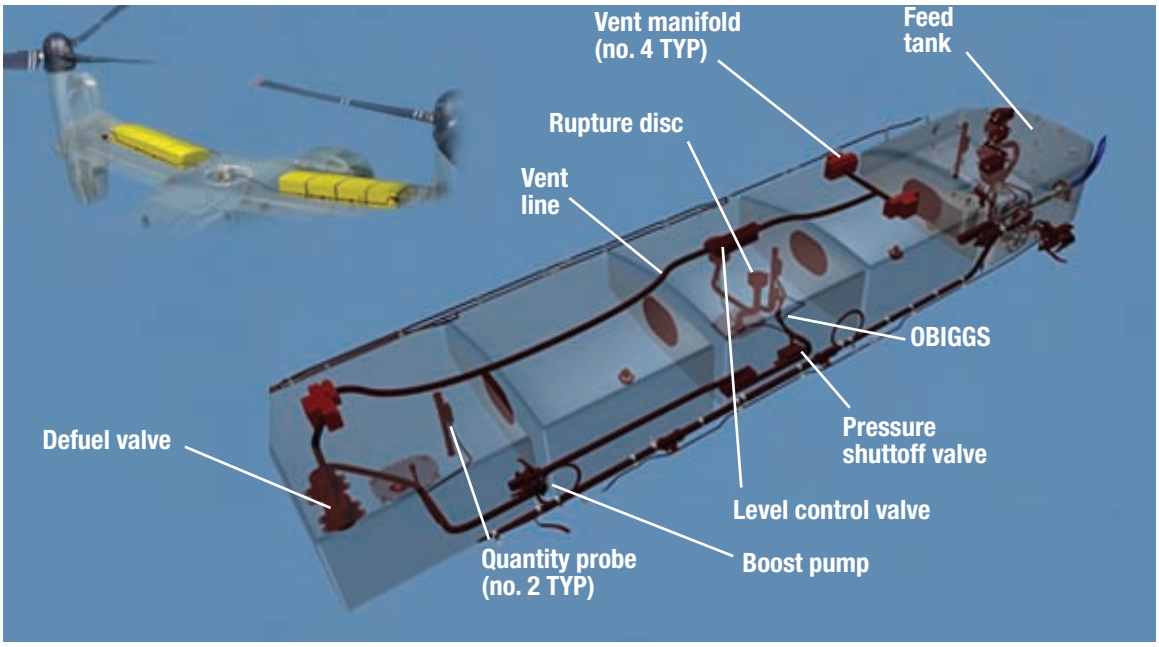
The automated transfer sequence empties the right aft sponson first (if installed), the mission auxiliary tanks second (if installed), the wing auxiliary tanks third (if installed), and then both the left and right forward sponson tanks last.

For ballistic and crash protection, a suction fuel system is used for normal operation. The boost pump is used for sponson-to-feed-tank transfer at altitude, for fuel jettison and gravity refueling, or in the event of a suction pump failure. Pressure switches indicate pump operation. Transfer flow passes through the pressure fueling level control and shut-off valves of each feed tank, which serve to stop the flow when a tank is full. Motorized valves with position indicators, located between the lower transfer and pressure fueling lines, allow selection of the desired system mode.

2.4.5.6 Fuel Tanks

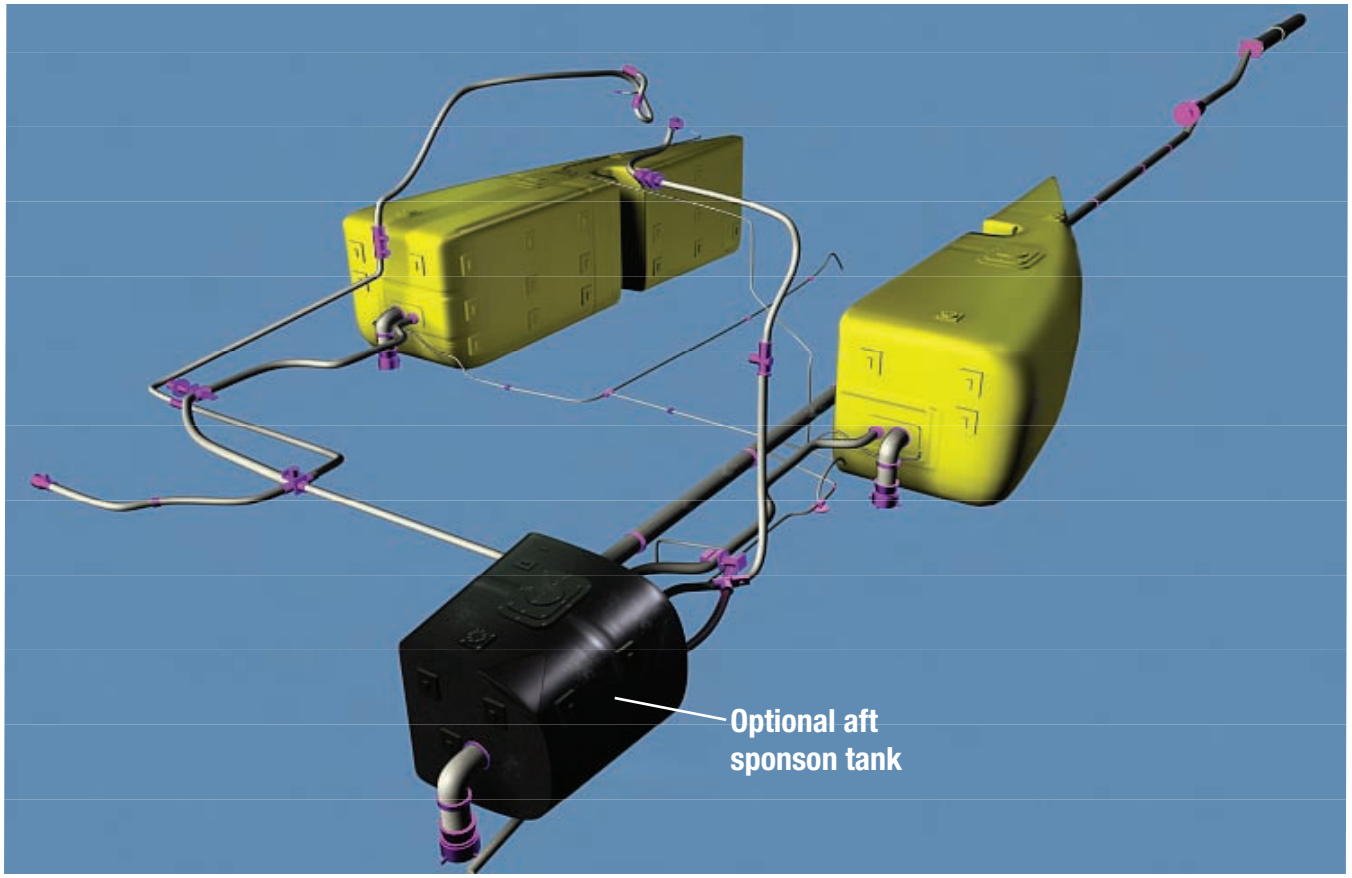
The fuel tanks are made of lightweight synthetic rubber that has high tensile strength. As fuel is depleted, an Onboard Inert Gas-Generating System (OBIGGS) supplies nitrogen-rich air to the wing and sponson tanks. The inert gas pressure displaces fuel vapor and reduces the possibility of fire. Each tank includes fuel vent systems and rupture discs. All tanks can withstand a 65 ft (19.8 m) drop when filled with water.

Wing Fuel System – In the wing, the outboard feed tank holds more than 30 minutes of reserve fuel. The tank is fully self-sealing to a 12.7 mm Armor Piercing (AP) threat and will withstand a 65 ft (19.8 m) drop when filled with water. A removable nonstructural door in the lower wing panel gives access to the tank. An access cover in the bottom of the tank allows access to internal components.



Wing Fuel System

Sponson Fuel System – One crash resistant, partially self-sealing tank is installed in the forward part of each sponson. A crash resistant, partially self-sealing auxiliary tank option is available for the aft part of the right sponson. A removable panel on top of the sponsons allows access for tank installation. Access to the tank interior is through covers on the top of each tank.



Sponson Fuel System (View Looking Forward)

2.4.5.7 Fuel Vapor Inertion

The Onboard Inert Gas Generating System (OBIGGS) supplies nitrogen enriched air to the wing and sponson tanks as fuel is used. The nitrogen enriched air reduces the vulnerability of fire and explosions due to incendiary projectiles that may otherwise ignite the flammable fuel/air mixture found in a tank's ullage space. The OBIGGS unit processes air from the SDC to separate the nitrogen, which is then directed into each tank. The climb/dive valves maintain 1.5 to 2.25 psi pressure in the fuel tanks. At altitude, the climb/dive valves reduce fuel evaporation and assist the engine suction-feed system.

2.4.5.8 Refueling Capability

Ground pressure, ground gravity, and air-to-air refueling capabilities are provided in the V-22. Ground refueling may be done with the wing in either the extended or stowed position. The V-22 fuel flow rates are tabulated below.

	Gallons per minute	Liters per minute	Pounds per minute	Kilograms per minute
Ground pressure refuel	300	1,136	2,040	925
Aerial refuel	300	1,136	2,040	925
Jettison	118	445	800	363
Boost pump transfer	10	38	68	31
Engine burn	4	14	25	11

Fuel Flow Rates (JP-5)

Gravity Refueling – The forward left-hand sponson tank has a lightning-safety filler cap. The sponson-tank boost pumps transfer fuel from this tank to all the other tanks. The pressure fueling level controls the components and as each tank becomes full, it stops the flow into an individual tank.

Aerial Retractable Refuel Probe – The V-22 can be fitted with an aerial retractable refuel probe kit to provide for inflight refueling from an aircraft with a suitably configured drogue refueling system. The probe is positioned to the right of the cockpit and has a separate illumination light for night refueling operations. At full extension, the probe is 110.5 inches in front of the nose. The retracted position extends 6.5 inches in front of the airframe nose. It is controlled electrically or manually, while powered hydraulically or manually.

V-22 Aerial Refueling from C-130

Ground Pressure Refueling – The single-point pressure refueling system consists of an adapter, tank mounted level control shutoff valves, and a control panel. The control panel in the aft left sponson is called the Ground Refuel/Defuel Panel (GRDP). It contains the receiver, a precheck indication, a total fuel quantity display, a tank loading selector, and a flow indicator. The GRDP is a microprocessor-based unit that interfaces with the fuel management/gauging subsystem via an ARINC 429 data bus.

2.4.5.9 Defueling

The V-22 incorporates defueling via suction and gravity drain, and inflight fuel jettisoning. The defueling rate is approximately 80 gal/min (303 L/min). A minimum suction of 3 psi (0.21 kg/sq cm) is required. Fuel jettison allows fuel to be dumped overboard during an emergency situation. Fuel is jettisoned at an average rate of at least 800 lb/min (363 kg/min). All fuel may be jettisoned, except for the fuel in the engine feed tanks.

2.4.5.10 Aft Sponson Auxiliary Fuel Option

To add additional permanent extended range capability, the V-22 can be equipped (during fabrication or as a kit installation) with an additional internal fuel tank in the right aft sponson. This tank provides up to 316 gal (1,196 L) of additional fuel capacity. The aft sponson tank provides the same ballistic tolerance as the basic sponson tanks. The kit weight is 101 lb (46 kg).

2.4.5.11 Mission Auxiliary Tank System

Mission auxiliary fuel tanks are available for use in extended range operations. These tanks include self-contained fuel lines, breakaway fittings, and electrical connections. The system is designed to withstand aircraft crash conditions. In accordance with mission needs, one or more tanks may be installed in the cabin. The V-22 is equipped to accept up to three internal tanks including the fuel connections and tiedown provisions.

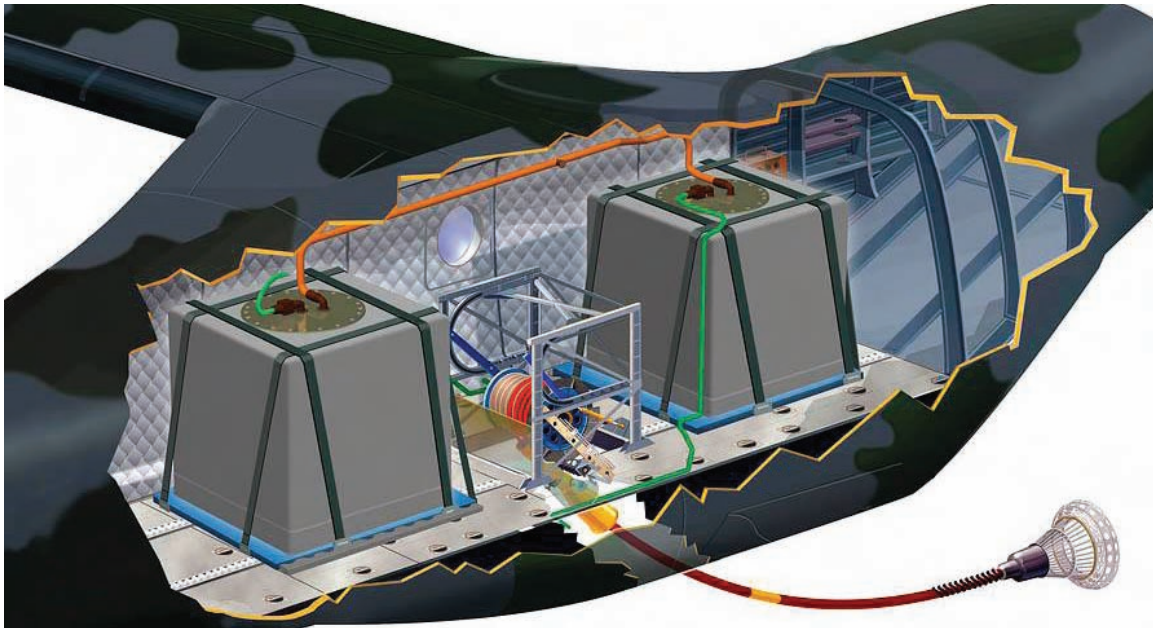
The tanks are integrated into the fuel management system through quick disconnects and an electrical line plug. Tank drainage is provided through the standard aircraft fuel drain system. Each tank can be installed in less than one hour using the existing tiedown rings.

2.4.5.12 Refueling Tanker Capability

Rapid Ground Refueling Kit – A Rapid Ground Refueling (RGR) kit, including the offload pump, hoses, connectors, and three refueling nozzles, is available to add to the cabin MATS. It allows for ground transfer of fuel from up to three MATs to forward located ground vehicles, helicopters, other V-22 aircraft, and/or other systems.

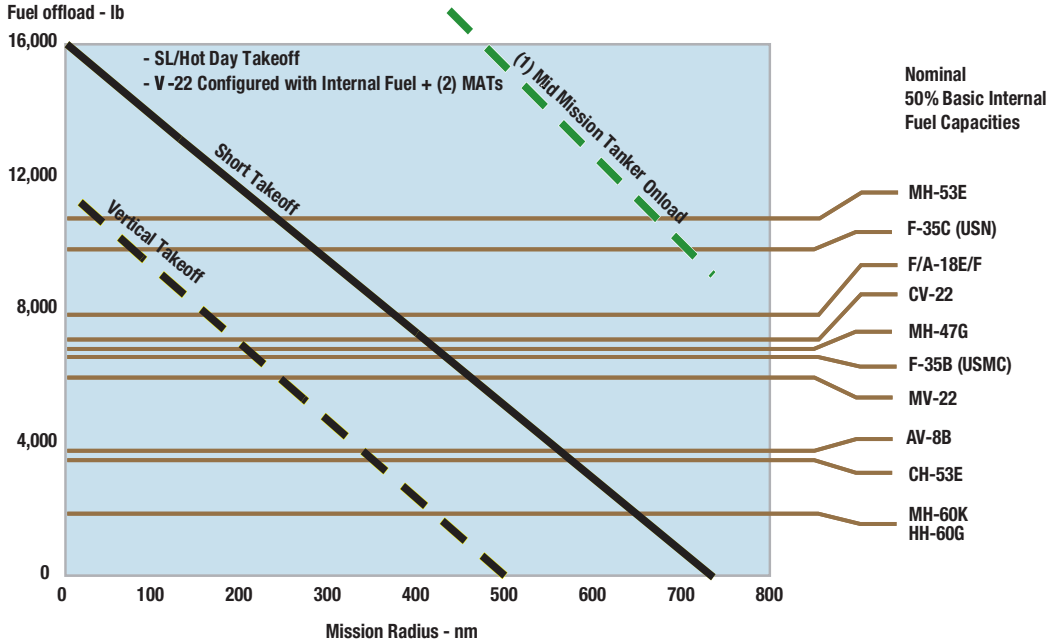
Aerial Refueling Tanker Concept

With its wide range of cruise speeds, large cabin, and ample useful load, the V-22 could readily accommodate an aerial refueling kit. It is well suited as a refueler for many different types of aircraft, accommodating receiver speeds from 120 kt or less for helicopters, up to 230 kt for probe-equipped, fixed-wing aircraft. The kit would enable the V-22 to supply any probe-equipped aircraft with up to 10,000 lb of fuel or more, at tactically useful ranges.



Aerial Refueling Kit Configuration

The aerial refueling kit uses the same fuel supply system already incorporated into the V-22 for self-deployment. The kit is integrated with the baseline fuel system. Using this kit, along with its aerial refueling probe, V-22s can refuel other V-22s for long-range missions, thus reducing a force's dependence on fixed-wing refueler aircraft or on the availability of runways.



Aerial Tanker Fuel Delivery Capability

2.4.6 Lubrication

The lubrication system for the V-22 is designed to provide a high level of safety, survivability, and ease of maintenance. The aircraft contains a number of independent lubrication systems. The servicing of these systems and their main components is described below.

2.4.6.1 Engines

The AE1107C engine has a self-contained lubrication system. It has been designed and tested to operate in all required vertical and horizontal attitudes. It provides clean, pressurized oil at all distribution points at the proper temperature to cool and lubricate the bearings, seals, and gears.

Oil is supplied from the engine-mounted oil tank to dual pressure elements in the oil pump and regulating assembly. The pressurized oil is filtered, cooled by a fuel/oil heat exchanger, and regulated before being sent to the distribution points. It is then collected in the joint accessory gearbox, front sump, center sump, and aft sump, where it is returned to the oil tank (by seven scavenge elements in the oil pump). The scavenged flow passes through a static air/oil separator before returning to the oil tank.

Both the oil filter and fuel/oil heat exchanger have bypass valves installed. An Oil Level Sensor (OLS) is installed in the oil tank. An Oil Debris Sensor (ODS) is installed at the air/oil separator.

2.4.6.2 Gearboxes

Each gearbox has an independent pump, which (through a series of internal oil jets to gears and bearings) provides a constant source of pressurized oil. The oil is fully filtered and circulated through an oil cooler. Chip detectors are strategically positioned throughout the system to detect metallic debris and report a potential problem to the flight crew.

The oil reservoirs are designed to accommodate all flight attitudes as well as the rotation of the gearbox as the rotor is tilted from helicopter to airplane mode.

An additional safety feature of the V-22 lubrication system is an emergency lubrication system. After loss of the primary lubrication system, the emergency system supplies the proprotor gearbox with oil for 30 minutes of operation. It uses a completely independent oil source and pump, both of which are located in in the Midwing Gearbox (MWGB) assembly.

The maintenance features of the lubrication system include: oil level reporting through the Ground Refuel/Defuel Panel (GRDP); fault monitoring through the central integrated checkout system; oil level sight-glass locations where needed by maintenance crew; and, oil filter bypass indications for each primary filter.

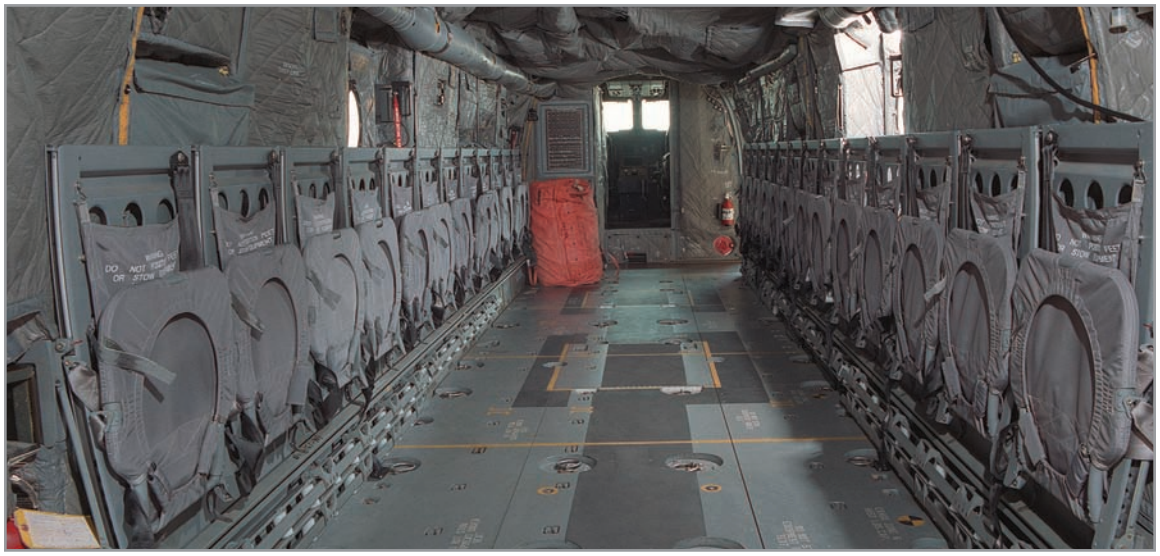
2.4.6.3 Oil Monitoring

The oil monitoring system provides for a rapid turnaround time in preparing the aircraft for a mission. It presents the oil level status to the ground maintenance crew without requiring them to open a number of separate inspection doors. The oil system monitoring display is located on the Ground Refuel/Defuel Panel (GRDP), mounted in the left-hand aft sponson. The oil level status is presented for the:

- Drive system gearboxes
- Engines
- Variable Frequency Generators (VFG)
- Shaft-Driven Compressor (SDC)
- Auxiliary Power Unit (APU)
- Emergency lubrication system

2.5 Payload Systems

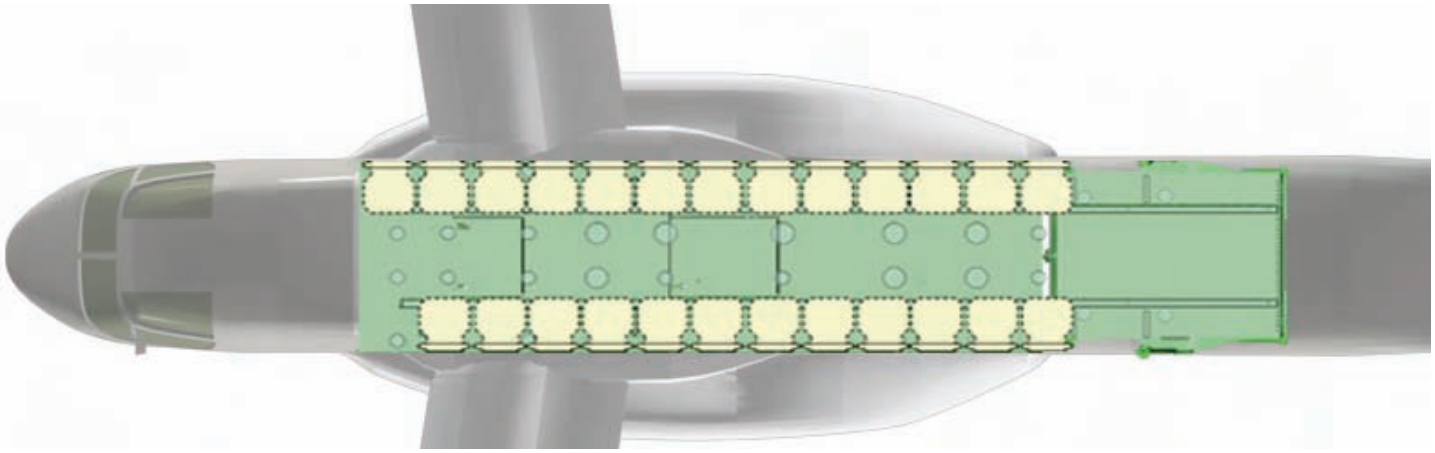
The V-22 has an open passenger and cargo cabin with a rear-loading ramp for easy access. Numerous cabin and cargo systems have been designed for the V-22 and are available to satisfy a range of mission tasks.



View of Forward Cabin

2.5.1 Cabin Seating

The standard troop transport role carries crashworthy seating in the cabin for one flight crewmember and twenty-four troops (facing inward, with twelve seats on each side of the cabin) with full equipment. The crew chief seat is installed just aft of the cabin door on the right side. The off-loading of troops can be accomplished within 15 seconds after the opening of exit(s).

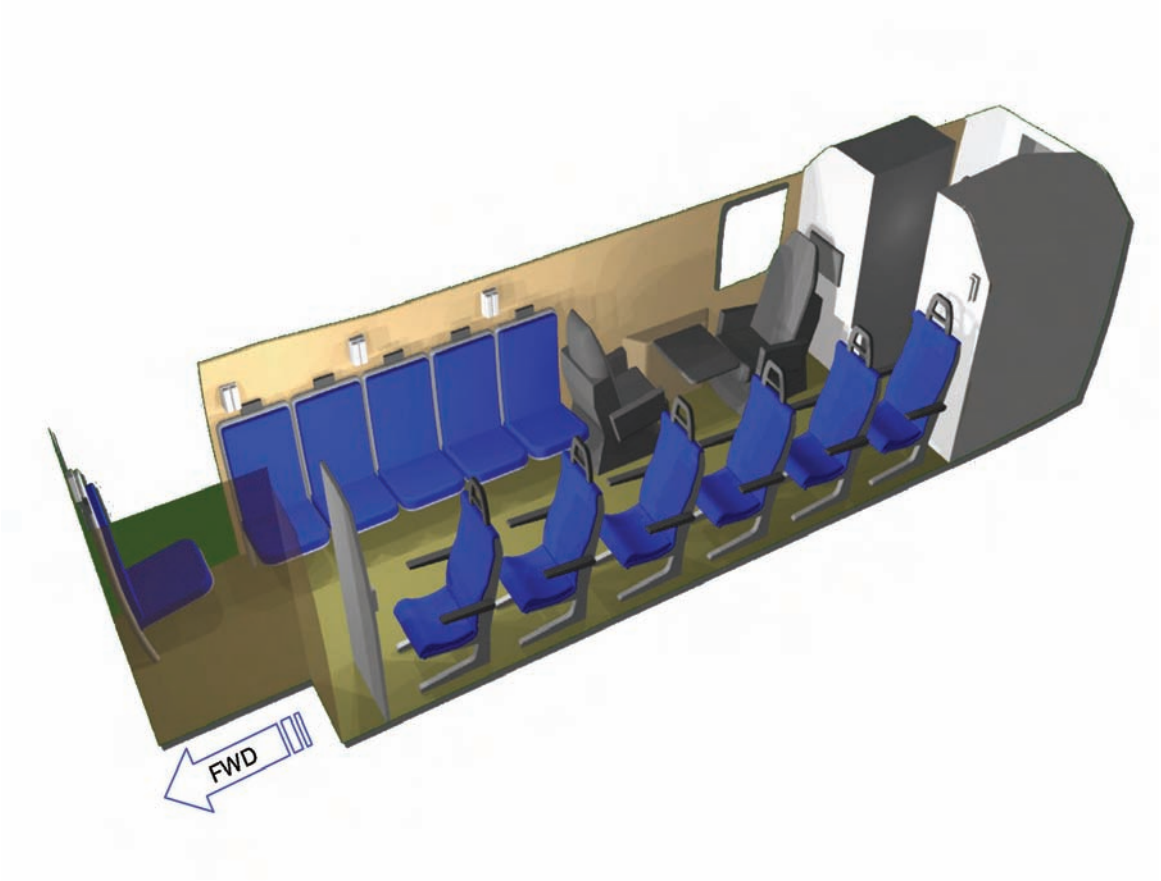


Cabin Seating

The seats fold manually up (stow), allowing rapid egress through the cabin door and ramp. The seats contain individual restraints. Two removable pins attach the seats to the supporting airframe structure at the emergency exits. A single action will simultaneously retract both pins, thus allowing for rapid egress.

All seats in the cabin are crash attenuating with a maximum vertical stroke of 12.81 in (32.5 cm). They are built to attenuate vertical crash loads to 13.5 g for the 50th percentile occupant. The three-point restraint straps will withstand 10 g longitudinally and ±3.4 g laterally (relative to aircraft axes). The ingress/egress systems consist of the jettisonable cockpit side windows, cabin door, four cabin escape hatches (three window escape hatches and an aft upper ditching hatch), and the cargo ramp.

Alternate cabin arrangements can be provided to specification. Alternative seating arrangements have been examined and additional non-crashworthy seats can be installed to provide seating for up to 31 troops. Executive transport layouts have been evaluated to provide comfortable seating for up to 14 with a crew of three.

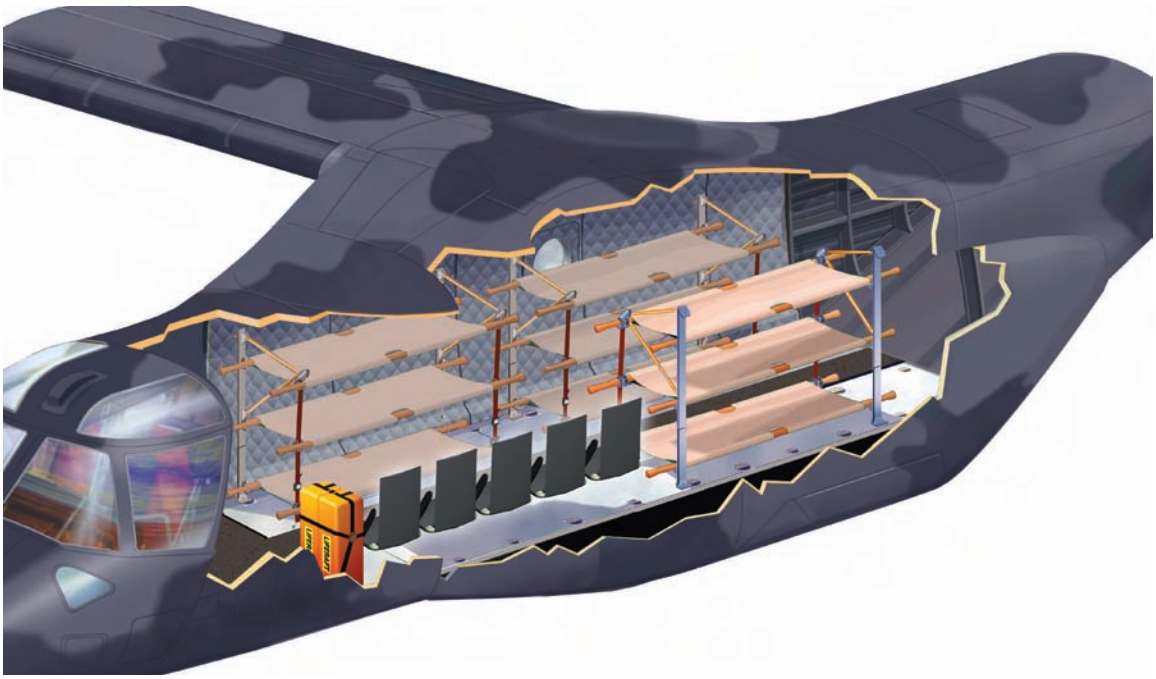


Executive Cabin Configuration

2.5.2 Aeromedical Evacuation Litter Provisions

Provisions for aeromedical evacuations of 12 litters are provided for the aircraft (Block C configuration). Cabin litters can be arranged lengthwise in four banks of three high, allowing for a center aisle with a minimum 16.76 in (42.5 cm) and maximum 20.21 in (51.33 cm) width at the inboard support fittings, and vertical clearance between litters of 17 in (36 cm) or more.

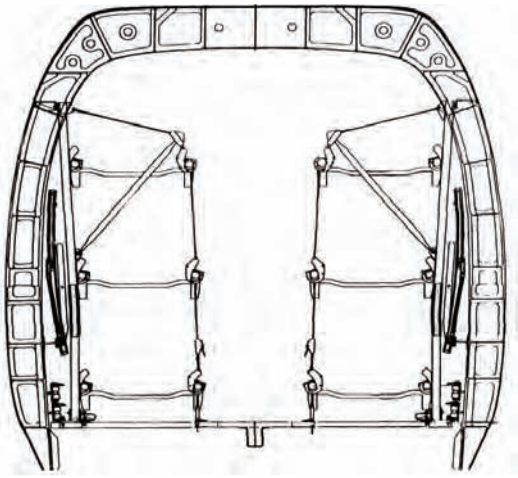
A litter support system of stanchions, struts, and straps are supplied in kit form with a litter-handle restraint arrangement for easy removal of individual stretchers. The support system is designed to 10 g static downward, 10 g longitudinal, 5 g lateral, and 8 g upward acting separately or in combination along the three aircraft axes. The cabin arrangement system is flexible and, for example, the V-22 can accommodate a 9-litter installation with crashworthy seating for a total of five medical attendants or three medical attendants and two crewmen. Cabin space and accommodations are available for additional critical care equipment, as needed.



MEDEVAC Cabin Litter-Configuration

The kit weight for supports and fittings for 12 litters is 196 lb (89 kg). Additionally, litter sets can be removed and replaced with mission auxiliary fuel-tanks to provide for longer-range operations.

Critical Care Capability



Interior MEDEVAC Litter Configurations

2.5.3 Avionics Storage

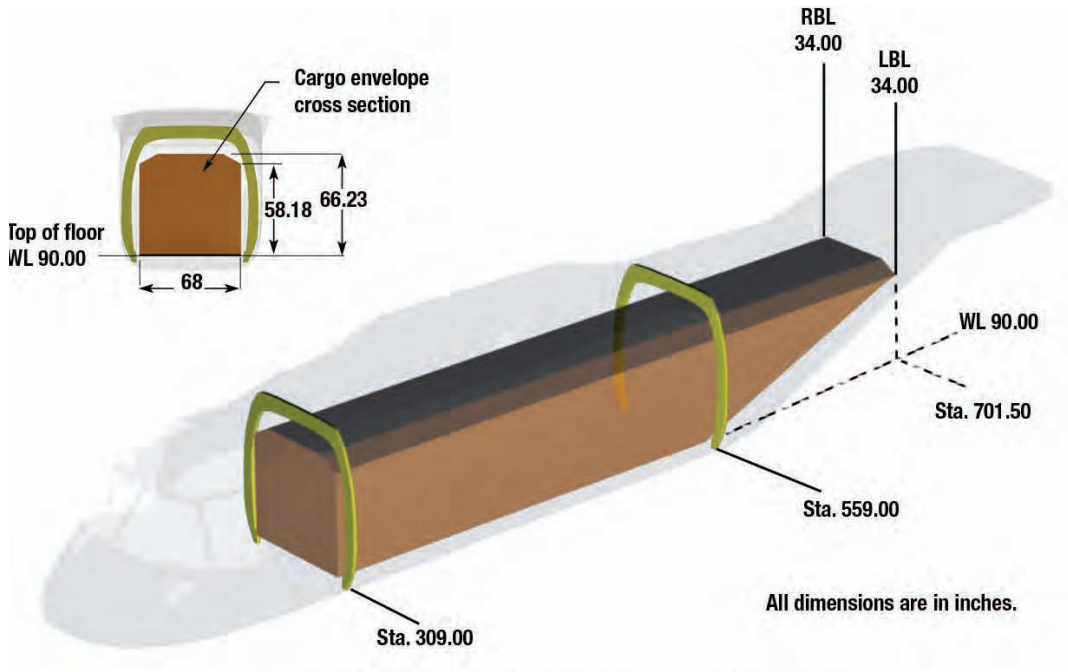
The V-22's avionics storage compartments are located in the left-forward and right-forward portion of the cabin. The compartments are cooled and filtered by an independent Avionics Cooling System. The compartments are shielded from electrical disturbance by aluminum honeycomb EMI filters via the interior ducting of the compartments.

2.5.4 Life Rafts and Stowage

Two 14-man life raft sets are available, each stored in a soft case. Both rafts are secured against the aft face of the left-hand avionics rack. The rafts are equipped with required maritime survival equipment, including a radar reflector and weather cover. These rafts will accommodate all embarked passengers and/or troops and the flight crew. The kit weight is 148 lb (67 kg).

2.5.5 Internal Cargo

The cabin and rear ramp are capable of accepting cargo pallets or containers as large as 5.67 ft (1.72 m) wide, 5.52 ft (1.68 m) high and 20.83 ft (6.35 m) long; the object must be capable of achieving the necessary restraint criteria. The usable cabin volume is 739 ft^3 (20.9 m^3), and is designed to carry up to a 20,000 lb (9,072 kg) load internally.



Note: Dimensions define the shape that must be clear from sta. 309 to sta. 559, and from sta. 559 to 701.5 in the aft fuselage, with the ramp floor level with the cabin floor.

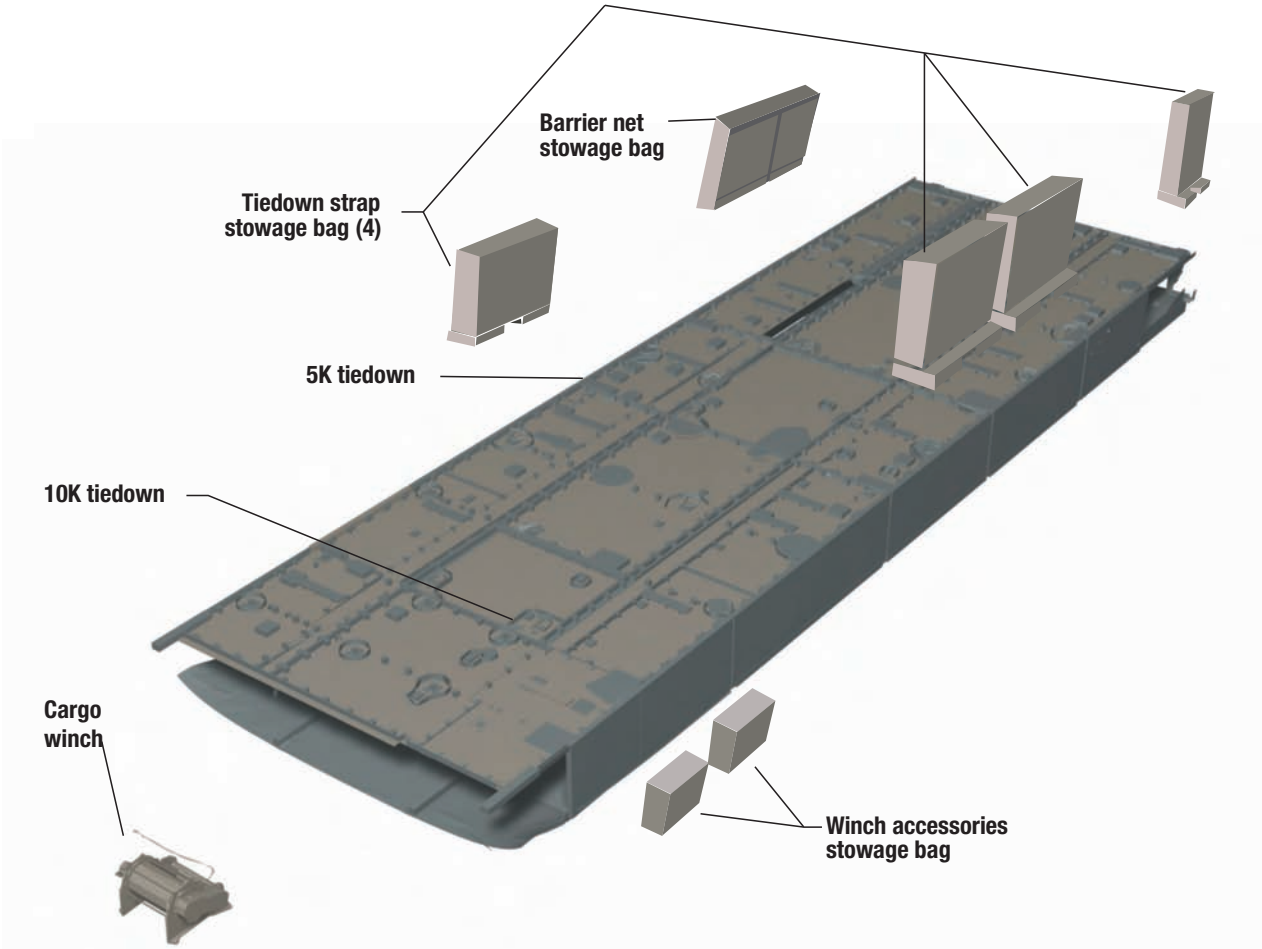
Internal Cargo Envelope

The cabin floor is constructed of composite honeycomb sandwich material. This material has been made into panels, which are mechanically attached to the underfloor structure. The panels form a high impact, watertight, rugged cargo floor with a 300 lb/ft^2 (1,464 kg/m^2) load capacity.

The cabin floor can withstand a 50 psi (344.8 kPa) load applied to any single 0.5 ft^2 (4.6 cm^2) area within any 6 ft^2 (0.56 m^2) area. It can withstand more than 1500 ft-lb (207 kg-m) of bending moment at any location. Over 40 lb (18.1 kg) can be applied to a 0.79 in (2 cm) ball on the floor – without severe deformation. Drop tests and rolling load tests have confirmed minimal deformation under normal operations. All of these load criteria include up to 3 g of normal acceleration.

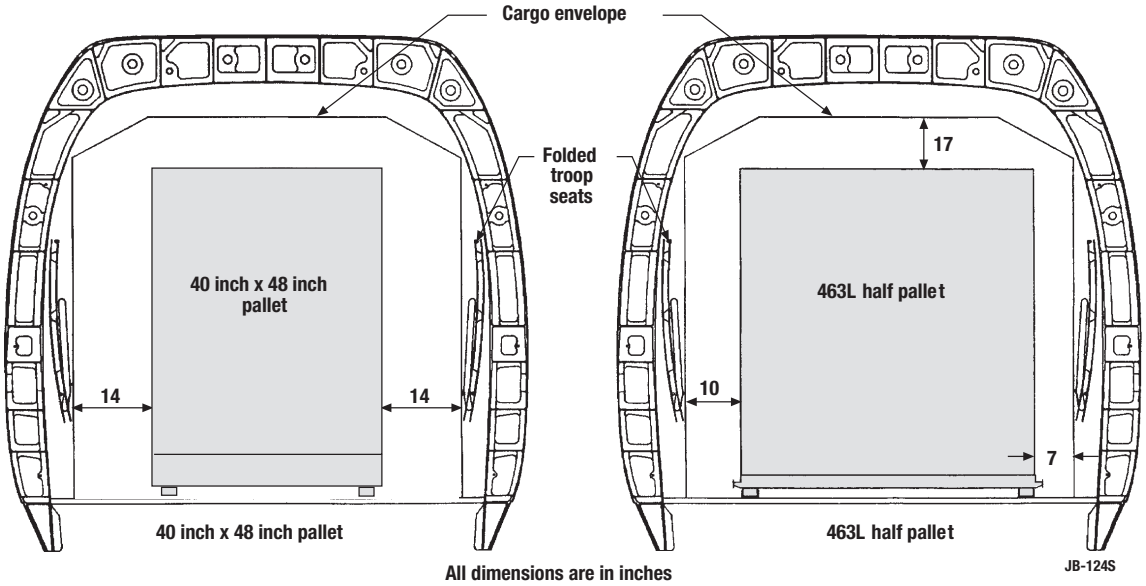
Cargo tiedown rings are installed in recesses in the floor panels. They lie flush with the floor surface when not in use. There are 22 fittings rated at 3,500 lb (1,588 kg) for use with traditional (unattenuated) tiedown devices (increased rating of 5,000 lb (2,268 kg) is available for use with load attenuated devices) and 18 fittings rated at 7,000 lb (3,175 kg), or 10,000 lb (4,536 kg) attenuated. Three 3,500 lb (1,588 kg) capacity tiedown rings are located on the side frames at Stations 371, 422 and 505. Four 3,500 lb (1,588 kg) capacity tiedown rings are located on the ramp floor, which lie flush when not in use.

The internal cargo handling system includes: a roller conveyor system with guide rails and a hydraulically powered cargo winch. The capacity of the winch is 2,000 lb (907 kg) and includes 150 ft (45.7 m) of cable. It is installed under the cockpit passageway floor. Together with four accessory pulleys, the winch system can be used to move cargo through the main cabin for loading and unloading. Storage compartments are provided for all of the cargo tiedown straps and the barrier netting. The maximum winch speed is 30 fpm (0.15 mps).

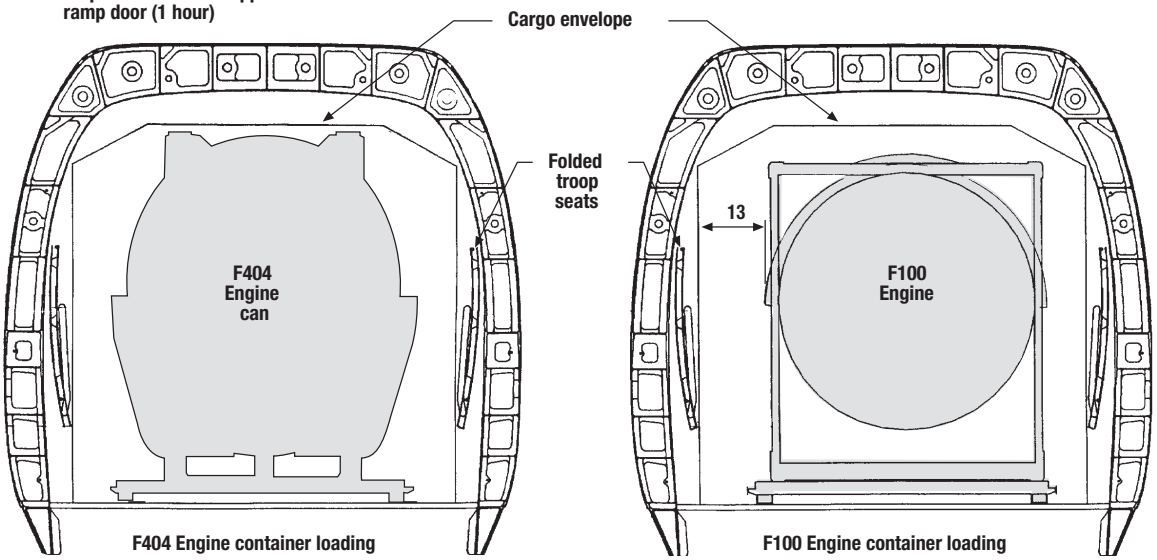


Internal Cargo Handling Equipment

The figures illustrate several of the unique payloads that may be carried internally on the V-22. These include standard warehouse pallets (up to four), 463L half-pallets, and the F404 and F100 engines if placed on the 463L half-pallet. Several vehicles can also be loaded internally, including the M151 Jeep (top cover removed and windshield folded down), and the M274 Mechanical Mule. The U.S Marine Corps is designing a family of internally transportable vehicles (ITV) sized to be carried in the V-22.



Note: Requires removal of upper ramp door (1 hour)



Ramp extensions may be used to assist wheeled vehicles in negotiating the height from the ground to the lip of the aft cargo ramp. They fold in to allow the ramp to close and fold out to extend the ramp. They are adjustable so that flush contact with the ground can be made.

Internal Loading of a Concept ITV

2.5.6 External Cargo Capacity

The V-22 is fitted with two external cargo hooks, either of which can support a load of 10,000 lb (4,536 kg). When the hooks are used together, the combined capacity can be up to 15,000 lb (6,804 kg). Depending on the load configuration and CG limits, stabilized external loads may be transported at speeds up to 200 knots. Two hinged hatches provide access to the external cargo hooks.

Stabilized External Load Carriage Using Dual Hooks (Shown with HMMWV)

A multifunction control system provides electric control of the hooks. It includes load sensors and center-of-gravity indicator systems. The crewmember in the cabin can release the load from either hook by a selectable electrical switch or a manual release. Either pilot may release the load via a selectable auto-jettison function in the flight control software. A manually-operated lever located in the cabin (aft cargo hook bay) may be activated for release of the load.

External Load Carriage Using Single Hook
(Shown with Lightweight 155mm Howitzer)

2.5.7 Rescue Hoist

The Rescue Hoist is an electrically driven and electronically controlled assembly. It is attached to the rear of the aircraft in the ceiling forward of the STA 724 empennage bulkhead. The Rescue Hoist is installed as a kit and permits rescue, and/or insertion/extraction, of personnel when landing is not practical or desired.

The Upper Ramp Door Access Panel must be open during hoisting operations. The Hoist system is capable of hoisting devices into the cabin like the stokes litter, two-man rescue team, three-man forest penetrator, or a stokes litter with attached floatation device. The Rescue Hoist has: a lift capacity of 600 lb (272 kg); a continuously variable speed of 0 to 225 FPM (1.14 mps); and a maximum distance of 250 ft (76.2 m) below the aircraft. The maximum load limit of the cable is 2100 lb (952 kg).

Rescue Hoist

Remote Hover Control

A remote hover control capability for a cabin crew member is available. Upon pilot command, the aircraft flight control system can provide the rescue hoist operator with limited [2 percent or 15 knots (27.8 km/hr)] lateral and longitudinal control. Using a cabin-mounted control stick, the hoist operator can precisely position the aircraft over the desired pickup point.

Parachutists Free Fall from an MV-22 at 10,000 feet
Rear ramp air drop

2.5.8 Rear Ramp Flight Operations

Parachute drops by personnel and drops of cargo can be made from the open rear ramp. The ramp can be opened in flight to a horizontal (level) position for operations up to 240 knots.

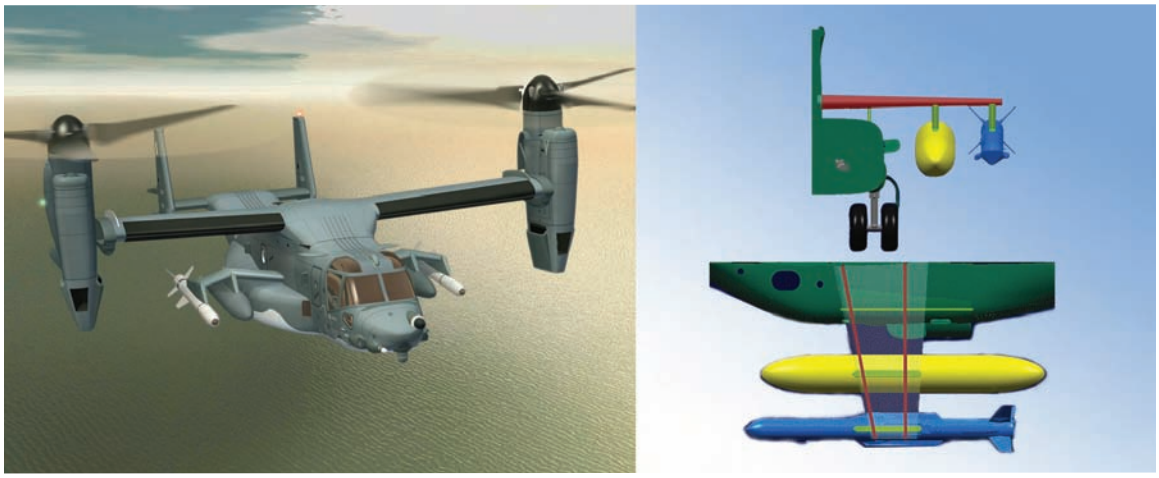
2.5.9 Fast Rope

Optional fast rope equipment can be installed that provides for two fast ropes in the cargo area. One mounting system is located above the end of the cargo ramp so that the rope can hang vertically at a nominal distance of 14 inches aft of the ramp floor; the second is located above the aft cargo hook bay. Each mounting system includes a quick-disconnect pin which, when pulled, allows the aircrew member to strike primary and secondary pivoting release arms (double-pommel release mechanism.) The aft fast rope position is located next to the rescue hoist. The attachment structures are designed for three combat loaded troops at a time.

Fast Rope System at Rear Cabin

2.5.10 External Stores Concept

For selected missions, an external stores kit could be accommodated on the V-22 for carriage of equipment such as auxiliary fuel tanks, droppable stores, and mission equipment pods. Externally mounted fuel tanks could greatly extend mission range while maintaining full cabin volume.



External Stores Concept

2.6 Avionics

The V-22 Integrated Avionics System (IAS) is a fully integrated avionics suite that uses existing off-the-shelf equipment as well as specially developed hardware and software. The functionality integrated into the system provides capabilities for communications, navigation, sensor management, systems controls, instruments, and displays. The open design of the avionics architecture allows new capabilities to be added to meet the future needs of the users.

2.6.1 Communications

The communications system provides voice transmission and reception of radio signals on the frequencies selected by the pilot or copilot. The frequency selection and radio tuning can be performed by a preset method or a manual method through the Cockpit Management System. Pre-mission communication information is loaded through the Mission Planning cartridge. The communication system also has an audio distribution intercommunication system that provides audio communications for crewmembers on the aircraft and the ground crew.

2.6.1.1 Intercommunication System

The V-22 intercommunication system includes seven stations: pilot, copilot, jump seat, troop commander, forward cabin, aft cabin, and an external station for ground operations or maintenance support. Each station, with the exception of the ground operators, can provide intercabin communications and connection to the aircraft radio systems.

2.6.1.2 Radios (AM/FM/UHF/VHF)

The V-22 can accommodate up to four MIL-STD-1553B-compatible radios. Depending on radio modes selected, ADF and FM homing direction finders (using available bearing pointers) can be displayed on the pilots' MFDs. The -1553 compatible radios provide clear and secure voice communications in the 30-400 MHz radio frequency band, and can support Single Channel Ground and Airborne Radio System (SINCGARS) and HAVEQUICK tactical communications, and UHF SATCOM beyond line of sight communications.

2.6.2 Navigation

The navigation system provides primary navigation data. It controls inertial and radio navigation sensors. The system data includes:

- Position
- Heading
- Attitude
- Geographic frame velocities
- Magnetic variation
- Radar Altitude
- Marker beacon station passage
- Radio navigation data such as distance and bearing to ground station

The navigation system also receives barometric altitude, calibrated airspeed, and temperature data. This data is used to calculate true airspeed, wind speed, and wind direction. The navigation system can accommodate the following sensors:

- Lightweight Inertial Navigation System (LWINS)
- Radar Altimeter
- VOR/ILS/MB receive
- Tactical Air Navigation (TACAN)
- Dual Digital Map System (DDMS))
- Global Positioning System (GPS)
- VHF FM homing
- VHF/UHF Automatic Direction Finder

2.6.2.1 Inertial Navigation System

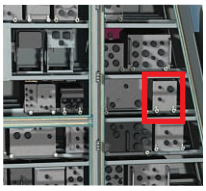
The standard (triple-redundant) Lightweight Inertial Navigation System (LWINS) provides an output of aircraft acceleration, velocity, position, altitude, magnetic heading, and true heading. It provides this information to the Flight Control Computers (FCC).

2.6.2.2 VHF Omni-Range/Instrument Landing System/Marker Beacon

This system provides terminal area landing aides for standard approaches and departures. It provides: VHF Omni-Range (VOR) relative bearing, Instrument Landing System (ILS) localizer/glideslope data, and approach-Marker Beacon (MB) indications to the aircrew.

2.6.2.3 VHF/UHF Automatic Direction Finder

Working with onboard radios, an Automatic Direction Finder (ADF) provides continuous indication of the relative direction of tone-modulated or continuous wave signals on VHF or UHF radio transmissions from 100 to 400 MHz. Audio reception is also provided to the aircrew.

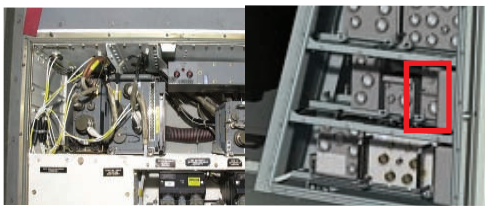


2.6.2.4 VHF FM Homing Module

FM homing capability is provided by a homing module and a VHF homing antenna. FM homing provides port-starboard homing onto radio transmissions from 30-88 MHz.

2.6.2.5 Radar Altimeter

The radar altimeter provides aircraft altitude above ground level from 0 to 4,500 ft (0 to 1,372 m). A Low Probability of Intercept Altimeter (LPIA) is available in order to provide a lesser chance of detection by hostile forces. When the LPIA is installed, the radar altimeter effectiveness increases to 10,000 ft (3,048 m).



2.6.2.6 Tactical Air Navigation

Tactical Air Navigation (TACAN) is a line-of-sight, heading reference, navigation system that operates in conjunction with a compatibly equipped ground station, ship, or aircraft. The system provides relative bearing and/or distance to the selected station.

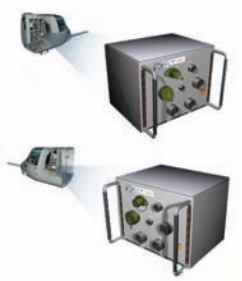
2.6.2.7 Global Positioning System

The global positioning system (GPS) receiver is a satellite-based, radio global positioning system that consists of an internal receiver/signal processor, data processor, antenna interface, and power supplies. The GPS receives, tracks, and processes GPS signals from the antenna subsystem and provides highly accurate position, velocity, and time (reference) information to the IAS.

2.6.2.8 Dual Digital Map Set

The V-22 uses a Dual Digital Map System (DDMS) to enhance cockpit situational awareness. It provides a color-moving digital map through display of digitized aeronautical charts, digital imagery, and other digitized information. It allows for the display of stored static images such as checklists, diagrams, landing and departure plates, and digitized photographs required to fly a mission. The DDMS provides the capability to have two different maps displayed simultaneously, providing greater flexibility.

2.6.3 Identification



The Identification, Friend or Foe (IFF) system provides reception of interrogations and transmission of responses to aid other stations in determining the identity of the aircraft.

2.6.4 Data Processing

The data processing system provides redundant processing using two Advanced Mission Computers (AMC) that process and control communications, navigation, controls and displays, identification, surveillance, and defensive functions.

- The Mission Data Loader (MDL) system provides for upload/download of mission and maintenance data.
- The Interface Units (IU) control and monitor aircraft and avionics systems that are not compatible with the MIL-STD-1553 data bus protocol. The IUs allow the AMCs to communicate information to and from ARINC-429, RS-422, and discrete signal devices.

2.6.5 Surveillance

The surveillance system supports sensors that allow the pilot and copilot to fly the aircraft under day, night, or adverse weather conditions. The cockpit is completely compatible with the Aviator's Night Vision Imaging System (ANVIS). The Forward Looking Infrared (FLIR) sensor receives infrared signals that can be used by the pilot/copilot as an aid in piloting, navigation, search, detection, and recognition activities.

2.6.6 Defensive

The defensive system provides detection and crew notification of missiles, radars, and laser signals that pose a threat to the aircraft. The defensive response to such threats often consists of expendable countermeasures. Some configurations of the aircraft also provide for radio, radar, and laser jamming.

2.6.7 Controls and Displays

The controls and displays system provides aircrew and maintenance personnel with resources to monitor cockpit information and control aircraft functions. The hardware includes:

- 2 electronic display units,
- 4 Multifunction Displays (MFD),
- 1 Control Display Unit (CDU),
- 2 CDU keyboards (for operator data entry),
- 1 Flight Director Panel (FDP),
- 1 Standby Flight Display (SFD),
- Night Vision Goggle/Heads-Up Displays (NVG/HUD), and
- Standby Flight Instruments.

2.7 Cockpit Systems

2.7.1 Crew Systems

Extensive design requirements were imposed on the man-machine interface with V-22 subsystems, including the interfaces between the aircrew and flight and avionics related controls and displays, postural support and restraints, life support and furnishings, and equipment/workstations throughout the aircraft. The table below identifies these interfaces, associated aircrew, and their location in the airframe.

Aircrew	Interface	Location
Crew Chief	Crew Chief Station	Center Fuselage
Crew Chief	Winch Operators Station	Center Fuselage (adjacent to the main cabin door)
Crew Chief	Ramp Control Station	Aft Fuselage
Crew Chief	Hoist Control	Aft Fuselage
Pilot, Copilot	Cockpit	Forward Fuselage
Troop Commander	Troop Commander Station	Center Fuselage

Interfacing Subsystems

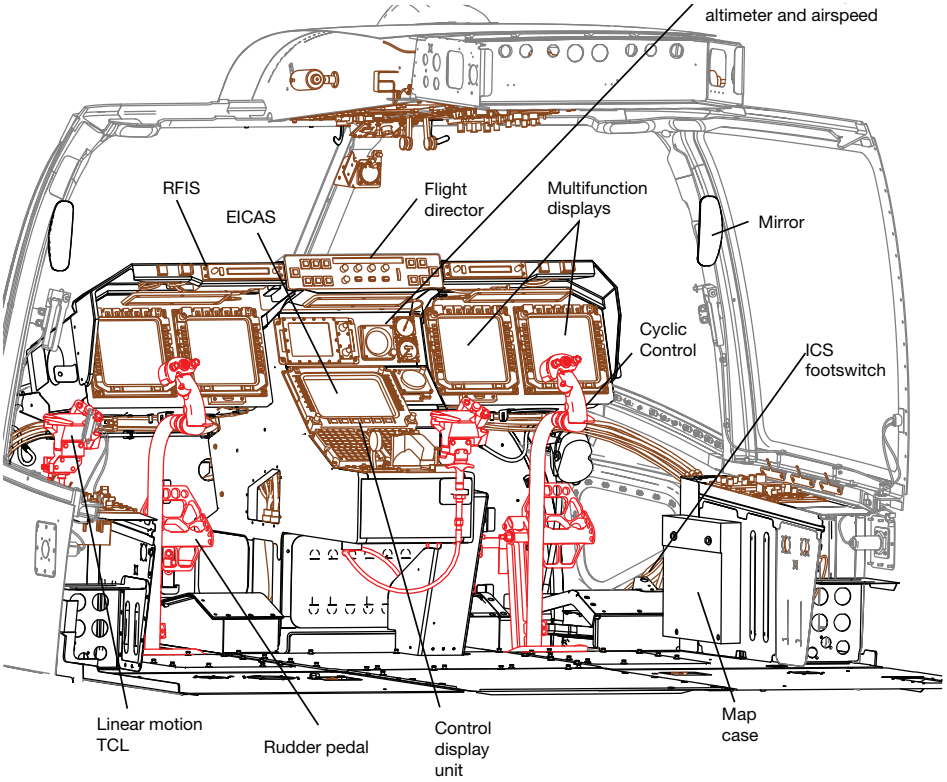
Crew Cockpit

2.7.2 Crew Interface Design

The cockpit is the aircraft's most sophisticated crew station. It is comprised of four tightly integrated elements:

- The physical elements (e.g., seats, instrument consoles, furnishings and equipment)
- Mechanical flight controls (e.g., primarily Vehicle Management System (VMS) interfaces)
- Cockpit Management System hardware (e.g., primarily avionics and systems interfaces)
- Informational interfaces (e.g., software-driven control and display functions)

Extensive research has been performed using piloted simulation to design an intuitive and comfortable set of cockpit controls. The general crew station is shown below.



Crew Station Overview

The controls and displays used primarily by the aircrew for aircraft situational and tactical awareness are located in the forward console and include:

- Multifunction Displays (MFDs)
- Control Display Unit/Engine Instrument Crew Alerting System (CDU/EICAS) Display and Keyboard
- Standby Flight Display and Dedicated Standby Instruments
- Flight Director Panel (FDP)
- Remote Frequency Indicator Selector (RFIS)

2.7.3 Vibration and Sound Levels

The V-22 tiltrotor aircraft combines design features of both the helicopter and turboprop, which results in a combination of the vibratory and acoustic environments of both. The excitation characteristics of the proprotor, which turns much slower than a propeller, are discrete like a helicopter rotor rather than narrowband random like a propeller.

Cockpit vibration levels are maintained at a comfortable level through an active vibration suppression system in the cockpit and cabin. Vibrations are minimized at the rotor source by incorporation of vibration pendulum absorbers in the rotor hub system. Vibration levels are monitored for safety and maintenance through the Vibration, Structural Life, Engine Diagnostics (VSLED) system.

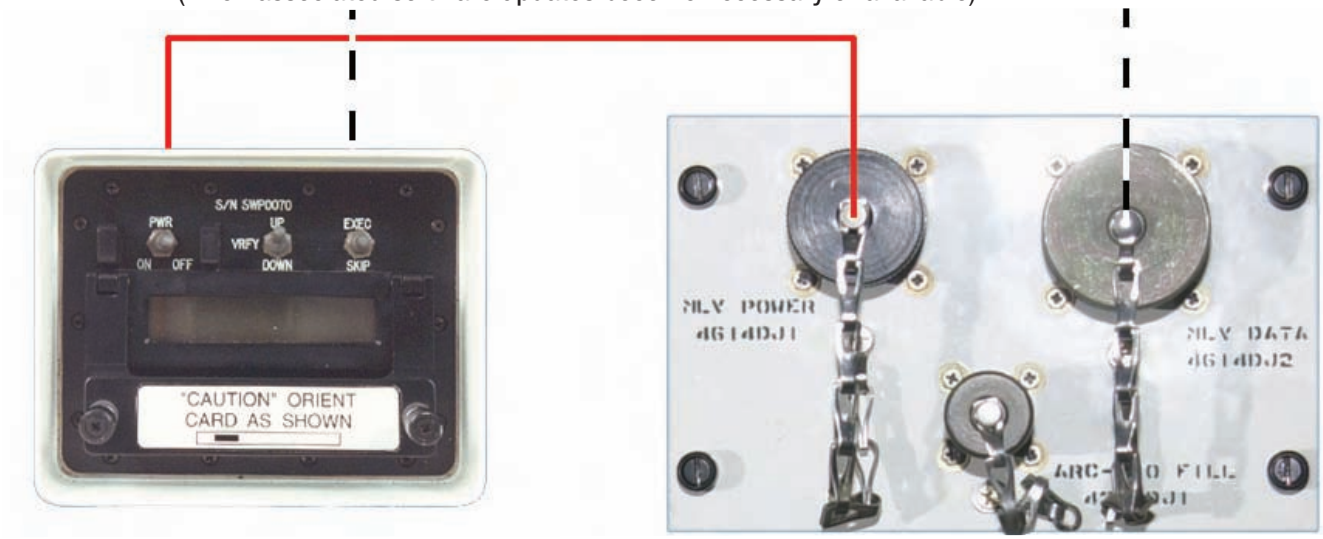
When all noise attenuation devices and subsystems (e.g., aircrew helmets) are in use, the interior cockpit ambient sound levels are predicted to be attenuated so that they do not exceed safe levels for extended exposure times (85 A-weighted decibels) at the aircrew ear. Noise levels in the cockpit and cabin do not interfere with, or prevent transmission of, other required auditory signals or communication.

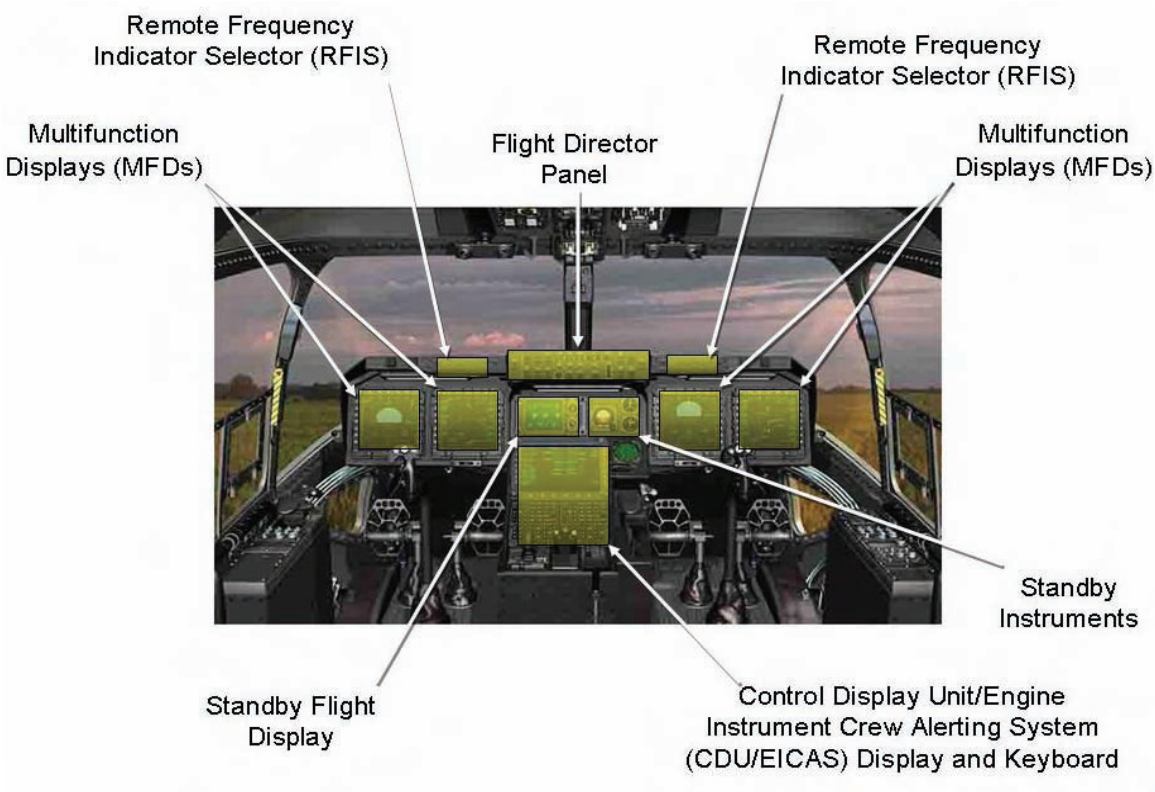
2.7.4 Cockpit Management System

The Cockpit Management System (CMS) is the primary interface between the flight crew, the aircraft flight control systems, and the avionics equipment suite. The CMS replaces many traditional flight instruments and system indicators with an electronic cockpit display system. This display system is configured to provide normal aircraft performance and flight monitoring as well as provide an extensive Warning, Caution, and Advisory (WCA) system (including voice warnings and other integrated tones).

The CMS is a redundant design. Dual components and data busses ensure that system operation will not be disrupted by a single-point failure. The CMS components are made up of two distinct subsystems: data processing, and controls and displays.

The data processing subsystem is comprised of two Avionics Mission Computers (AMC). An AMC is a militarized general-purpose digital-computer. They process data, solve equations, manage display processing, and serve as bus controllers for the MIL-STD-1553B data bus structure. The V-22 applications system software is loaded into each AMC by a portable memory loader-verifier device. The loader-verifier is also capable of reloading most of the equipment-unique software (when associated software updates become necessary or available).





Instrument Panels and Center Console

Flight instrument data is presented on the Primary Flight Display (PFD), Vertical Situation Display (VSD), Horizontal Situation Display (HSD), and hover formats on the Multifunction Displays (MFDs). An independent Standby Flight Display (SFD), Standby Instrument, and magnetic compass are provided for emergency backup.

Aircraft attitude and other primary flight data are presented on the PFDs and VSDs. The HSD provides flight path and navigation information as viewed on a horizontal plane.

2.7.4.1 Multifunction Displays (MFD)

The V-22 control and display system architecture incorporates a combination of hardware and software design features to facilitate maximum flexibility for incorporating new technologies and to adapt to new mission roles. The control and display subsystem is comprised of four MFDs driven by two Display Electronics Units (DEUs).

The symbology and message definition is provided to the DEU from the mission computer software for display on the MFD. This design approach allows flexibility because the mission computer software can be easily modified to incorporate new messages or new crew displays. Two MFDs on each pilot instrument panel provide flight symbology, sensor video, communication-navigation, and system status displays.

Active Matrix Liquid Crystal MFD

The navigation HSD may be displayed on any four 6-inch square color MFDs, which are off-the-shelf Active Matrix Liquid Crystal Displays (AMLCD). The HSD symbology is sized appropriately, providing a clearly visible and readable display when viewed from a distance of 30 inches. AMLCD technologies are usable during all phases of the mission. It is both sunlight readable and night vision goggle compatible.

2.7.4.2 Control Display Unit

A single, full-time display surface for both the left and right pilot seats is provided for the EICAS. It is comprised of a center-mounted 6 by 8 inch color AMLCD. The EICAS utilizes: preprogrammed messages, graphical status display formats, and two keypad entry units. The keypad entry units are used to enter mission or flight control data, control aircraft systems parameters, and perform other required flight supervisory functions.

This display also incorporates the CDU functions for managing mission and flight data through the mission computers. The CDU design on the V-22 replaces most of the individual system control panels found in conventional cockpits.

CDU/EICAS Display

The CDU functions are allocated to the outside edges of the display surface, while the center portion of the display is used for the EICAS and list data. The CDU/EICAS is reconfigurable and can be used to display all CDU and/or EICAS formats in the system.

These displays can be modified by changing the CDU software to display new aircraft parameter data. The CDU keyboards provide display data to the Remote Frequency Indicator/Selector (RFIS) through a dedicated serial data bus. In addition, the system status can be displayed in both graphical and textual form upon its surface.

The default EICAS display area contains basic aircraft engine and drive train parameters (in a gauge type instrument format) as well as predefined text areas for Aircraft State Indicators (ASIs). The CDU function provides the primary means of data entry to the CMS. The CDU keyboard has 64 alphanumeric, text-editing, and dedicated function keys used for data entry and mode control of aircraft systems.

CDU Keyboard

The control and display subsystem also features two Remote Frequency Indicator Selectors (RFIS) located in the glareshield in front of each pilot. The RFIS provides for heads-up control and tuning of the onboard radios through preprogrammed communications plans.

Each of these display systems (MFD or CDU) can be updated to newer technology with modest software modifications to the mission computer software. This technology migration will be made easier because of the MIL-STD-1553 data bus interface which each of them incorporates.

2.7.4.3 Night Vision Goggle/Heads Up Display (NVG/HUD)

The V-22 is provided with a NVG/HUD system that provides the pilots with aircraft status and displayed data. A carry on display unit is provided for each pilot. It is fitted onto one side of the pilot's goggles. The side selected depends on pilot eye dominance. A switch is provided to set which side is selected so that the display symbology is properly oriented.

There are eight flight symbology display layers for each pilot which are made up of four Primary Flight Display layers – with a declutter option for each. The layer formats include forward flight, hover, navigation, and flight navigation to support the various phases of flight.

The purpose of this system is to allow the pilots to take in information on the HUD instruments without taking their eyes off the outside screen. This minimizes the pilot workload and enhances situational awareness.

2.7.4.4 Standby Flight Instruments

Standby flight instruments provide essential flight and system information should the normal cockpit displays become inoperative. These standby instruments consist of airspeed, altitude, attitude, and the SFD (which provides nacelle angle, engine performance, hydraulic system health, flap angle, and fuel quantity data).

The standby attitude indicator is a self-contained, electrically powered, and gyro-horizon. A conventional aircraft magnetic compass is also provided. These standby instruments provide a complete system for flying the V-22 until a safe landing site is available.

2.7.4.5 Crew Decision Aid Requirements

Crew decision aid requirements are defined through careful human engineering. Analyses are conducted to define minimum decision aid requirements.

Information is organized and prioritized to be consistent with the specific missions in each operating environment. This method of organization supports the efficient use of the system capabilities in all operating conditions, as verified by operational pilot input. The following guidelines were adopted and applied:

- Dedicated displays and controls are to support frequently used information. Especially, information which controls or affects the safety of flight related functions. They are functionally grouped to the maximum extent possible.

- Like-type MFD hardware is functionally interchangeable so that a maximum replacement capability exists. Where non-redundant display hardware is utilized to display flight or mission critical information, a backup display capability is also provided.

- Default MFD control layers are set as those most commonly used for normal flight operations. Underlying display and control layers are ordered in a priority based upon the frequency and criticality of use. Display control layers classified as highly critical or high usage require the least number of keystrokes to access – preferably one keystroke.

- Systems status/control displays are utilized to the maximum extent possible so that their use will: enhance rapid assimilation of information; or, significantly aid systems fault isolation of malfunctions/failures.

- Cautions and Warnings. The WCA system provides cockpit indications of abnormal aircraft/system conditions. Its components are comprised of the CDU/EICAS, master caution lights, fire pull switches, Primary Flight Control System (PFCS) fail lights, landing gear warning, parking brake on light, audio tones, and the four MFDs. Warning indications appear on the MFDs, while caution and advisory indications appear on the CDU/EICAS. Dedicated panels are used to display indications of: engine and APU fire warning, primary flight-control system failure, landing gear not down and locked, and parking brake on.

The V-22 aircraft contains many redundant systems and advanced avionics system monitoring sensors. A WCA philosophy was established to increase the usability of those systems and minimize pilot confusion.

Visual warning legends are displayed in dedicated locations within the dedicated warning area near the top of all MFDs and are augmented by a visual signal (master alert indicator on the glareshield) and a voice warning. Cautions and advisories appear on the EICAS display. Summary display of all warnings, cautions, and advisories is provided on all displays.

2.7.4.6 Cockpit Design

The cockpit incorporates a side-by-side seating configuration with access provided through a door from the cabin of the aircraft. A folding crashworthy jump seat for a third crewmember (or flight engineer) is mounted onto the forward face of the cabin/cockpit-interconnecting door. The jump seat folds up to allow the door to be opened.

The cockpit is designed and optimized to accommodate a wide range (5th to 95th percentile) of U.S. Armed Services pilots in terms of physical size and arm/leg reach. The crew stations and controls are identical on both sides of the cockpit so that the V-22 can be flown from either station.

2.7.4.7 Jump Seat

A folding jump seat is installed on the forward side of the cockpit door. The seat is qualified for use during takeoff and landing. The seat is attached to the door on fittings to allow for 13 inch (33 cm) stroke crash attenuation up to 13.5 g for a 50th percentile occupant. A four-point restraint system is also provided. In place of the jump seat, an optional flight engineer seat is designed with an extension to the front of the seat to allow comfort when leaning forward to assist in crew coordination.

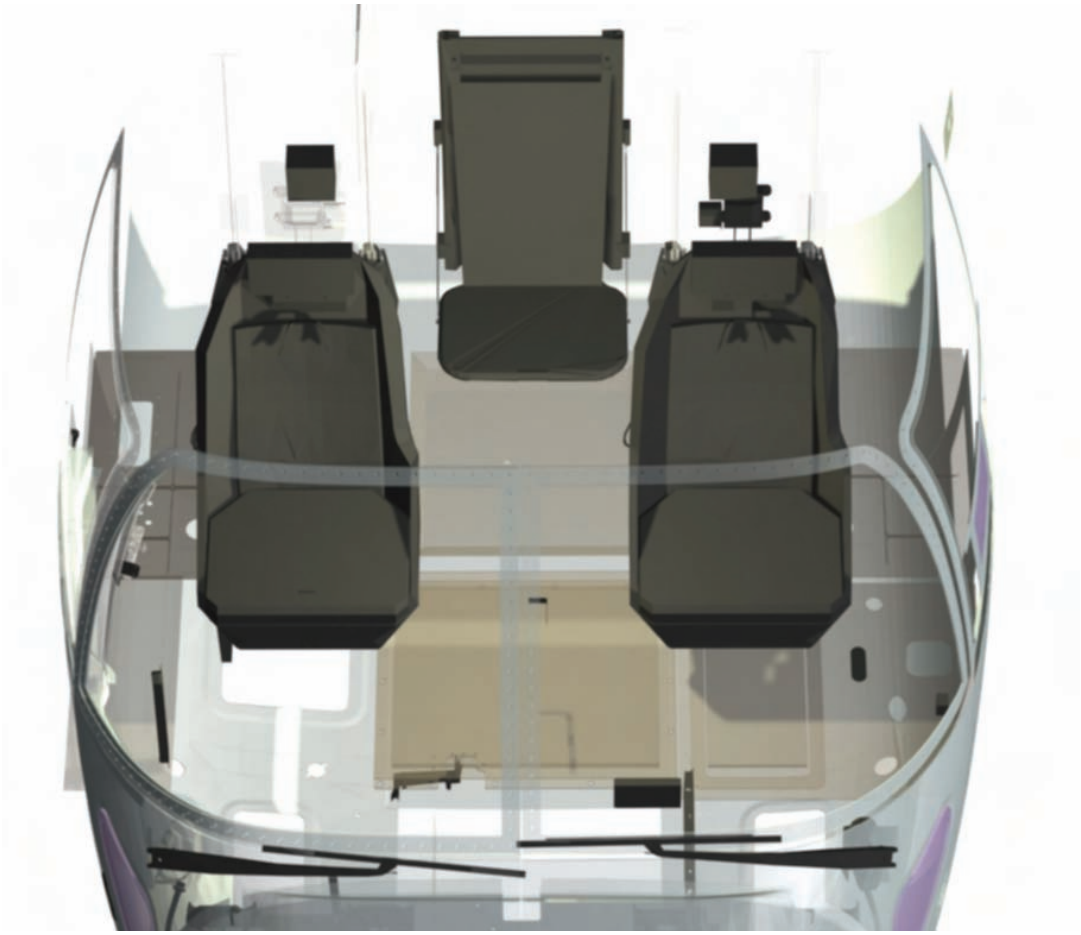
2.7.4.8 Pilot Seats

The pilot seats are interchangeable between the pilot crew stations. They provide a 14.5 g variable stroking load, 35 g forward and 20 g lateral strengths. They are mounted to seat support structure attached to the canted bulkhead. The seats are a composite bucket covered with armor plate. Each seat has a five-point occupant restraint system: lap belts, shoulder harness, and crotch strap connected to a central release mechanism. They adjust through an arc over a range of 5 in (12.7 cm) vertically and 3 in (7.6 cm) horizontally.

The pilot seats consist of a molded composite seat bucket covered with boron carbide ceramic armor plate. The polyurethane foam cushion on the seat bottom is covered with sheepskin for comfort and to provide a path for the escape of body heat and perspiration. The cushions on the seat back and headrest are fabric covered. Armrests on the left side of each seat are adjustable for both height and tilt.

If unstable and uncontrolled flight is experienced, the restraint system provides sufficient body positioning so that flight control for aircraft recovery can be maintained or an emergency escape/bailout easily initiated and operated by the crewman. A lock/unlock lever located on the lower-aft right-side of the seat bucket controls the shoulder harness inertia reel.

Crash attenuation is provided in the seating by a wire-bender energy absorption system. This system absorbs impact loads, while allowing the seat to stroke vertically up to 16 in (40.6 cm). An adjustment control must be set to the occupant's actual weight (including flight equipment). It provides a 14.5 g variable stroking load, 35 g forward, and 20 g lateral strengths.



Cockpit Arrangement

2.7.4.9 Crew Chief Seat

In addition to the 24 troop seats in the cabin, a crew chief seat is provided in the cabin area. The seat is identical to the other troop seats except it is configured with a 5-point restraint system.

2.7.4.10 Cockpit Lighting

Cockpit lighting is fully compatible with an NVG HUD night vision imaging system. Thus, the aircrew is provided with the capability for night operations.

Cabin lighting consists of dome lights, the Forward Cabin Control Station (FCCS) panel, the Intercommunication Set Control (ISC) panel, compass bezel, and the EELS. Dome lights are located overhead, centered laterally, spaced along the length of the cabin. The dome lights are selectable between Night Vision Imaging System (NVIS) compatible and white illumination.

2.7.4.11 Crew Coordination

The avionic system has been designed so that either pilot can perform all of the mission functions effectively, while giving due attention to his assigned flight duties during each stage of the mission profile. Cockpit controls and displays are arranged so that either pilot may fly the aircraft and monitor all phases of the operation.

Because the aircraft can be flown from either pilot station, Crew Systems employs the concept of a Pilot Flying (PF) and a Pilot Not Flying (PNF). The crew coordination concept on the flight deck calls for the PF and the PNF to perform complementary duties with a work split. The work split allows for separate and distinct tasks to be performed by separate crewmembers. Pilot displays can be individually set to allow for a work split.

2.8 Mission Planning System

The V-22 provides both onboard and ground-based mission planning systems (MPS). The onboard systems support mission replanning in flight, while the ground-based systems support preflight planning, postflight planning, and debriefing functions.

2.8.1 Ground-Based Mission Planning System

V-22 MPS

The Windows NT® based MPS includes: a laptop PC (with a ruggedized case), a SCSI II interface adapter (for loading the Digital Map System [DMS] Remote Memory Unit [RMU]), a printer (for generating pilot knee cards), and associated interface cables.

The V-22 MPS incorporates:

- Digitized maps, charts, diagrams, photos, landing and departure plates, and checklists in the aircraft as well as enroute planning;
- Threat information and terrain masking in route planning;
- Entry of waypoints;
- Generation and evaluation of multiple flight plans;
- Computation of aircraft weight and balance through a planned mission;
- Preselection of mission communication and navigation frequencies;
- Provisions for checklists, diagrams, charts, and other information on hard copy outputs (e.g., color printouts, transparencies), typically used on pilot kneeboards or for mission briefs;
- A Mission Data Loader (MDL) cartridge to upload flight and communication plan data, and GPS almanac data; and
- Full support of the V-22 flight modes (fixed-wing mode, rotary wing mode, intermediate "VSTOL" mode) and transition between modes.

The ground MPS can overlay map data with threat, weather, navigation, and mission scenario information to determine mission feasibility and safety as well as generate primary and alternate flight plans. Once a flight plan is defined, the MPS data can be uploaded into the aircraft. The system can also output data for use on kneeboards, color printouts, and/or transparencies.

In its postflight mode, the ground MPS can analyze and compare preflight data, postflight data, and provide reports. The MPS provides full support of all V-22 flight modes and transition between modes. Additionally, the pilot can choose to upload a modified file for use after it was modified in the cockpit. This capability allows the cockpit to serve as an alternate Mission Planning System that can generate or modify mission plans which can then be transported to other V-22 aircraft and uploaded for their mission plans.

2.8.2 Onboard Mission Replanning

After the mission has commenced, the Cockpit Management System (CMS) provides the capability to update the following databases: communication plan, waypoint, threat information, and flight plan.

- The communication plan database includes the definition of clear and secure channels as well as SATCOM channels.

- The waypoint database defines specific geographic locations. It includes waypoints in the flight plan, or a point of interest not specifically on the flight plan.
- The threat database provides the capability to transfer threat data to the data transfer module.
- The flight plan database consists of a departure waypoint, intermediate waypoints, flight legs, and a destination waypoint.

The communication plan can be updated manually via the CDU control layers. Waypoints, threats and flight plans can be updated manually via CDU control layers, or graphically using a combination of MFD control layers, CDU control layers, and track handle functions. Once an update is made to the active flight plan (including the modification of a waypoint in that flight plan), all of the flight plan's parameters are automatically recomputed. An alternate flight plan is recomputed by operator command only.

At the end of the mission, the pilot can download a modified flight plan or communication plan to the MDL cartridge which can be uploaded for future missions, and can also be hand carried to other aircraft to allow for sharing of modified mission plans.

2.8.2.1 Replanning System Interface to the Digital Battlefield

The operator has the ability to modify the flight plan, waypoints, flight legs, the communications plan, and threats. The operator uses the existing avionics mission management functions to update the flight plan and update any new threat information.

Using the available multimission advanced tactical terminal and an additional SATCOM antenna, the V-22 is able to integrate intelligence updates and detected threat data into the avionics system. Intelligence updates are displayed to the operator on the digital map system. When updates of this kind are received, conflicts with the preplanned flight path are identified to the pilots.

2.8.2.2 Display of Updated Tactical Information from the Digitized Battlefield

Intelligence updates are entered into the avionics system by editing the existing symbology or by adding a symbol via the MFD controls (bezel keys). The display of information is similar to preplanned mission symbology. The operator, however, is allowed to edit a few selected fields, such as the threat symbol display text displayed under each threat symbol.

The V-22 can incorporate a unique display system symbology to identify the source of the newly received intelligence data (i.e., detected or received).

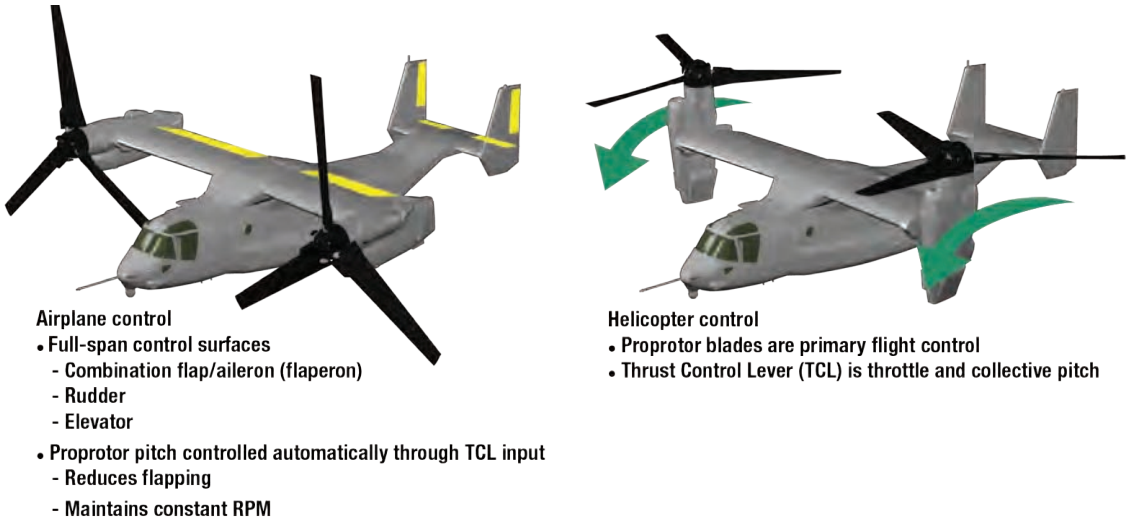
2.9 Aircraft Flight Control

2.9.1 How Tiltrotors Fly

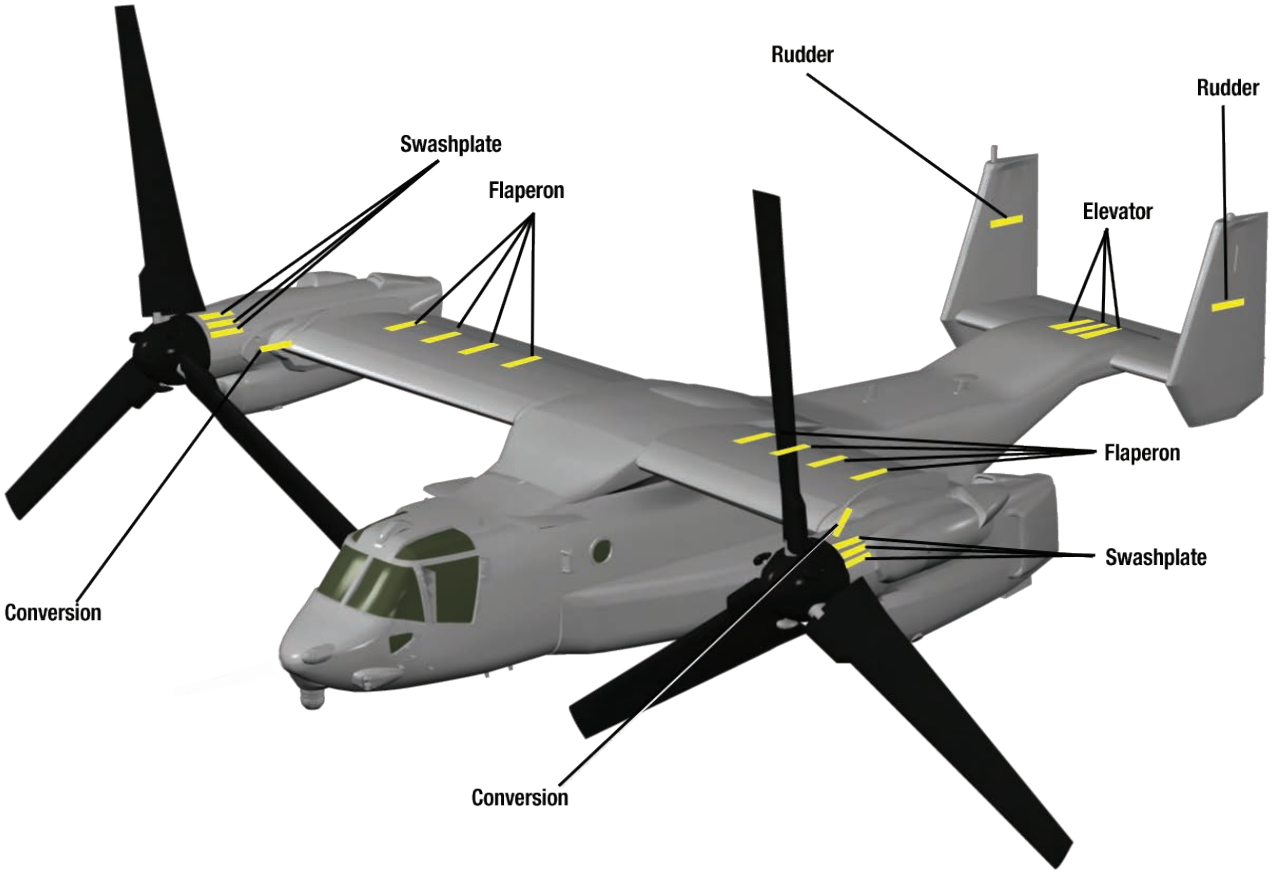
The V-22 tiltrotor combines the vertical takeoff and landing capabilities of helicopters with the speed and range of conventional fixed wing aircraft. As such, tiltrotor flight control mechanization and pilot control strategy is similar to helicopters in hover and low speed operating conditions and more resembles a fixed wing aircraft in high speed cruise. The principle characteristic of the tiltrotor is a moveable proprotor at the end of each wingtip. The rotors are oriented in a horizontal plane for hover and low speed flight to provide lift for the aircraft. They tilt down to a vertical plane for airplane mode to provide propulsive thrust with lift provided by the wings similar to a conventional airplane. This section describes the components and systems used to enable flight through the full range of speeds and proprotor position.

The thrust vectoring control is achieved through the nacelle thumbwheel on the Thrust Control Lever (TCL). Forward or aft displacement of the thumbwheel from center commands the nacelles to rotate at a rate proportional to the displacement up to a maximum of 8 deg/sec. The thumbwheel is used to transition between helicopter, conversion, and airplane modes. The desired flight path is achieved through proper coordination of TCL, longitudinal and lateral control stick, and pedals. The fuselage and wing remain relatively level during the entire transition. Continuous trimmed flight can be maintained safely at any nacelle angle between helicopter and airplane mode.

The figure below shows the aircraft flight control mechanisms in the airplane and helicopter mode configurations.



Flight Control Mechanisms



Hydraulic Flight-Control Actuators

The V-22 proprotors and control surfaces are commanded by hydraulic actuators, with types and locations shown in the figure. These include three swashplate actuators per rotor (six total actuators), two actuators per flaperon (four flaperon surfaces, for eight total actuators), one actuator per rudder (two rudders), three actuators on the elevator, and three drive units per nacelle conversion actuator (two nacelles for six total drive units).

2.9.1.1 Proprotor Control

In each nacelle, there are three dual hydraulic swashplate actuators connected to the stationary portion (inner ring) of the swashplate. The rotating portion (outer ring) of the swashplate rides on top of the stationary swashplate and transmits pitch change commands from the actuators to the proprotor blades. The swashplate assembly moves in response to flight control commands on a mast-mounted gimbal ring. Each proprotor is powered by the engines through the proprotor gearboxes.

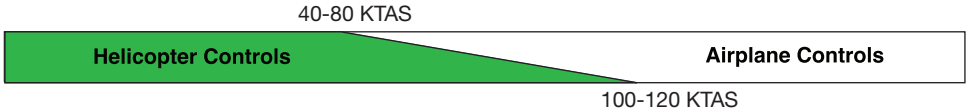
- When the three actuators extend or retract as a group, the proprotor blades change pitch-angle collectively. This change in pitch angle causes the thrust to increase or decrease correspondingly. The Flight Control Computer (FCC) maintains constant proprotor rpm during changes in collective pitch by corresponding increasing or decreasing engine power output commands.

- When the three actuators extend or retract individually, the rotor blades change pitch cyclically as the rotor turns. This cyclic change causes the proprotor disk to tilt, which produces changes in the direction of the proprotor thrust.

The combined collective and cyclic inputs provide rotor control.

2.9.1.2 Transition and Conversion

During takeoff and low speed flight, the pilot's controls work like those of a conventional helicopter - nearly all the control effectiveness is through the rotors. As airspeed increases, the wing and tail surfaces become more effective. Correspondingly, the pitch, roll, and yaw control transfers from the rotors to the elevator, flaperons, and rudders. During transition to the airplane mode, the cyclic rotor controls are gradually phased out by the fly-by-wire flight control system. This control phasing is automatically managed by the flight control system and is transparent to the pilot.

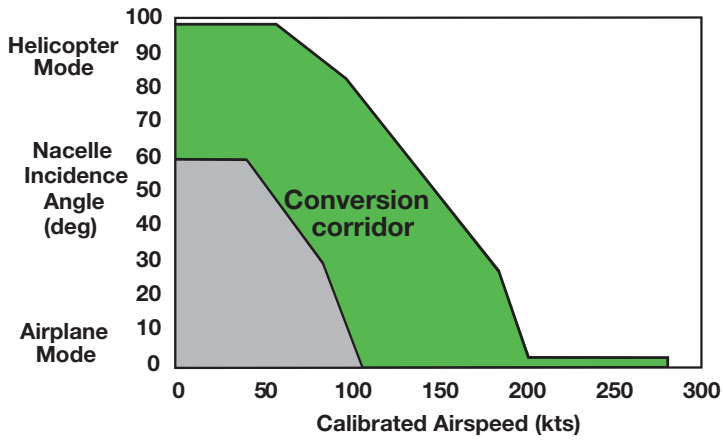


Through the use of the nacelle and traditional controls, the aircraft may be flown at any nacelle angle between helicopter and airplane modes within the conversion corridor. Full transition from helicopter mode to airplane mode begins when the nacelles are rotated forward from 90°, and is completed when the nacelle angle is 0° (i.e., the nacelles are on the downstops).

In airplane mode the rotor speed is reduced from 100% (397 rpm) in the helicopter (V/STOL) and conversion modes to 83.9% (333 rpm). This is done to obtain optimal rotor cruise efficiency within structural load limits.

The V-22's ability to control the direction of its thrust vectors by tilting the proprotor nacelles or by rotor longitudinal cyclic, gives pilots a limited ability to control the aircraft's attitude independent of its flight path. Each pilot has a separate thumb-wheel control built into the thrust control lever, which provides vernier control of the nacelle position.

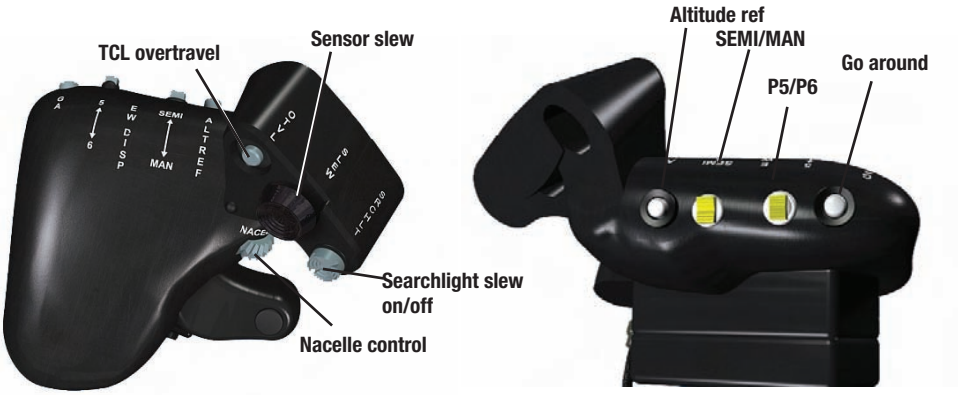
Automatic conversion corridor protection has been incorporated into the design of the flight control system. As the maximum allowable airspeed for a given nacelle is approached, the nacelles are automatically lowered towards airplane mode. If the pilot commands the nacelles down too quickly then conversion protection will modulate nacelle rate to avoid airspeeds that are too low for the wing to develop the necessary lift as the conversion progresses.



Conversion Corridor

2.9.1.3 Controls

The primary pilot flight controls consist of cyclic sticks located in front of each crew seat, thrust control levers mounted to the left of each seat, and floor-mounted directional pedals. The pilot and copilot controls are mechanically connected under the cockpit floor by push-pull control tubes. Position transducers detect control displacements in each of the four axes and relay this information directly to the FCCs. These computers directly command the aircraft's flight control actuators. The rudder pedals also control the nose wheel steering and the wheel brake systems.



Thrust Control Lever (TCL) Switches

The following control switches are installed on each thrust control levers grip.

- **Nacelle Control Switch** – A knurled-rotary thumbwheel-switch (spring loaded to center) used to control the nacelle position conversion through the actuators.
- **TCL Overtravel Button** – Depression of this button allows the TCL to travel to the overtravel position.

- **Searchlight Control Switch** – A momentary five-position switch used to control searchlight operation.
- **Sensor Slew/Capture Switch** – A momentary five-position switch used to control the FLIR or map system operation.
- **Altitude Reference** – A momentary pushbutton switch. It is one of two methods used for setting the reference altitude for the flight director and coupler (autopilot).
- **SEMI/MAN** Chaff/Flare Dispense Switch – A momentary three-position switch used to dispense chaff/flare. The distribution of the chaff/flare is dependent upon the selected mode.
- **P5/P6** – A momentary three-position switch used to select the chaff/flare dispense sequencing program.
- **Go Around Switch** – A momentary pushbutton switch that allows selection of the "Go Around" flight director function.

Cyclic Control Grip

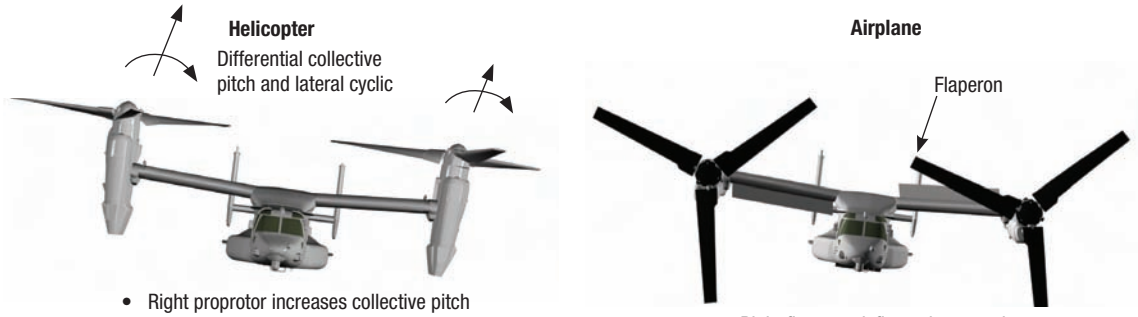
Cyclic control sticks are installed in the cockpit in front of each pilot seat. Each stick provides lateral and longitudinal control inputs to the Flight Control Computers (FCCs.) The following switches are installed on each cyclic stick grip:

- Trim release switch (MAG BRAKE/FLIGHT DIRECTOR DECOUPLE) – A momentary pushbutton switch used primarily to release trim.
- MFD cursor switch (MFD MODING CURSOR) – A momentary four-position switch that provides the pilot with the ability to manage the MFD hands-on.
- NVG/HUD control switch (HMD MODE) – A momentary four-position switch that provides the pilot with the ability to manage the NVG/HUD.

- Trim control switch (TRIM BEEP) – A momentary four-position switch that provides the pilot with a trim function to minimize control forces during steady-state flight conditions.
- Intercommunication radio control switch (ICS/RADIO TRANSMIT) – A momentary pushbutton switch used to select intercommunication transmit for internal communications or radio transmit for communications outside the aircraft.
- Cargo release switch (CARGO HOOK RELEASE) – A momentary pushbutton switch used to release the cargo hooks during normal sling load operations, if electrical release is enabled.

The wing flap control-lever is located on the aft-right side of the center instrument panel. The aircrew can select manual flap detents for FULL (72 deg), 40 deg, 20 deg, 10 deg, and 0 deg. In the AUTO detent, the flight control system automatically positions the flaps as a function of airspeed and nacelle throughout the flight envelope, alleviating the need for the aircrew to change flaps during conversions.

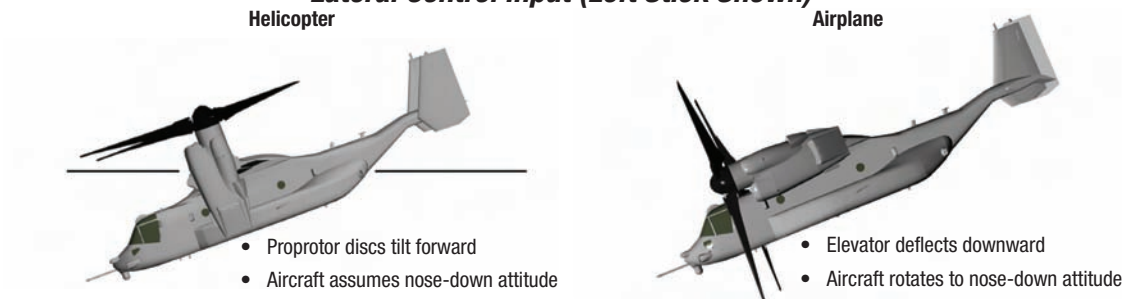
The pilot TCL and cyclic control inputs are used for full envelope vehicle flight control, with appropriate automatic phasing of rotor control and control surface (flaperons, elevator, rudders) deflections. The figures following illustrate the effect of the pilot's control input on the actuator commands and resultant motions of aircraft, in both helicopter and airplane modes.



- Right proprotor increases collective pitch
- Left proprotor decreases collective pitch
- Proprotor discs tilt to left
- Aircraft rolls to left

- Right flaperon deflects downward
- Left flaperon deflects upward
- Aircraft rolls to the left

Lateral Control Input (Left Stick Shown)

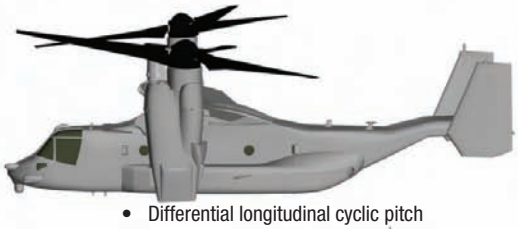


- Proprotor discs tilt forward
- Aircraft assumes nose-down attitude
- Airspeed increase

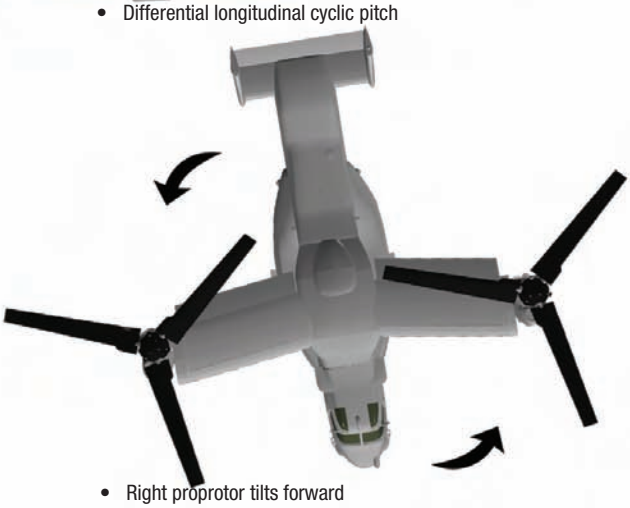
- Elevator deflects downward
- Aircraft rotates to nose-down attitude
- Altitude decreases
- Airspeed increases

Longitudinal Control Input (Forward Stick Shown)

Helicopter



- Differential longitudinal cyclic pitch



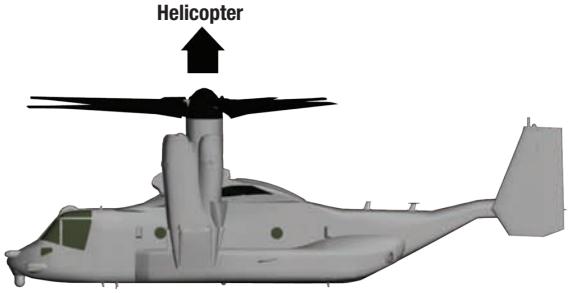
- Right proprotor tilts forward
- Left proprotor tilts aft
- Aircraft yaws left

Airplane

- Rudders deflect to the left
- Aircraft yaws left

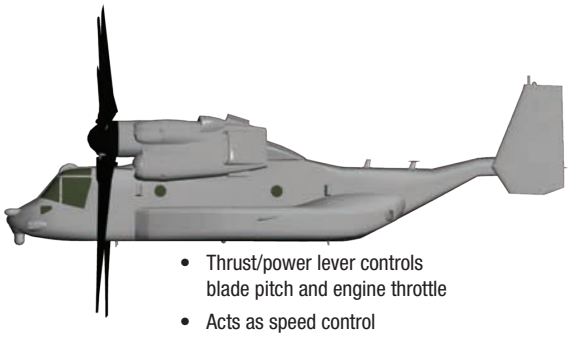
Directional Control Input (Left Pedal Shown)

Helicopter



- Thrust/power lever controls proprotor collective pitch and throttle
- Acts as altitude control

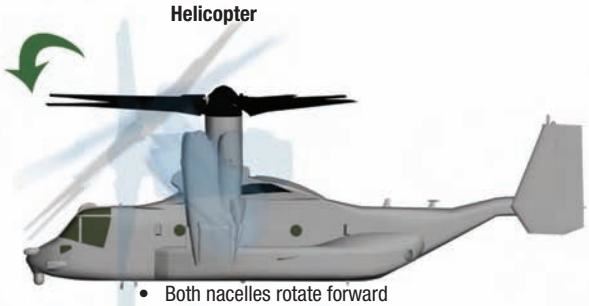
Airplane



- Thrust/power lever controls blade pitch and engine throttle
- Acts as speed control

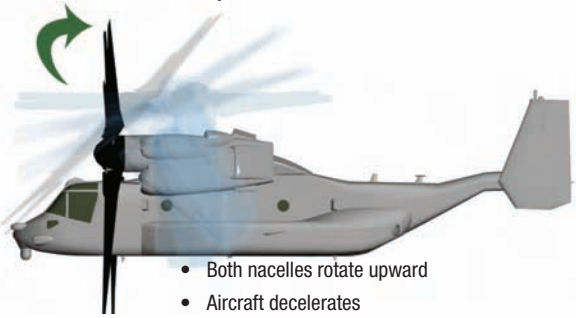
Thrust/Power Input (Forward/Increase Shown)

Helicopter



- Both nacelles rotate forward
- Aircraft accelerates

Airplane



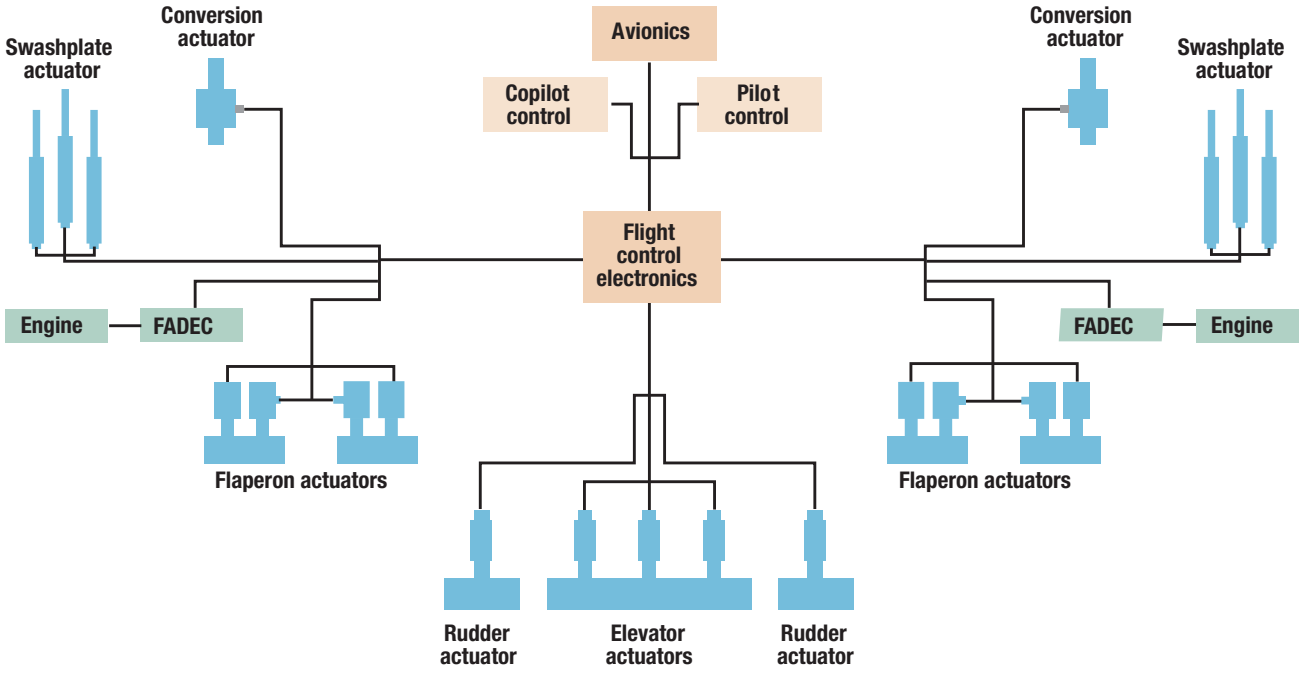
- Both nacelles rotate upward
- Aircraft decelerates

Nacelle Control Input

Flap Input

2.9.2 Flight Control System

The V-22 Flight Control System (FCS) is an electronic fly-by-wire system. The digital flight control laws offer exceptional flexibility for rotary wing and fixed wing flight, and provide effective and smooth control throughout the operating envelope.



FCS Block Diagram

The FCS is designed to ensure stability and control, acceptable flying qualities, and structural loads limiting throughout all flight regimes. It also provides ground operations and maintenance support capabilities. There are three Flight Control Computers (FCCs). Each is capable of verifying the incoming signals locally as well as in conjunction with the other FCCs through a cross channel data link for redundancy management. Checks include validity, range, rate of change, and cross channel compare. There are redundant electrical systems to provide power to the FCCs.

The primary input to the FCCs is the cockpit controls. Pilot and copilot controls in each axis are mechanically cross-coupled and linked to a force drive actuator to provide force feedback and trim functionality. Cockpit Control Position Transducers (CCPT) attached to the linkages provide control positions to the FCCs through an analog-wiring interface. Analog to digital conversion occurs within the FCCs. Other important analog inputs to the FCCs include rotor azimuth/rpm, rotor flap angle, mast torque, nacelle thumbwheel, flap lever, engine control lever (ECL), and aircraft angle of attack.

There are also many discrete button and switch inputs to the FCCs. Some, such as landing gear "weight on wheel" switches, are directly wired to the FCCs. However, most of the cockpit buttons and switches relevant to the FCS are wired redundantly to Cockpit Interface Units (CIUs) that in turn transmit to the FCCs over a MIL-STD-1553B digital bus. Other critical sensor inputs supplied over the MIL-STD-1553B digital bus include the Air Data Units (ADUs) and Light Weight Inertial Navigation Systems (LWINS).

Two of the main digital processes executed within the FCCs include Primary Flight Control System (PFCS) and Automatic Flight Control System (AFCS). The PFCS and AFCS control laws use the pilot control inputs and sensor inputs to generate swashplate, control surface, and engine power demand commands. Power demand to the engines is sent via MIL-STD-1553B digital bus to the Full Authority Digital Engine Controllers (FADEC) of which there are two per engine. Swashplate and control surface commands are converted from digital to analog within the FCCs, which in turn are wired to the hydraulic actuators.

The Primary Flight Control System (PFCS) is designed with system redundancies to provide safe continued flight following any two control system failures. The Automatic Flight Control System (AFCS) is designed with limited authority and provides the necessary augmentation for Level 1 Handling Qualities to aid mission performance. The AFCS is also interfaced to the mission system to support the flight director and autopilot (coupled) modes. Both PFCS and AFCS subsystems contain parts of the Structural Loads Limiting (SLL) system to protect the aircraft structure from excessive loads due to very aggressive pilot inputs.

2.9.2.1 Primary Flight Control System (PFCS)

The PFCS consists of the basic longitudinal, lateral, directional, thrust, and nacelle control systems. It also provides mixing and limiting functions for rotor and control surface commands to the actuators. The PFCS control laws translate pilot inputs and AFCS commands to the appropriate control surface deflection, depending upon mode of flight and the existing flight conditions. Some functions of the PFCS within the FCC include:

- **PFCS Pitch Rate Damping/Angle of Attack Limiting** - In steady airplane mode maneuvers, it limits the maximum achievable angle of attack of the aircraft. It also provides full time pitch rate damping.
- **Torque Command Regulating System (TCRS)** - generates engine and rotor commands to provide linear mast torque response to thrust axis input commands, up to specified mast torque limits.
- **Rotor RPM Governor** - generates engine and rotor commands to maintain rotor RPM at the selected value.
- **Manual flaps** - provides pilot-commanded direct flap control.
- **Flapping Trim Controller** - reduces excess steady state rotor flapping.
- **Control Power Management System (CPMS)** - limits rotor cyclic commands to prevent excessive rotor blade flapping.
- **Conversion Protection System** - prevents the nacelles from exceeding structural or aerodynamic limits.
- **Engine Start logic** - provides the ability to smoothly start-up and shutdown the engines.

2.9.2.2 Automatic Flight Control System

The AFCS provides stability augmentation such as rate damping, attitude retention, heading hold. The AFCS also interacts with the Integrated Avionics System (IAS) to provide control loop closure for coupled (autopilot) guidance and navigation modes. Flight director and coupled modes are described in a subsequent section. Some functions of the AFCS within the FCC include:

- **Pitch Stabilization** - Provides for a pitch attitude command / attitude hold response type.
- **Roll Stabilization** - Provides for a roll rate command / attitude hold response type.
- **Yaw Stabilization and Heading Hold** - Provides yaw rate damping. Provides a heading hold function below 50 KCAS when the pilot is not commanding pedal inputs from trim. The directional command response is yaw rate command/heading hold.
- **Automatic Turn Coordination** - Provides automatic turn coordination above 50 KTAS. The turn coordination loop maintains a ball-centered condition throughout the turn.
- **Vertical Velocity Compensation** - Provides vertical axis damping in helicopter and conversion mode.

2.9.3 Flight Director System

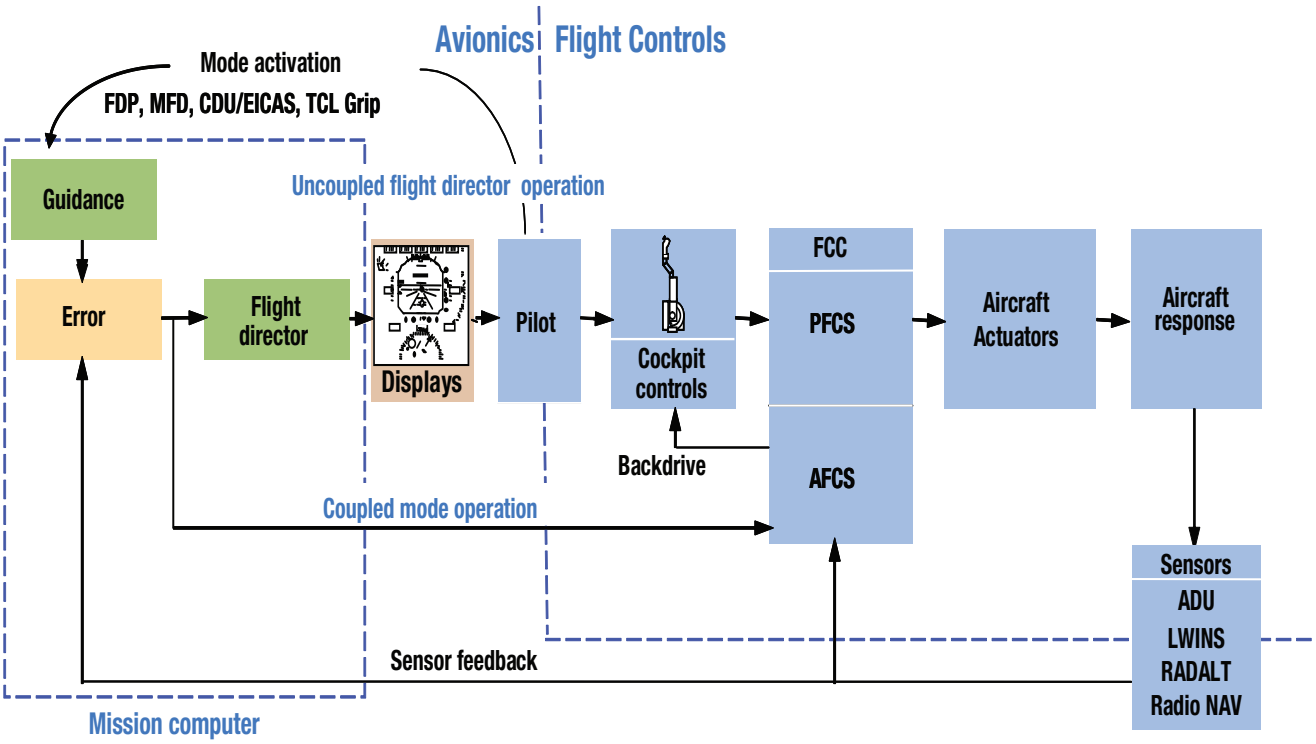
The flight director system provides command symbology to the pilot, used to maintain the aircraft along selected flight modes. The commands include: longitudinal stick (pitch), lateral stick (roll), thrust control lever (power), and nacelle. The flight director can be used for core flight path control (airspeed, barometric altitude, and/or heading), inertial navigation (waypoint direct, flight plan, or search pattern), electronic navigation (VOR, ILS, TACAN), and specialty modes (approach to hover and go-around). Each of these modes can be flown uncoupled (symbology guidance only) or coupled (limited authority commands provided to the flight control system.) An autonacelle mode is available for any speed mode during both uncoupled and coupled operation. Additionally, a non-flight directed hover coupled mode is available. This mode provides radar altitude hold in vertical axis and either a position hold or groundspeed hold up to 50 KTAS in the ground plan axes. The pilots can allow the crew chief to adjust groundspeed between 0 to 10 KTAS using a remote hover controller in the aircraft cabin.

The flight director system has four primary crew interfaces:

- The Flight Director Panel (FDP), which provides primary mode control and displays command references for the flight director functions.
- The TCL grip, which includes altitude re-reference and the go-around mode activation buttons.
- The Control Display Unit/Engine Instrument and Crew Alerting System (CDU/EICAS), which is a center console display and keypad that includes sub-mode selection and setup for flight director functions.
- The MFDs (four), which include display of flight director commands and mode status annunciators.

The FDP provides control and display for the flight director functions and is centrally located on the glare shield, along the aircraft centerline, between the right and left remote frequency indicator selector displays for use by either aircrew member. It incorporates operational functions of the flight director allowing mode reconfiguration based on either flight path obstacles or navigation/ flight path change requirements. The panel displays flight director data to the flight crew under both day (direct sunlight and shade) and night conditions. The FDP is NVIS compatible.

Flight Director Panel (FDP)



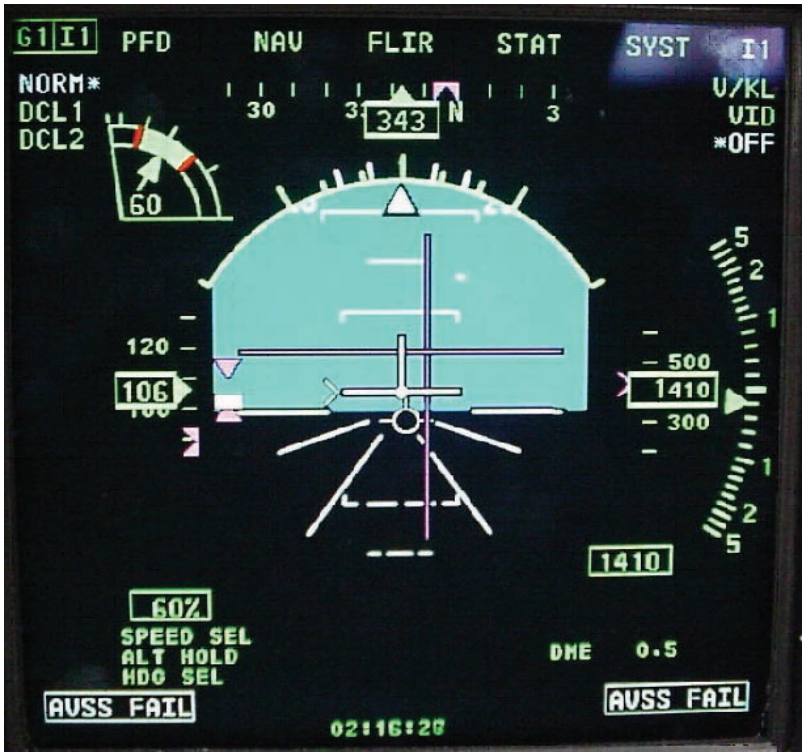
Flight Director and Coupled (Autopilot) Mode Architecture

During operations with the Flight Director, longitudinal, lateral, and vertical command profiles are computed based on the pilot settings and planned flight scenarios, which generate steering commands displayed on an MFD. The flight director symbology directs the pilot where to position the longitudinal stick, the lateral stick, thrust control lever, and nacelles.

- For uncoupled flight director operation, the pilot responds with the appropriate flight control inputs to satisfy the flight director steering commands, and the aircraft will converge on the reference values selected. The flight director "fly-to" symbology for the aircraft attitude control is displayed on the MFD as an overlay of the Primary Flight Display or the Vertical Situation Display pages. In general, these displays provide basic airspeed, nacelle angle, pitch attitude, roll attitude, barometric altitude, radar altitude, rate of climb, flight path angle, heading, and drift information.
- For coupled operation, the errors are sent to the flight control system to compute commands to null the errors and converge on the selected reference values. The flight control system commands the appropriate rotor and control surfaces as well as backdrives the cockpit controls. Although no pilot input is required during the operation of the coupled mode, the flight director commands are still displayed to allow the pilot to monitor the coupler.
- Nacelles are typically in autonacelle mode for both uncoupled and coupled operation to alleviate pilot workload. Autonacelle works in conjunction with autoflaps.

A typical Flight Director MFD display is shown below –

- Nacelle position indicator in the upper left corner,
- Flight director commands for the longitudinal and lateral stick shown as the command bars referenced to the aircraft attitude symbol (inverted T) in the center of the display, and
- Flight director power command is shown on the left side of the display as a pair of inward pointing triangles referenced to a rectangular box adjacent to the airspeed tape.



Typical Flight Director MDF Display

2.10 Electrical System

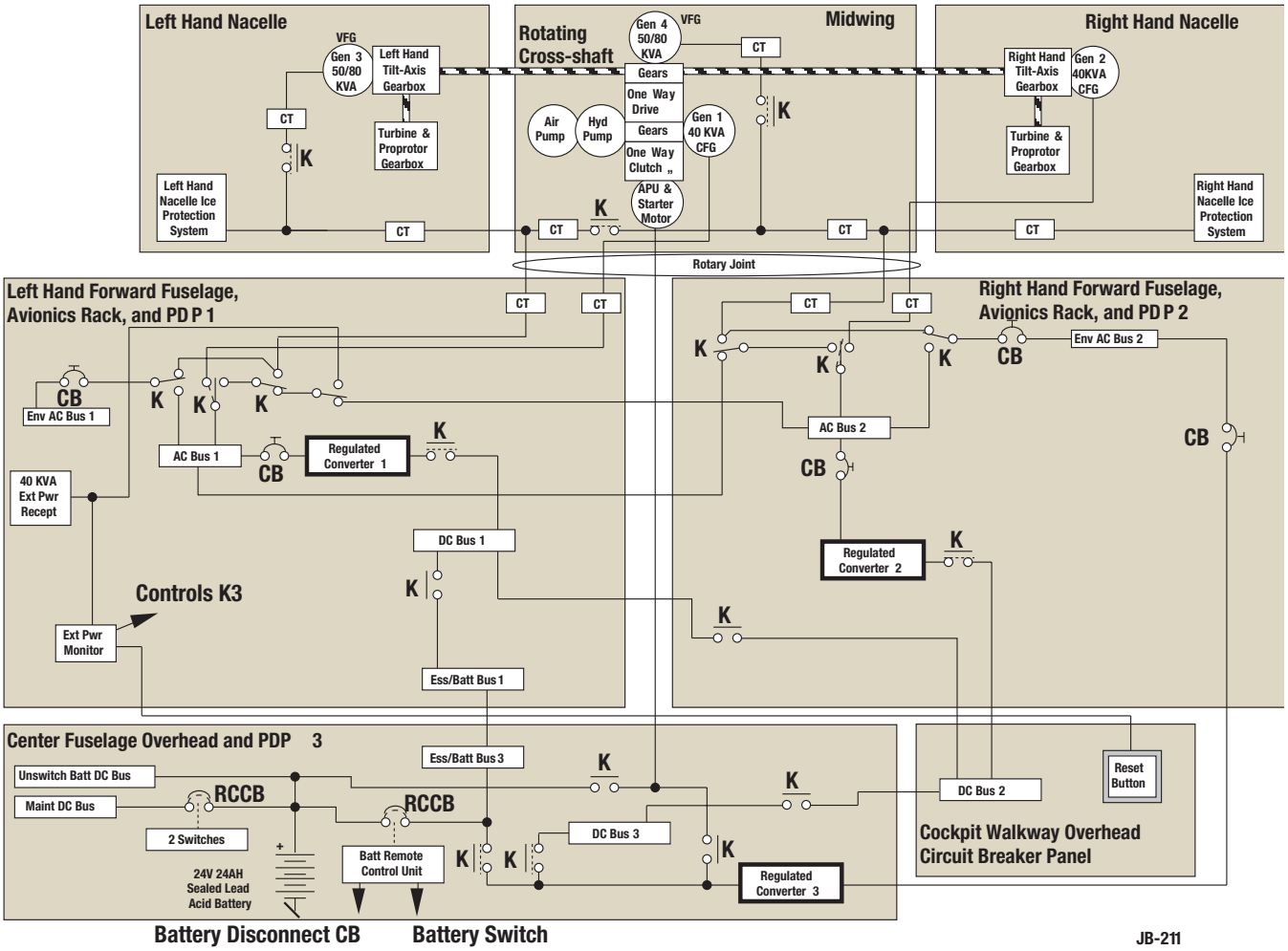
2.10.1 Power Generation and Distribution

The V-22 is equipped with multiple AC power sources, multiple AC to DC converters, and a large capacity battery to provide AC and DC power to aircraft systems. The four generators are capable of producing up to 240 kVA. The three AC to DC converters are capable of providing up to 600 A. The crossties designed into the electrical bussing arrangement allow individual power sources to automatically provide back-up power to the aircraft systems (including deicing and heaters). Power may also be provided to the aircraft systems by an external AC ground power source or by a generator driven by the on-board APU. There are four utility electrical outlets provided in the cabin.

2.10.1.1 AC Electrical System

The V-22 AC electrical system supplies power to: the primary aircraft AC electrical loads, the ice protection system, and the environmental control subsystems. The AC power system consists of:

- Two Constant Frequency Generators (CFGs),
- Two Variable Frequency Generators (VFGs),
- Associated Current Transformers (CTs), and
- Bus contactors.



Legend			
—— De-energized State ····· Normal State	K - Contactor CT - Current Transformer CB - Circuit Breaker	AC - Alternating Current DC - Direct Current	RCCB - Remote Control Circuit Breaker

Electrical Power Distribution System

Constant Frequency Generators

The two identical and interchangeable constant frequency generators (CFGs) are rated at 40 kVA each. They supply 115/200 VAC, 400Hz power to the primary AC electrical system busses. CFG 1 is driven by the midwing gearbox (MWGB) and CFG 2 is driven by the right tilt-axis gearbox. Each CFG uses its associated gearbox lubrication system for cooling. In the event of a CFG failure, an automatic bus tie will automatically disconnect the failed generator from its bus and allow the other operating generator to assume the load of both busses.

Variable Frequency Generators

The two identical and interchangeable variable frequency generators (VFGs) are rated at 50 kVA hot day /80 kVA cold day each. They provide 115/200 VAC, 360 to 457 Hz power to the Nacelle Ice Protection and ECS busses. VFG 4 is driven by the MWGB and VFG 3 is driven by the left tilt-axis gearbox. Each VFG has its own cooling system, independent of the gearbox lubricating system. Each VFG contains a separate 420 VA Permanent Magnet Generator (PMG) winding dedicated to supplying power to the FCS. In the event of a VFG failure, an automatic bus tie will automatically disconnect the failed generator from its bus and allow the other operating generator to assume a limited portion of the ice protection load of the failed generator.

Current Transformers

There are 10 current transformers (CTs) in the AC Power System. They measure current in the feeder lines and enable the generators to identify and isolate a failure in the feeder lines.

AC Power Contactors

Ten contactors direct the flow of power between the four generators and the six AC busses. In the event of a generator failure, crosstie contactors provide alternate sources of power to the AC busses.

Four generator control switches and an external power control switch are located on an overhead panel in the aft part of the cockpit.

Power Distribution

The AC power is distributed as 115/200 volt (3-phase), and 115-volt, (single phase). There are four utility electrical outlets provided in the cabin.

2.10.1.2 DC Electrical System

The V-22 DC electrical system supplies 28 Volts Direct Current (VDC) to the flight-essential systems, the primary aircraft DC electrical loads, the electrical components powered from the essential bus, and the electrical components powered from the battery bus. The DC electrical system consists of:

- Three AC to DC regulated converters (RCU 1, RCU 2, and RCU 3)
- A 24 volt battery with integral heater
- A battery indicator and test panel
- A Battery Relay Control Unit (BRCU)
- An external battery disconnect panel
- Nine power contactors

Battery

The battery is a sealed lead-acid battery. It provides 24 VDC and is rated at 24 amp hours. It is located in the cabin ceiling.

At an 80 percent charge, the battery provides sufficient power for pressure fueling of the aircraft, a 3-minute prestart period, and two APU start cycles. After having performed these activities, the battery will still have greater than 40 percent capacity remaining. The battery is automatically charged by the DC electrical system.

If all onboard generators fail, the installed battery will provide 20 minutes of emergency power for all flight-essential equipment. A thermostatically controlled heater is built into the battery case so that the battery's performance is improved during cold temperatures.

DC Regulated Converters

The regulated converters provide AC to DC conversion for those systems requiring DC voltage. The DC busses remain at 28 VDC regardless of any fluctuations in AC bus voltage or DC bus loading. These regulated supplies and busses result in significant advantages. One advantage is a higher bus voltage reduces the required wire weight by permitting increased voltage losses. The regulated converters also monitor and provide control of the DC electrical system.

Battery Indicator and Test Panel

An NVG compatible battery indicator and test panel is located on the overhead console in the cockpit. The console provides a direct reading of the battery voltage level and allows for the battery to be selected ON/OFF.

Battery Relay Control Unit

The battery relay control unit (BRCU) is a solid-state device that automatically disconnects the battery from the aircraft DC busses after five minutes of ground operation without any AC sources powering the aircraft. This is done in order to prevent battery drain during ground servicing.

External Battery Disconnect Panel

An external battery disconnect panel is provided on the right aft sponson. This panel provides the ground crew a means to turn off aircraft battery power without entering the aircraft.

DC Power Contactors

Nine identical and interchangeable contactors are used to connect the DC power sources to their respective busses. In the event of regulated converter or main-bus contactor failure, they provide an automatic crosstie connection.

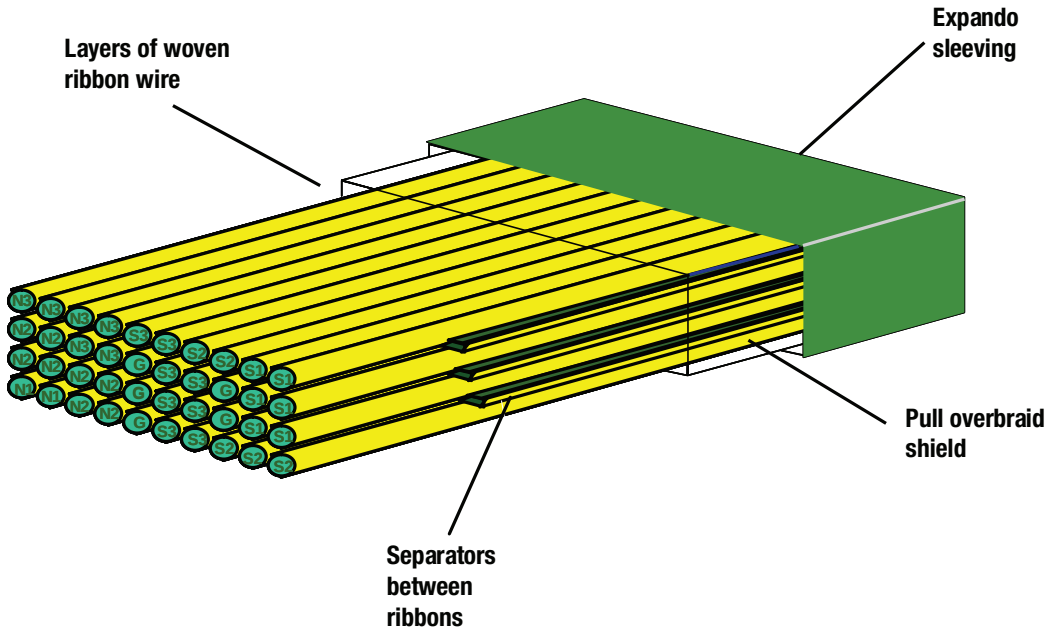
Power Distribution

The DC power distribution system consists of four busses and the associated contactors. The primary DC loads are supplied by DC busses No. 1, No. 2, and No. 3. Flight-essential loads are supplied from the essential bus, the battery bus, and PMGs.

2.10.1.3 Wiring

The aircraft wiring is a combination of integrated and conventional wiring. Conventional wiring is used in harnesses of less than six wires only, or where it is more suitable than integrated wiring.

The integrated wiring consists of woven round wire ribbon separated by foil shields. The signals are organized on the ribbons. Carefully arranged and organized wires ensure signal compatibility and avoid interference among signals on adjacent wires. The ribbon assembly is protected by pull-on overbraid shielding and an external sleeve. Each wire is uniquely marked for ease of troubleshooting. Wire repair is made with conventional tools and hardware.



Ribbonized Wiring System

Careful arrangement is very important for electromagnetic interface (EMI) considerations. Each wire location is fixed and repeated from aircraft to aircraft, thus enabling consistently good EMI performance on all aircraft.

Wiring Integration Assemblies (WIAs) are used to connect both the integrated and conventional wire harnesses. The wire harnesses are run in trunk-line fashion between the WIAs. This arrangement greatly simplifies replacement of a damaged harness.

2.10.1.4 External Electrical Power

The external power receptacle is located forward of the left sponson. It provides the capability to apply 115/200 VAC, 3-phase, 400 Hz power to the aircraft from an outside source for ground maintenance. The external power system connects, disconnects, and monitors the external electrical power applied to the aircraft.

2.10.2 Lighting

The V-22 is equipped with multiple cockpit, passenger compartment, and exterior lighting systems.

2.10.2.1 Cockpit Lighting

Cockpit primary lighting consists of:

- Electroluminescent and incandescent internal panel lighting,
- Illuminated switches, and
- Cockpit indicators used during day and night operations.

The cockpit secondary lighting provides an alternate source for illuminating the flight compartment and consists of:

- Cockpit dome lights (2),
- Cockpit utility lights (2),
- Secondary console lighting, and
- Alternate power for console panel illuminated switches.

All cockpit lighting (except the white dome and white utility lights) is Night Vision Imaging System (NVIS) compatible. The dome and utility lights can be switched to a blue-green mode for NVIS compatibility. The cockpit lighting intensity controls are provided via panels on the cockpit overhead console.

2.10.2.2 Cabin Lighting

The passenger-compartment lighting system consists of:

- Cabin dome lighting,
- Cabin panel lighting,
- Cabin compass lighting, and
- Emergency egress lighting.

2.10.2.3 Cabin Dome Lighting

There are four identical and interchangeable dual-lamps in the general passenger compartment. They are selectable to either visible white or NVIS green. These lights are controlled and adjusted from the passenger compartment.

2.10.2.4 Cabin Panel Lighting

There are four identical and interchangeable dual-lamps in the general passenger compartment. They are selectable to either visible white or NVIS green. These lights are controlled and adjusted from the passenger compartment.

2.10.2.5 Cabin Compass Lighting

The intensity control for the cabin-compass bezel light is provided by a switch-potentiometer. This switch is built into the cabin compass bezel.

2.10.2.6 Emergency Egress Lighting

The emergency egress lighting system (EELS) provides electroluminescent emergency lighting for the cabin entry door and the four cabin emergency exits. The EELS may be armed from the cockpit and controlled from the passenger compartment. When armed, self-contained, rechargeable 24 VDC battery packs ensure that the EELS light assemblies will come on (once the rotor rpm has decreased to 20 percent). When illuminated, EELS provides a visible yellow-green lighting arranged in an inverted ‘U’ pattern around each emergency exit (the illumination lasts for a period of ten minutes).

2.10.2.7 Exterior Lighting

The V-22 external lighting system consists of:

- Formation lighting,
- Proprotor tip lighting,
- Position lighting,
- Anti-collision lighting,
- Hoist operator's floodlight,
- In-flight refuel probe light,
- Search/landing lights, and a
- Landing-gear down light.

Position Lighting

Formation Lighting

2.10.2.8 Formation Lighting

There are six infrared electroluminescent, NVIS compatible formation lights. These lights provide a three-axis aircraft attitude reference to other aircraft while flying in formation. Two lights are on top of the aft-wing fairing, one is on the inboard top of each nacelle, and one is on the outboard side of each vertical stabilizer.

2.10.2.9 Proprotor Tip Lighting

Proprotor tip lights aid in showing the position of the aircraft proprotors to other aircraft during formation flights. Two interchangeable dual mode infrared/visible green Light-Emitting Diode (LED) light assemblies are installed on the top and bottom of each proprotor blade. The light controls selectable from a single panel on the left cockpit overhead are: Normal/NVG, Top/Bottom, On/Off, and intensity level.

2.10.2.10 Position Lighting

Three position lights are used to help others determine an aircraft's direction and position at night or during low-visibility conditions. The nacelle position lights are located on the outboard side of the engine nacelles: red is on the left; green is on the right. A white position light is located on the left vertical stabilizer trailing edge. The light controls selectable from the cockpit CDU are: On/Off, Bright/Dim, and Steady/Flash position.

2.10.2.11 Anti-Collision Lighting

There are two red anti-collision strobe lights installed: one on the top of the left vertical stabilizer; the other on the bottom of the fuselage.

The anti-collision lights are located to provide visibility in all modes of flight, and to assist in the prevention of aircraft collisions. Each anti-collision light has its own power supply. During NVIS mode of operation the top anti-collision light is switched to infrared and the bottom anti-collision light is disabled.

2.10.2.12 Hoist Operator's Floodlight

A fixed light is flush mounted on the bottom of the aft fuselage and positioned to provide lighting for ramp rescue hoist or external cargo operations. The Hoist/Winch Operators Grip (HWOG) provides a push-button switch for turning the hoist operators floodlight on and off. The hoist operator's floodlight has two lamps: one clear for visible lighting; one infrared for NVG operation.

2.10.2.13 Inflight Refuel Probe Light

A dual-mode white/infrared light is mounted on the nose of the aircraft to illuminate the in-flight refueling probe during night operations. When the NVG lighting mode is selected, the white light is disabled and the infrared light enabled.

2.10.2.14 Search and Landing Lights

Two retractable search and landing lights are located on the bottom of the fuselage to provide illumination of the landing/takeoff area for night operations. They may also be used as searchlights. Each light is independently controlled by the pilot or copilot: each is capable of 360-degree rotation and +20 to -90 degree elevation. When operating in NVIS mode, the lights are switched from visible light to infrared.

2.10.2.15 Landing Gear Down Light

A white indicator light on the bottom of the fuselage comes on when all three landing gear are down and locked. The light is used to provide a safe-to-land indication to the deck or ground signalman. It is automatically disabled when the NVG lighting mode is selected.

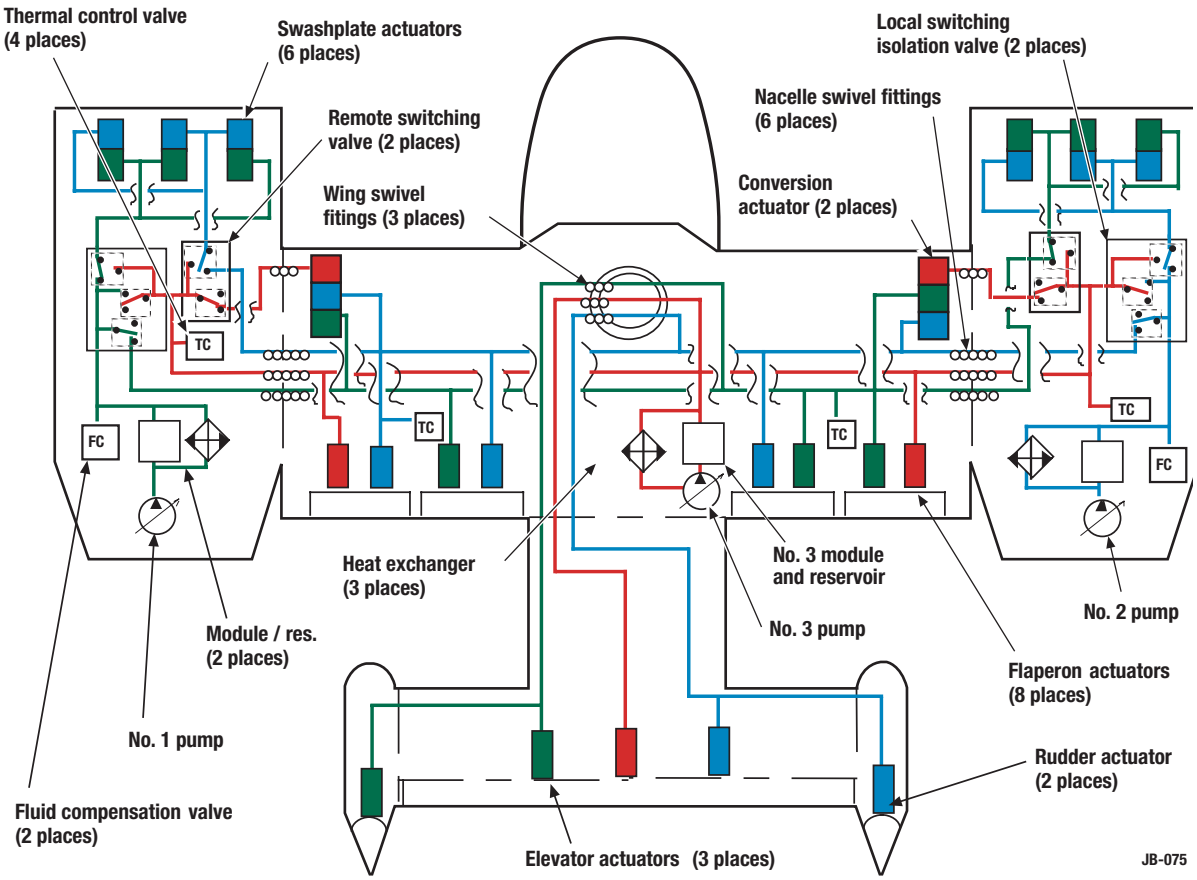
2.11 Hydraulic and Pneumatic Systems

There are three independent 5,000 psi (34.5 MPa) hydraulic systems:

- Systems 1 and 2 are designated as the primary hydraulic system. They are dedicated to the flight control systems.
- System 3 is designated as the utility hydraulic system.

In the event of failure in the primary hydraulic system (Systems 1 and 2), the utility hydraulic system (System 3) will provide pressure to the swashplate and conversion actuators, thus providing additional redundancy. The hydraulic services required for ground operation are supplied by the utility hydraulic system (through ground checkout valves).

The hydraulic system supplies pressure and control of hydraulic fluid. The return components of the hydraulic system are packaged in modules. The use of modules reduces the number of individual components, hydraulic lines, and leak points, thus increasing reliability.



Flight Control Hydraulic System (Systems 1 and 2)

Hydraulic power to the rotor system controls and the control surfaces is triply redundant.

- The failure of one system will not prevent mission completion.
- The failure of two systems will not prevent safe flight.

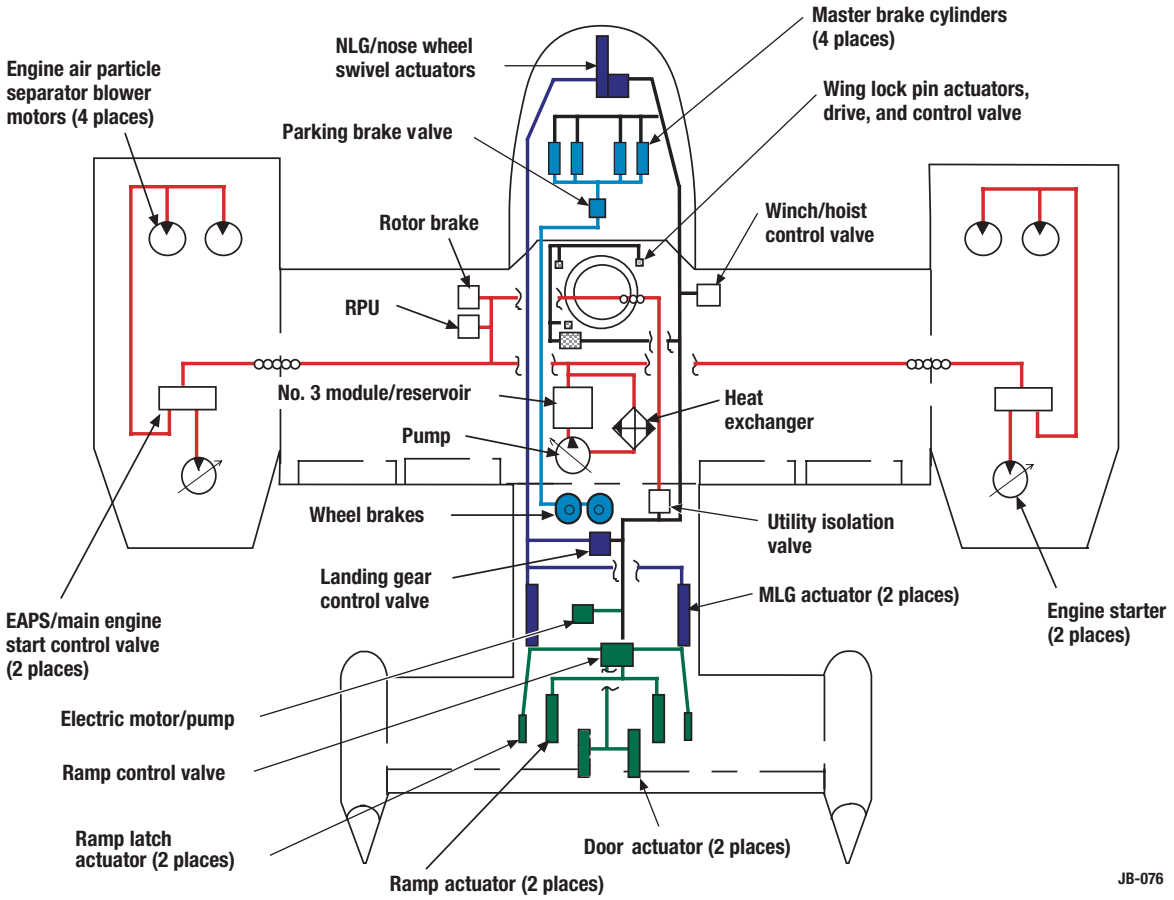
A failure in one subsystem does not adversely affect the functioning of the other subsystems. The systems are separated and installed so that a failure of an adjacent system does not result in a failure in the other two hydraulic systems.

The systems necessary for flight are separated a minimum of 18 inches (except where the survivability and vulnerability analyses showed that less separation is satisfactory). The design includes:

- Jam resistant and jam override protection where required to ensure that no single failure or malfunction in any part or component can cause failure of other flight control power or boost systems.
- Where additional power is required to actuate essential flight controls, all assist components and power sources are redundant, well-separated, and independent.
- There are also provisions for emergency landing after total loss of engine power.

The FCC monitors the system pressures and fluid levels. When loss of pressure or fluid is detected, the switching logic automatically attempts to isolate a defective system.

Variable displacement hydraulic pumps are mounted on each tilt-axis gearbox. These pumps provide fluid flow for Systems 1 and 2. These systems provide hydraulic pressure to the actuators (for the rotor swashplates, wing flaperons, tail elevators and rudders as well as for nacelle conversion). Each system is designed to protect the critical swashplate actuators from hydraulic failures in the wing and/or fuselage.



Utility Hydraulic System (System 3)

The utility hydraulic system (System 3) is powered by the APU. It is used for ground system checkout of the dedicated flight control systems prior to rotor spin up. This system also powers the following equipment/functions:

- Landing gear extend/retract
- Wheel brakes
- Rear ramp/door
- Nose wheel steering
- Engine start
- Cargo winch
- Engine air particle separator
- Wing stow
- Rotor brake
- Arial retractable refuel probe

Compressed air for the pneumatic system is supplied by the Shaft Driven Compressor (SDC), which is mounted on the MWGB (and operates when the APU or engines are running). The pneumatic system supplies low pressure (50 lb/sq in or 3.5 kg/sq cm) compressed air to the ECS. The ECS distributes conditioned air to the cockpit, cabin, wing deicing boots, and avionics cooling air-particle separators.

2.12 Environmental Control Systems

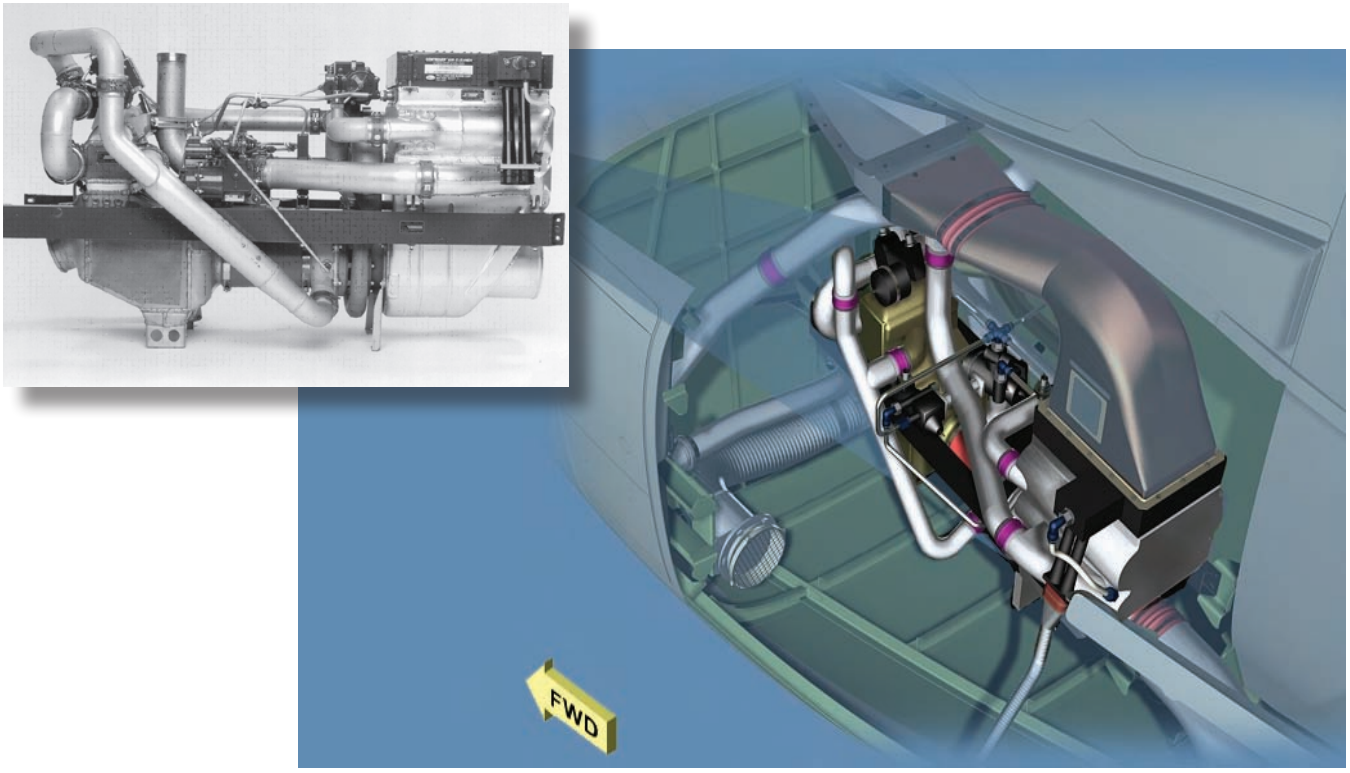
2.12.1 Cockpit and Cabin

The V-22 incorporates a modern Environmental Control System (ECS). It provides for crew and passenger health, safety, and comfort over a wide range of aircraft and environmental operating conditions. The system is designed to protect the avionics and mission systems during operation in extreme climatic conditions as well as under thermal stress due to prolonged operation at maximum system capacity.

The ECS consists of the pneumatic power system, air conditioning via an Air Cycle Machine (ACM), Onboard Oxygen Generating System (OBOGS), an Onboard Inert Gas Generating System (OBIGGS), and a pneumatic wing deicing system.

The ECS provides ventilation, heating, and cooling throughout the entire aircraft operating envelope, which is -65°F to + 125°F (-54°C to +52°C) outside ambient air temperatures. The ECS can maintain the cabin at 70°F (21°C) down to an Outside Air Temperature (OAT) of -39°F (-39°C) .

The ECS provides a minimum of 280 cubic feet per minute of conditioned or emergency ventilation airflow. It is designed to maintain cockpit temperatures between 60°F (16°C) and 80°F (27°C) and cabin temperatures between 40°F (4°C) and OAT + 10°F (5.6°C) throughout the aircraft's operating range.

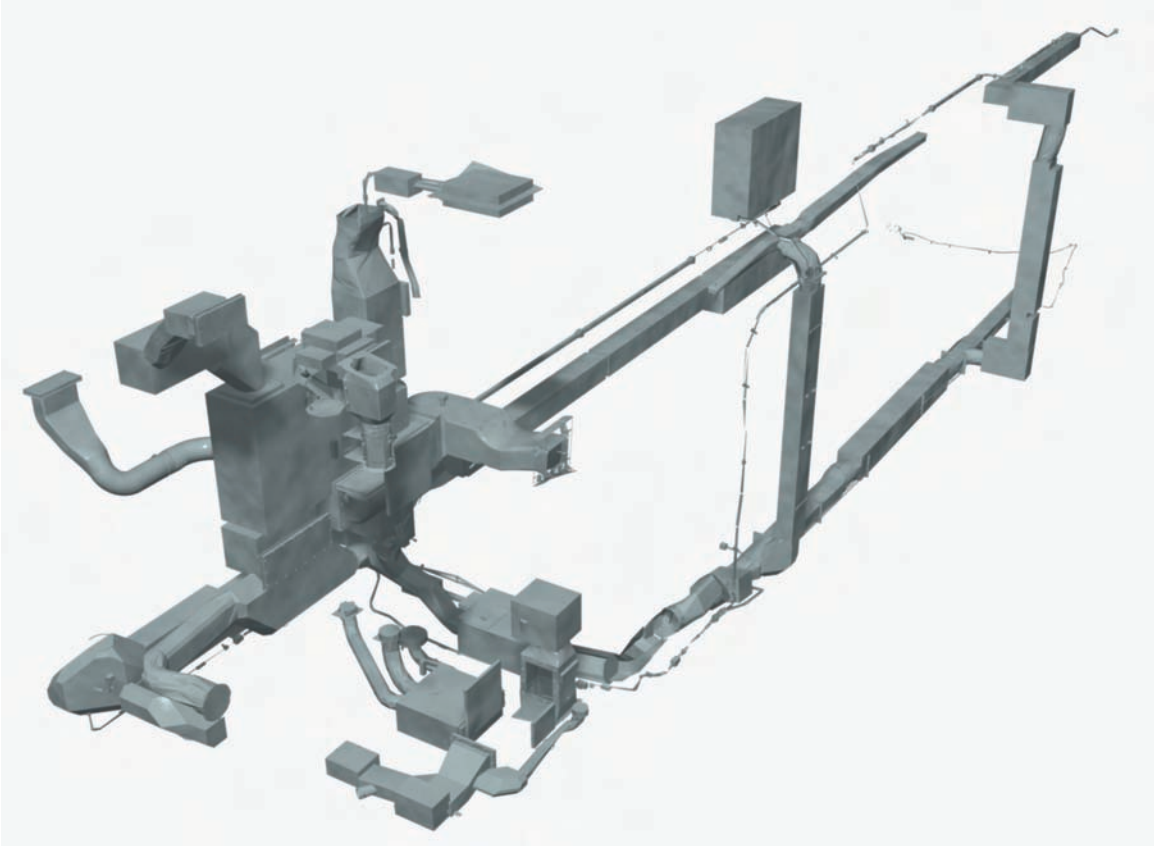


Environmental Control Unit (ECU)

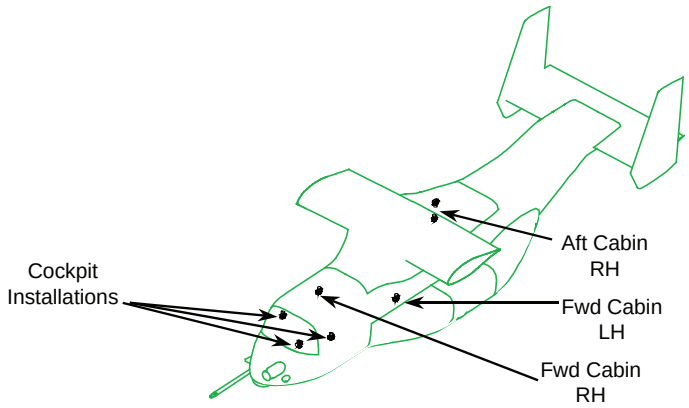
Crew comfort is provided by an air conditioning system capable of delivering supply air within a temperature range of 35°F to 201°F (2°C to 94°C). The ECS is designed to maintain a desired cockpit/cabin temperature environment, as selected by the pilot/copilot CDU – the range is between 54°F to 84°F (12°C to 29°C), with the cockpit having priority in cooling mode. The ECS uses feedback from the temperature sensors located in both the cockpit and cabin. The automatic cockpit/cabin temperature control system has a manual override.

A SDC attached to and driven by the MWGB provides 40 lb/min at 52.8 psi of compressed air (at sea level) to the Environmental Control Unit (ECU), located in the left aft sponson. The ECU conditions the air for use by the ECS systems.

The ECU consists of: a primary and secondary heat exchanger, ACM, reheater/condenser, water separator, and the associated valves and sensors. Conditioned air from the ECU is supplied to the compartments via the Environmental Control Distribution (ECD) system. High pressure air is bled off (upstream of) the ACM turbine and is supplied to the O2N2 concentrator, wing deice boots, and avionics cooling inlet particle separator.



Environmental Control Distribution (ECD) System



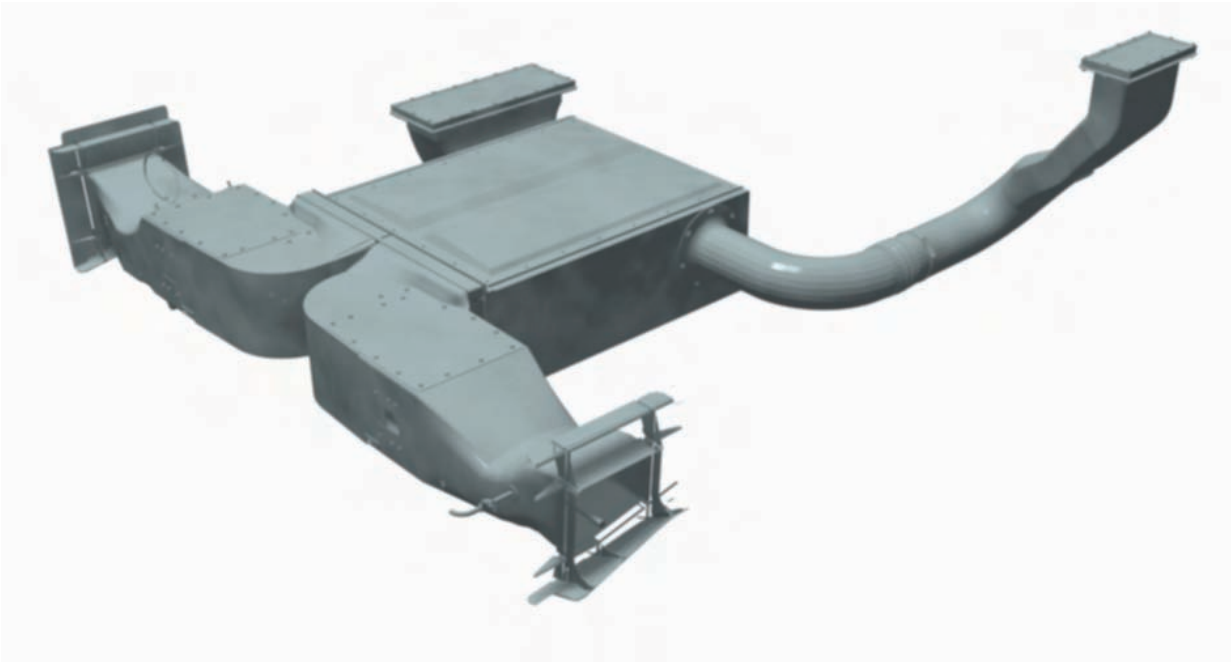
AERPS (NBC Filter) Stations

Seven stations (three located in the cockpit and four in the cabin) provide the necessary power (28 VDC) and connections for interface with the Aircrew Eye Respiratory Protection System (AERPS). The AERPS, comprised of Nuclear, Biological and Chemical (NBC) filters, protective garments and masks, is customer furnished, carry-on gear.

Flight Engineer with Mask-Hood Assembly Attached to NBC Filter

2.12.2 Avionics Cooling

The avionics system is provided with filtered cooling air separate from the cockpit and cabin ECS. Ambient air is drawn into the avionics compartment though ram air inlets, fans, and filters. The airflow cools the components before it is exhausted. The avionics cooling distribution system is located underneath the floor of the avionics compartment.



Avionics Underfloor Cooling Distribution System

2.12.3 Onboard Oxygen Generating System/Onboard Inert Gas Generating System

The onboard oxygen generating system (OBOGS) produces oxygen-enriched air for crew breathing. It supports seven stations (three in the cockpit, four in the cabin) and is designed to provide oxygen enriched air to support high altitude and specialized low altitude operations.

The capacity of the OBOGS is 220 Ambient Liters per Minute (ALPM) at sea level and 112 ALPM at 25,000 feet altitude. Nominal distribution is 40 ALPM per person at sea level and 23 ALPM per person at 25,000 feet altitude. The system uses the same molecular sieve process that is used by most hospitals. Thus, the OBOGS can produce enriched air with up to 93% oxygen content.

The onboard inert gas generating system (OBIGGS) produces nitrogen-enriched air for fuel tanks. The purpose of enriching the tanks with nitrogen is to lessen the risk of a fire in the fuel tanks. The nitrogen is provided under pressure in order to displace the air in the tanks.

2.12.4 Emergency High Altitude Oxygen Kit

In the event of an OBOGS failure, emergency oxygen is available for four persons for a duration of four minutes. This time period is sufficient for the aircraft to reach safe atmospheric conditions, while continuing flight operations. The emergency oxygen system consists of a storage bottle and regulator assembly capable of holding 400 ambient liters of oxygen. This kit includes the necessary tubing and cockpit switch for easy installation and operation.

2.12.5 Cold Weather Kit

For operations at cold temperatures, an optional set of cabin sidewall and overhead blankets are available. This equipment provides additional insulation in the cabin areas. The existing thermal/acoustic blankets that cover the upper portion of the cabin are replaced with a blanket of double thickness. The kit includes additional blankets that extend to the floor and a retractable thermal curtain, which extends across the ramp area.

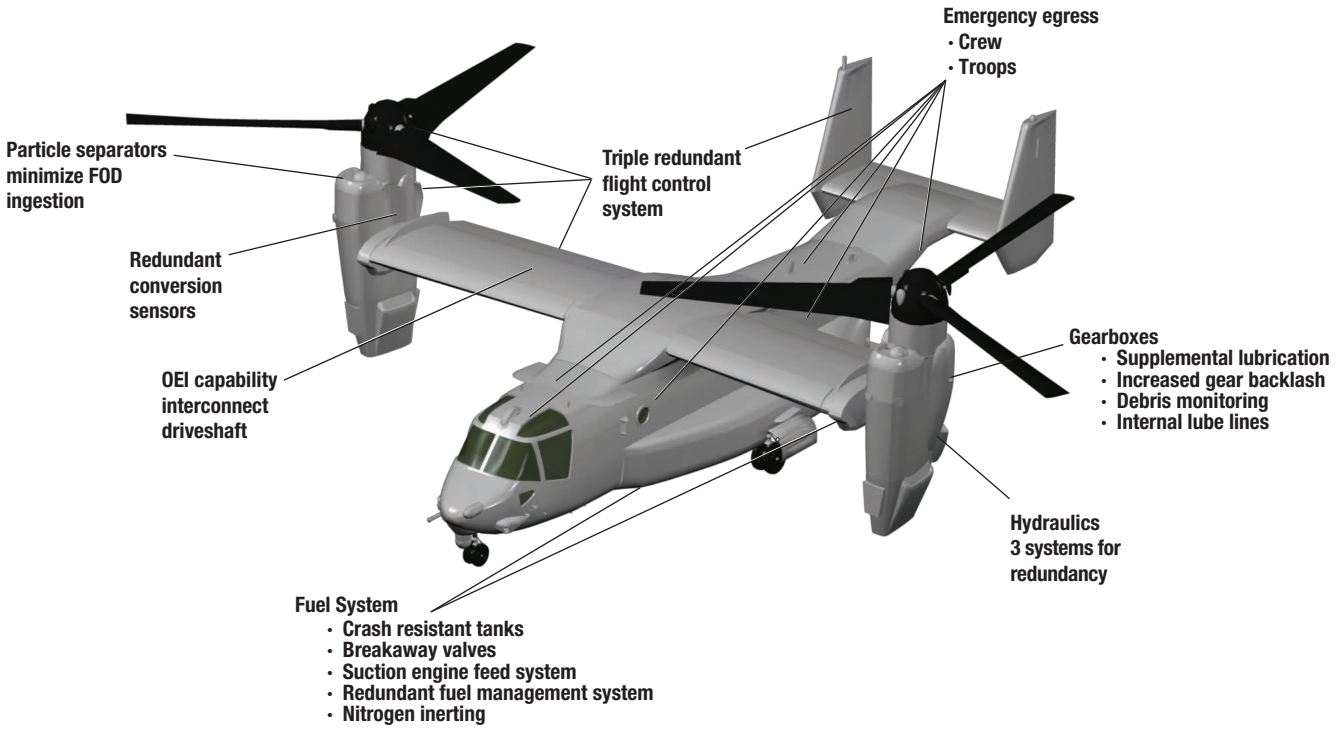
2.12.6 Windshield Defog, Wipers, and Washers

Separate ducts and outlets are provided to defog the cockpit windshield and chin windows. The air used to defog this equipment is supplied from the ECS.

A two-speed electric motor provides the power to operate the windshield wipers. For rain removal, there are windshield wipers for the pilot and copilot windshield. Washer spray bars are integral components.

2.13 Safety Equipment

Flight safety has been an integral part of the V-22 design. The V-22 includes key safety features depicted below.



Safety Features

2.13.1 Flight Controls

The safety features of the flight controls include:

- A triple-redundant flight control system.
- Quadruple-redundant nacelle position sensors. These sensors ensure that the pilot receives accurate knowledge of the nacelle positions.
- Conversion actuators that have telescoping ball screws with redundant load paths and other design features to protect against jams and damage from ballistic projectiles.

2.13.2 Drive System

The interconnecting driveshaft allows the V-22 to remain aloft during one engine inoperative (OEI) operation capability. When operating in OEI condition, the aircraft may maintain level flight (at an altitude of 1,000 ft) with a maximum internal mission payload (at combat weight) and a 60% fuel load.

In the event of an oil pressure loss, the proprotor gearboxes are designed to continue operation. They can continue to operate (in a dry run condition) for at least 30 minutes. After an oil pressure loss, oiljets inside the transmission case are activated and provide oil to the critical areas of the transmission.

All gearboxes are equipped with a fuzz-burning chip detector. These chip detectors alert the crew each time debris is burned off. If the material cannot be burned off, a different alert is sent to the cockpit warning system.

2.13.3 Propulsion System

The engine air induction inlets have ice protection and integral particle separator systems. These systems control ice and particle damage to the engines when active. The main rotor blades and spinners have integral ice and lightning strike protection.

The main rotor and rotor hub/grip structural design utilizes a composite construction. Redundant load paths were designed into the structure to carry the centrifugal forces. These load paths eliminate the potential for a sudden catastrophic failure.

The main rotor blades, rotor controls (swashplate rings, pitch links, etc.), and rotor control actuators have been designed with ballistic tolerance features. Damage-tolerant metallic components were incorporated into the rotor design. Most of the bearings in the rotor system require no lubrication. Any deterioration in bearing performance is detected by the onboard monitoring systems.

2.13.4 Fire Detection and Suppression

A combination of active and passive systems provides fire protection.

- An active system detects and extinguishes a fire once it starts.
- A passive system prevents a fire from starting or contains an existing fire.

2.13.4.1 Active System

Active fire detection and suppression is provided in the following fire zones:

- Nacelle Fire Protection. There are two redundant and independent gaseous pneumatic fire detectors located on the upper, forward, inboard, aft, and horizontal firewall of each nacelle. Each monitors the nacelle engine compartment area (defined by the forward, aft, and horizontal nacelle firewalls). A 224 in^3 (3671 cm^3) fire bottle containing 6 lb (2.7 kg) of HFC-125 fire extinguishing agent is located forward of the firewall and is installed in each nacelle. Tubing is routed around the forward firewall to four dispensing locations in the engine compartment. Each of the fire bottles is manually armed and discharged from the cockpit.
- Wing Fire Protection. The wing fire protection system is automatically activated when a fire is detected in the midwing area, the aft wing cove areas, or the dry bays surrounding the wing fuel tanks. The wing fire protection controller monitors and controls the system. It sends system status and fire detection signals to the CMS. Seven gas generators and six optical fire detectors are located in the midwing area. If a fire is detected in either the midwing or inboard aft wing cove areas, the system will automatically shut down the APU if it is operating and activate the gas generators in the area of the fire. The gas generators are activated in a predetermined sequence.

There are 10 gas generators in the wing:

- Three gas generators are spaced throughout each aft wing cove, and
- Two gas generators are located in the dry bays surrounding the fuel tank.

Each of the five gas generators (in the left wing and right wing) is connected to an optical fire detector, which provides localized detection and fire suppression. The two outboard gas generators in each aft cove and the two gas generators adjacent to each wing fuel tank are activated independently of the wing fire protection controller.

When a fire is detected in the wing, the associated warning light displays on the fire suppression panel. In addition, the associated voice warning, MFD warnings, and master alert lights alert the crew to the location of the fire.

2.13.4.2 Passive System

The passive fire protection system includes:

- Self-sealing fuel cells and fuel lines,
- Fuel-line breakaway valves,
- Flammable fluid drains,
- Firewalls,
- Hot surface insulation, and
- Suction fuel transfer.

Passive fire suppression is provided by powder-filled panels. These panels are forward of the wing fuel cells. If the panel is penetrated by an incendiary round, then aluminum oxide powder is dispersed into the surrounding area to suppress the fire.

The onboard inert gas generating system (OBIGGS) provides pressurized nitrogen for the suppression of explosive fuel vapors inside the fuel tanks.

2.13.5 Alternate Landing Gear Extension

The landing gear can be extended in the event of a power failure of the normal extension system. The alternate landing gear extension system provides a single shot extension of the landing gear, powered by compressed nitrogen.

2.13.6 Fuel Jettison System

The V-22 can jettison fuel at a rate of at least 800 lb (363 kg) per minute.

2.13.7 Emergency Equipment

The standard emergency equipment onboard the aircraft consists of a first-aid kit, portable fire extinguishers, and provisions for the raft stowage. Two fire extinguishers are installed on the aircraft. One is forward of the cabin crew door, while the other is in the cargo ramp area.

2.14 Operating Environment

The V-22 is designed to perform in a broad spectrum of operational environments encompassing both afloat and ashore envelopes, under all climatic conditions and for all types of terrain.

Each component in the V-22 has been designed to operate in a specified set of environmental conditions. These environmental conditions are summarized below:

Ambient Temperature	-65°F (-54°C) to 125°F (+52°C)
Pressure Altitude	Method 520.0, Procedure III, MIL-STD-810; Temperature, Humidity, Vibration, Altitude.

Humidity	Method 507.3 of MIL-STD-810; Humidity 45% RH at 21°C 95% RH at 38°C 80% RH at 52°C 20% RH at 71°C
Tropical Exposure	The combination of temperature, humidity, rain, solar radiation, and sand/ dust requirements allow the V-22 to be suitable for operation within a tropical environment.
Vibration	Method 514.3, Procedure I, MIL-STD-810; Vibration.
Shock	Method 516.3, Procedure I and V, MIL-STD-810; Shock.
Sand and Dust	Method 510.1, Procedure I, MIL-STD-810. Sand and Dust Particle concentrations of 1.32 X 10-4 pounds per cubic foot in multidirectional winds of 45 knots. Except for the upper nacelle blower. The upper nacelle blower will withstand particle concentrations of 4.0 X 10-6 pounds per cubic foot.
Water Resistance	Method 512.3 of MIL-STD-810; Leakage (Immersion).
Mold Growth	Method 508.4 of MIL-STD-810; Fungus.
Salt Mist	Method 509.2, MIL-STD-810; Salt Fog.
Salt Spray	Sea salt fallout of 200 parts per billion. Aircraft components will reliably operate after exposure to Method 510.1, Procedure I, MIL-STD-810.
NBC	Power, wiring, and connections are provided for seven stations for NBC protective garments and masks: three are located in the cockpit; and, four are located in the cabin.
Exposure to Solar Radiation	Radiant energy at a rate of 355 BTU per square foot per hour or 104 watts per square foot (1120 W/M2).
Bird Strike	The windshield shall be capable of resisting the impact of a three (3) pound bird at a velocity of 275 knots.
Rain and Wind	8 inches per hour minimum, with 45 knots of wind from any direction.
Hail Strike	The aircraft shall be able to withstand 1 inch hail stones in multiple aircraft conditions. These conditions include: in-flight, takeoff and landing, taxi, hover, and parked.
Snow	A snowload capability of 20 pounds per square foot on horizontal surfaces. This capability assumes that the aircraft is not operating and will be cleared of snow between storms.
Icing	The aircraft shall be designed and constructed for operation at full mission capability in icing conditions, ice fog and hoar frost up to moderate intensities down to -20ºC ambient temperatures.

Lightning	No lightning susceptibility that could result in loss of life or the aircraft from a severe lightning attachment with a 200 kAmp first return stroke and a peak rise time of 1.4×10^{11} Amp/sec to the air vehicle. No lightning susceptibility that could result in personnel injury or endanger mission completion from a lightning attachment with a 50 kAmp first return stroke and peak rise time of 3.5×10^{10} Amps/sec to the air vehicle.

The V-22 has been tested at the Climatic Test Chamber (Eglin Air Force Base, Florida). The aircraft performed successfully in extreme temperature conditions (-65°F to +131°F) as well as in various operating configurations. The operating configurations tested included: engines running, helicopter mode, airplane mode, landing gear down, and landing gear stowed.

The V-22 operational theater also includes engagements to both conventional and unconventional threat warfare environments. The aircraft is required to be survivable, operational, and maintainable in a Chemical, Biological and Radiological (CBR) contamination warfare environment. Survivability has been enhanced through the proper selection and use, to the maximum extent practicable, of materials offering the highest resistance to the deleterious effects resulting from chemical agent exposure. Special attention was afforded to all Flight Critical components to ensure continued safety of flight, with no attrition or forced landing, for 30 minutes following exposure to a CBR contamination encounter.

Conduct of Flight and Mission Operations have been successfully demonstrated with aircrew/troops in the CBR Flight Individual Protection Ensemble (IPE) and limited maintenance actions by maintainers in MOPP IV protective gear. Although both CBR protective gear variants will have a degrading effect on overall flight, mission and maintenance performance through heat stress and encumbrance, the aircraft has been designed to be operated and maintained by garmented personnel in the CBR contamination environment.

The ability to decontaminate the V-22 A/C is of critical importance to both operators and maintainers. Through typical aircraft design practices, the smooth aerodynamic contours of the V-22 in conjunction with runoff / drainage provisions for rainfall serve to mitigate entrapment regions and assist to facilitate the effective removal of gross contamination residing on A/C surfaces that have not been absorbed by non-resistant, painted surfaces and elastomers. Aircraft components that cannot be effectively decontaminated are configured for removal and replacement.

The aircraft's avionics equipment and bays are protected by a dual stage filtration system. The first stage is an inertial particle separator that is designed to remove 95 percent of the particles, sand, dust, dirt, aerosols, and liquids in the air stream. These particles are then centrifuged out and dumped overboard. The second stage filters out 98 percent of the remaining particulate, aerosol and liquid contaminates larger than a 0.3-micron diameter particle-size. Gaseous agents, that are not considered hazardous either to the avionics bay or equipment, are self-purged with clean air as the aircraft leaves the contaminated zone.

2.14.1 Wind

The V-22 has hover and low speed control characteristics, which allow for:

- Rotor start/stop and automated blade fold/wing stow (BFWS) in winds of 45 knots from any direction.
- Vertical takeoff and landing in winds up to 30 knots from +/- 120° off the nose, and rear +/- 60° is limited to 25 kts.
- Rolling takeoff or landing – in crosswinds up to 20 knots.
- Operation in the presence of vectoring wind shears (at the most critical orientation and height) – as defined in MIL-F-8785.

The V-22 is capable of taking off or landing on ship decks that are pitching and/or rolling with orientations of the aircraft up to 45° off the ship centerline. Specific launch/recovery wind limits are determined by test for each certified ship class, with existing wind clearances typically up to 25 knots for selected headings.

The V-22 has the means for securing the aircraft, under the following conditions:

- Wing stowed – blades folded in up to 100 knot winds from any direction.
- Automatic proprotor blade and wing stowing or unstowing can be performed in winds up to 45 knots from any direction and throughout the full range of ship motion (+/- 3° pitch, +/- 15° roll, and 0.3 g vertical acceleration).

2.14.2 Sand and Dust

The V-22's design is such that routine field operations in rough environments can be performed without damage to the aircraft or personnel. For example, the proprotor blades are designed with an erosion protection system. If continually operated in sand, dust, and rain, the proprotor blades have a wear life of 250 hours.

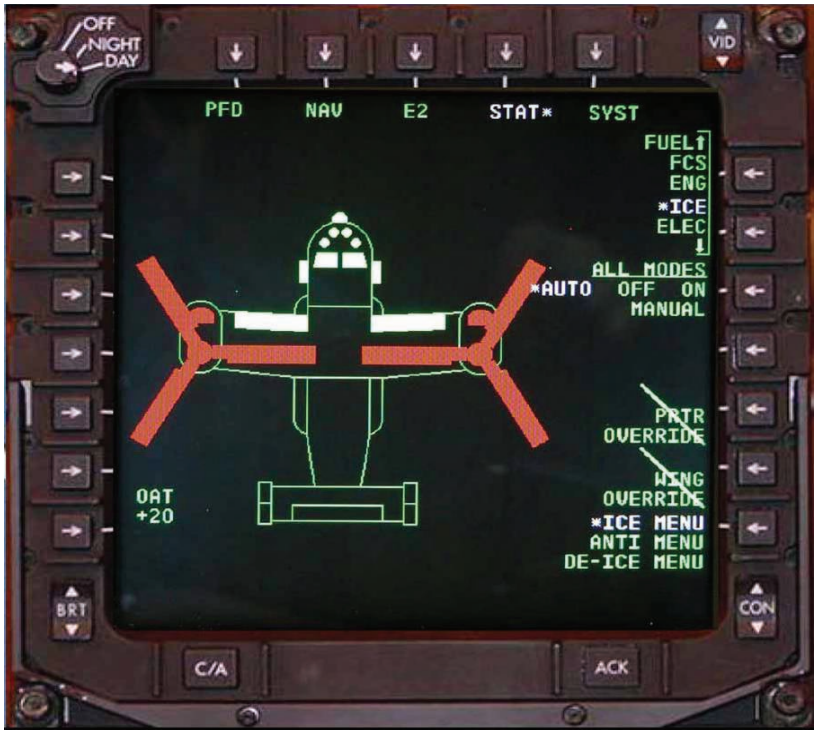
The engines are protected by the Engine Air Particle Separator (EAPS). This system turns at 10,500 rpm and provides for a forced separation of debris from the engine's inlet airflow. The particles separated by the EAPS are directed out of and away from the engine nacelle (i.e., they become harmless to the aircraft's continued operation).

2.14.3 Ice Protection

The V-22's ice protection system allows for full mission capability in moderate icing conditions down to -20°C. The ice protection system incorporates ice detection, anti-icing and deicing systems.

2.14.3.1 Ice Detection

There is one heated ice detection probe mounted on each side of the forward fuselage. As ice forms on the probes, their oscillating high frequency decreases. When ice accumulates to the trigger point, an "Ice Detected" signal is sent to the MFD to alert the crew and to activate the ice protection system.



Typical Ice Detection Status Display

2.14.3.2 Anti-icing

Anti-icing is provided for: the windshield, the engine air inlets, the engine air-particle separator scrolls, the proprotor blades parting strips, the proprotor pendulum dampers, the proprotor spinners, the pitot-static/angle-of-attack probes, and the multimode radar radome, if installed.

Anti-icing is pilot selectable function. It is supported by an ice detector for automatic operation. The protecting of components against icing is accomplished though varied means:

- A conductive film heating-layer embedded in the pilot's windshield electrothermally protects it.
- Electrically powered heating elements are used to protect the engine air inlets.
- Engine bleed air is used to protect the engine air particle separator scrolls.
- A heater element on the rotor-parting strip protects each proprotor blade.
- Electrically powered internal heating elements are used to protect: the proprotor pendulum dampers, proprotor spinners, pitot-static/angle-of-attack probes, and the multimode radar radome, if installed.

2.14.3.3 Deicing

Deicing is incorporated into the wing, proprotor blade, blade root fairings, and proprotor spinner. Areas of the fuselage where the shedding of ice may impact operational performance have been reinforced or shielded to prevent damage.

Deicing is a pilot selectable function. It is supported by an ice detector for automatic operation. The protecting of components against icing is accomplished though varied means:

- Air pressure is used to deice the wing. There are six neoprene boots installed, with chordwise tubes, on the wing's leading edge (three on the right-wing and left-wing). They deice the wing by inflating and deflating at a rate of twice per minute. They are inflated with positive air pressure from the MWGB-mounted SDC. The vacuum condition (i.e., negative air pressure) for deflating the boots is provided by a venturi-shaped port on the deice solenoid valve.
- Electrically powered heating elements are used to deice the proprotor blades, blade root fairings, and proprotor spinners. There are seven integral zoned heater elements on each blade, two on each root fairing, and two on each proprotor spinner.

2.14.4 Electromagnetic Environmental Effects Protection

The V-22 Electromagnetic Enviroment (EME) is the environment to which the V-22 equipment is exposed during the lifetime of the system. This enviroment consists of self generated emissions and externally generated emissions. Some emissions are a product of atmospheric electricity and other natural occurring events, and others are results of emissions from man-made radiating sources.

The overall process whereby electromagnetic environments cause responses by the on-board equipment involves three, somewhat, independent steps:

a. Interaction of the environment with the vehicle

b. Coupling to interior wire bundles, chassis and other conductors

c. Interaction with components and circuits in equipment

Control of Electromagnetic Environmental Effects (E^3) consists of design criteria for the external skin and structure of the aircraft, criteria for the internal wiring, avionics bays, and enclosures, and criteria for design of the individual subsystems/equipment.

In the event of a lightning strike (which exhibits an exception to the independence assumption above) the V-22 has been designed to survive and continue safe operation.

- Airframe skins incorporate conductive copper mesh in selected areas to improve the electrical path for lightning currents.
- The wings are designed to conduct lightning away from sensitive areas that might damage their internal structure.
- Critical areas around the avionics bays are shielded with aluminum skins that form the avionics bays.
- The proprotor blades are capable of withstanding a direct lightning strike at any part of the blade without catastrophic damage.
- Equipment stations are covered with composite materials or aluminum to prevent personnel injury due to lightning.

Major electromagnetic environmental effects and lighting protection tests have been successfully completed, with periodic retesting as the aircraft has evolved.

2.15 Shipboard Compatibility

The U.S. Marine Corps and U.S. Navy primarily require the utilization of naval ships for operational maneuvers from the sea. The aircraft's primary operating and support (intermediate level maintenance) sea base are amphibious assault ships in the Tarawa class (LHA) and Wasp (LHD) class. Except as limited by deck strength or hangar size capability of the ship, the V-22 is designed to conduct the same level and class of flight operations as the H-46. However, the speed, range, and payload of the V-22 increases its capability beyond the H-46.

V-22s Aboard USS Bataan (LHD 5)

The requirements for shipboard compatibility address adequate mission operations, O-level maintenance and I-Level maintenance requirements to include but not limited to: below-decks stowage, flight deck elevators, flight deck edge clearance (for the wheels), elevator, deck spotting, hangar maintenance, control island clearance (for the rotors), rapid turn-around times, and the limited availability of maintenance facilities onboard aircraft air capable ships. The V-22's airframe footprint, as well as logistical footprint, configuration, and stowed dimensions are all affected by these requirements. In addition, the Air Force Special Operations Command (AFSOC) will periodically operate the V-22 aboard naval vessels.

2.16 Shipboard Navigation and Landing

For navigation to and around ships, the V-22 possesses a moving waypoint guidance capability. Given the ship speed, course, and location at a known time, the V-22 is capable of locating the ship prior to landing. GPS and TACAN guidance may also be utilized to locate the ship.

The V-22 is capable of position hover holds and groundspeed holds up to 50 knots (in winds up to 45 knots). Groundspeed hold can be utilized to stabilize the V-22 (over the ship) to prepare for landing.

For prepared and semi-prepared surfaces (including ships and expeditionary airfields), the V-22 can perform level 3-point landings up to: 12 feet per second sink speed, at a forward velocity of 0-101 knots, with +/-2 degrees of roll, and for gross weights up to 46,000 lb. When gross weights are between 46,000 lb to 60,500 lb, maximum sink speeds are determined by the ratio of kinetic energy to the structural design takeoff and landing gross weight.

The aircraft is capable of landing in wind speeds up to:

- 30 knots from +/-120º off the nose for vertical landings (and rear +/- 60° is limited to 25 kts).
- 20 knots crosswind component for rolling landings.
- Specific launch/recovery wind limits are determined by test for each certified ship class.

The V-22 can conduct landings at up to 8 feet per second sink speed with a zero forward velocity on the following slopes:

- 12 degrees up/down-slope or 6 degrees cross-slope, to VTOL weight (approximately 52,600 lb).
- +/-15 degrees roll and +/-3 degrees pitch in the ship axes system. The aircraft centerline may be at all angles from -45 to +45 degrees with respect to the ship centerline for gross weight to VTOL weight.

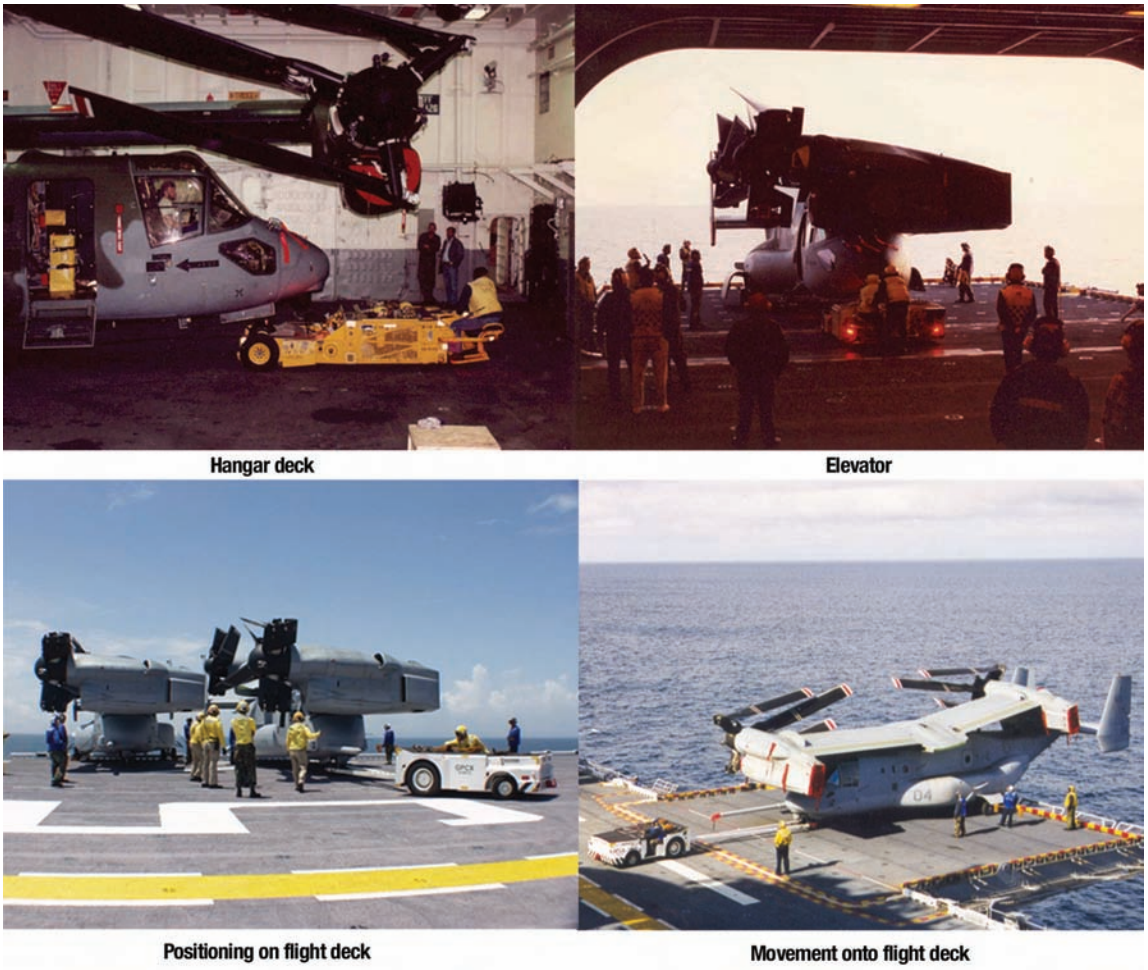
For operations above the maximum VTOL weight, the sink speed is determined by the ratio of kinetic energy from the structural design VTOL gross weight.

V-22 Preparing for Shipboard Landing

2.16.1 Footprint

The V-22 has been designed to permit timely spotting on shipboard flight decks and inside hangars. The aircraft can be positioned using standard spotting dollies connected to the nose landing gear for hangar spotting, or tow tractor with 8 or 15ft tow bars primarily on the flight deck. During hangar towing operations and rotations of ± 90º, the SD-2 Spotting Dolly requires a 3 in (76 mm) clearance. This is accomplished utilizing a nose landing gear "hiking" feature. The feature allows unobstructed use of the SD-2 Diesel Spotting Dolly. The hiking feature allows a full 14 in (356 mm) strut extension for clearance of the nose landing gear doors and system components.

The V-22 Logistical Footprint of SE, AVCAL, Mission Kits, MATS, ARRP and squadron personnel requirements is continuously monitored for maintenance concepts, engineering design changes, reduction in size and cubic space requirements.

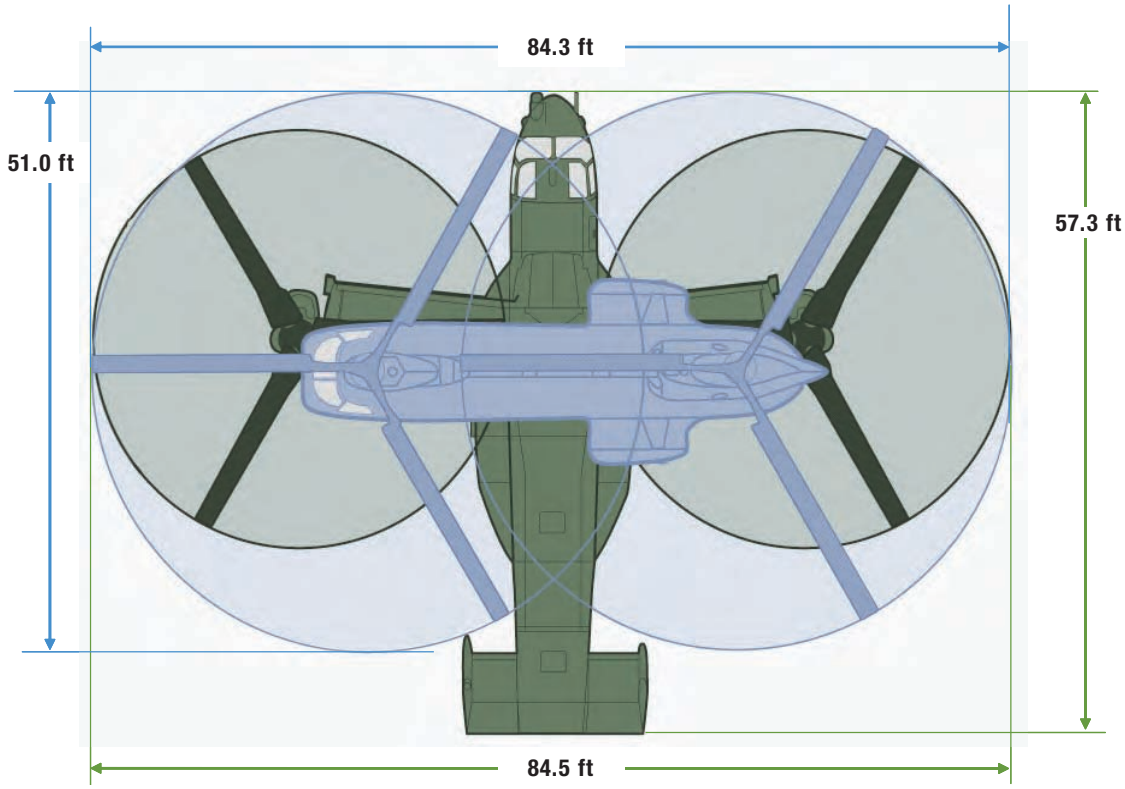


Spotting V-22 between Flight Deck and Hangar

The static dimensions of the V-22 are as follows:

		Feet	Meters
Wings and rotors spread:	Width	84’7”	25.8
	Length	57’3”	17.5
	Height	22’1”	6.7
Wing and rotors folded:			
	Width	18’11”	5.8
	Length	63’0”	19.20
	Height	18’3”	5.5

The size of the V-22 is compatible with flight decks of smaller ships designed to operate with current naval helicopters such as the H-3, H-46, and H-60. Below is an overlay of the footprint of the V-22 compared with the H-46 Sea Knight.



Comparison of V-22 and H-46 Spread Footprint

2.16.2 Mooring

The V-22 has been designed to be secured on the flight deck of an amphibious assault ship, during heavy weather conditions. Heavy weather is defined as 100 knot winds with a forward inertial load factor of 0.30, a lateral inertial load factor of 0.80, and a vertical inertial load factor of 1.70. V-22 Aircraft Tiedown points are designed to accept standard U.S. Navy TD-1A and TD-1B type tiedown chains.

Aircraft tiedown points are easily accessible. Specific mooring procedures have been developed using a computer modeled strain-energy method for all mooring requirements. These mooring requirements include shipboard operations for Normal (45 knot winds), Moderate (60 knot winds), and Heavy Weather (100 knot winds). Each tiedown chain has a safe working strength of 10,000 lb.

V-22 Secured on Launch Spot

2.16.3 Engine Exhaust

To minimize the effect of engine exhaust on deck surfaces, the design of the IR suppressors on the V-22 aircraft incorporate deflectors that turn the exhaust up to 40º outward, away from the fuselage. With this design, the maximum temperature at deck level on a hot day should be at/under 400° F (while at 100% RPM). The temperature drops very rapidly when the RPM is decreased. The temperature also decreases if the rotors are tilted a few degrees forward of the 90° (full helicopter) position – as would be the case when preparing for a short takeoff.

2.16.4 Environmental Protection

The V-22 design is seaworthy. The effects of salt water and spray were carefully considered in the design and testing of the V-22. Major components were subjected to salt spray tests to verify integrity.

Items of environmental protection include:

- Electrical connectors are environmentally sealed to prevent corrosion and conform to U.S. military requirements
- Exterior paints offer further protection from salt spray and water
- All electrical items are designed to be compatible with the shipboard electromagnetic environment

2.16.5 Shipboard Maintenance

The V-22 is designed with shipboard maintenance, including limited clearance of below-deck maintenance areas and ship motion during maintenance, in mind. Any peculiar support equipment (special stands, etc.) are designed to compensate for ship pitch and roll. Safety harness attach points are also provided to protect maintainers.

Most post-maintenance systems checks on the V-22 can be performed above deck using only APU power, with the wing stowed and rotors folded. All electrical and avionics systems can be checked, as well as the integrity of the hydraulic and flight control systems. The V-22 will require a flight deck turn-up after major maintenance has been performed on its propulsion or drive systems. The wing must be in flight ready position in order to perform a full checkout on the propulsion system, the drive system, engine start-up and rotors. The engines cannot be started unless the wing is in flight ready position and rotors are spread.

2.16.6 Blade Fold and Wing Stow

To minimize storage area and still meet flight readiness times, the V-22 is designed to quickly transform to and from a compact size. The V-22's automatic blade fold/wing stow system has demonstrated the ability to fold/stow in winds up to 45 knots in all directions. The blade fold/wing stow process is accomplished within the time span of 120 seconds. Once initiated, the procedure can be halted at any point. In the event of a system failure, provisions for manual blade fold and wing stow are available. Additionally, the blade fold/wing stow system has a selectable rotor blade positioning process for maintenance actions, and a 'Blades Folded Nacelles Horizontal' position.

Blade Fold/Wing Stow Sequence

SECTION 3.0 - INTEGRATED LOGISTICS SUPPORT

Integrated Logistics Support (ILS) plays an integral role in the V-22 design and systems engineering process. ILS places a premium on efforts to design, introduce, and sustain aircraft systems and components that conform to the capabilities and limitations of military and civilian personnel who use and maintain those systems. ILS interacts with internal and external customers, suppliers and sub-contractors throughout the product lifecycle. ILS leads other logistics organizations by coordinating, integrating and managing activities to ensure successful sustainment of our products and services. ILS directs complex activities and leads others on advanced solutions to resolve supportability related problems. ILS responds to customer inquiries and complex technical issues to provide technical support and integration between supportability, engineering, customer and program management. ILS coordinates and integrates all supportability efforts with contracts, business operations, engineering and suppliers to assure cost and schedule coordination and compliance. ILS also includes efforts to improve logistics standardization and interoperability within other corporations, manufacturers, military services and allied nations. ILS is a management function intended to provide planning and program control. The goals of ILS are to:

- Provide readiness and cost improvements throughout the operational life-cycle.
- Integrate support products requirements into system design and/or selection.
- Define support requirements and readiness objectives.
- Provide required support at minimal cost.
- Develop and acquire required support to the user.

All elements of ILS are coordinated during the systems engineering effort. Trade-offs may be required between each element to acquire a system that is affordable, operable, supportable, sustainable and transportable (using available resources). The basic ILS elements are:

- Technical Data
- Training & Training Support
- Supply Support/Spares
- Support Equipment
- Reliability & Maintainability
- Facilities
- Design Influence
- Maintenance Planning
- Packaging, Handling, Storage & Transportation (PHS&T)
- Manpower & Personnel
- Computer Resources

ILS requirements are defined and shared throughout the V-22 program through the Integrated Product Team (IPT) organizational concept.

3.1 Design Influence

Bell Boeing engineering, supportability, and customers have worked together to ensure that the reliability and maintainability design features were incorporated early in the design process. The ILS organization has been extensively involved in all aspects of the V-22 since its initial inception. ILS continuously provides design influence by working concurrently with engineering on design changes and trade studies to ensure high reliability, easy maintenance, and lower operational and support costs.

3.2 Support Analysis

The V-22 is designed to use a paperless maintenance system. Virtually all V-22 design requirements, drawings, and Support Analysis Record (SAR) data have been developed and maintained in electronic media. This process is facilitated by a computerized maintenance system linking Organizational level (O-Level), Intermediate level (I-Level) and Depot level (D-Level) maintenance functions with the supply and logistics support system. This process includes the capability to upload mission planning information to the aircraft prior to flight and then download performance data after a flight. Currently, there are two alternatives for providing the appropriate levels of V-22 aircraft maintenance. The first is the three levels of aircraft maintenance implemented in order of increasing capability: O-Level, I-Level and D-Level maintenance. The second alternative tailors the needs and capabilities of each V-22 operator and results in two levels of maintenance by combining the I-Level and D-Level.

Assignment of specific maintenance functions to the O, I or D levels, or to discard, is based on an economic Level of Repair Analysis (LORA), operational constraints, and other non-economic factors.

3.2.1 Organizational Level

O-Level maintenance functions are normally performed by squadron personnel on a day-to-day basis in support of its own operations. These functions can be grouped as: equipment inspections, servicing, troubleshooting, “on-equipment” repair, and removal and replacement of defective components. Configuration and other changes mandated by designated technical directives are made at this level. In addition, the squadron maintains records and submits required reports. O-Level tasks include:

- Inspect – Airline style pre-flight, turnaround, and post-flight walk around inspection: designed to detect incipient failure conditions that could affect mission readiness. Included at this level of maintenance are phased inspections, periodic inspections to control corrosion, check for cracks, etc.
- Troubleshoot – Extensive use of Built-in-Test (BIT), visual detection means, and general purpose test equipment are used to isolate failures.

- Service/Calibrate/Adjust/Replenish – Easy access to all servicing points is a major design focus of the Supportability IPT. Fluid monitoring is conducted remotely and access to reservoirs is only required when servicing is indicated.
- Repair in place (structures and other permanent installations) – Standard repairs for graphite/epoxy structures have been developed and demonstrated. In situation repair of hydraulic lines and electrical wire harnesses has been made possible by the easy access to these systems.
- Repair-by-Remove/Replace of Weapons Replaceable Assemblies (WRAs) – Components are located such that their removal and replacement can be performed without disturbing other systems or components. WRA designs include handles where necessary to permit easy lifting and positioning as well as connections designed to eliminate incorrect installation.

3.2.2 Intermediate Level

I-Level maintenance functions are normally performed in support of O-Level squadrons by a designated maintenance activity, e.g., the U.S. Navy Aviation Intermediate Maintenance Department (AIMD) or Marine Aviation Logistics Squadron (MALS). These functions can be grouped as: accomplishment of specific periodic inspections, calibration of equipment, off-equipment repair, replacement of damaged/unserviceable components, manufacture of specific non-available parts, and providing technical assistance to the various squadrons.

Only those assets determined by a Level of Repair Analysis (LORA) to be economically repairable or strategically important undergo this level for repair. I-Level maintenance activities are normally co-located with the operating squadrons – afloat and ashore. This maintenance activity is typically performed by more specialized personnel (often with augmentation from supported squadrons).

I-Level tasks include the repair of WRAs like the avionics “black boxes,” mechanical components such as actuators, control modules, landing gear components, etc. WRAs and their internal Shop Replaceable Assemblies (SRAs) may be efficiently fault isolated using Automated Test Equipment (ATE) and associated Operational Test Program Sets (OTPSs).

3.2.3 Depot Level

D-Level maintenance functions are utilized (as required) for the complete rebuilding, manufacture of components, modifications, testing, and reclamation of equipment. This level of maintenance supports the lower categories of maintenance by performing repairs or modifications that are beyond their capability and by providing them with engineering assistance.

There are no scheduled D-Level maintenance activities or overhauls planned for the V-22. All components that are sent to Depot are done so to identify and repair defects identified by O or I-Level maintenance activities (i.e., unscheduled repairs only).

The V-22 is also compatible with a two-level (O- and D-) concept. The depot function can be performed by combining the capabilities of the customer, Bell Boeing, and/or the Original Equipment Manufacturer (OEM).

3.3 Maintenance Concept

The requirements to meet tough life cycle cost and reliability and maintainability goals resulted in an aircraft that balances redundancy, condition monitoring, and inspection accessibility to achieve an "On-Condition Maintenance" concept.

On-Condition Maintenance is defined as a combination of BIT and on-board diagnostics used to detect failures, sufficient redundancy to withstand failures without impacting mission capability, and scheduled inspections to detect potential failures or to meet calibration performance requirements. This significantly minimizes "hard time" removals for overhaul and replacement. The V-22 has minimal scheduled maintenance requirements, and very few Time-Between-Overhaul (TBO) or hard-time regulated components. The exception for hard-time components is for items like landing gear components, pyrotechnics, batteries, and fire extinguishers.

The overall V-22 support philosophy is to minimize scheduled maintenance and to simplify unscheduled maintenance through the application of technology. Maintenance is further accommodated by designing numerous access panels to ensure accessibility to all systems and by positioning components to minimize the stacking of installations.

To establish this support philosophy, the Supportability Analysis (SA) organization:

- Used Failure Modes, Effects, and Criticality Analyses (FMECA) for identification of all unscheduled maintenance actions,
- Performed Reliability Centered Maintenance (RCM) analyses for identification of all scheduled maintenance requirements,
- Initiated Level Of Repair Analyses (LORA) for defining an optimum maintenance concept, and
- Performed other detailed analyses for identification of all logistic support resources required at all levels of maintenance.

A part is removed only when there is evidence of failure or its impending failure. There are few removals of major components based solely on flight hours, engine hours or any other operational measure. The V-22 has been carefully designed to reduce maintenance times, especially for major dynamic components.

3.3.1 Onboard Monitoring

The Onboard Monitoring System has two major components: (1) The Central Integrated Checkout (CIC) system, and (2) The Vibration Structural Life and Engine Diagnostics (VSLED) monitoring system.

The CIC system performs fault detection and fault isolation. Fault detection monitors system health and assists the pilot in determining functional loss. Fault isolation identifies to maintainers the equipment that has failed. This arrangement achieves a workload reduction for the pilot, while maximizing the maintainer's information.

The CIC system collects the results for the three types of Built-in-Tests (BITs): (1) individual equipment checks at start-up, (2) periodic checks during system operation, and (3) initiated checks upon operator command.

The BIT is designed so that any failure within its circuitry has no effect upon the system's normal operation. Display of BIT health-monitoring results is accomplished using the avionics suite maintainer system status displays.

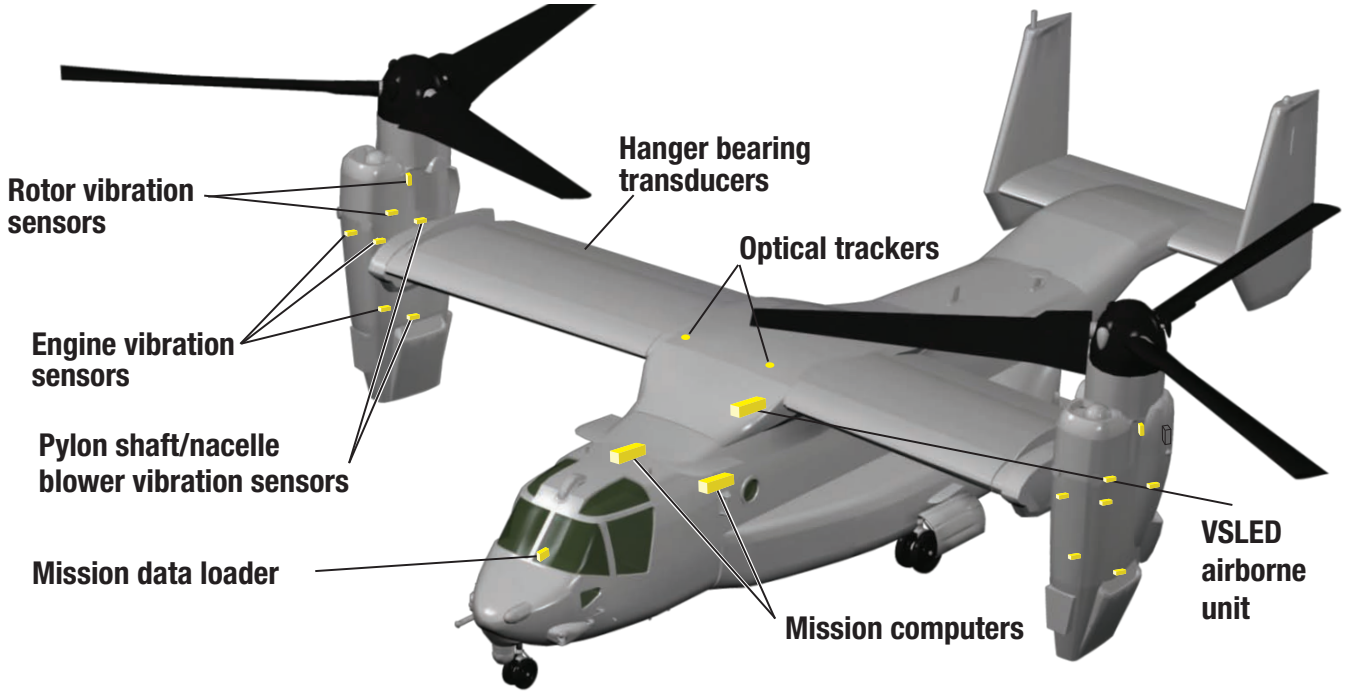
Aircrew and/or maintenance personnel can download the flight-data from the Mission Data Loader (MDL) to its removable Data Transfer Module (DTM) cartridge. This provides the capability to transfer aircraft health and mission information to an Aircraft Maintenance Event Ground Station (AMEGS) terminal. AMEGS is a ground-based, centralized, fleet maintenance data management system and can provide immediate identification and assessment of aircraft discrepancies.

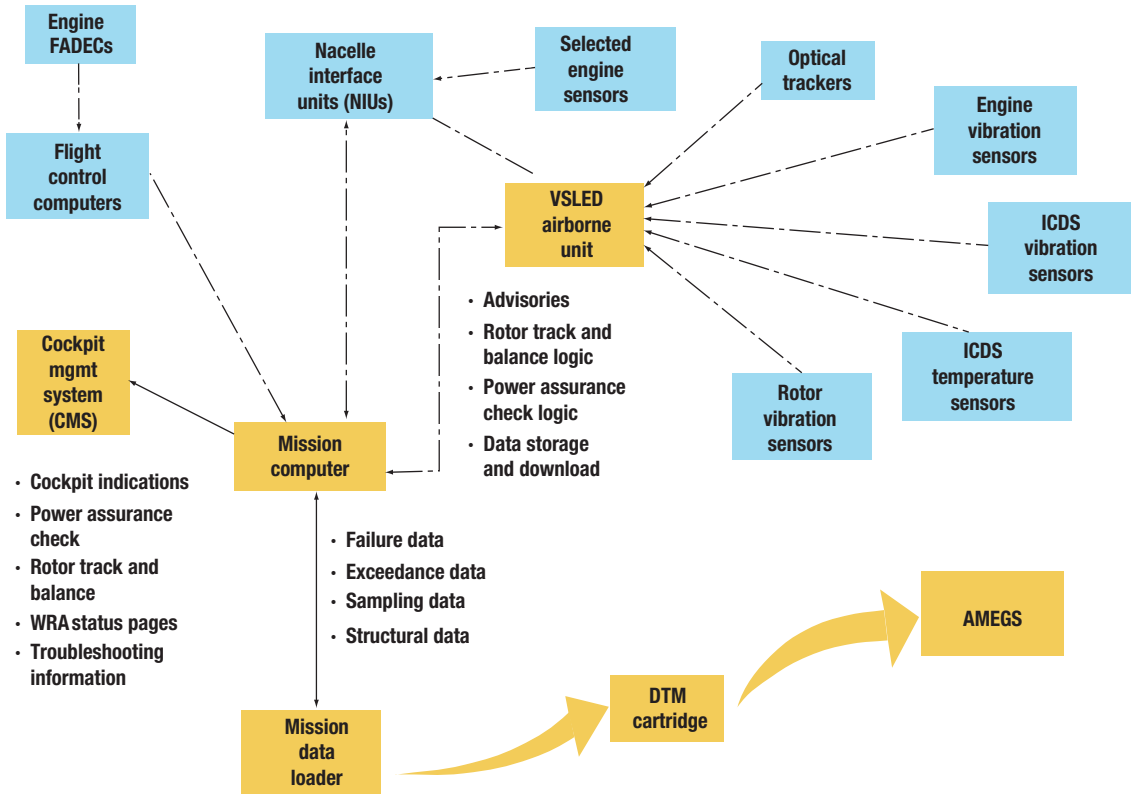
The AMEGS software generates an evaluation of an aircraft's post-flight or post-ground run operational status. This evaluation identifies necessary maintenance actions, which are inline with the on-condition maintenance philosophy. In addition, AMEGS provides the ability to track life-limited components and provides for archiving of maintenance data. Through the AMEGS, maintenance personnel can utilize the data recorded on the DTM cartridge for assisting in fault isolation, determining maintenance to be performed, generating Maintenance Action Forms (MAFs), conducting engine performance and vibration trending and diagnostics, and updating aircraft and system status.

3.3.2 Vibration, Structural Life and Engine Diagnostics

The Vibration, Structural Life and Engine Diagnostics (VSLED) system supports aircraft maintenance diagnostic capabilities for a wide range of systems. Normally, this type of support would require detailed breakdown inspections at fixed time intervals.

The VSLED system is wired directly to dedicated vibration and temperature sensors on the engines, rotors, and the cross-shaft hanger bearings. The primary functions of VSLED are: engine monitoring, structural load monitoring, vibration monitoring, rotor track-and-balance (including optical tracker), and transmission gearbox monitoring.





VSLED Equipment Distribution and Functional Interfaces

3.3.3 Technical Publications and Manuals

The Bell Boeing team has developed state-of-the-art Interactive Electronic Technical Manuals (IETM) for the V-22 through the use of a variety of software applications and modern computer hardware. While paper technical manuals or electronic technical manuals (ETM) could be produced, IETM provides several advantages to the customer:

- Increase in system availability
- Decrease in maintenance downtime
- Decrease in time to obtain support data
- Increase in accuracy and completeness of data
- Reduced maintenance costs

IETM Technical Manuals

The maintenance manuals for the V-22 have been developed as a digital database. A user interactively accesses the database in a logical, flexible sequence using a laptop sized Portable Electronic Display Device (PEDD). The PEDD replaces the traditional volumes of conventional paper manuals.

The V-22 IETM provides rapid access to information pertaining to a specific individual aircraft configuration. The technical data was developed once and used many times minimizing redundancy, file size, and increased costs. The clear and detailed graphics used were produced directly from digital engineering data.

Graphic understanding is further enhanced by the ability to: (1) magnify any portion of the graphic, (2) access a second graphic showing the location on the aircraft, and (3) access graphic hot-spots. The clarity and speed of the IETM reduces maintenance time, false removals, and training hours.

The information on the PEDD may be downloaded to an electronic parts-ordering system. This ability adds speed and accuracy to part ordering and maintenance history. It decreases manpower and required spares inventory. Similarly, quality data and audit trails are digitally available.

A significant use of technical manuals is in the training of personnel. The IETM is assigned to support training applications, in the schoolhouse as well as on the job. In the operational maintenance environment, the IETM can be routinely used for: safety-related tasks in checklist form, reference material, parts ordering, and step-by step aircraft maintenance.

IETM and PEDD use reduces the space requirements required for volumes of hard-copy manuals to a laptop-sized computer. This capability drastically reduces troubleshooting and maintenance time. PEDDs exploit the increasing computer skills of aircraft maintenance personnel to allow access to the expansive knowledge base required to support complex weapon systems. This system helps to limit maintenance documentation by: electronically interfacing with maintenance data collection systems and providing a keystroke-by-keystroke collection of historical maintenance data.

With immediate access to technical maintenance data tailored to specific aircraft effectivity, faults can be quickly isolated and the pursuit of incorrect troubleshooting paths avoided. Unnecessary component removal and replacement is eliminated, thereby decreasing supply support requirements while increasing aircraft availability and overall organic readiness.

By eliminating the long lead times required to provide publication changes and revisions, the total lifecycle costs are also decreased with the use of the IETM. Unlike the traditional processes for reordering lost or torn pages of paper manuals that can take more than 90 days, IETM software is updated by simply downloading it to the PEDD hard drive. Printing and distribution costs are significantly reduced and the risk of technicians working with incorrect, incomplete, or outdated information is greatly reduced.

3.3.4 Life Cycle Support

The Bell Boeing team has developed a Life Cycle Support (LCS) concept to provide lifetime support for the V-22 aircraft. This concept is designed to provide the V-22 operator with a “Best Value” support program for the life of the V-22 aircraft.

One of the keys to providing “Best Value” is a virtual support center approach that ties together the U.S. Government V-22 program, Bell, Boeing, suppliers, and international operators. This is accomplished through a state-of-the-art information management and communications system. The support center concept is comprised of the following major elements:

- Training
- Supply chain management
- Support equipment

- Aircraft/hardware maintenance
- Sustaining engineering technical support
- Software maintenance

3.4 Training

3.4.1 Flight Crew and Maintenance Mechanic Training

The Bell Boeing V-22 training program is designed to provide initial contractor training for U.S. DoD particular customers.

The V-22 Training System is comprised of fully integrated aircrew and maintainer training and training devices. Safety, proper procedures, and effectiveness are stressed within all training courses. Training courses and courseware requirements were identified and developed through the LSA process. Operational flight and maintenance training simulators also support the V-22 program.

3.4.1.1 Pilot/Operator Training

The V-22 pilot/operator training syllabus is designed to meet the needs of initial entry and transition pilot personnel. The training is accomplished through the use of a building block approach of Interactive Multimedia Instruction (IMI) lesson modules, high-fidelity flight training simulators, and actual aircraft. It is accomplished using instructor-led, computer-aided instruction, and self-paced interactive courseware.

3.4.1.2 Enlisted Aircrew Training

Similar to the pilot/operator training, the crew chief/flight engineers are trained through use of the same building block approach: IMI lesson modules, high-fidelity maintenance training devices, coordinated flight simulators, and aircraft exercises. The training is accomplished using instructor-led, computer-aided instruction, and self-paced interactive courseware.

3.4.1.3 Maintenance Training

Maintenance training is designed for initial entry maintenance mechanics and technicians. Training is accomplished using instructor-led, state-of-the-art, computer-aided instruction, and self-paced interactive courseware. It is reinforced by practical demonstrations and exercises using a fully-integrated maintenance training device suite.

3.4.2 Training Devices

The Bell Boeing training strategy takes advantage of a full suite of training services and equipment developed for the V-22. These include:

- A Federal Aviation Agency (FAA) Level-D equivalent full flight simulator (FFS),

- Level 7 equivalent Flight Training Device (FTD),
- Interactive audio/video computer-based training (CBT) devices, and
- Computer-based presentation system supporting instructor-led training.

3.4.2.1 Full-Flight Simulator

The V-22 Full-Flight Simulator (FFS) replicates the look and feel of the V-22 cockpit for use in full motion-based simulated flight training. It is comparable in performance and training capability to the simulators developed under the FAA Regulations.

V-22 Full-Flight Simulator

The major components of the FFS include:

- A full-size replica of the V-22 cockpit. Direction and movement of controls and switches are identical to those of the aircraft. All cockpit instrument indications are simulated automatically in response to control movement, simulated aircraft performance, instructor-inserted actions, and environmental effects.
- The assemblage of equipment and system software necessary to represent the aircraft and all systems in every mode of operation.
- Primary flight-control loading system, vibration system, and aural cueing system.
- Maintenance and operation support equipment.
- A visual display system mounted on a six degree-of-freedom motion system.
- A visual image generation system featuring real-time out-of-the-cockpit, RADAR, and FLIR imagery views.
- An on-board instructor/operator station.
- A debrief station for playback of aircrew video, simulator flight parameters, and a visual scene for mission review.

3.4.2.2 Flight Training Device

The V-22 Flight Training Device (FTD) is identical to the FFS but without a motion base system. The FTD is capable of fully supporting all simulator training events (except those events requiring motion) in the syllabus of instruction.

3.4.2.3 Interactive Multimedia Instruction System

The pilot/operator, aircrew, and maintenance Interactive Multimedia Instruction (IMI) system provides electronic instructional training media that depicts the V-22's system components and operation. It is designed for presentation in organizational maintenance training and for pilot ground school classrooms. The IMI system includes: computer-aided instruction, interactive courseware, a question presentation system, and computer managed instruction.

The selection of training topics included in the IMI system and the determination of presentation methods used are the result of extensive analysis. The analysis included a determination of the support and maintenance requirements needed to fully field the USMC V-22. Topics are modified to support a customer's configuration.

3.4.2.4 Cabin Part Task Trainer

The Cabin Part Task Trainer (CPTT) is a full-sized replica of the V-22 fuselage (from the nose to just aft of the ramp closure). An Instructor Operator Station (IOS) aids the V-22 instructor in training tasks associated with the CPTT by providing controls for normal operation, fault insertion, and emergency shutoff. The CPTT provides capability for training the following:

- Troop and passenger loading and unloading
- Cargo handling (loading and unloading)
- Ingress/egress procedures
- Ground refuel operations
- MEDEVAC kit installation
- Manual release and operation of the windows and doors
- Para drop procedures

3.4.2.5 Maintenance Trainers

The Maintenance Trainer Suite for the V-22 Program is comprised of different Part Task Trainers. These trainers allow for the hands-on training of all the skills required to maintain the V-22 at the O-Level.

The design of the suite was derived through the use of the Instructional Systems Design (ISD) process. Over 8,000 O-Level tasks were identified and developed through the LSA process. Bell Boeing instructors analyzed each task using a Bell Boeing developed computer program called V-22 Task Analysis System (VTAS). Tasks analyzed as trainable were then broken down into hands-on or classroom training.

The hands-on tasks were then further analyzed to determine which were required to be trained on the maintenance trainers. This was done to ensure all students would acquire the skills and knowledge to perform all trainable tasks. This final step ensures a cost effective and efficient maintenance training system.

A series of Part Task Trainers were designed to provide the proper fidelity required. Their purpose is to perform the hands-on training necessary to qualify maintainers in all specialties. Each Part Task Trainer was derived from a thorough systems requirements analysis. They were further broken out by aircraft system and corresponding Military Occupational Specialty (MOS).

The Part Task Trainers are used to train heavy maintenance tasks. These tasks are primarily mechanical in nature and require several well coordinated teams to accomplish (e.g., engine replacement). In order to ensure a realistic training environment, the trainers utilize both actual aircraft components and simulated aircraft components. The trainers have no requirement for software, power, or fluids. Thus, they are easily maintained and extremely dependable.

Airframe Part Task Trainer

3.4.2.6 Pilot Transition Course

A pilot transition course is used for training U.S. military flight-test and acceptance pilots. These pilots typically have a significant level of previous flying experience. Currently, U.S. military pilots transitioning to the V-22 are required to be helicopter-qualified as "pilot-in-command." Fixed wing experience is also required, but basic flight training may satisfy this requirement.

Bell Boeing provides student pilots with 120 hours of ground school. Once ground school is completed, each pilot receives 20 hours of flight simulator training. After the simulator training is completed, on-aircraft flight training begins. Flight training is conducted until an acceptable level of proficiency is developed (the customer's aircraft is used). This proficiency typically requires only 5 to 10 flight hours.

3.4.2.7 Maintenance Course

V-22 maintenance courses are designed for a mixture of personnel. These personnel may be previously trained on other aircraft and/or junior personnel with limited training and skills.

A generic V-22 familiarization (FAM) course is taught to all personnel. This course is a prerequisite to maintenance courses. Hands-on practical training is conducted using the customer aircraft as a training device. O-Level maintenance actions peculiar to the V-22 are trained, including:

- Removal and replacement of major components
- Use of the V-22 BIT electronic systems
- Use of the Interactive Electronic Technical Manuals (IETMs)
- Use of the V-22's peculiar tools and test equipment
- Operational tests

Junior personnel will receive practical training through hands-on work on operational V-22 aircraft. These individuals are teamed with more experienced personnel of the same MOS code. Together, they perform maintenance actions under instruction.

The maintenance courses currently available are:

Course	Length
V-22 Familiarization	16 hours
Airframe/Structures	76 hours
Hydraulic Systems	80 hours
Power Plant and Related Systems	184 hours
Environmental Control Systems (ECS)	80 hours
Electrical Systems	120 hours
Vehicle Management Systems (VMS)	120 hours
Cockpit Management Systems (CMS)	80 hours
Crew Chief	85 hours
Flight Training Requirement	20 hours

3.4.2.8 Other Training

Additional training has been developed. The following courses are also available:

Course	Length
Staff Personnel Familiarization	24 hours
Ground Handling and Safety Briefing (for airfield and ship personnel)	4 hours
Electronic Wiring Suite Familiarization	6 hours

3.4.2.9 Supply Chain Management (Spares)

Bell Boeing provides supply planning activities, including supportability analysis, spares engineering assessment and spares modeling support, that optimizes initial provisioning spares packages for production aircraft lot deliveries. In addition, replenishment spares and component repairs are processed based on customer retail and wholesale stock position, consumption usage and repairable carcass turn-ins for original equipment manufacturer (OEM) maintenance. Supplier management coordination and integration is leveraged for spares and production procurement and for asset reallocation based on requirements priorities. Bell Boeing also offers strategic supply planning, inventory optimization analysis, spares and repair part sourcing & procurement, physical logistics support with warehousing & distribution, asset management for wholesale supply, and customer direct retail supply requisition demand fulfillment.

3.5 Support Equipment

Although significantly more sophisticated and capable than other aircraft, the extensive use of on-aircraft BIT and general-purpose test-equipment for diagnostics allows the V-22 to minimize the use of complex test equipment.

The design of the V-22 recognizes that customers want to minimize required maintenance equipment and tools. Thus, its design has been to leverage the use of standard maintenance equipment and common aviation tools so that the Peculiar Support Equipment (PSE) is minimized.

Additionally, through the Integrated Product Team (IPT) approach, the design of the aircraft was influenced to minimize PSE to the greatest extent possible.

- Common tools include those tools that are identified by the customer that are common to platforms already existing within their current inventory. Bell Boeing may recommend that customer common tool sets be augmented to include V-22 standard fastener tools such as wrenches and rivet tools; wire and connector tools; tubing repair tools; and hoisting equipment for heavy dynamic components such as gearboxes and rotors.
- Standard handling equipment includes tugs, servicing carts, and jacks.

All requirements for hand tools and support equipment for O, I and D-Levels of maintenance are identified through the Supportability Analysis process. The SA process determines the tool and support equipment requirements for the entire aircraft as well as for specific maintenance and servicing tasks.

Acquisition costs for support equipment are determined after the number of aircraft, operational organization, and basing plans are determined.

The design requirements that have minimized the need for PSE during routine O-Level maintenance are:

- Routine scheduled maintenance is to be minimized.
- Design influence to eliminate or reduce the need for PSE.

- Extensive use of aircraft component handling adapters, thereby minimizing unique single-purpose trailers.
- The Mean Flight Hours between Replacement (MFHBR) for major components is designed and as necessary upgraded to be high – i.e., greater than 1,500 hours.

3.6 Reliability and Maintainability

The on-condition maintenance design of the V-22 reduces maintenance down time. It allows users to be proactive rather than reactive in maintenance planning and reduces spares costs. The other advantage of reliability and maintainability designed into the aircraft is:

- The amount of time spent performing maintenance is reduced.
- The use of standard parts and tools reduces maintenance complexity, training requirements, and maintenance error.
- The onboard monitoring minimizes troubleshooting and fault isolation time, supports on-condition design and reduces false alarms.
- The reduced scheduled maintenance requirements improve the aircraft's availability and reduce the maintenance manpower costs.
- The improved design reliability reduces the frequency of unscheduled maintenance.

3.6.1 Reliability Program

The use of ongoing user feedback allows reliability engineers to analyze and correct recurring failures. The Failure Reporting, Analysis and Corrective Action System (FRACAS) database warehouse Components Assessment and Reliability Tracking System (CARTS) captures data from various sources. The database warehouse and its corresponding analysis capabilities can be used to obtain and analyze maintenance/reliability data across the full spectrum of V-22 test and operational sites.

3.6.2 Maintainability Program

The V-22 was designed with maintenance and support in mind. By incorporating new maintenance concepts, enabling technologies, built-in-test, diagnostics monitoring, and employing a substantially different scheduled maintenance philosophy, the maintenance personnel requirements and operating costs have been reduced.

The main objectives of the V-22 maintainability design approach are to:

- Reduce unscheduled maintenance frequency, by increasing the reliability of each component.
- Ensure that components and installations have adequate access, and are easily removed and installed.
- Reduce maintenance downtime by providing extensive fault detection and isolation

capabilities.

- Reduce scheduled maintenance frequency by lengthening inspection intervals and eliminating scheduled replacements.
- Minimize the need for V-22 Peculiar Support Equipment (PSE) and tools.
- Minimize the number of work platforms required and allowing simultaneous task work.

3.6.3 Failure Mode, Effects and Criticality Analysis and Reliability Centered Maintenance

Failure Mode, Effects and Criticality Analysis (FMECA) were developed for every assembly on the aircraft. FMECAs were prepared at each level of the aircraft subsystem, line replaceable unit, and shop replaceable unit. FMECA results were utilized in the design process by IPTs, as well as by Safety personnel to develop hazard analyses. Additionally, the FMECAs provided the basis for a comprehensive support analysis down to the aircraft component level. Based on the results of the Failure Modes, Effects, and Criticality Analysis (FMECA), a Reliability Centered Maintenance (RCM) analysis was performed on all V-22 systems and subsystems. The results of the RCM analysis were recorded in the Integrated Reliability Centered Maintenance System (IRCMS) software and in the Support Analysis Record (SAR).

3.7 Facilities and Site Activation

For the U.S. military, additional facilities analysis is required to determine the delta's in a hybrid platform that has both helicopter and fixed wing capabilities. These requirements have been identified over and above those of existing CH-46 helicopters. The O and I-Level support facilities for the CH-46 or CH-53D have been used as the baseline for comparison when determining the requirements for the V-22. The helicopter maintenance facilities used by specific customers will also need to be evaluated for operational and maintenance requirements. Facility requirements are directly impacted by upgrades or modification to the aircraft and O/I/D maintenance concept changes derived from the Maintenance Decision Boards, customer direction, and technology development.

3.8 Sustaining Engineering Technical Support (Service Engineering)

Contractor Sustaining Engineering and Technical Support is provided to customers to assist in identifying, providing, and supporting the ILS requirements necessary to meet full O/I-Level capability upon arrival of the first aircraft at V-22 operational sites. Contractor support is also utilized to provide support of the O to D-Level maintenance concept prior to and during the establishment of full O, I and D-Level maintenance capability throughout the life cycle of the weapon system.

This support consists of seven basic elements that can be tailored to a customer's unique support requirements. The basic elements are described below.

3.8.1 Contractor Maintenance Support

The Contractor Maintenance Support (CMS) consist of mechanics and technicians located in and working with customer's airframes shop, avionics shop, flightline, aircrew life support systems, maintenance control, and quality assurance work centers. Their primary purpose is to provide On-the-Job-Training (OJT) through the conduct of routine maintenance in support of the customer's flight schedule. Contractor maintenance support technicians are highly skilled artisans that hold Airframe and Powerplant (A&P) licenses, and are knowledgeable in military aircraft systems/subsystems, as well as customer maintenance practices, processes, and procedures.

3.8.2 Field Service Representatives

Contractor Field Service Representatives (FSR) possess specialized knowledge, experience, and skills relative to V-22 system/subsystem operation, maintenance, and repair. They have access to information covering the installation, operation, modification, and maintenance of the V-22 weapons system at the O/I/D level. They are responsible for supporting customer maintenance departments by solving difficult aircraft problems, formal/On-the-Job training, and technical manual improvement. Support services provided as follows:

- Provide Ashore/Afloat based O/I-Level maintenance pending availability of organic capabilities;
- Support on-site structural and composite repair;
- Support development of I-Level WRA/SRA work-around procedures;
- Provide on-site technical/logistic liaison with suppliers and prime contractors;
- Support local manufacture of aircraft parts (lines, brackets, etc.);
- Develop/provide local training course outlines and lesson plans as required;
- Support and attend Logistics/Technical support meetings, briefings, telecoms, etc. as required/requested;
- Rendering technical assistance to resolve difficult and unusual maintenance anomalies;
- Provide liaison with contractor plant engineering and Field Support Team (FST);
- Participate in on-site HMR/EI evaluations as requested by FST;
- Provide on-site classroom and on-the-job training to military and civilian personnel on: maintenance and trouble-shooting, bench checks, routine maintenance, inspection and repair of prime system and equipment, special tools and test equipment;
- Devise local training course outlines and lesson plans;
- Render technical assistance to resolve difficult and unusual maintenance anomalies; and
- Provide an analysis of maintenance anomalies and informing the supported activities of changes to maintenance, inspection, and training programs designed to improve the quality of maintenance.

3.8.3 Contractor Plant Engineering Services

Sustainment services are provided to the government and DoD personnel by Bell Boeing. These services are provided to DoD and the Government at Bell Boeing manufacturing facilities. In-plant services provided include:

- Respond to all fleet Technical Assists (TAs) and Digital Field Service Reports (DFSRs);
- Release Bell Boeing Service Bulletins, Alert Service Bulletins, and Service Letters;
- Prepare response to customer requested NAMDRP reports (i.e. Engineering Investigations (EI), Deficiency Reports, etc.);
- Participating in component EI investigations and the follow-on testing;
- Provide subcontractor/supplier analysis for service related problems;
- Provide feedback loop for recurring & non-recurring AIT/IPTs of service related problems;
- Participate in the validation of IETM procedures;
- Develop and track program metrics to assess fleet support performance;
- Provide V-22 Field Services data/access through established Internet Fleet Support Web page; and
- Provide on-site classroom and on-the-job training to DoD military and civilian personnel on maintenance and trouble-shooting, bench check, routine maintenance, inspection and repair of prime system and equipment; special tools and test equipment.

3.8.4 Contractor On-Site Acquisition Logistics Support

The Contractor shall provide on-site Acquisition Logistics Support (ALS) representation to facilitate issue reporting / corrective action planning / execution and customer coordination with respect to post DD-250 aircraft and logistic support system performance. The ALS representative provides the following:

- Detailed planning including schedule development, tracking, and updates with regard to waivers/open work and accelerated ECP incorporation;
- Integration, administration, organizational control, and functional coordination for post DD-250 aircraft/kits received on-site;
- Interface between Supportability IPTs, MV-22 FST, Type Commander, and with IPTs in other departments;
- On-site ALS functions coordination between Bell Boeing and the customer;
- Front line on-site maintenance analysis management tasks including identification, definition, reduction plans, and management reporting;

- Interface with military customers, company field service engineering, and manufacturing to identify delivered aircraft/product quality;
- Customer support programs monitoring from concept through disposal to satisfy requirements for ongoing product support, spares, repairs, overhaul, equipment provisioning, tooling, data, and other related services;
- Company representation with military customers to plan, budget, and schedule ongoing support programs; and
- Work with FSRs to analyze and provide customer solutions to complex maintenance-related questions involving spares, repairs, or processes.

3.8.5 Post Delivery Engineering Support

Post delivery engineering support provides technical support and engineering services to customer engineering agencies, field activities, and fleet activities. Services and products delivered include:

- Review/evaluate preliminary maintenance and technical reports such as Unsatisfactory Reports, Field Services Reports, requests for Engineering Investigations (EIs), Accident Investigation Reports, Engineering Data Request (EDR), Digital Field Service Reports (DSFRs), Technical Assistance Reports System (TARS), Mishap Reports, and other written reports of anomalies or incidents with a V-22 aircraft;
- Support/conduct preliminary investigations and recommend corrective action for anomalies, assess associated technical impacts and recommend structural flight envelope restrictions, temporary repairs, revisions to operating and/or maintenance procedures, and identification of any safety concerns. This includes providing engineering data and supporting development of Service Bulletins and Interim Technical Directives;
- Provide technical specialists to respond to preliminary structural, weights loads, dynamics, thermodynamics, aerodynamics, and vehicle systems investigations, and analysis to support MV-22 aircraft and associated systems;
- Evaluate/respond to IETMS and NATOPS inquiries. Provide support to ILS as required in performing field inquiries and investigations;
- Participate in operational site visits to obtain information from MV-22 users and provide initial participation in Air Safety Investigations when requested.

3.8.6 Logistics Support Representatives

Contractor Logistics Support is provided to customer personnel on-site at operational facilities. Logistics Support Representatives (LSRs) possess specialized knowledge, experience, and skills, and have access to information/systems to research, expedite and monitor usage of all V-22 parts requirements. Services and products delivered are as follows:

- Perform technical research on all part requirements;
- Assist with expediting all part requirements and provide status and estimated delivery dates when requested;
- Monitor usage of all V-22 part requirements and coordinate appropriate allowance change/addition requests;
- Participate in review and negotiation process for existing and future allowance requirements;
- Assist in review and development of required pack-ups as well as "L" Class AVCAL allowances required for deployment;
- Assist in maintaining V-22 peculiar material on the MALS Relational Supply/NALCOMIS database;
- Provide stock posture on material required in development/installation of Technical Directives and Service Bulletins as required;
- Conduct receipt process of retrograde materials into the Commercial Asset Visibility System (for Carcass Tracking purposes) and provide contractor personnel with required paperwork for induction to the Repair of Repairable (ROR) cycle; and
- Receive material, prepare shipping paperwork, and coordinate prompt shipment of all V-22 repairable retrograde to appropriate vendors.

3.8.7 Technical Data Support Representatives

Contractor Technical Data Representatives provide IETM/OTIS hardware and software support to customer personnel as it pertains to the V-22 IETM/OTIS products. This support includes the following:

- Maintain, upgrade, troubleshoot, and provide the first level repair for all V-22 IETM/OTIS hardware;
- Maintain, upgrade, troubleshoot, and provide the first level repair for all V-22 IETM/OTIS software;
- Manage, track, and update Portable Electronic Display Devices, servers, hardware, and software configurations;
- Provide hardware and software training in support of all V-22 IETM/OTIS products to the end user as required;
- Coordinate and track distribution, repairs, and upgrades of all V-22 IETM/OTIS products; and
- Provide technical liaison that coordinates with and assists the customer to ensure coordination, management, and prompt individual or joint problem solving with assigned action responsibilities, as required.

3.9 Software Management

Bell Boeing provides software updates, as required, for both software deficiencies and desired enhancements. State of the art software development/integration laboratory complexes are used for software development, integration, testing, and anomaly resolution.

The Bell Boeing V-22 Integrated Product Teams (IPTs) maintain the software baseline and support software configuration management activities. Depending on the program customer, contract, and licensing agreements, Bell Boeing can structure a suitable software management approach that either follows the existing U.S. Government structure or meets other requirements.

3.10 Aircraft Battle Damage Repair

The V-22 is designed as a combat aircraft with ballistic toughness consistent with its vertical assault mission. It can sustain small arms and automatic weapon hits, while still continuing its mission.

There are a substantial number of built-in features to significantly reduce the potential for aircraft damage or loss. Its ballistic vulnerability is further minimized through:

- Redundancy;
- Separation of key components and systems;
- Inherent and parasitic hardening of key components;
- Extensive use of composite;
- Damage-tolerant materials;
- Redundant load paths throughout the primary aircraft structure; and
- Extensive fire protection and prevention measures.

The V-22 development has included an Aircraft Battle Damage Repair (ABDR) program. The objective of the ABDR program was to develop the capability to restore sufficient strength and serviceability to permit a battle damaged aircraft to fly additional operational sorties (of at least partial mission capabilities) in time to contribute to the outcome of the ongoing battle. A secondary objective was to develop repairs that will enable those aircraft damaged beyond ABDR repair capability to make a one-time ferry flight to a rear area or a depot repair facility for major repairs.

The ABDR program developed an institutional method for field personnel to assess and restore the aircraft to service in an expedient and safe manner. The program provided information on likely damages, damage assessment procedures, generic repair techniques, and logistics requirements (i.e., spares, training, maintenance planning, technical data and manpower). These elements provide the capability to sustain the V-22 under combat condition.

SECTION 4.0 - OPERATING CHARACTERISTICS

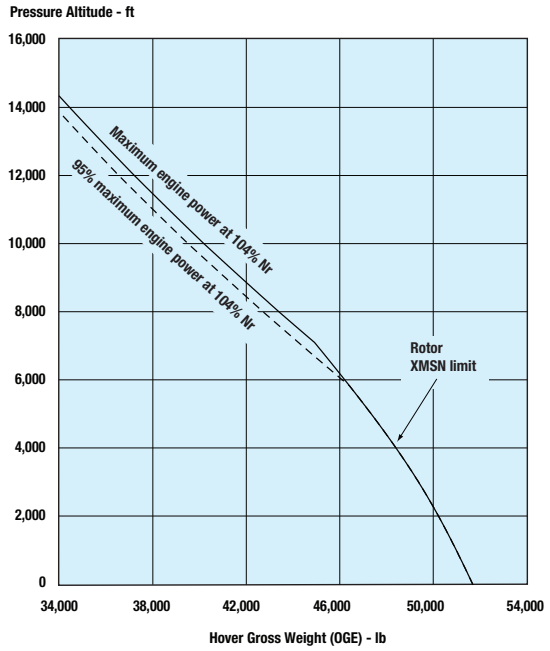
4.1 Flight Performance

The data presented in this section is general in nature. Specific performance characteristics and operating limitations (for any specific flight mission) are contained in the approved flight manual.

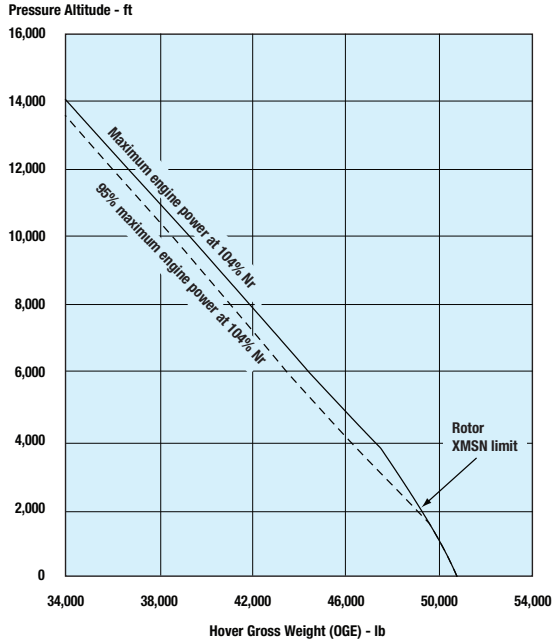
The V-22 tiltrotor provides exceptional speed, range, and altitude flight performance for a Vertical/Short Takeoff and Landing (V/STOL) vehicle. The flight performance data present a range of operational gross weights using standard day conditions (except as noted), with (2) Rolls Royce AE1107C engines for installed power available and fuel flow. Shipboard and land-based mission capability can be enhanced with the nacelles partially rotated to conversion mode for Short Takeoff (STO) and Roll-on Landing (ROL) operations.

4.1.1 Hover and Short Takeoff Performance

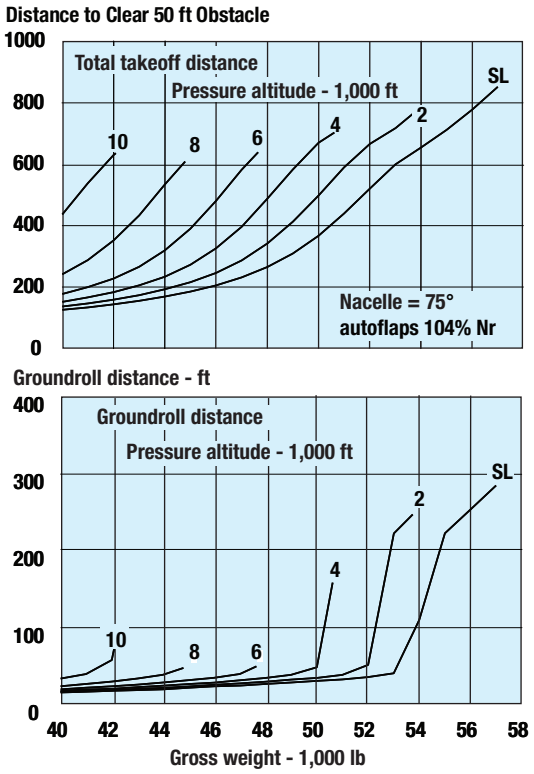
V-22 operators choose which takeoff mode best suits their operating locations, mission, and payload requirements. Vertical Takeoff (VTO) performance data are presented for Hover Out-of-Ground Effect (HOGE) for standard and hot day atmospheric conditions with no winds. Short Takeoff (STO) performance data are shown for two primary rolling takeoff procedures, 75° nacelle Level Attitude Takeoff and 60° nacelle Attitude Rotation Takeoff, with no winds.



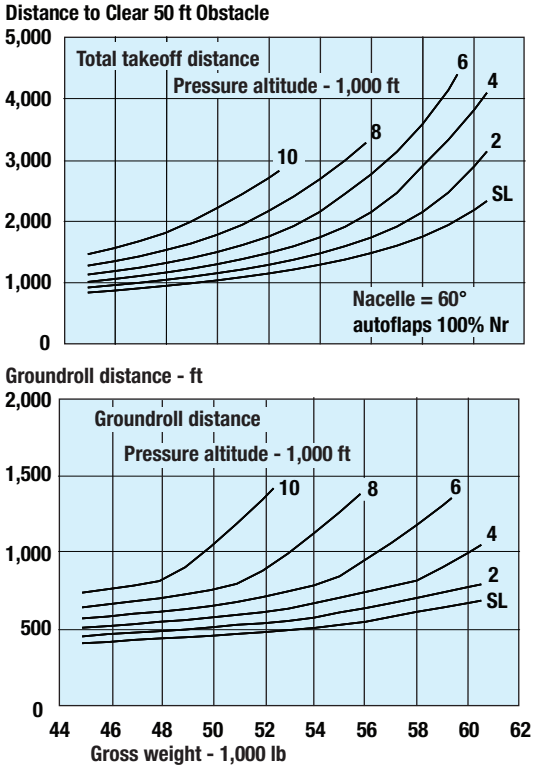
V-22 Standard Day Hover Envelope (OGE)



V-22 Hot Day Hover Envelope (OGE)



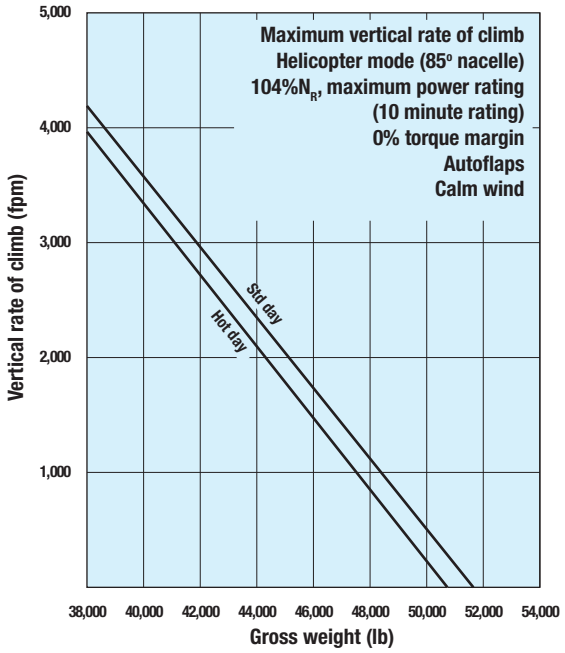
75° Nacelle Takeoff Distances – Level Attitude (Std Day)



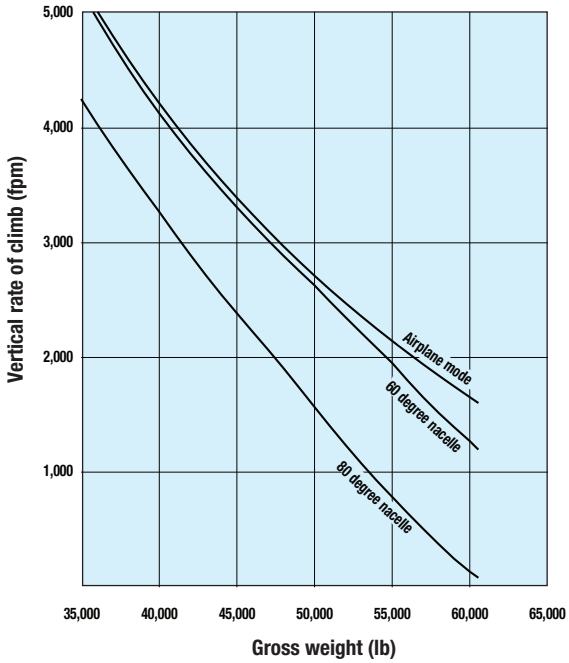
60° Nacelle Takeoff Distances – Attitude Rotation (Std Day)

4.1.2 Climb Performance

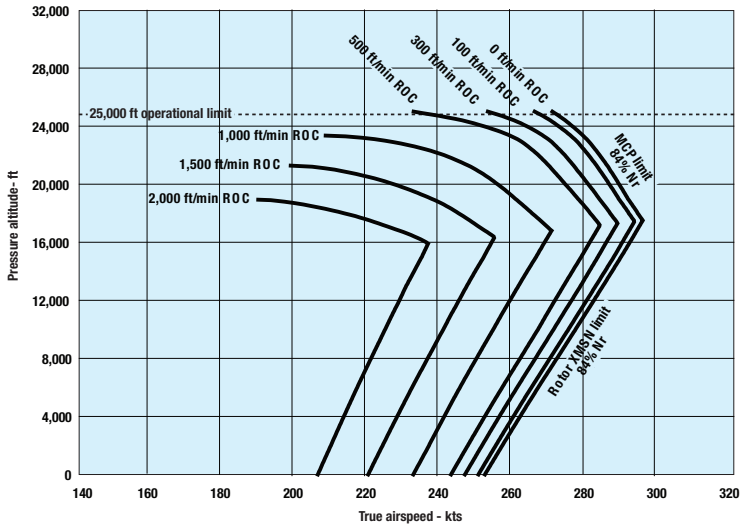
V-22 climb performance capability with Maximum Power (10 min rating) is presented for vertical climb (85° nacelle) and forward flight climb (conversion and airplane modes.) Cruise climb capability with Maximum Continuous Power at a typical mid-mission gross weight is also presented.



Helicopter Mode Vertical Climb Capability (Sea Level)



Maximum Forward Flight Climb Capability (Sea Level, Standard Day)



V-22 Cruise Climb Envelope (Standard Day, 45,000 lb [20,412 kg] Gross Weight)

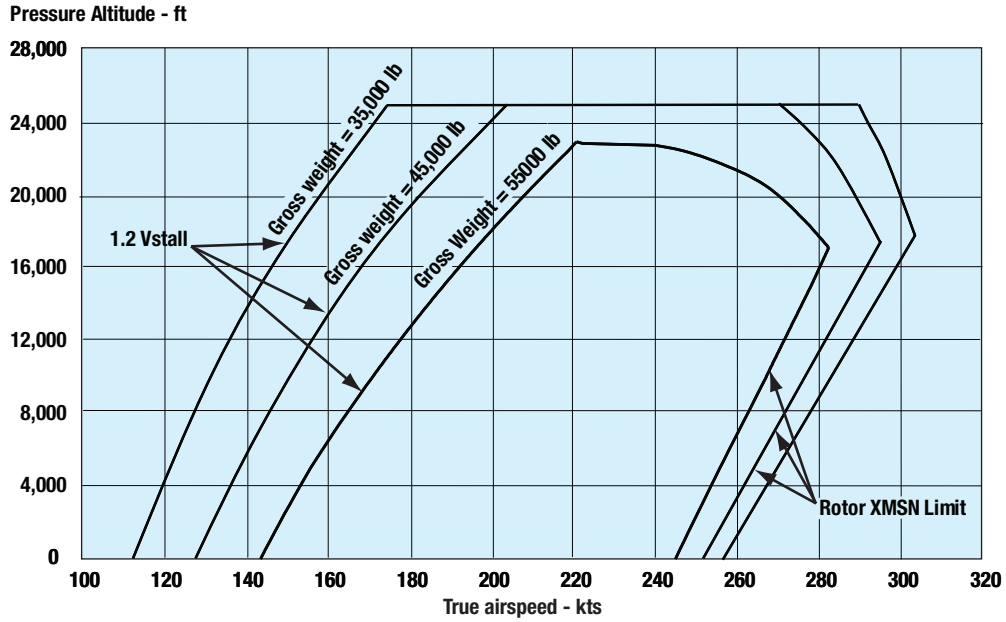
4.1.3 Load Factors

The V-22 is designed for flight maneuver normal load factors from +4.0 G to -1.0 G in Airplane Mode at the Structural Design Gross Weight (SDGW) of 39,500 lb (17,916 kg). The maneuver envelope is proportionately lower for higher gross weights. VTOL Mode and Conversion Mode are designed for +3.0 G to -0.5 G load factor at SDGW.

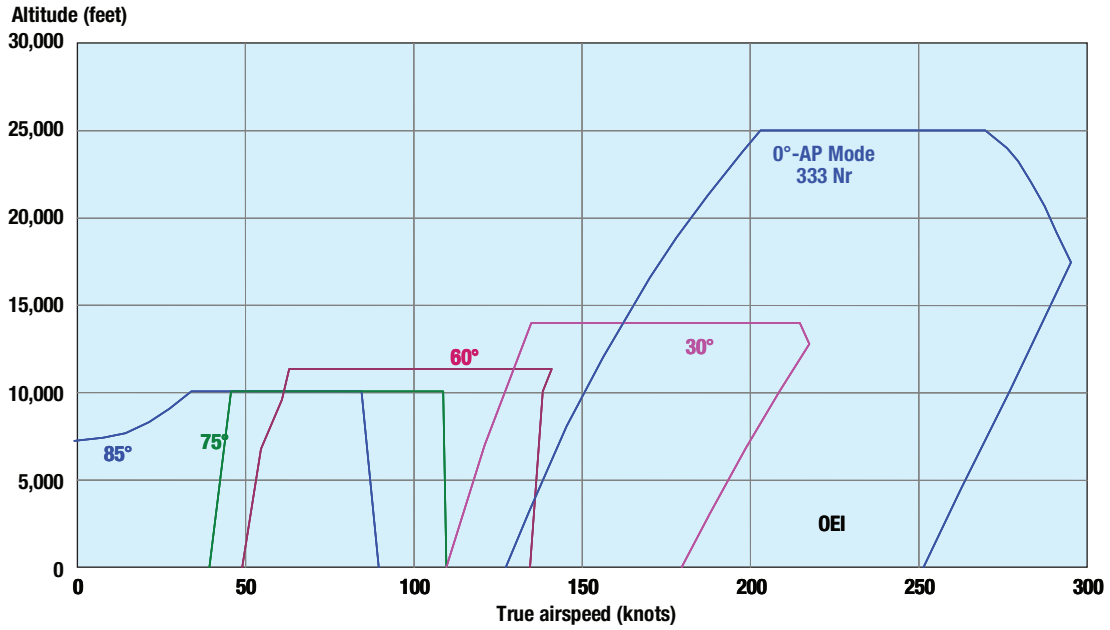
4.1.4 Cruise Flight Envelope

The V-22 has a much larger flight envelope than either conventional fixed-wing aircraft or helicopters. The V-22 is an unpressurized aircraft, and as such has an operational altitude limit of 25,000 ft. V-22 flight envelopes are presented for:

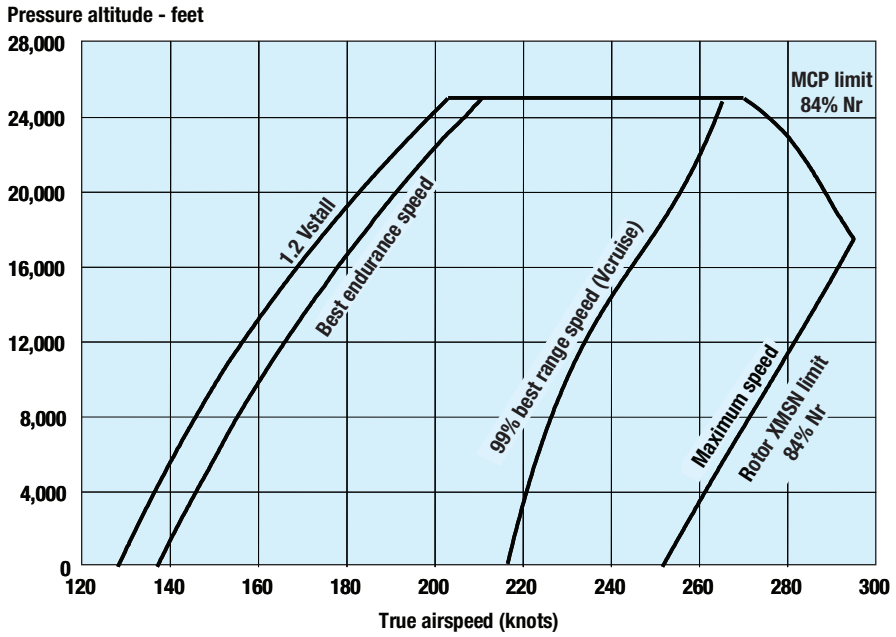
- Airplane Mode, at a range of gross weights.
- Operational flight envelope through several conversion mode nacelle angles, for a typical mid-mission weight of 45,000 lb (20,412 kg).
- Mission-specific speeds for a typical mid-mission weight – Best Endurance, Speed for 99% Best Range, and Maximum Continuous speed.



V-22 Airplane Mode Flight Envelopes (Standard Day)



V-22 Composite Flight Envelope with Conversion Mode (Standard Day, 45,000 lb [20,412 kg] Gross Weight)



V-22 Flight Speeds V-22 Flight Speeds (Standard Day, 45,000 lb [20,412 kg] Gross Weight)

4.2 Mission Performance

The data presented in this section is general in nature. Specific performance characteristics and operating limitations for any specific flight mission are contained in the approved flight manual.

Mission performance is directly related to the total weight and drag configuration of the air vehicle. Thus, each individual mission configuration requires a weight review. To determine the mission flight weight, the following items must be accounted for:

- Pilots, crew, minimum flight equipment, and operating fluids (Basic Fixed Useful Load),
- Payload (equipment, cargo, and/or passengers), and
- Fuel for the mission.

There are limitations to the maximum takeoff gross weight that depend on the desired mission characteristics and the availability of runways (or landing pads) during the mission. Prior to performing an operation, the pilot must assess the need to land or takeoff vertically during the mission. V-22 maximum takeoff weights are:

- 52,600 lb (23,859 kg), for missions requiring VTOL operations.
- 57,000 lb (25,855 kg), if available runways are suitable for short rolling takeoffs.
- 60,500 lb (27,442 kg), for self-deployment from a smooth runway.

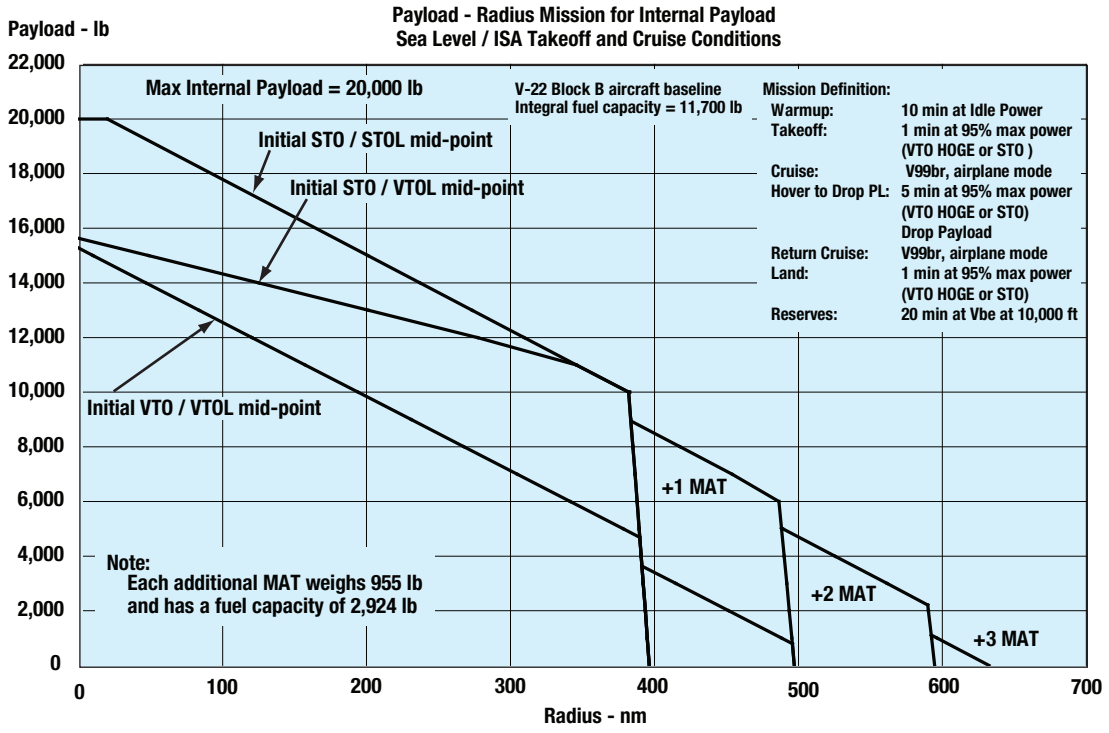
Using standard jet fuel (JP-5) at 6.8 lb/gal (0.82 kg/l), the maximum usable fuel capacity for the basic configuration V-22 is 11,700 lb (5,307 kg).

4.2.1 Mission Descriptions

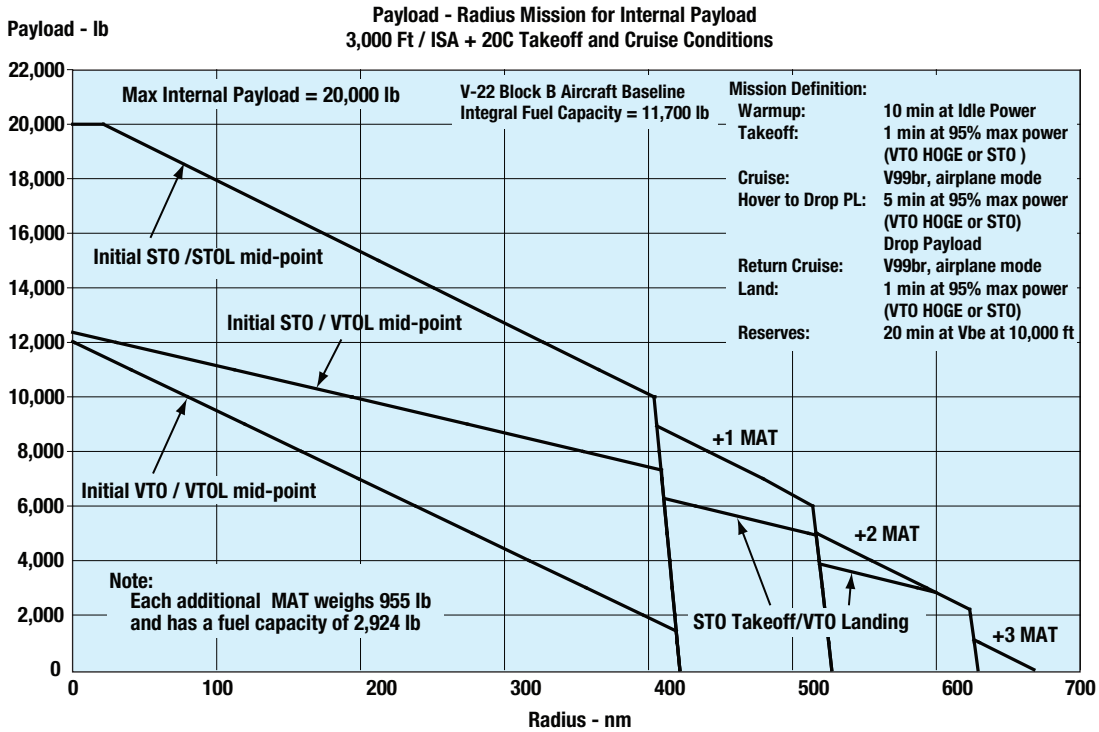
Generally, missions fall into one of four categories: internal payload and external payload missions (unrefueled), deployment (or one-way) payload mission, or search and rescue (or loiter) mission. Bell Boeing has developed basic mission scenarios and calculated the mission performance for each of these four categories.

4.2.2 Internal Payload Mission

Typical internal payload missions will include vertical or short takeoff and landing criteria (based on the initial and mid-point sites),troops or payload delivery at the midpoint, unrefueled return to base, and a landing criteria for reserve fuel capacity. Flight performance for this mission profile is provided below, for two different atmospheric conditions - sea level standard temperature, and 3,000 ft mean sea level at standard temperature plus 20° C.



Internal Payload Mission Performance – Sea Level/Standard Day



Internal Payload Mission Performance – 3,000/ISA+20°C

4.2.3 External Payloads

The V-22 is designed to carry external loads up to 15,000 lb (6,804 kg) on dual hook rigging, or 10,000 lb (3,402 kg) on either single hook. The maximum airspeed allowed for external load carriage will normally be limited by one of three conditions:

- Aircraft maximum power,
- Load integrity, or
- Combined aircraft-load center of gravity (CG) and dynamic stability.

To take advantage of V-22's power capability to carry various external loads up to 200 kts, as compared to typical helicopter carriage maximum speeds of 130 kt, requires specific loads to be evaluated for their air load strength integrity, and their combined load/aircraft dynamic stability.

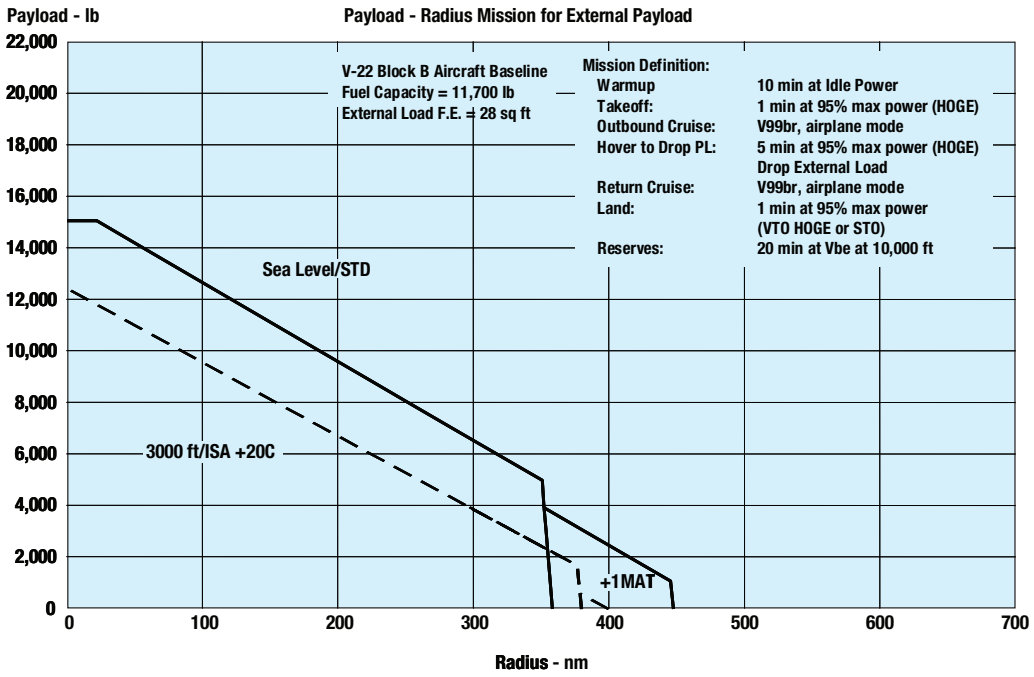
Typical external loads that are carried by the V-22 include: field Howitzers, battlefield vehicles (e.g., the High Mobility Multipurpose Wheeled Vehicle [HMMWV]), trailers, ISO containers, liquid containers, and netted, palletized loads.

The patented V-22 auto jettison system is a key integrated flight control system that provides for safe, high speed flight with dual hook external load carriage. It provides a reliable identification of suspension system failures, while minimizing the risk of false failure identifications in the context of the high level of maneuverability offered by the tiltrotor configuration during high speed flight. This system provides a means of automatically jettisoning an underslung load carried by a dual point suspension system when one of the two suspension points fails. It is self-adaptive to a broad range of external loads and flight conditions. The V-22 auto jettison system provides protection from load/aircraft collision, center of gravity envelope exceedance, and transmission of excessive shock loads to the airframe in the event of a suspension point failure.

The V-22 has also incorporated several other technologies in order to provide an unprecedented capability for high speed carriage of underslung loads. Its handling qualities are optimized through the full-time stability augmentation provided by a fully digital, electronic, redundant, fly-by-wire flight control system. Aeroservoelastic stability requirements for the coupled dynamics of the aircraft, underslung load, slings, airframe structural dynamics, rotor dynamics, sensor dynamics, and pilot biomechanical characteristics have been met through the flight-control system design and the incorporation of variable characteristic structural filters.

4.2.4 External Payload Mission

A typical external payload mission will include a vertical takeoff for payload pickup, payload delivery at the mid point, unrefueled return to base, and a landing criteria for reserve fuel capacity. Flight performance for this mission profile is provided below, for two different conditions - sea level standard temperature, and 3,000 ft mean sea level at standard temperature plus 20° C.

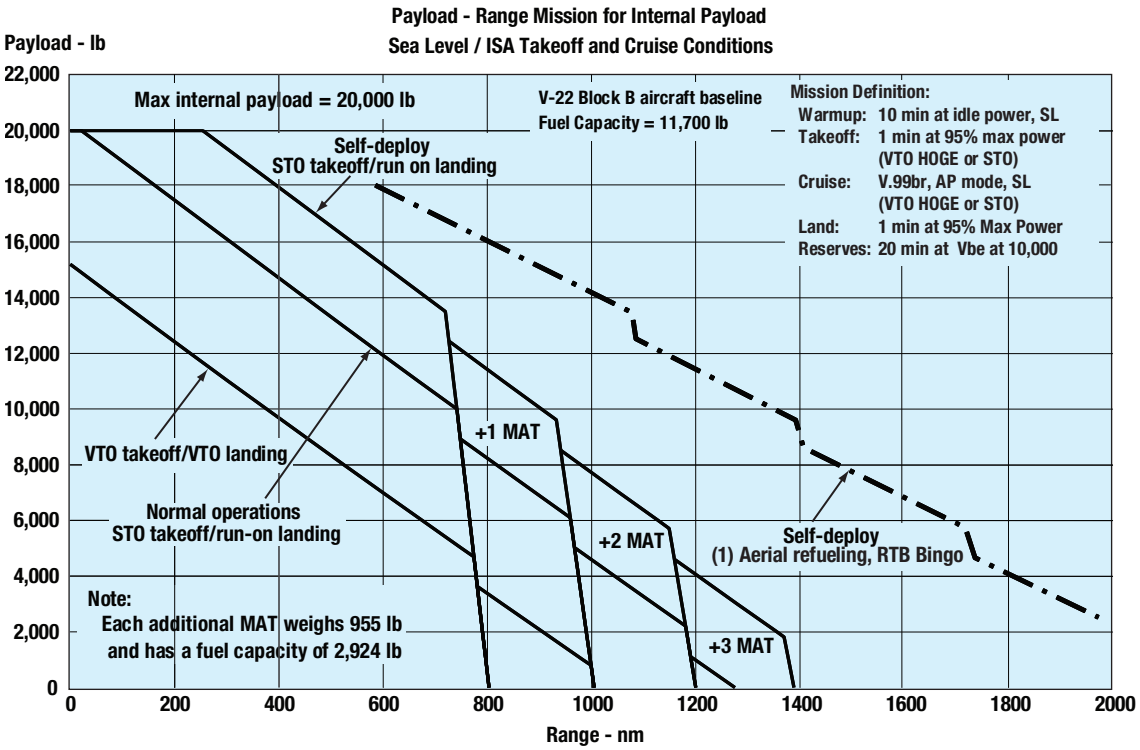


External Cargo Mission – Standard and Hot Day Missions

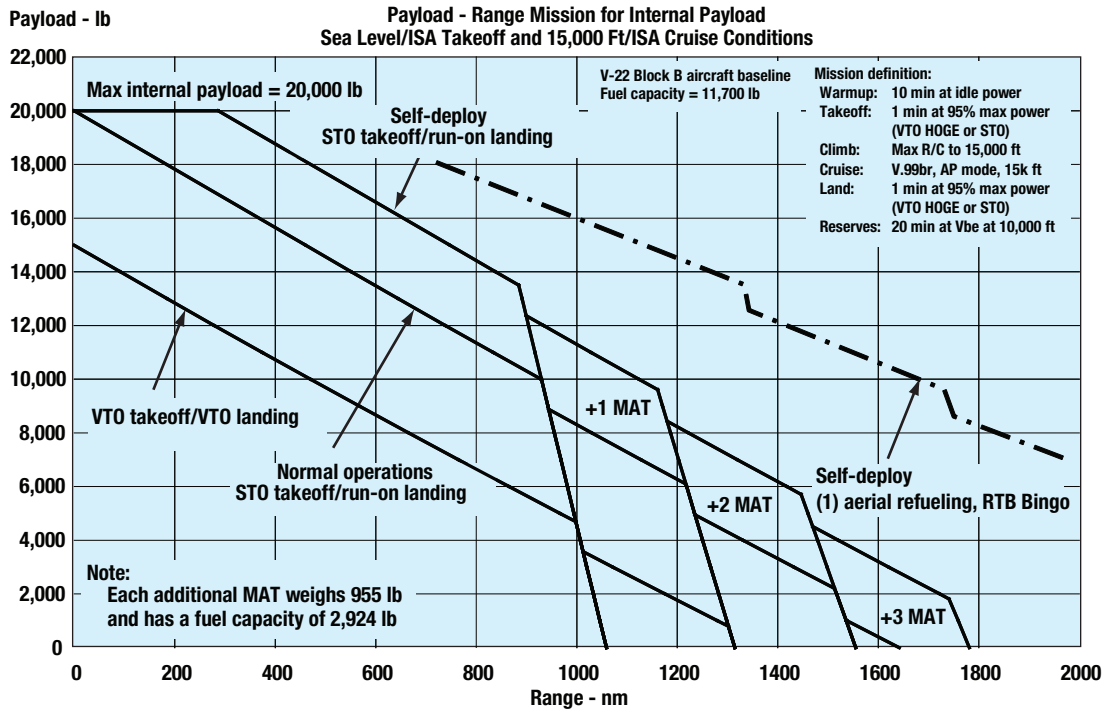
4.2.5 Deployment Mission

The long range cruise efficiency of the V-22, along with its large integral and auxiliary fuel capacity, provides unrefueled range capability well over 1,000 nm. With mission planning allowance for one aerial refueling (and bingo fuel reserve for return-to-base), self-deployment range is over 2,400 nm.

A typical deployment mission, or one-way payload-range mission, will include a takeoff based on the constraints of the specific mission launch site, climb to altitude for best range capability (depending on mission clearances), and a landing criteria for reserve fuel capacity. Flight performance for this mission profile is provided below, for sea level takeoff and two different cruise altitude conditions - sea level standard temperature (same as the takeoff condition), and 15,000 ft mean sea level at standard temperature. Extended range capability is also shown, for one aerial refueling with sufficent fuel to return to the original base if the refueling rendezvous is not successful.



Long Range Deployment Mission – Sea Level Cruise

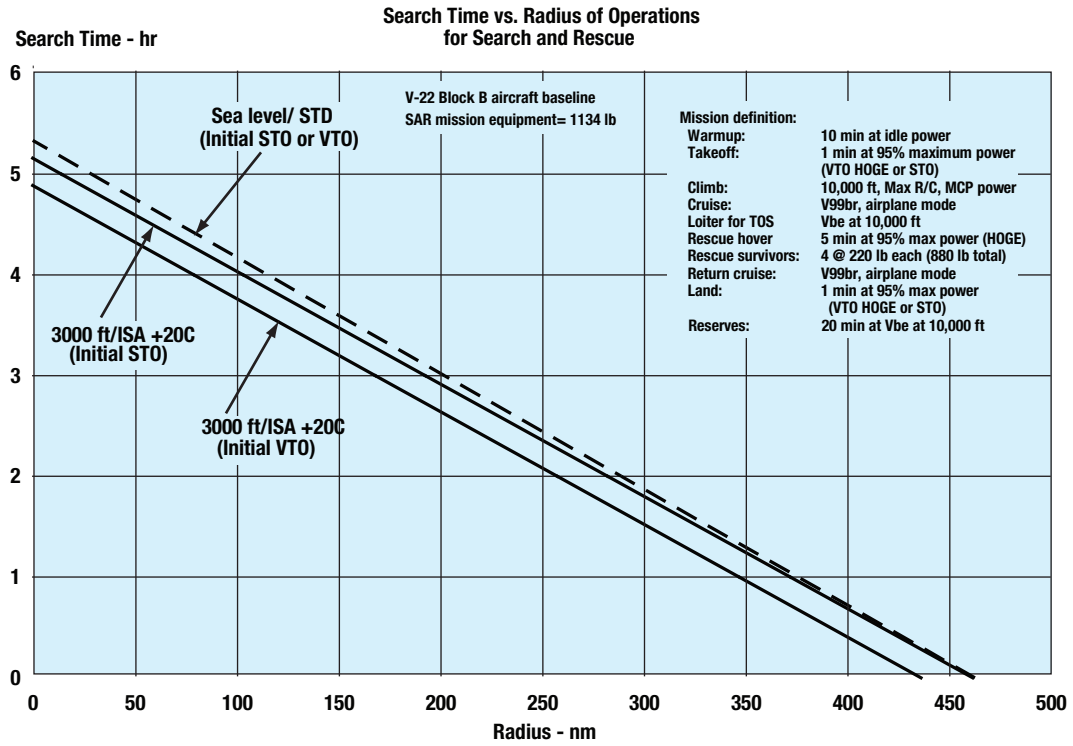


Long Range Deployment Mission – 15,000 ft Cruise

4.2.6 Endurance/Search and Rescue Mission

A typical search mission will include additional mission equipment, takeoff criteria based on the constraints of the specific mission launch site, climb to altitude for best range and endurance capability, area loiter at best endurance speed (for search or other mission activities), unrefueled return to base, and a landing criteria for reserve fuel capacity. For a rescue mission, a vertical and/or hover is typically also needed at mid-mission. Flight performance for a search and rescue missison profile, with additional equipment as shown in the following table, is provided below, for different takeoff criteria.

Additional SAR equipment above basic FUL			
Additional crew	220 lb (100 kg)	Oxygen resuscitation kit	50 lb (23 kg)
Additional crew equipment	100 lb (45 kg)	SCUBA tank	50 lb (23 kg)
Litter kit	196 lb (89 kg)	Pyrotechnic box	60 lb (27 kg)
Litters	79 lb (35 kg)	Forest penetrator	25 lb (11 kg)
Rescue hoist	89 lb (40 kg)	Pararescue kit	25 lb (11 kg)
MEDEVAC kit	98 lb (44kg)	Miscellaneous	142 lb (64 kg)
			Total additional equipment 1,134 lb (514 kg)



Typical Search and Rescue Mission – Mid-mission Hover Pickup

4.3 Rotor Downwash Effects

To succeed in critical military missions, the V-22 frequently relies on good hover performance. All aircraft hovering near the ground create an associated rotor downwash (vertical induced airflow) and groundwash (horizontal airflow). Groundwash from a hovering V-22 is comparable to that of conventional single or tandem rotor helicopters operating at similar gross weights.

The V-22 has successfully demonstrated that with only minor precautions, the ground maintenance crew and others (e.g., downed survivors) can be accommodated safely under the aircraft.

Ground Crews Perform External Load Hook-ups

For missions with personnel insertion or extraction, extensive developmental and operational testing has been conducted with various devices, such as rescue hoist or fast rope. The testing to date has identified no parameters where the downwash or adverse wind conditions are limiting factors to operational missions. These missions are normally conducted at a hover height of 50 feet or higher.

Typical Insertion/Extraction Methods

- Rescue Hoist
- Litter Hoist
- Fast Rope
- SPIE Rig
- Helo casting
- Paradrop

Litter Hoist from V-22

4.4 Emergency Flight

The V-22 possesses features and characteristics for safely managing in-flight engine failures.

In the event of a single engine failure, an interconnecting driveshaft in the wing allows one engine to provide power to both proprotors. Thus, the pilots may either continue flight or make a safe landing. The other engine provides adequate power for all but the most demanding flight operations. The driveshaft provides the added advantage of minimizing or eliminating lateral and directional transients, which follow during an engine failure.

- Following a single engine failure in helicopter mode (at conditions outside of the height-velocity avoid region), a safe landing can be conducted, or the aircraft can be converted to airplane mode for continued flight.
- Following a single engine failure in airplane mode, the aircraft can be safely converted to helicopter mode for a run-on.

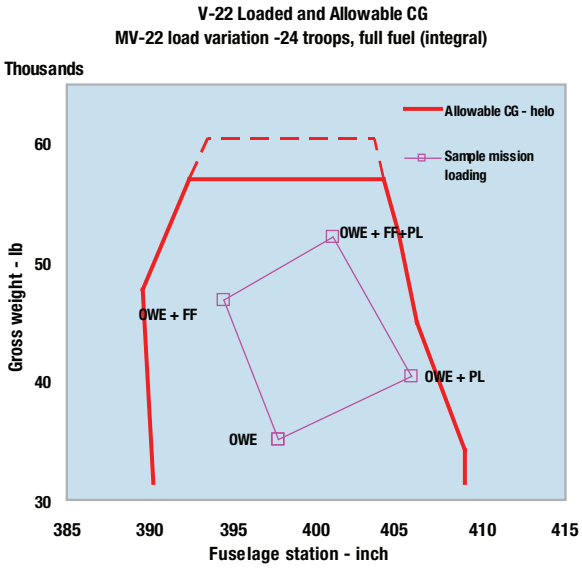
In the event of a dual engine failure, continued flight to a safe landing is possible in either airplane mode or helicopter mode.

- Following total engine power loss in airplane mode, a glide ratio of 4.5:1 is achievable. This ratio allows the aircraft to be flown to an airplane mode landing using normal flight controls. The proprotors automatically set into the windmilling mode so that power is provided to all essential electrical and hydraulic aircraft systems.
- Following a dual engine failure in helicopter/conversion mode, autorotation is established at 110 KCAS with the nacelles on the aft stop. This speed provides the energy at landing to manage a touchdown sink rate. As in the windmilling condition, the auto-rotating proprotors provide power for all essential systems, allowing the aircraft to be maneuvered for a safe run-on landing at 60 KCAS. Rotor speed governing remains active in this flight condition to reduce pilot workload.

4.5 Aircraft Weights

The V-22 incorporates advanced composites, advanced machining technologies, and other modern technologies to reduce aircraft weight. Numerous design trade studies have been conducted to identify areas for weight savings without significantly increasing the production costs, maintenance, or delaying program development.

The V-22's longitudinal center of gravity (CG) varies between the airplane and helicopter modes due to the movement of the proprotors, engines, and nacelles. The figure below shows the full longitudinal CG envelope in Helicopter mode, with a sample mission loading representing the Operating Weight Empty (OWE), OWE plus Full Fuel (FF), OWE plus 24 troops payload (PL), and combined OWE plus FF plus PL.



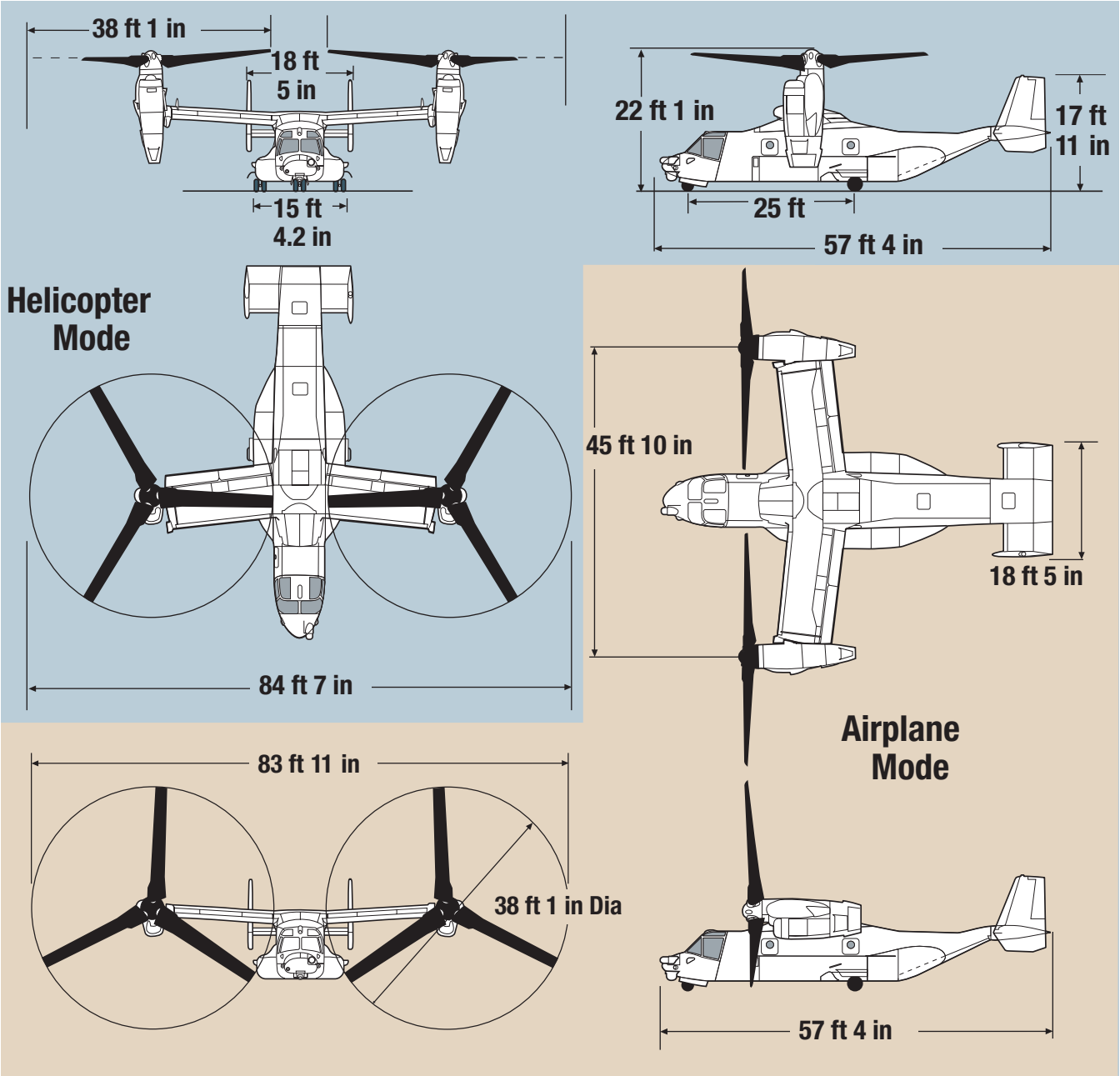
Longitudinal CG Envelope

The V-22 has been designed so that any valid CG condition in one mode (helicopter, conversion, or airplane) is also valid in any other mode. There is no requirement to move payloads or shift fuel in order to convert between helicopter or airplane mode.

4.6 Aircraft Dimensions

4.6.1 General Dimensions

The overall dimensions of the V-22 are depicted in the figures below. Additionally, key aircraft dimensions and surface areas are provided in tabular form.



Key Dimensions	Feet	Meters
Overall length	57.3	17.5
Overall width	84.6	25.8
Overall height	22.1	6.7
Width at nacelles	50.9	15.5
Vertical fin height	17.9	5.5
Proprotor ground height	20.8	6.3
Proprotor diameter	38.1	11.6
Main gear centerline	13.0	4.0
Main to nose gear wheelbase	25.0	7.6
Fuselage ground clearance	1.5	0.5
Tail ground clearance	6.9	2.1
Cabin interior width	5.7	1.7
Cabin interior length	20.8	6.35
Cabin interior height	5.5	1.7

General Aircraft Dimensions

4.6.2 Landing Pad Dimensions

The V-22 is capable of operating in and out of small areas – to include commercial heliports. The minimum recommended elevated landing pad is 36 by 23 feet (11 by 7 meters). Minimum area for surface landing zones, such as discussed in the U.S. Air Force Instructions for landing zone operations, is 135 ft by 110 ft (41m x 33m), which provides an area with at least 25 ft (8m) clearance from the aircraft.

SECTION 5.0 - LIST OF ACRONYMS AND ABBREVIATIONS

A

ABDR	Aircraft Battle Damage Repair
AC	Alternating Current
ACM	Air Cycle Machine
ADF	Automatic Direction Finder
ADM	Acquisition Decision Memorandum
AEO	All Engines Operating
AFACS	Avionics Forced Air Cooling System
AFCS	Automatic Flight-Control System
AGL	Above Ground Level
AIMD	Aviation Intermediate Maintenance Department
AIT	Analysis and Integration Team
ALPM	Ambient Liters Per Minute
ALT	Altimeter
AMC	Advanced Mission Computer
AMEGS	Aircraft Maintenance Event Ground Station
AMLCD	Active Matrix Liquid Crystal Display
AN	Army-Navy Standard
ANVIS	Aviation Night Vision Imaging System
AP	Armor Piercing
API	Armor Piercing Incendiary
APU	Auxiliary Power Unit
ARINC	Aeronautic Radio Incorporated
ASC	American Standard Code
ASI	Aircraft State Indicators
ASuW	Anti-Surface Warfare
ASW	Anti-Submarine Warfare
ATV	All Terrain Vehicle
AUX	Auxiliary

B

BIT	Built-In Test
BITE	Built-In Test Equipment
BL	Butt Line
BF/WS	Blade Fold/Wing Stow

C

C	Degrees Celsius
C2	Command and Control
CAS	Calibrated Airspeed
CAT	Cabin Auxiliary Tank
CATIA™	Computer-Aided Three-Dimensional Interactive Application
CBR	California Bearing Ratio
CCOC	Contractor Controlled Operating Costs
CDR	Critical Design Review
CDU	Control Display Unit

CFG	Constant Frequency Generator
CG	Center of Gravity
CIC	Central Integrated Checkout
CLS	Contractor Logistics Support
CMDS	Countermeasures Dispensing Set
CMPT	Cockpit Maintenance Procedures Trainer
CMS	Cockpit Management System
CMT	Composite Maintenance Trainer
CNA	Center for Naval Analysis
COMINT	Communications Intelligence
Comm	Communication
CONT	Continuous
CPI	Crash Position Indicator
CPMS	Control Power Management System
CPTT	Cabin Part Task Trainer
CRT	Cathode Ray Tube
CSAR	Combat Search and Rescue
CSE	Common Support Equipment
CV	Aircraft Carrier
CV	Converters

D

D	Depot (maintenance level)
DA	Density Altitude
DC	Direct Current
DEU	Display Electronics Unit
DEW	Directed Energy Weapon
DFM	Design for Maintainer
DMS	Digital Map Set
DOC	Direct Operating Cost
DoD	Department of Defense
DPS	Data Processing System
DSIU	Drive System Interface Unit
DTM	Data Transfer Module
DTUR	Data Transfer Unit Receptacle

E

E^3	Electromagnetic Environmental Effects
EAF	Expeditionary Air Field System
EAPS	Engine Air Particle Separator
EAS	Equivalent Airspeed
ECS	Environmental Control System
ECU	Environmental Control Unit
EELS	Emergency Egress Lighting System
EICAS	Engine Instrument Crew Alerting System
EL	Electroluminescent
ELT	Emergency Locator Transmitter
EMC	Electromagnetic Compatibility
EMD	Engineering and Manufacturing Development
EMI	Electromagnetic Interference
EMP	Electromagnetic Pulse

EMS	Engine Monitoring System
EMU	Electronic Mockup
ENAV	Electronic Navigation
ENG	Engine
EO	Electro-Optical
ER	Extended Range
ETM	Electronic Technical Manuals
EW	Empty Weight

F

F	Degrees Fahrenheit
FAA	Federal Aviation Agency
FADEC	Full Authority Digital Engine Control
FAM	Familiarization
FARP	Forward Arming and Refuel Point
FAT	Free Air Temperature
FBW	Fly-by-Wire
FCC	Flight-control Computer
FCCS	Forward Cabin Control Station
FCS	Flight-control System
FDP	Flight Director Panel
FFS	Full Flight Simulator
FH	Flight Hour
FLIR	Forward-Looking Infrared
FM	Frequency Modulation
FMECA	Failure Modes, Effects and Criticality Analysis
FMU	Fuel Management Unit
FOBs	Forward Operating Bases
FOD	Foreign Object Damage
fpm	Feet Per Minute
FRACAS	Failure Reporting and Corrective Action System
FSR	Field Service Representative
FSD	Full-Scale Development
FST	Field Support Team
FTD	Flight Training Device
FUL	Fixed Useful Load
FWD	Forward

G

g	Gravity
GA	Go Around (wave-off)
GAL	Gallon
GEN	Generator
GFE	Government Furnished Equipment
GPS	Global Positioning System
GRDP	Ground Refuel/Defuel Panel
GR/EP	Graphite/Epoxy
GSE	Ground Support Equipment
GW	Gross Weight

H

HEDAD-M	Human Engineering Design Approach Document-Maintainer
HELO	Helicopter (mode of tiltrotor flight)

HF	High Frequency
HIFR	Hover In-Flight Refueling
HISS	Helicopter Icing Spray System
HMD	Helmet-Mounted Display
HMMWV	High-mobility Multipurpose Wheeled Vehicle
HMS	Helmet Mounted Sight
HOGE	Hover Out-of-Ground Effect
HSD	Horizontal Situation Display
HSI	Horizontal Situation Indicator

I

I	Intermediate (maintenance level)
IAS	Indicated Airspeed
IAS	Integrated Avionics System
IC	Integrated Circuits
ICDS	Interconnecting Driveshaft
ICS	Intercom System
IETM	Interactive Electronic Technical Manual
IETMS	Interactive Electronic Technical Manual System
IFF	Identification, Friend or Foe
IFPM	In-Flight Performance Monitoring
IFR	Instrument Flight Rules
IGE	In Ground Effect
ILS	Instrument Landing System
ILS	Integrated Logistics Support
IMC	Instrument Meteorological Conditions
IMI	Interactive Multimedia Instruction
IN	Inch(es)
INAV	Inertial Navigation
INBD	Inboard
INS	Inertial Navigation System
IOC	Initial Operational Capability
IOS	Instructor Operator Stations
IPS	Ice Protection System
IPT	Integrated Product Team
IR	Infrared
IRCMS	Integrated Reliability Centered Maintenance System
ISA	International Standard Atmosphere
ISAR	Inverse Synthetic Aperture Radar
ISC	Intercommunication Set Control
ISD	Instructional Systems Design
ISP	Integrated Support Plan
ISS	Integrated Support System
IU	Interface Unit

J

JDF	Japanese Defense Forces
JMVX	Joint Multi-Mission Vertical Lift Aircraft
JROC	Joint Requirements Oversite Committee

JSOR	Joint System Operational Requirements
JVX	Joint Vertical Experimental

K

K	Thousand
KCAS	Knots Calibrated Airspeed
KPP	Key Performance Parameters
KTAS	Knots True Airspeed
Knots	Knots

L

lb	Pound(s)
LBL	Left Butt Line
LCC	Life Cycle Cost
LDS	Laser Detection Set
LH	Left Hand
LHA	Landing Helicopter Assault
LHD	Landing Helicopter Dock
LORA	Level of Repair Analysis
LRIP	Low Rate Initial Production
LRU	Line Replaceable Unit
LSA	Logistics Support Analysis
LSAR	Logistics Support Analysis Record
LSE	Landing Signalman, Enlisted
LUI	Life Usage Index
LWC	Liquid Water Content
LWINS	Lightweight Inertial Navigation System

M

MAGTF	Marine Air/Ground Task Force
MAT	Mission Auxiliary Tank
MATT	Multi-mission Advanced Tactical Terminal
MATS	Mission Auxiliary Tank System
MAX	Maximum
MB	Marker Beacon
MC	Mission Computer
MCAS	Marine Corps Air Station
MCP	Maximum Continuous Power
MDL	Mission Data Loader
MDPS	Maintenance Data Processing Station
MEDEVAC	Medical Evacuation
MEF	Marine Expeditionary Force
MEU	Marine Expeditionary Unit
MFD	Multifunction Display
MFHBF	Mean Flight Hours Between Failures
MFHBR	Mean Flight Hours Between Replacement
MGW	Maximum Gross Weight
MK	Mark
MLG	Main Landing Gear
MLR	Medium Lift Replacement
MLV	Memory Loader Verifier
MMH/FH	Maintenance Manhours per Flight Hour

MMR	Multimode Radar
MOS	Military Occupational Specialty (code)
MPS	Mission Planning System
MSL	Mean Sea Level
MTBMF	Mean Time Between Mission Failures
MTBUMA	Mean Time Between Unscheduled Maintenance Actions
MTG	Mounting
MTTR	Mean Time to Repair
MVX	Multi-mission Vertical Lift Aircraft
MWGB	Midwing Gearbox

N

NAMTS	Naval Aviation Maintenance Trainer
NASA	National Aeronautics and Space Administration
NATO	North Atlantic Treaty Organization
NATOPS	Naval Air Training and Operating Procedures Standardization
NAWCADPAX	Naval Air Warfare Center, Aircraft Division, Patuxent River, Maryland
NBC	Nuclear, Biological, Chemical
NBCD	Nuclear, Biological, Chemical, Decontamination
NDI	Non Destructive Inspection
Nf	Free Power Turbine Speed
Ng	Gas Producer Turbine Speed
NLG	Nose Landing Gear
nm	Nautical Miles
No.	Number
NOE	Nap of the Earth
NR	Not Required
Nr	Rotor Speed
N_2	Nitrogen
NVG	Night Vision Goggles
NVG/HUD	Night Vision Goggle/Heads Up Display
NVIS	Night Vision Imaging Systems

O

O	Organizational (maintenance level)
O_2	Oxygen
O&S	Operating and Support
OAT	Outside Air Temperature
OBIGGS	Onboard Inert Gas Generating System
OBOGS	Onboard Oxygen Generating System
ODS	Oil Debris Sensor
OEI	One Engine Inoperative
OEM	Original Equipment Manufacturer
OGE	Out of Ground Effect
OLS	Oil Level Sensor
OPEVAL	Operational Evaluation
ORD	Operational Requirements Document
OWE	Operating Weight Empty

P

PA	Pressure Altitude
PD	Preliminary Design
PDP	Power Distribution Panel
PEDD	Portable Electronic Display Device
PF	Pilot Flying
PFCS	Primary Flight-control System
PFD	Primary Flight Display
PGSE	Peculiar Ground Support Equipment
PLS	Personnel Locator System
PMG	Permanent Magnet Generator
PNF	Pilot Not Flying
PRGB	Proprotor Gearbox
PSE	Peculiar Support Equipment
PSI	Pounds per Square Inch

R

RADALT	Radar Altimeter
RAST	Recover, Assist, Secure, and Transverse
RBL	Right Butt Line
RCM	Reliability Centered Maintenance
REF	Reference
REQD	Required
RES	Reserve
RF	Radio Frequency
RFI	Radio Frequency Interference
RFIS	Remote Frequency Indicator Selector
RGR	Rapid Ground Refuel
RIU	Radar (Remote) Interface Unit
RMI	Radio Magnetic Indicator
ROC	Rate of Climb
rpm	Revolutions per Minute
RWR	Radar Warning Receiver

S

SAR	Search and Rescue
SAR	Synthetic Aperture Radar
SARTF	Search and Rescue Task Force
SDC	Shaft-Driven Compressor
SDGW	Structural Design Gross Weight
SDLM	Scheduled Depot Level Maintenance
SERD	Support Equipment Recommendation Data
SFD	Standby Flight Display
SHP	Shaft Horse Power
SIF	Secure Identification Friend
SINCGARS	Single Channel Ground and Airborne Radio System
SIRFC	Suite of Integrated RF Countermeasures
SL	Sea Level
SLIC	Systems and Logistics Integration Capability
SLM	Structural Load Monitoring

SLS	Sea Level, Standard
SOC	Special Operations Capable
SOCOM	Special Operations Command
SOF	Special Operations Forces
SPON	Sponson
SQ	Square
SRA	Shop Replaceable Assembly
STA	Station
std	Standard
STO	Short Takeoff
STOL	Short Takeoff and Landing

T

TACAN	Tactical Air Navigation
TAGB	Tilt-axis Gearbox
TAS	True Airspeed
TBD	To Be Determined
TBO	Time Between Overhauls
TCL	Thrust Control Lever
TCRS	Torque Command Regulating System
TF/TA	Terrain Following/Terrain Avoidance
TM	Technical Manuals
TOGW	Takeoff Gross Weight
TOS	Time on Station
TOT	Turbine Outlet Temperature
TPMS	Thrust/Power Management System
TR	Tiltrotor
TR	Transformer/Rectifier
TSEC	Transmission Security
TYP	Typical

U

UHF	Ultra-high Frequency
USA	United States of America
USAF	United States Air Force
USMC	United States Marine Corps
USN	United States Navy
USSOCOM	United States Special Operations Command

V

V	Velocity or Airspeed
VAC	Volts, Alternating Current
V_{BE}	Velocity, Best Endurance
V_{BR}	Velocity, Best Range
VDC	Volts, Direct Current
VFG	Variable Frequency Generator
VHF	Very High Frequency
VIDS/MAFS	Visual Information Display System/Maintenance Action Forms
VIP	Very Important Personnel
VMAT	Vertical Assault Medium Transport
VMC	Visual Meteorological Condition
VMS	Vehicle Management System

VOGS	V-22 Open Ground System
VOR	VHF Omnidirectional Range
VROC	Vertical Rate of Climb
vs	Versus
VSD	Vertical Situation Display
VSI	Vertical Speed Indicator
VSLED	Vibration, Structural Life, and Engine Diagnostics
Vstall	Velocity, Stall
V/STOL	Vertical or Short Takeoff and Landing
VTAS	V-22 Task Analysis System
VTO	Vertical Takeoff
VTOL	Vertical Takeoff and Landing

W

WCA	Warnings, Cautions, and Advisories
WE	Weight Empty
WL	Water Line
WOD	Wind Over the Deck
WOW	Weight on Wheels
WRA	Weapons Replaceable Assembly

X

XMSN	Transmission

Z

Z	Greenwich Mean Time
(ZULU)	Greenwich Mean Time

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