XV–15 FLIGHT RESEARCH AND DEVELOPMENT: PREPARING THE WAY FOR TOMORROW'S TILTROTOR AIRCRAFT

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Abstract

The XV–15 Tiltrotor Research Aircraft, first flown in 1977, continues to support the technology development and to expand the knowledge base for this type of aircraft. The main focus of recent research efforts has been to develop ways to enhance and exploit the unique operational capabilities offered by tiltrotor aircraft. This paper presents a summary of the array of research activities being conducted using the XV–15 as a test bed; specifically, the following areas are included: (1) vibration and loads reduction efforts directed towards improved passenger comfort and increased component life; (2) the development of advanced flight controls that reduce pilot workload and optimize flying qualities throughout the range of aircraft configurations and speeds; (3) testing and evaluation of operational techniques intended to provide noise abatement by means of optimized flight trajectories and deceleration schedules; and (4) the development and testing of differential GPS-based guidance and cockpit displays for accomplishing precision flight path control.

Introduction

The promise of an aircraft capable of hovering, vertical takeoffs and landings, and cruising at turboprop speeds over extended distances has fueled the imagination for many years. After a multitude of conceptual and demonstration programs, the tiltrotor has emerged as the configuration that effectively fulfills that promise. The increasing presence of tiltrotor technology in the marketplace is apparent with the initial production of the V–22 Osprey for the U.S. Marines and Air Force, as well as the recent announcement by the Bell–Boeing team of plans to develop, certify, and field the Model 609 commercial aircraft.

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A summary of the array of research activities being conducted using the XV–15 as a test bed is presented. Specifically, the areas discussed include the following:

1. Vibration and loads reduction efforts directed towards improved passenger comfort and increased component life.

2. The development of advanced flight controls that reduce pilot workload and optimize flying qualities throughout the range of aircraft configurations and speeds.

3. Testing and evaluation of operational techniques intended to provide noise abatement by means of optimized flight trajectories and deceleration schedules.

4. The development and testing of differential GPS-based guidance and cockpit displays for accomplishing precision flight path control.

Notation

BVI	blade–vortex interaction
DAFCS	digital automatic flight control system
DGPS	differential global positioning system
DOD	United States Department of Defense
GPS	global positioning system
ILS	instrument landing system
KIAS	knots indicated airspeed
kn	knots
LCD	liquid crystal display
LTM	lateral translation mode
NASA	National Aeronautics and Space Administration
PCM	pulse-code modulation
SCAS	stability and control augmentation system

Description of the XV–15 Aircraft

The XV–15 aircraft (Fig. 1) is representative of those aircraft which employ the tiltrotor concept (Ref. 1). The hover lift and cruise propulsive force is provided by rotors having low disc loading at each wingtip. The rotors and their performance are described in Refs. 2 and 3. The rotor axes rotate from the vertical (for hover and helicopter mode flight) to the horizontal (for airplane mode flight). Hover control is provided by rotor-generated forces and moments, while airplane mode flight control is accomplished by the use of conventional aerodynamic control surfaces.

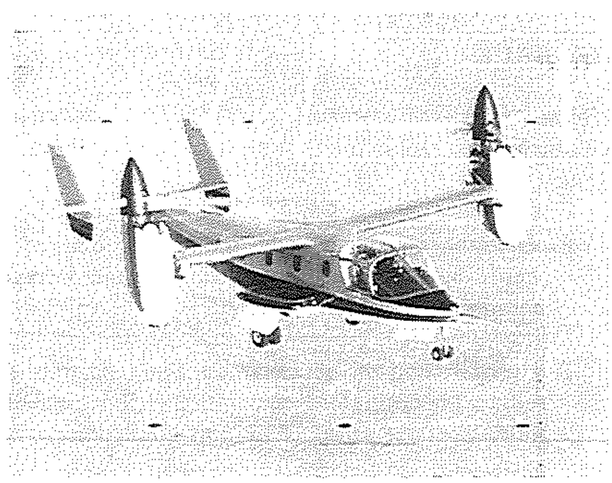


Fig. 1. XV–15 in helicopter mode flight.

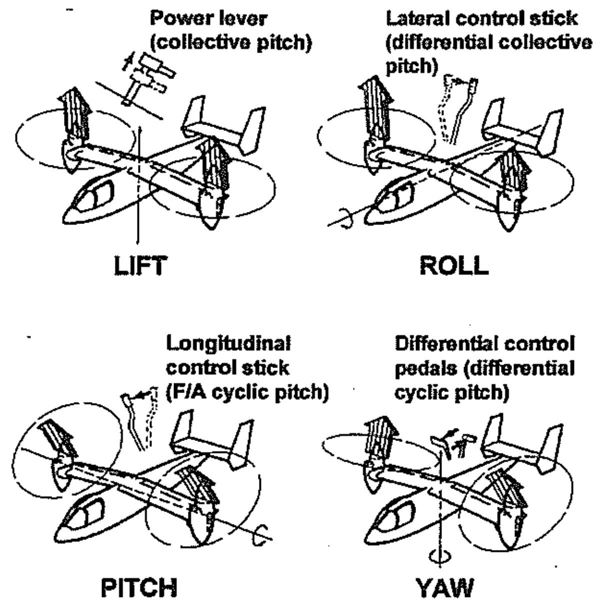


Fig. 2. Flight control functions in helicopter mode.

Separate power plants are located within the nacelles at each wingtip, and a cross-shafting system with a center gearbox interconnects the rotor systems. This interconnecting drive system precludes the complete loss of power to either rotor due to a single engine failure without generating adverse yaw of the aircraft, permits power transfer for transient conditions, and provides rotational speed synchronization. Nacelle tilt synchronization is achieved by a separate interconnect shaft.

The nacelles at each wingtip house the Lycoming LTC1K–4K free turbine engines (modified T53–L–13B power plants) and main transmissions, along with the ancillary equipment for hydraulic power and oil cooling. The nacelles tilt as complete units on spindles that rotate on bearings within the wingtip ribs. The free turbine engines permit the reduction of rotor rotational speed for airplane mode flight to improve proprotor performance and reduce cruise noise. Rotational speed control is governed by an electrohydraulic actuator in the collective control system. It is a closed loop system that maintains a pilot-selected rotational speed by controlling collective blade pitch.

For hover flight, the wing flaps and flaperons are deflected downward to reduce the wing download and to increase hovering efficiency. Hover roll control is provided by differential rotor collective pitch, pitch control by conventional cyclic pitch, and yaw control by differential cyclic pitch. Pilot controls in the helicopter mode are similar to that of a conventional helicopter (Fig. 2). A collective stick (or "thrust control lever") adjusts power and collective pitch for height control while conventional stick and rudder controls provide longitudinal, lateral, and yaw inputs.

For flight in airplane mode, the stick and rudder pedals are employed while the collective stick continues to be used for power management. An H-tail configuration (two vertical stabilizers) has been utilized for improved directional stability around a zero yaw angle. Control authority for the collective, blade pitch governor, cyclic, differential cyclic, and differential collective are phased with nacelle conversion angle by mechanical mixing linkages.

Nacelle position (conversion angle) is variable between the horizontal (0 degrees) for airplane mode flight to 5 degrees aft of the vertical (95 degrees) for helicopter mode flight. The aircraft has a relatively large corridor of operations for different combinations of conversion angle and airspeed, the boundaries of which are defined by acceptable loads, vibration, handling qualities and wing stall. Airspeeds ranging from 30 knots (kn) rearward to 230 kn forward are routinely accomplished during testing.

Since it was originally conceived to be and remains a research aircraft, the XV–15 has not been optimized for useful load, range, or endurance. The aircraft is fitted with relatively heavy ejection seats, an auxiliary fuel system that increases fuel capacity by nearly 50%, and an instrumentation package that presently provides data for approximately 200 parameters. Its design gross weight is 5,897 kg (13,000 lb) and maximum gross weight is 6,804 kg (15,000 lb). Typical takeoff weights (with two pilots and full fuel) in its present configuration are 6,170 to 6,440 kg (13,600 to 14,200 lb).

The size, capabilities, and full complement of instrumentation make the XV–15 highly useful for testing various tiltrotor-specific concepts. Its success has been responsible in part for the development and resulting production of the V–22, and it continues to be a useful tool for the design and development of future tiltrotor aircraft. A look at the current research and development efforts underway with the XV–15 is provided below.

XV–15 Research and Development

Vibration and Loads Reduction

Hooke's joint couplings provide for gimballing of the rotor hubs on the XV–15. When the rotors flap, a Hooke's joint inherently causes a 2/rev acceleration, which results in a corresponding vibration. The gearboxes that couple the cantilevered engines to the rotor transmissions respond at this 2/rev frequency during airplane mode operations; thus a means to control the resulting 2/rev gearbox bending loads was desired.

There is natural tendency of the rotors to flap due to the in-flow during conversion and airplane mode operations. In order to alleviate this tendency and the resulting loads, a system to control rotor flapping was first developed using analog components in conjunction with electrohydraulic actuators attached to the rotor swashplates. This system was recently replaced with a more robust digital flapping control system.

The system uses redundant transducers that measure the deflection of the nonrotating hub springs to sense the magnitude and direction of flapping of each rotor. The control system accepts these measurements as inputs and then acts to nullify rotor flapping by commanding movement of limited-authority longitudinal and lateral cyclic actuators in each nacelle.

Fore/aft flapping control authority is increased according to a predefined conversion angle schedule as the aircraft converts from helicopter to airplane mode. This flapping control is deactivated during helicopter mode operations so as not to impact control inputs made by the pilot. Lateral flapping control remains active in all operating modes. The flapping control system has a long time constant and therefore effectively minimizes steady-state flapping (and the attendant loads and vibration) in airplane mode without significantly affecting the dynamic stability of the rotor system. The ultimate result of the development and installation of the flapping control system has been increased component life for the engine coupling gearboxes and an overall reduction in 2/rev vibration in the airframe (Fig. 3).

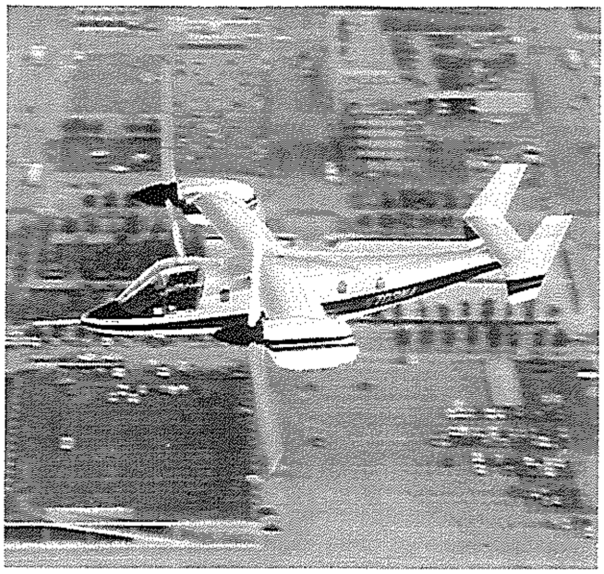


Fig. 3. XV–15 in airplane mode flight.

Digital Automatic Flight Control System (DAFCS)

The XV–15 was originally designed and equipped with a dual-channel analog stability and control augmentation system (SCAS) with gains that varied corresponding to predefined airspeed and nacelle angle schedules. The replacement of the analog flapping control system with a digital one, however, provided the opportunity to develop a digital flight control computer that could serve the flapping control function and provide an improved SCAS.

The objectives for developing the digital automatic flight control system (DAFCS) were to

1. Enhance the XV–15 as a tool for evaluating civil tiltrotor concepts such as nacelle conversion control, lateral translation mode (LTM), improved dynamic and trim stability, turn coordination, and pitch rate compensation in turns.

2. Provide a system with the flexibility to operate in a flight test environment, where frequent changes are required in order to evaluate alternate control options in a safe manner.

3. Reduce the pilot workload for maneuvers and operations, which will be similar to those performed in a civil tiltrotor aircraft.

4. Optimize handling qualities by gain modifications as functions of nacelle position and airspeed.

5. Provide fault management that would detect and identify faults, and store fault codes to simplify aircraft maintenance and troubleshooting.

Digital System Hardware. The digital system hardware consists of a self-checking processor pair. This is consistent with the existing aircraft analog SCAS architecture. Also, the analog input circuit card is a new design which allows processor interface to the XV–15 aircraft sensors and systems. Each channel within the processor contains its own input and output hardware. Included in each channel are 48 discrete input paths, 20 discrete output paths, 28 twelve-bit resolution output paths, and 30 differential analog input paths.

Additional hardware required to interface to the aircraft components and crew include three control panels (flapping control/LTM, SCAS, and semiautomatic conversion control). A nacelle conversion interface and actuator servovalve interface is also required. With the exception of the flapping sensors, all sensing and actuation functions were provided by existing aircraft sensors and actuators.

Digital System Software. The control system program is divided into 23 functional modules. Fourteen of these modules are dedicated to power-up, boot, power-up test, executive overhead, user interface, fault storage and retrieval, and embedded control functional support. The remaining nine modules contain the embedded control functional instructions required to control rotor flapping, LTM, SCAS, and the semiautomatic nacelle positioning (conversion control) system. These modules provide pilot interface, mode control logic, linear and nonlinear system control, and fault monitoring for each of the above stated systems. The software program provides extensive built-in test functions. Some are performed once upon system power-up, and others are performed on a periodic basis during system operation. Future system expansion will include modules for pitch and roll attitude retention and airspeed hold.

Aircraft handling quality development has been simplified by the incorporation of a mechanism for selectively changing control system gains. This is accomplished by means of a user interface terminal without the need for an immediate software program change, which reduces the flight test time required to complete AFCS development by allowing the engineer to change selected gains on the ramp between flights within seconds.

Fault Management and Codes. The DAFCS processor is used to digitally close nine servoactuator loops. Each actuator loop is monitored for faults by a dedicated software actuator model. This method detects differences between each actuator and corresponding actuator model, causing the bad actuator to disengage when differences exist.

Faults detected within the DAFCS are stored in nonvolatile memory within each channel of the DAFCS processor. The XV–15 DAFCS processor contains over 120 different fault monitors, each of which stores a unique fault code. Each fault code stored contains information relating to that fault along with a time tag. This information can be displayed on a user terminal for later analysis.

DAFCS Functions. Although the primary purpose of the DAFCS is to provide stability and control augmentation, other functions provided by the DAFCS include the flapping control system, the lateral translation mode (LTM), and conversion system control. A description of the flapping control system was provided in the Vibration and Loads Reduction section, and these other systems are described below.

Using LTM, the aircraft can be made to translate laterally using lateral rotor cyclic control while the aircraft roll attitude is controlled by differential collective inputs. While operating in helicopter mode with nacelle angles at or near 90 degrees, a thumb-operated wheel on the pilot's thrust control lever (collective stick) can be rolled left or right from its detent position, thus commanding movement of the same lateral actuators used for flapping control in airplane mode to provide lateral cyclic inputs to the rotors. This gives the aircraft the ability to translate laterally with a wings-level attitude, rather than requiring differential collective inputs which cause the aircraft to roll. LTM can also be used to offset cross winds during takeoffs and landings, thereby lessening the yaw angle required to maintain the desired ground track.

Conversion system control consists of the manual system originally installed on the aircraft and a newly implemented semiautomatic system. Both systems accomplish nacelle positioning using common conversion actuators and hydraulic and electrical sources. The manual system utilizes several switch and relay assemblies, while the semiautomatic system employs the DAFCS processor to control conversion. This system is continually monitored for conversion asymmetry and failures of the DAFCS processor, automatic conversion command switches, actuator control circuitry, and conversion angle measurement system.

Manual positioning of the nacelles is accomplished by a pilot- or copilot-activated switch on the power lever. The nacelles can be moved to any position between 0 degrees (airplane mode) and approximately 95 degrees (helicopter mode) using one of these momentary, return-to-center toggle switches (Fig. 4). The nacelles move until the switch is released or until an endpoint is reached. The

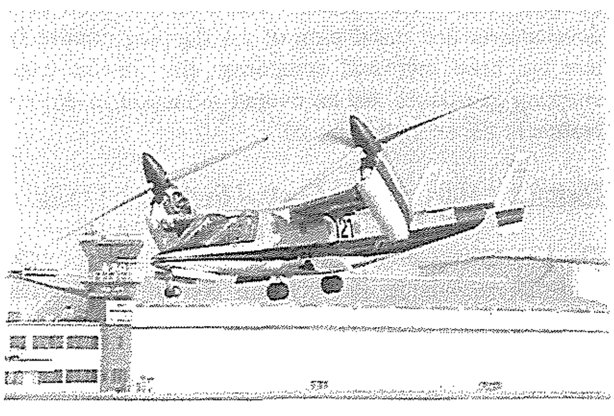


Fig. 4. XV–15 in conversion mode flight.

rate at which the nacelles convert is selected by the pilot to be either normal (7.5 deg/s) or slow (≈2 deg/s). To manually reposition the nacelles requires the pilot to continually activate the conversion control switch while simultaneously monitoring the current nacelle position. The nacelle conversion stops when the control switch is released.

Semiautomatic conversion control is activated by momentary switches located on the pilot and copilot's power levers adjacent to the manual conversion control switch. The semiautomatic conversion system allows the conversion to airplane mode and reconversion to helicopter mode to be accomplished in discrete nacelle increments and at the fast or slow rate. The desired conversion/reconversion schedule is preprogrammed and is readily modified between evaluation flights. This system provides a noticeable reduction in pilot workload and helps in maintaining a level aircraft attitude during conversion/reconversion. It also has logic to inhibit semiautomatic conversion at airspeeds above 155 kn. The semiautomatic conversion system can be over-ridden at any time by activating the switch in the opposite direction or by activating the manual conversion switch located adjacent to it.

The primary function of the DAFCS is that of the Stability and Control Augmentation System (SCAS). Dual electronic channels drive dual actuators in pitch and roll, and dual channels drive a single actuator in yaw. The dual channels provide a fail-operate capability for most faults, with automatic reconfiguration. If one dual channel fails, it is detected by the monitor functions, and the bad channel is automatically disengaged. The remaining good channel automatically adjusts its gain to compensate for the failed channel. If a failure occurs in the yaw axis the total yaw SCAS is disengaged, since there are not two yaw actuators.

The system is very flexible, allowing gain changes to be made easily in the development/test environment. Several gains are programmed as options, and one is selected. The selected one can be readily changed from an external terminal or hand-held keypad. This concept prevents a potentially dangerous condition where a very large gain change could be input in error. Only the preprogrammed changes can be input without a software change. This feature has been used to improve the efficiency of the test and evaluation process with great success.

Trouble-shooting the SCAS has been improved with the implementation of stored failure codes. Each detectable fault is assigned a fail code, which is stored in the DAFCS memory at the time the fault is detected. If an intermittent condition exists, such as a wiring fault, it is detected and logged even if it occurs for a very short time. At the time the fault is noted, the value of the signal in question is also logged. The storage of the fault codes is very useful in post-flight maintenance of the aircraft.

Transient-free engagement/disengagement/reconfiguration of the SCAS is provided. The SCAS channels can be engaged or disengaged in flight without causing objectionable transient inputs to the control system. This is accomplished with faders, which increase the gains from 0 to 100% over a 2-second time period when engaging, and fade from 100% to zero for disengagement.

The system uses both nacelle position and airspeed gain scheduling in order to optimize the performance of the SCAS over the entire airspeed range. This is an improvement over the original analog SCAS, which did not have gain scheduling as a function of airspeed. The turn coordination feature, used in the yaw axis to reduce the pilot workload associated with maintaining zero sideslip while turning, is an example of the advantage of including airspeed gain scheduling.

In summary, the DAFCS

1. Produces a significant reduction in pilot workload.

2. Increases the dynamic and static stability of the XV-15.

3. Results in a flexible means of modifying the XV–15 control system to evaluate the effects of system changes.

4. Provides an increased level of safety and reduced maintenance time by implementing fault monitoring and automatic reconfiguration.

5. Makes the XV–15 a more effective test aircraft for evaluation of civil tiltrotor concepts related to the Bell Boeing Model 609 and other tiltrotor aircraft.

Acoustic Research Using the XV–15

The ability to take off and land vertically or on short runways make tiltrotor aircraft viable for operations from locations other than conventional airports. While this capability can potentially reduce airport congestion by providing an alternate means to connect urban centers, the aircraft must be sufficiently quiet to be accepted by the general public in the areas near the terminals.

Acceptable noise levels are expected to be achieved in part with reduced source noise levels (quieter rotors) and partly with the development of noise abatement operating techniques which expose smaller areas on the ground to lower noise levels. The XV–15 aircraft is being used to address both source noise issues as well as to evaluate operational techniques that reduce the noise footprint of the aircraft during near-terminal operations.

In-Flight Acoustic Measurements. While the XV–15 rotor was not specifically designed for minimizing its source noise, it has recently been used to collect data which will ultimately be used to design quieter rotors. In 1995, the YO–3A aircraft from the National Aeronautics and Space Administration (NASA) Ames Research Center, was used to acquire acoustic data during flight conditions where blade–vortex interaction (BVI) occurs (Ref. 4).

NASA's YO–3A is an aircraft which has been modified specifically for acquiring acoustic data when flying in proximity to another aircraft. Microphones are mounted at each wingtip and at the top of the conventional tail. Acoustic data from the microphones are recorded onboard the aircraft, as is pertinent air data. The propeller on the YO–3A is driven slowly via a cogged rubber belt speed reduction drive, and the engine compartment and exhaust system are heavily muffled to minimize the noise emanating from the aircraft itself. The soundproofing is effective enough to make the aircraft nearly imperceptible when it passes overhead at heights greater than 50 meters above the ground.

During flight tests to acquire BVI data, the XV–15 was flown in tight formation with the YO–3A (Fig. 5). The intent was to place the right rotor of the XV–15 at a predetermined distance and orientation to the microphones mounted on the YO–3A. Markings on the wing and fuselage of the YO–3A were used to provide visual sight cues to the XV–15 pilot for consistent lineup, and a laser rangefinder was operated by the XV–15 copilot to maintain a predefined spacing.

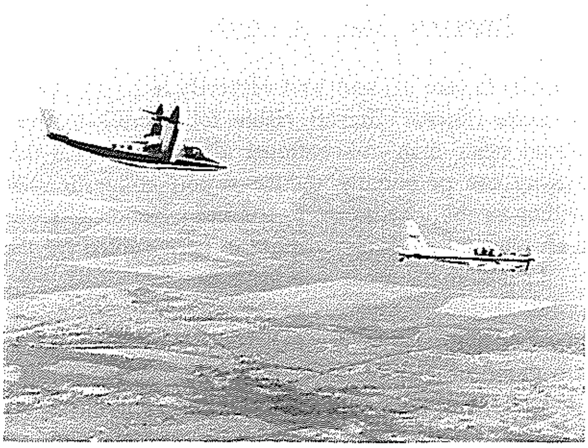


Fig. 5. XV–15 in formation with YO–3A. (Photo courtesy of NASA)

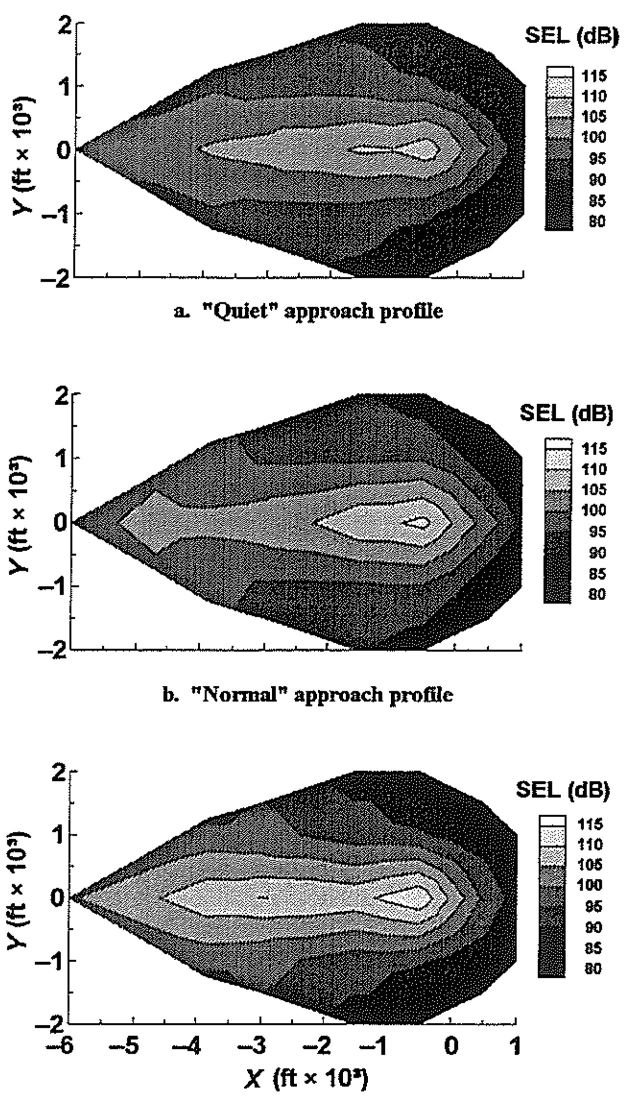
Various airspeed, descent rate, and nacelle angle configurations were tested. The conditions in which BVI occurred were determined, as were the resulting noise levels. These data will be used by NASA as baseline conditions for validating acoustic measurements during isolated rotor tests in their wind tunnel facilities (Ref. 5). By contributing to a better understanding of rotor source noise mechanisms, tests of this type should ultimately result in quieter rotor designs.

Ground-based Acoustic Measurements. Extensive acoustic testing of the XV–15 has been accomplished over its 20 year history. Baseline measurements have been made both in hover and forward flight, with the more recent tests directed toward establishing noise abatement techniques for near-terminal area operations (approaches and departures). Test results have indicated that approaches to landing generate the highest noise levels, and related XV–15 testing has been focused primarily in this area in order to establish operational techniques which reduce the noise footprint on the ground.

The variable nacelle tilt capability of tiltrotor aircraft give them the ability to fly specified flight paths at many different rotor operating conditions. Likewise, the flaps on the wing can be used to adjust aircraft attitude to some degree. The speed range possible with the number of nacelle tilt configurations provides another variable that can be manipulated in order to establish techniques for reducing the noise footprint.

NASA-funded acoustic tests of the XV–15 in 1995 (Ref. 6) and 1997 focused on evaluating the effectiveness of these variables in achieving noise abatement during terminal area operations. Two different ground-based microphone arrays were utilized in the 1995 tests. A linear array of microphones was used to measure the lower hemispherical acoustic characteristics of the XV–15 during steady-state flight operations (constant airspeed and glideslope, fixed nacelle angle). The second array utilized microphones arranged over a 600-m by 2,100-m area. This microphone array configuration is useful for measuring the noise footprint on the ground during simulated terminal area operations, and allows a quantification of the acoustic characteristics of the test aircraft during non-steady state approaches and departures.

Results from the 1995 tests indicate that the magnitude of the noise and the area over which it radiates can be strongly affected by the nacelle angle, speed, and glidepath angle over which the aircraft is flown (Fig. 6). For a given noise contour, the size of the impacted area could be varied by as much as a factor of four simply by changing the operational techniques that affect nacelle angle, airspeed, and glidepath. The shape of the noise footprints could be tailored to a given vertiport configuration by use of segmented curved approaches. The test results also showed that the takeoff condition has only a



a. "Quiet" approach profile

b. "Normal" approach profile

c. "Loud" approach profile

Fig. 6. Measured noise footprints. (Courtesy of NASA)

secondary effect on the total noise impact of tiltrotor operations, affecting land areas which are only 10% of the size of those impacted during approaches.

The results from the 1995 tests were used to refine the test conditions for XV–15 tests in 1997. In the 1997 tests, a large ground-based microphone array was arranged over an area measuring approximately 600 meters by 2,700 meters. The test was conducted to utilize the variable configuration options of the tiltrotor aircraft in combinations which were shown to yield some of the quieter approaches from the 1995 tests. Approach paths were flown that included nacelle angle changes, varying deceleration rates, and glide path angle changes. While the data acquired during this test are still being analyzed, it is anticipated that multiple operational techniques will be identified which can be effectively utilized to accomplish some measure of noise abatement for tiltrotor aircraft.

Differential GPS Guidance and Aircraft Tracking

Full utilization of future tiltrotor aircraft will require access in unfavorable weather conditions to vertiports that may be located on rooftops, in urban centers, and at remote locations. It would be cost-prohibitive to configure each of these potential terminal areas with conventional instrument landing systems (ILS). Without some navigation/guidance source, however, flight operations will likely be restricted by weather considerations.

The development of satellite navigation for use in global positioning systems (GPS) will potentially change all phases of flight. As systems are developed, the need for costly ground-based navigation beacons will be greatly reduced, and expensive conventional ILS may eventually be replaced by low-cost reference GPS stations.

In order to reach the level of dispatch reliability that passengers currently expect from scheduled airlines operating from vast airports, tiltrotors and future rotary-wing aircraft will likely rely on some type of GPS-based navigation to provide guidance during flight operations from these vertiports. The XV–15 aircraft, with its unique configuration capabilities, is currently being used to evaluate the use of GPS for navigation and guidance during precision approaches to simulated vertiports.

Fundamentals of GPS. The GPS satellite constellation is funded and maintained by the United States Department of Defense (DOD). It consists of a constellation of 24 satellites orbiting approximately 18,000 km (11,000 miles) above the earth's surface. Each satellite makes two orbits per day, and each satellite's broadcast signal and orbital position is monitored and controlled by the DOD.

In basic terms, positioning with GPS is accomplished using the timing signals (providing range information) from each satellite, and triangulation using the known, transmitted satellite positions in space. A minimum of three satellites can be used to define a position on the earth's surface, while additional satellites may increase the accuracy of the solution. Quoted position accuracies provided by GPS-receivers operating autonomously are typically 100 m horizontal, 150 m vertical. This accuracy is typically sufficient for conventional flight operations between waypoints, but is of little use in precision flight test applications.

Differential GPS (DGPS) has been developed to provide an increase in position accuracy of two orders of magnitude or greater over that offered by autonomous GPS. It does so by eliminating most of the sources of error in the GPS measurements. The technique of using DGPS requires a reference GPS receiver located at a known control point. The stationary reference receiver determines the error in the satellite range measurements, and a data link is used to transmit the correction information to the

GPS receiver in the aircraft. This correction information is applied to the GPS solution in the aircraft, and position accuracies can be improved to within 1 to 3 m or less.

The concept of using DGPS for airborne applications has been discussed widely in the literature (Ref. 7). Its unique application in the XV–15 aircraft is described in the paragraphs that follow.

DGPS Hardware Installation. The XV–15 aircraft is fitted with a 12-channel, dual frequency Ashtech Model Z–12 GPS receiver. This unit provides serial data outputs for corrected position, as well as velocity, correction data status, and satellite information. The receiver also stores the raw data for each position solution, which allows post-processing of the position and velocity data. The GPS antenna is located on top of the fuselage, aft of the wing. This location has proven to yield good reception of the satellite signals. Differential corrections are received by a VHF radio modem from G.L.B. Electronics. The antenna for the correction link is located on the belly of the aircraft, behind the cockpit.

The DGPS reference ground station consists of a matching GPS receiver and radio modem. A survey-type GPS antenna and the antenna for transmitting the correction information are located on a platform at the Bell Flight Research Facility in Arlington, Texas. Position and velocity solutions can be calculated at rates up to 5 Hz. Differential corrections are determined and transmitted to the aircraft once per second at 19,200 baud.

The information from the onboard DGPS receiver is passed from a serial data port to a Bell-designed interface unit. This unit parses the serial GPS data stream and formats the values into data words which can be inserted into the aircraft's pulse-code modulated (PCM) data stream. This approach allows the GPS measurements to be correlated in time with the remainder of the approximately 150 measured aircraft parameters. The PCM data stream, including the GPS parameters, is simultaneously recorded on the aircraft and telemetered to the ground data center for real-time monitoring.

XV–15 Flight Director. The XV–15 has been fitted with a Silicon Graphics, Inc. computer that computes flight director guidance for performing precision flight testing. The computer receives DGPS information and other aircraft state parameters by means of an ethernet communications link with the interface unit. The flight director computer utilizes guidance control laws developed in NASA/Bell simulations specifically for tiltrotor operations.

The flight director provides guidance commands for the desired aircraft configuration as well as for the desired flight path and velocity profile. Commands are given for the operation of flaps, landing gear, and nacelle conversion angle. The nacelle conversion angle and flaps can be used very effectively to reduce pilot workload and control fuselage attitude while flying very precise approach paths.

The XV–15 copilot's instrument panel has been modified with the installation of a color liquid crystal display (LCD). The display provides essential information for piloting the aircraft, and also provides the information needed for flight director guidance. Conventional command bars are used for flight path guidance, and raw data for horizontal and vertical errors are also provided. Ground speed errors are displayed, and power lever commands are given for airspeed and descent rate control (Fig. 7).

XV–15 Flight Testing of the Flight Director. Initial flight tests of the XV–15 with the DGPS-based flight director installation were conducted during the first half of 1997. Several approach paths were accomplished, some of which were initiated at 150 KIAS in airplane mode. The flight director guidance commanded deceleration of the aircraft, conversion to intermediate nacelle conversion angles, intercept of the approach flight path, and termination to landing/hover.

The DGPS proved to be quite capable of providing the precision position information required to accomplish the approaches, although some limitations were noted. Attempts to utilize the position information at 5 Hz while simultaneously storing raw satellite data occasionally overloaded the GPS processor, resulting in temporary interruptions of the GPS position output. Reducing the position calculation and data storage rate to 2 Hz eliminated the problem, and the performance of the DGPS has since been excellent. The smoothness of the displayed

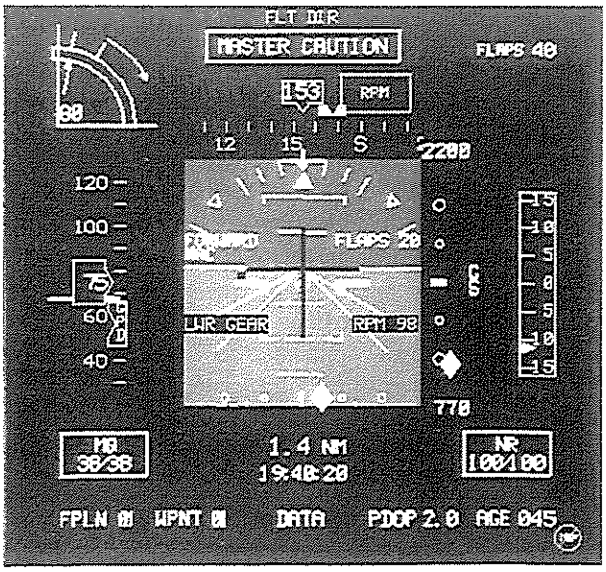


Fig. 7. Flight director display.

information did not suffer noticeably when the update rate was reduced.

Further enhancements of the DGPS-based flight director system are planned. Control law refinement is underway, aimed particularly towards reducing pilot workload and minimizing aircraft attitude extremes. The addition of an inertial-navigation system augmented by DGPS position updates is also being studied.

Conclusions

After flying 20 years and amassing over 1,300 airframe hours with two aircraft, the XV–15 continues to be a valuable tool for supporting technology development for tiltrotor aircraft, including the Bell–Boeing V–22 and Model 609 aircraft (Fig. 8). The efforts toward reducing loads and vibration will improve passenger comfort and reduce the maintenance costs associated with operating tiltrotor aircraft. Development of advanced automated flight control systems will result in aircraft which are even safer and easier to fly. Noise reduction measures will increase community acceptance and open the doors for increased access to urban centers and other populated regions. Finally, the development of DGPS-based navigation and guidance systems promises to provide precise aircraft positioning for safe, cost-effective terminal area operations.

References

1. Maisel, M. and Tiltrotor Project Office Staff, "Army/NASA XV–15 Tiltrotor Research Aircraft Familiarization Document," NASA TM X–62, 407, January 1975.

2. "Advancement of Proprotor Technology, Task 2: Wind-Tunnel Test Results," NASA CR 114363, September 1971.

3. Edenborough, H. K., Gaffey, T. M., and Weiberg, J. A., "Analyses and Tests Confirm Design of Proprotor Aircraft," AIAA Paper No. 72-803, in "AIAA 4th Aircraft Design, Flight Test, and Operation Meeting," Los Angeles, CA, August 1972.

4. McCluer, M. and Dearing, M., "Measuring Blade–Vortex Interaction Noise Using the YO–3A Acoustics Research Aircraft," in "22nd European Rotorcraft Forum," Brighton, UK, September 1996, Paper 82.

5. Kitapliogliu, C., McCluer, M., and Acree, C. W., "Comparison of XV–15 Full-Scale Wind Tunnel and In-Flight Blade Vortex Interaction Noise," in "53rd Annual Forum of the American Heli copter Society," Virginia Beach, Virginia, USA, April 1997.

6. Conner, D., Marcolini, M., Edwards, B., and Brieger, J., "XV–15 Tiltrotor Low Noise Terminal Area Operations", in "53rd Annual Forum of the American Helicopter Society," Virginia Beach, Virginia, USA, April 1997.

7. Hardesty, M., Metzger, M., Flint, J., and Fredrickson, D., "Developmental Test and Evaluation of Helicopters Using a Precision Differential Global Positioning System," in "53rd Annual Forum of the American Helicopter Society," Virginia Beach, Virginia, USA, April 1997.

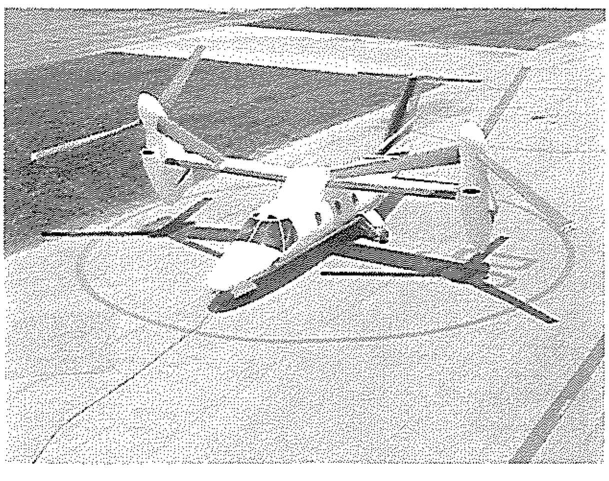


Fig. 8. Bell–Boeing Model 609 Full-Scale Mockup.