# HANDLING QUALITIES EVALUATION OF XV-15 NOISE ABATEMENT LANDING APPROACHES USING A FLIGHT SIMULATOR

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## ABSTRACT

A piloted simulation experiment was conducted in the Vertical Motion Simulator to evaluate the handling qualities of noise abatement approach procedures for a civil tiltrotor. Approach and landing procedures flown on the XV-15 tiltrotor research aircraft were evaluated in the simulator by a larger pilot population. The impact on handling qualities of attitude stabilization control responseand winds and turbulence were studied. Evaluations by nine pilots upheld rating commentary by the two pilots who flew the acoustic measurement flight tests. Simulation evaluations judged the noise abatement approach profile handling qualities satisfactory for the XV-15 in calm air, degrading into adequate handling qualities in winds and turbulence. Attitude stabilization assisted tracking precision, but at the expense of increased workload to compensate for aircraft trim changes associated with flap deflection and large nacelle movements.

## INTRODUCTION

External noise is a technology barrier to widespread civil rotorcraft use. NASA's Short Haul Civil Tiltrotor Program (Ref. 1) has focused on noise reduction technology development via source noise reduction (rotor design) and operational noise reduction. Noise reduction via flight operations design seeks to design flight operations to avoid or minimize operation in regions of intense noise generation. Blade vortex interaction has been identified as the dominant noise source for both helicopters and tiltrotors.

Tiltrotor noise abatement operations have been developed using the XV-15 aircraft (Fig. 1) in three flight experiments (Ref. 2). The first experiment documented noise levels generated in an array of steady flight conditions potentially usable during approach. Figure 2 portrays results of this effort with operating points of greater or lesser noise as a function of airspeed and descent rate. Nacelle positions were selected based on the routine tiltrotor pilot practice of flying with nearly level pitch attitude. Flight path angle lines are also plotted in Fig. 2. Note that flight along a descending six degree flight path angle (a common rotorcraft visual approach angle) produces increased noise at common approach speeds from 60 to 100 knots.

**Fig. 1. XV-15 Tiltrotor Research Aircraft shown on final approach during October, 1999 Noise Measurement Flight Test.**

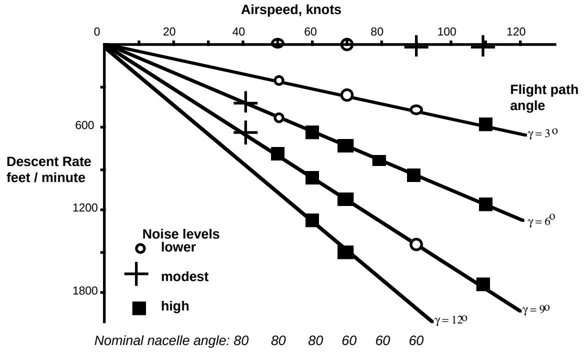

**Fig. 2. XV-15 operational noise survey.**

The XV-15 operating condition noise plot was used to design a potential two segment (3 to 9 degree flight path angle) noise abatement approach profile, as illustrated in Fig. 3. It was speculated that the final approach along a nine-degree flight path angle would concentrate noise at the landing facility and provide additional approach obstruction clearance compared to more conventional three-degree and helicopter six-degree glide slopes. The candidate two-segment approach profile was tested in a simulation

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experiment on the NASA Ames Vertical Motion Simulator (VMS) using a 40,000-lbs tiltrotor model. Speeds were scaled up from the XV-15 based on the nominal initial conversion point from airplane mode (150 kts for the XV-15, 180 kts for the larger transport tiltrotor). This simulation experience provided the initial operations and handling qualities constraints for subsequent noise abatement approach designs.

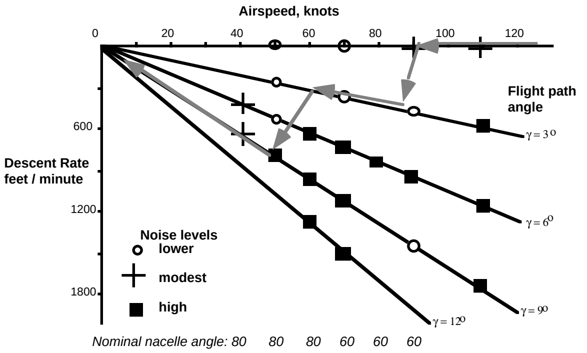


**Fig. 3. Noise abatement strategy.**

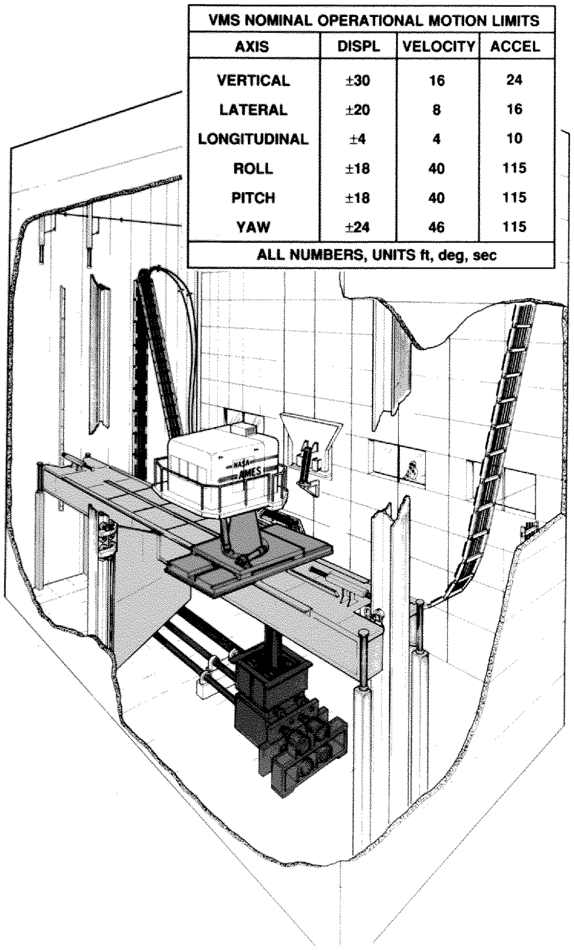
Two subsequent XV-15 flight experiments measured noise footprints and gathered pilot handling qualities commentary. An initial set of approach profiles was developed and measured in a flight experiment in June 1997. These profiles were refined and augmented for the final flight experiment, completed in October 1999.

Several handling qualities differences were noted between XV-15 flight work and the ground based simulation using the larger transport tiltrotor model. Aircraft control systems and test atmospheric conditions led to changes in approach profile design between flight and simulator. For example, a change in the final decision point–moving it back from 200 feet altitude to 300 feet–was done in the June 1997 test to provide a less rushed final landing maneuver. Tolerance of deceleration rates in instrument conditions was different. The XV-15 was provided with a rate response control system versus the attitude stabilization (rate command-attitude hold or attitude command) employed on the simulated large transport. An autoflap system was employed on the large transport, contrasting to the discrete flap stops of the XV-15. The XV-15 tests were flown in nearly calm- clear conditions, while simulator experiments tested calm and instrument meteorological conditions. Finally, the XV-15 flights and evaluations were performed by a limited set of experimental pilots. Handling qualities of noise abatement approach profiles selected from the final XV-15 flight test were evaluated in a large motion flight simulator using a larger pool of pilots.

# EXPERIMENT DESIGN

## Simulation Facility

The piloted simulation experiment was conducted on the VMS. The VMS features a reconfigurable, interchangeable cockpit cab mounted on a large motion platform as shown in Fig. 4. Maximum vertical acceleration capability is ±0.67 g. For tiltrotor approach operations studies, the cab was oriented for longitudinal motion along the main beam (turned 90 degrees to that shown in Fig. 4). With this simulator configuration, the maximum longitudinal acceleration was 0.5 g and a maximum lateral acceleration (across the beam) was 0.3 g. A description of the motion washout logic used in the VMS is provided in Ref. 3. Table 1 lists the motion gain and filter frequencies used for the low speed operations (nacelle angles above 50 degrees, approximately 100 knots) of this experiment.



VMS NOMINAL OPERATIONAL MOTION LIMITS

| AXIS | DISPL | VELOCITY | ACCEL |
|---|---|---|---|
| VERTICAL | ±30 | 16 | 24 |
| LATERAL | ±20 | 8 | 16 |
| LONGITUDINAL | ±4 | 4 | 10 |
| ROLL | ±18 | 40 | 115 |
| PITCH | ±18 | 40 | 115 |
| YAW | ±24 | 46 | 115 |

ALL NUMBERS, UNITS ft, deg, sec

**Fig. 4. Vertical Motion Simulator.**

**Table 1. Vertical motion simulator motion drive characteristics.**

| Motion axis | Gain | Filter break frequency (rad/sec) |
|---|---|---|
| Roll | 0.3 | 0.25 |
| Pitch | 0.5 | 0.7 |
| Yaw | 0.5 | 0.5 |
| Longitudinal | 0.7 | 0.7 |
| Lateral | 0.3 | 1.0 |
| Vertical | 0.6 | 0.4 |
| Pitch-tilt | 0.6 | 0.3 |
| Roll-tilt | 0 | N/A |

The simulator cockpit was configured with side-by-side crew seating typical of a transport aircraft, including the simulated XV-15, as shown in Fig. 5. Electronic displays provided primary flight information and horizontal situation indicators for each pilot. Annunciators for control system selection and landing gear position were on the panel below the glare shield.

**Fig. 5. Simulator cockpit interior. Final approach to notional San Francisco Vertiport shown in visual scene.**

A six-window cockpit view of the external scene was provided by an Evans and Sutherland ESIG-3000 Computer Image Generation system. Pilots were provided with a 205-degree horizontal field of view using the five horizontal windows. The right seat center window was repeated as the left seat center window, accepting the slight optical error. In addition to the five primary windows, the right seat pilot could view a "chin bubble" to the lower right. Evaluation operations were flown into a raised deck vertiport, with landings performed on a 150 x 600 feet rollway.

Control inceptors included a center stick, pedals and a vertically moving thrust control lever (TCL), similar to the XV-15. Table 2 lists center stick force characteristics. The force gradient increased linearly with dynamic pressure, q. A 7-inch TCL vertical travel was used in contrast to the XV-15's 10-inch TCL vertical travel. TCL control sensitivity was scaled accordingly. The 7-inch TCL throw was carried over from simulation experiments with a larger tiltrotor transport and fit within the physical constraints of the simulation hardware. TCL friction was set by the pilot. A pitch and roll trim switch was provided atop the center stick grip. The TCL control head (Fig. 6) had control switches for analog-beep or pilot-initiated, semi-automatic, discrete control of nacelle movement. Other controls explicit to the XV-15, such as the nacelle lock switch and the governor release button, were not activated for this experiment. Flap angle and landing gear position controls were on the center console, similar to the XV-15.

**Table 2. Stick force characteristics.**

$$\text{Stick Force} = \text{Breakout} + (G_0 + G_1 q)\delta$$

| | Longitudinal | Lateral |
|---|---|---|
| Breakout, lbs | 0.75 | 0.9 |
| $G_0$, lbs/in | 1.0 | 1.0 |
| $G_1$, lbs/in / lbs/ft$^2$ | 0.059 | 0.0131 |

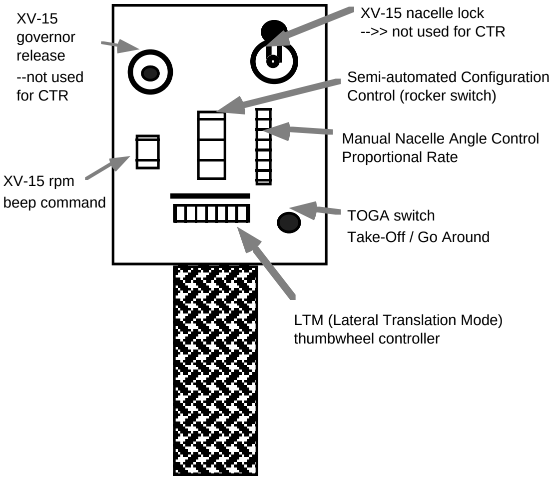


**Fig. 6. Thrust Control Lever control head.**

The aircraft was simulated with the Generic Tilt Rotor Simulation model (GTRS, Ref. 4), configured as the XV-15 aircraft. The XV-15 (Fig. 1) is a 13,500 lbs (nominal–average test weight) tiltrotor aircraft with 25 feet diameter proprotors. The host computer which simulated the aircraft, control system, and guidance drive laws, and cycled at 10 msec.

## Controls

Two control augmentation systems were provided for the primary angular modes of pitch and roll. The first simulated the rate augmentation used on the XV-15 (Ref. 5). Longitudinal response dynamics were documented using the frequency domain techniques of CIFER® (Ref. 6 and 7). First order response models for pitch due to longitudinal stick in hover and low speed flight (70 knots, 80 degree nacelle angle) are listed in Table 3. The XV-15 rate command control system is moderately damped with a bandwidth of 2 rad/sec in hover, with improved damping and a bandwidth around 5 rad/sec at higher airspeeds. Airplane mode (150 knots, 0 degree nacelle angle) pitch response characteristics are listed in Table 4 for the basic XV-15 rate system.

**Table 3. Reduced-order aircraft dynamic model characteristics, pitch rate due to longitudinal stick, with XV-15 rate command.**

$$\frac{q}{\delta_{LNG}} = \frac{K}{(s + a)}$$

| | Hover | 70 kts/80 deg |
|---|---|---|
| K,deg/sec$^2$/in | 0.31 | 0.52 |
| a, rad/sec | 2.06 | 4.57 |

**Table 4. Reduced-order aircraft dynamic model characteristics, pitch rate due to longitudinal stick, for airplane mode flight with XV-15 rate command.**

$$\frac{q}{\delta_{LNG}} = \frac{K}{(s^2 + 2\zeta\omega s + \omega^2)}$$

| | XV-15 Rate |
|---|---|
| K, deg/sec$^3$/in | 3.72 |
| ζ, ND | 0.64 |
| ω, rad/sec | 5.07 |

The second control system provided attitude stabilization and pilot selection of rate-command-attitude-hold (RCAH) or attitude command (ATT) in either pitch or roll. Control system design used a dynamic inverse technique (Ref. 8). Attitude command was used for helicopter mode flight, with nacelle angle above 60 degrees. First order pitch response models for this control mode were documented with the CIFER® technique and are listed in Table 5. Pilots used RCAH augmentation in airplane mode flight. The identified response model for this mode and flight condition are listed in Table 6.

**Table 5. Reduced-order aircraft model characteristics, pitch angle due to longitudinal stick, with attitude command control augmentation for low speed flight.**

$$\frac{\Theta}{\delta_{LNG}} = \frac{K}{(s^2 + 2\zeta\omega s + \omega^2)}$$

| | Hover | 70 kts/80deg |
|---|---|---|
| K, deg/sec$^2$/in | 12.97 | 13.61 |
| ζ, ND | .7 | 0.67 |
| ω, rad/sec | 1.97 | 1.94 |

**Table 6. Reduced-order aircraft dynamic model characteristics, pitch rate due to longitudinal stick, for airplane mode flight with rate command-attitude hold.**

$$\frac{q}{\delta_{LNG}} = \frac{K(\tau s + 1)}{(s^2 + 2\zeta\omega s + \omega^2)}$$

| | RCAH |
|---|---|
| K, deg/sec$^3$/in | 1.6 |
| τ, sec | 1.17 |
| ζ, ND | 0.7 |
| ω, rad/sec | 2.5 |

**Table 7. Reduced-order aircraft dynamic model characteristics, height rate due to thrust control lever for low speed flight.**

$$\frac{\dot{h}}{\delta_{TCL}} = \frac{K}{s + a}$$

| | Hover | 70 kts/80 deg |
|---|---|---|
| K, ft/sec$^2$/in | 4.15 | 5.93 |
| a, rad/sec | 0.11 | 0.48 |

The XV-15 uses a beta-governing system for proprotor speed control, similar to a constant-speed propeller. This is augmented in helicopter mode flight with a direct link to the pilot's thrust control lever. As a consequence, the XV-15's thrust-heave response to TCL command in helicopter mode flight is slower than most helicopters, as discussed in Ref. 7. First order response models for heave due to thrust control lever position are listed in Table 7. Thrust-heave response is lightly damped, with an inverse time constant of 0.11 rad/sec in hover.

A discrete nacelle movement control system was provided as developed in prior NASA civil tiltrotor simulation experiments and used in the XV-15 flight test. Nacelle position stops were set for rearward movement at 0 (airplane mode), 60, 75, 80, 85 and 90 degrees (helicopter mode). Forward movement stops were set at 90, 75, 60 and 0 degrees. The nacelle movement rate between stops was set at the XV-15 "slow" rate of 2 degrees per second. To use this discrete nacelle control system, the pilot depressed a rocker switch on the TCL control head once for each movement. When nacelles were set in motion, they came to a halt at the next discrete stop for the direction (fore or aft) of move commanded.

Flap angle control was provided by the center console flap handle with discrete position settings at 0, 20, 40 and 75 degrees for the main flaps. Movement between flap settings was at a fixed rate of 5 degrees per second.

## Guidance

Precision approach guidance was provided via a pursuit guidance model, augmented by a compensatory flight director for longitudinal control (pitch and thrust). The primary flight display (Fig. 7) was adapted for tiltrotor use from an electronic format used in modern conventional fixed wing transports. The display featured a central attitude field with drum-type indicators for airspeed (left) and altitude (right). Tiltrotor adaptations included 'thermometer' tapes for engine torque and a nacelle angle quadrant with digital indication.

**Fig. 7. Primary Flight Display.**

Pursuit guidance (Refs. 9 and 10) was provided for the approach path in addition to the pitch and roll attitude provided in the central display area. As diagrammed in Fig. 8, a leader symbol represented a lead aircraft flying a perfect path five seconds (longitudinal) ahead of the ownship. The ownship flight path symbol (Flight Path Vector, FPV) represented the aircraft's current flight path angle (vertical and horizontal) in relation to the leader. Using this symbol set, the pilot pursued the leader symbol with the ownship by moving the aircraft controls to overlay the ownship symbol on the leader.

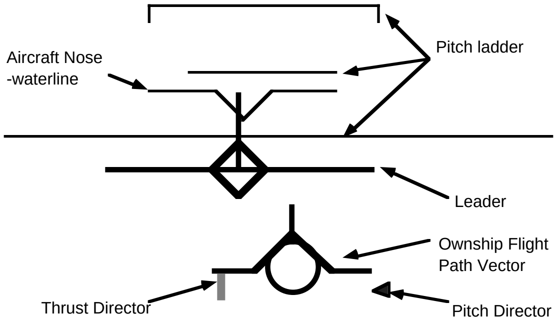
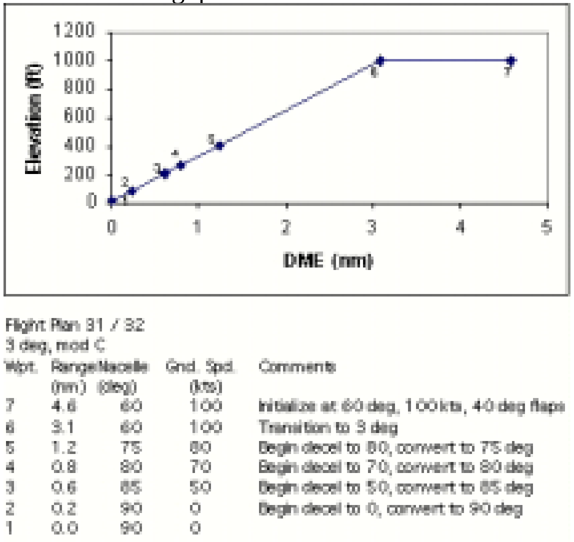


**Fig. 8. Flight path vector pursuit-oriented guidance.**

The pursuit pathway guidance was augmented by longitudinal flight direction for pitch and thrust (Ref. 9). Pitch guidance was displayed as a caret moving (fly-to) relative to the right wing of the ownship flight path vector symbol. Thrust direction was displayed as a thermometer (fly-from) on the left wing of the ownship flight path vector.

## Approach Profiles

Six noise abatement approach procedure profiles were selected from the 1999 XV-15 flight test for handling qualities evaluation. Flight cards for each are shown in Figs. 9 through 13. Each profile had a unique feature for which a handling qualities evaluation was desired.

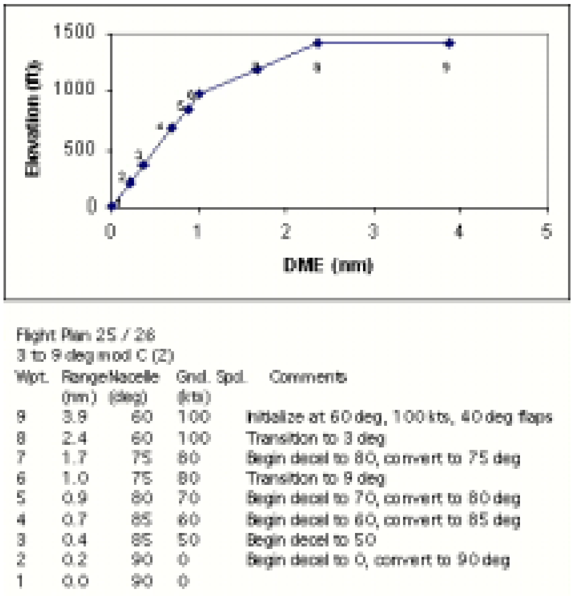


Flight Plan 31 / 32
3 deg, mod C

| Wpt. | Range (nm) | Nacelle (deg) | Gnd. Spd. (kts) | Comments |
|---|---|---|---|---|
| 7 | 4.6 | 60 | 100 | Initialize at 60 deg, 100kts, 40 deg flaps |
| 6 | 3.1 | 60 | 100 | Transition to 3 deg |
| 5 | 1.2 | 75 | 80 | Begin decel to 80, convert to 75 deg |
| 4 | 0.8 | 80 | 70 | Begin decel to 70, convert to 80 deg |
| 3 | 0.6 | 85 | 50 | Begin decel to 50, convert to 85 deg |
| 2 | 0.2 | 90 | 0 | Begin decel to 0, convert to 90 deg |
| 1 | 0.0 | 90 | 0 | |

**Fig. 9. Flight Plan 31, 3 degree decelerating approach.**

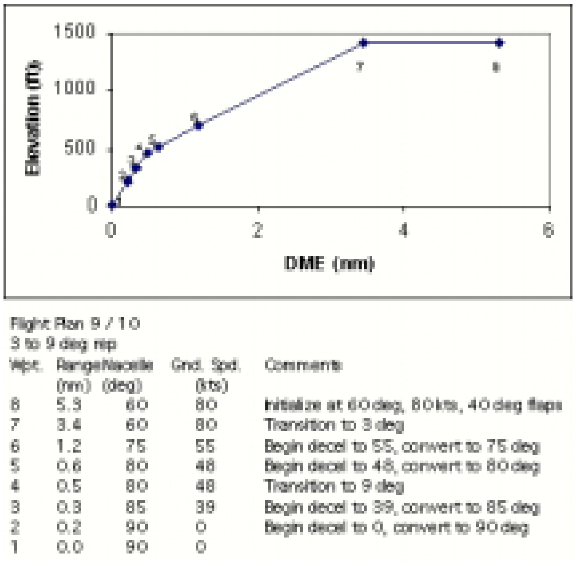
FP-31, shown in Fig. 9, was a straight-in three-degree approach with a rapid series of nacelle moves and decelerations just prior to the landing decision height. This profile provided the quietest sideline and overall noise measured during the XV-15 flight test.



Flight Plan 25 / 26
3 to 9 deg mod C (2)

| Wpt. | Range (nm) | Nacelle (deg) | Gnd. Spd. (kts) | Comments |
|---|---|---|---|---|
| 9 | 3.9 | 60 | 100 | Initialize at 60 deg, 100 kts, 40 deg flaps |
| 8 | 2.4 | 60 | 100 | Transition to 3 deg |
| 7 | 1.7 | 75 | 80 | Begin decel to 80, convert to 75 deg |
| 6 | 1.0 | 75 | 80 | Transition to 9 deg |
| 5 | 0.9 | 80 | 70 | Begin decel to 70, convert to 80 deg |
| 4 | 0.7 | 85 | 60 | Begin decel to 60, convert to 85 deg |
| 3 | 0.4 | 85 | 50 | Begin decel to 50 |
| 2 | 0.2 | 90 | 0 | Begin decel to 0, convert to 90 deg |
| 1 | 0.0 | 90 | 0 | |

**Fig. 10. Flight Plan 25, 3-9 degree double segment approach.**

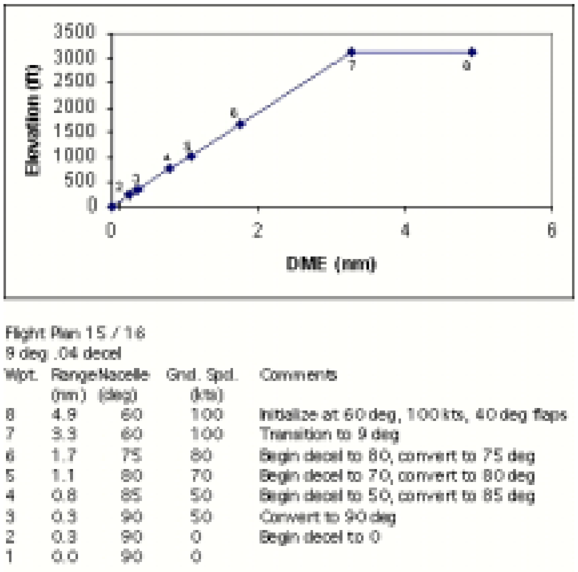


Flight Plan 9 / 10
3 to 9 deg mp

| Wpt. | Range (nm) | Nacelle (deg) | Gnd. Spd. (kts) | Comments |
|---|---|---|---|---|
| 8 | 5.3 | 60 | 80 | Initialize at 60 deg, 80 kts, 40 deg flaps |
| 7 | 3.4 | 60 | 80 | Transition to 3 deg |
| 6 | 1.2 | 75 | 55 | Begin decel to 55, convert to 75 deg |
| 5 | 0.6 | 80 | 48 | Begin decel to 48, convert to 80 deg |
| 4 | 0.5 | 80 | 48 | Transition to 9 deg |
| 3 | 0.3 | 85 | 39 | Begin decel to 39, convert to 85 deg |
| 2 | 0.2 | 90 | 0 | Begin decel to 0, convert to 90 deg |
| 1 | 0.0 | 90 | 0 | |

**Fig. 11. Flight Plan 9, 3-9 degree approach used with 40 and 75 degree maximum flap use investigation.**

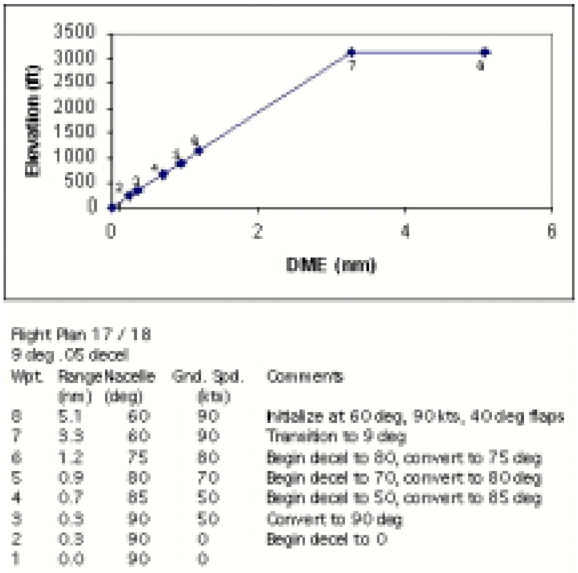
FP-25 (Fig. 10) and FP-9 (Fig. 11) were double-segment approach paths with an initial three-degree glide slope breaking to a final nine-degree approach. FP-25 was the quietest of the double-segment approaches, concentrating the noise impact near the landing pad. FP-9 was used to investigate the influence of the increased drag flap setting of 75 degrees versus the nominal 40-degree flap setting used for most XV-15 flights. For the XV-15, the 75-degree flap position provided slightly higher hover download than the 40-degree position. Simulations prior to the 1999 flight test suggested use of the higher flap setting to provide higher drag and to assist control and visibility on the nine-degree final approach segment. Flaps were moved from 40 to 75 degrees when the commanded airspeed fell below 90 knots.



Flight Plan 15 / 16
9 deg .04 decel

| Wpt. | Range (nm) | Nacelle (deg) | Gnd. Spd. (kts) | Comments |
|---|---|---|---|---|
| 8 | 4.9 | 60 | 100 | Initialize at 60 deg, 100 kts, 40 deg flaps |
| 7 | 3.3 | 60 | 100 | Transition to 9 deg |
| 6 | 1.7 | 75 | 80 | Begin decel to 80, convert to 75 deg |
| 5 | 1.1 | 80 | 70 | Begin decel to 70, convert to 80 deg |
| 4 | 0.8 | 85 | 50 | Begin decel to 50, convert to 85 deg |
| 3 | 0.3 | 90 | 50 | Convert to 90 deg |
| 2 | 0.3 | 90 | 0 | Begin decel to 0 |
| 1 | 0.0 | 90 | 0 | |

**Fig. 12. Flight Plan 15, 9 degree 0.04 g decelerating approach.**



Flight Plan 17 / 18
9 deg .05 decel

| Wpt. | Range (nm) | Nacelle (deg) | Gnd. Spd. (kts) | Comments |
|---|---|---|---|---|
| 8 | 5.1 | 60 | 90 | Initialize at 60 deg, 90 kts, 40 deg flaps |
| 7 | 3.3 | 60 | 90 | Transition to 9 deg |
| 6 | 1.2 | 75 | 80 | Begin decel to 80, convert to 75 deg |
| 5 | 0.9 | 80 | 70 | Begin decel to 70, convert to 80 deg |
| 4 | 0.7 | 85 | 50 | Begin decel to 50, convert to 85 deg |
| 3 | 0.3 | 90 | 50 | Convert to 90 deg |
| 2 | 0.3 | 90 | 0 | Begin decel to 0 |
| 1 | 0.0 | 90 | 0 | |

**Fig. 13. Flight Plan 17, 9 degree 0.05 g decelerating approach.**

FP-15 (Fig. 12) and FP-17 (Fig. 13) used nine-degree glide slopes and explored different commanded decelerations prior to the landing decision point. FP-15 used a 0.04-g deceleration. FP-17 used a 0.05-g deceleration. Flight test measurements suggested the greater deceleration reduced the noise footprint, but at the expense of degraded handling qualities.

### Task Standards

Evaluation task standards were based on the tight flight path tracking requirements of the XV-15 flight test. Desired tracking was within ±100 feet, vertically, and ±200 feet horizontally. Both of these necked down to about half those values (±57 feet, vertically) within a half mile of the landing aim point. Adequate tracking performance was defined as double the desired performance. Raw error for glide slope and lateral tracking was indicated on the primary flight display with one dot of error equal to the desired standard. Desired speed control was specified as within ±5 knots of the command profile, indicated by a notched gray tab on the airspeed drum. Adequate tracking was twice the desired (±10 knots).

### Atmospheric Conditions

Atmospheric conditions included both the clear-calm conditions prevalent during the acoustic measurement flight tests and adverse weather of a 200 feet ceiling with 1200 feet RVR (runway visual range) and 10 knots crosswind (90 degrees to the final approach heading) with moderate turbulence (4.5 feet per second root-mean-square).

### Pilots

Nine pilots representing NASA, the FAA and rotorcraft manufacturers participated as evaluation pilots. Eight had tiltrotor flight experience. All had participated in prior NASA civil tiltrotor simulation experiments, which provided background experience with the flight path vector guidance display system.

## RESULTS

Handling qualities were evaluated for three segments of the approach: the initial approach which included conversion from airplane mode to the powered lift mode at 60 degrees nacelle, glide slope tracking down to the landing decision point, and the final landing. Handling qualities ratings (HQR) were provided using the Cooper-Harper pilot rating scale (Ref. 11). HQR results are plotted on Figs. 14, 15, and 17 for the three rating subtasks. Average and range of HQRs are shown for the six tasks with variations in control response type (rate versus attitude-stabilized) and atmospheric conditions (calm-clear, "C", versus IMC with winds, "W").

### Initial Approach With Conversion

The level flight conversion subtask was nearly identical for all of the profiles with the level flight initial approach segment. For FP-31 with its constant three-degree glide slope, the initial conversion was performed on glide slope, eliminating a level conversion task. The level flight conversion began with the flaps deployed at 20 degrees and the nacelles moved from zero to 60 degrees. The aircraft was decelerated to 90 knots after the nacelles stopped at 60 degrees. Forty-degree flaps were selected as the aircraft decelerated through 100 knots. When pilots used the attitude-stabilized dynamic inverse control system stayed in rate command-attitude hold throughout the initial conversion task. This task had no direct corollary in the noise measurement flight tests, since all of those test runs were begun with nacelles at 60 degrees.

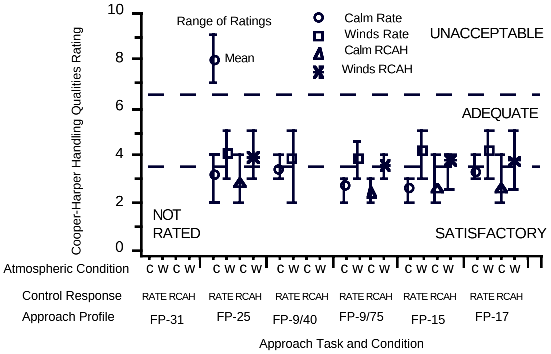


**Fig. 14. Initial approach handling qualities ratings.**

As shown in Fig. 14, conversion handling qualities were judged satisfactory (averaging HQR=3) in calm conditions, and good-borderline adequate ratings (averaging HQR=4) in IMC and winds. The level flight conversion required pitch activity–initially nose down, followed by nose up–to maintain altitude. Both the rate response and rate-command-attitude-hold control systems provided acceptable response for this subtask. All pilots were able to maintain desired task performance (altitude control within 50 feet) during the level flight conversion. A minor deficiency consistently commented upon concerned flap deployment from 20 to 40 degrees. This rapid deployment produced an altitude ballooning that had to be countered by pilot action.

### Glide Slope Tracking

The glide slope tracking subtask was where the major differences were expected between approach profiles. Placement of nacelle moves and the glide slope transition from three to nine degrees for the double segment profiles (FP-9 and FP-25) differentiated the profiles. Attitude command was used for the glide slope tracking task when flown with the dynamic inverse attitude-stabilized control system. The two pilots who flew the flight tests evaluated most of the profiles as HQR=3 in the good atmospheric conditions of those tests. They evaluated the single segment nine degree approaches as only adequate (HQR=4 or 5) during the flight test, as they dealt with the rapid decelerations and low power settings needed to maintain glide slope tracking.

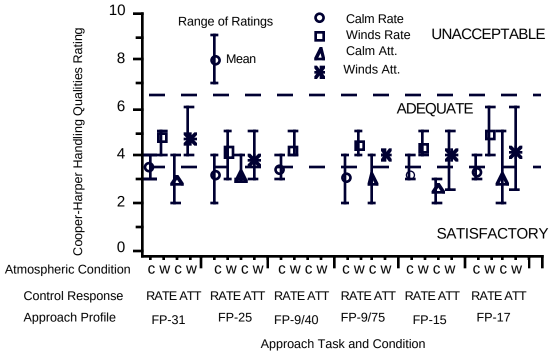


**Fig. 15. Glide slope tracking handling qualities ratings.**

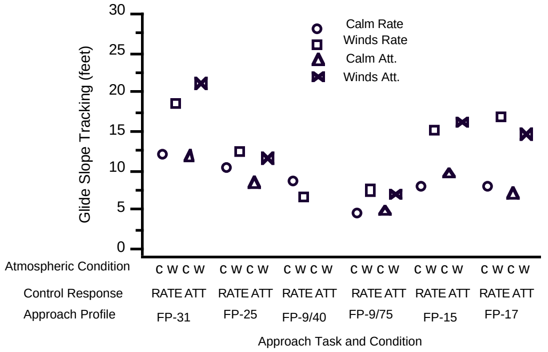


**Fig. 16. Final glide slope vertical tracking.**

The pilots judged the calm air handling qualities satisfactory for all approach profiles and both control response types, as shown in Fig. 15. Final glide slope height tracking performance is shown in Fig. 16. Winds and turbulence increased the workload and degraded tracking performance, leading to adequate handling qualities in IMC. Pilots maintained desired tracking performance (±57 feet for the final glide slope) in IMC, although performance degraded significantly for FP-31, -15 and -17 in winds and turbulence. With crosswinds and turbulence, pilots had to work harder to maintain the required tracking with the rate command response type. Attitude stabilization relieved this requirement somewhat, but caused pilots to work a bit harder with pitch control to track the commanded airspeed with the linear deceleration command profile. The XV-15 approach profiles used a constant deceleration command velocity profile during nacelle movement. Earlier simulations with an attitude-stabilized large transport used a command velocity profile derived from a constant pitch attitude during conversion. Pilot comments from this experiment suggest that such a tailored velocity command profile might help when using an attitude stabilization control mode.

The three-degree approach profile (FP-31) received the most favorable comments during the flight test. In flight, it was evaluated as a solid HQR=3 task. During the simulation evaluations, however, the rapid series of nacelle moves and decelerations close to the landing decision point used with FP-31 produced significant pilot comments. Although height control (glide slope tracking) during the nacelle moves was easily accomplished, pilots felt rushed. The landing gear deployment limit of 90 knots delayed this critical task on approach until the aircraft was below 500 feet on final approach. Pilots commented that such a late gear deployment led to anxiety as to landing checklist completion and a need for clear cockpit crew coordination on this key item. The combination of a rushed series of nacelle moves and a late landing gear call and deployment led to all pilots rating this approach as an HQR=4 or worse in IMC.

The baseline two-segment approach, FP-25, received satisfactory handling qualities evaluations in clear-calm conditions and adequate (HQR=4) evaluations in IMC. This pattern held for the other double-segment approach (FP-9) used for the approach flap angle setting investigation. The flight test pilots evaluated both approaches satisfactory (HQR=3) in the clear-calm test conditions.

The use of full 'drag' flaps (75-degree flaps) versus the conventional XV-15 use of 40-degree flaps produced similar handling qualities rating values for FP-9. Pilots commented, however, on their better field of view with the lower pitch attitude with full 75-degree flaps. The higher drag led to a modest increase in power on the nine-degree approach path. This led to better thrust control as pilots had slightly more down-thrust control lever control margin. The simulator model predicted a modest impact on thrust/power control margin with drag flaps deployed Stronger flap effects on power were observed and commented upon in the flight tests. Unmodeled in the simulator was tail buffet experienced with the 40-degree flap position at 90-knots/60 degrees nacelle, which separated the two flap use cases further in the flight test. The use of only 40-degree flaps was evaluated as marginally satisfactory in clear-calm conditions. Use of 75 degrees flaps improved the evaluations to solidly satisfactory in clear-calm and acceptable in IMC.

The pair of continuous nine-degree approaches (FP-15 and FP-17) received similar evaluations in flight and simulation. Marginally satisfactory (HQR=3.4) evaluations were recorded with the rate command control system in clear-calm conditions. Use of rate command in IMC produced only adequate handling qualities, with the faster decelerations of FP-17 degrading slightly more. Use of attitude command improved these evaluations to solidly satisfactory in clear-calm. The attitude command control system assisted pilots to maintain tracking precision in IMC with winds and turbulence, but the workload in such conditions was still judged as moderate compensation (HQR=4).

## Landing

Landing handling qualities are shown in Fig. 16. The landings were evaluated generally satisfactory in clear-calm conditions and borderline satisfactory-adequate in the 10-knot crosswind with turbulence. Pilot comments for the poor ratings captured the essence of issues influencing all pilots. The nine degree final approach angle used for FP-25, -9, -15 and -17, placed the landing aim point near the bottom of the windscreen at the landing decision point ("breakout"). The series of decelerations just prior to the landing decision point often left the aircraft with a pitch attitude higher than the five degrees of the nominal profile. In poor visibility, this could leave a pilot searching for visual references to the landing aim point which was obscured by the aircraft nose. Pilot comments called for additional marking and lighting to augment the "broken wagon wheel" vertiport symbol specified by the Vertiport Design Guide (Ref. 12).

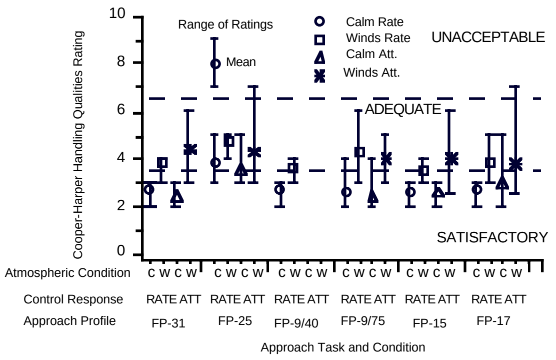


**Fig. 17. Landing handling qualities ratings.**

The three degree approach, FP-31, followed a similar pattern. Landing task handling qualities evaluations were influenced by recovery from conditions at the landing decision point. The rapid series of decelerations just prior to that point could leave the aircraft with a high pitch attitude for deceleration, obscuring the landing aim point. Continued deceleration requirements in the visual flight segment could require additional pitch maneuvering. Indeed, such pitch maneuvering while in attitude command control mode led to the HQR=7 evaluation recorded for use of the dynamic inverse control system in winds and turbulence. The same pilot evaluated the landing task as HQR=3 when employing the rate command-attitude hold control mode.

Simulation results generally tracked handling qualities evaluations provided during the XV-15 noise measurement tests. The expansion to a larger pool of pilots led to additional comments not highlighted during the flight test, such as the late gear deployment issue raised on the otherwise favorable three-degree approach. Both flight test and simulator evaluations point to desired handling improvements in IMC and winds. Altitude tracking upsets with flap deflection suggest the need for some form of compensation in either the guidance or via gentle flap deflection with an automated system.

## CONCLUSIONS

A piloted simulation experiment evaluated noise abatement landing approaches developed for the XV-15 tiltrotor research aircraft. Evaluations were provided by a larger group of pilots than was possible during noise measurement flight tests. The simulator also provided for evaluations in controlled instrument meteorological conditions.

1 Evaluations by nine pilots upheld those provided by the two XV-15 experimental test pilots. Additional pilot comments from the larger simulation evaluation pool highlighted approach design and aircraft control difficulties associated with flap deflection and a relatively low landing gear deployment limit.

2. Handling qualities of all six approach profiles were judged satisfactory in calm air and degraded into the adequate region with reduced visibility, crosswinds and turbulence.

3. Control response type had a negligible effect on the numerical handling qualities ratings. Pilots appreciated attitude stabilization in IMC and turbulence, but had to work harder to maneuver, including following an arbitrary speed profile.

4. Rapid decelerations late on final, close to the landing decision point degraded both tracking performance and handling qualities, particularly in IMC. Tracking performance on final degraded in IMC for all three of the profiles (FP-31, -15 and -17) with a set of rapid decelerations just prior to the landing decision point.

5. Use of "drag flaps" assisted pilot control and improved approach field of view in both flight and simulation and received favorable handling qualities comments.

## RECOMMENDATIONS

The two double-slope approach profiles, FP-25 and FP-9 provided satisfactory handling qualities combined with acceptable noise reductions (measured in flight). With its lower measured noise impact, FP-25 provided a good balance of handling qualities with noise reduction while providing for obstruction clearnace or altitude separation with a nine degree final glide slope.

As with all approach profiles, the handling qualities for the three-degree glide slope approach, FP-31, degraded in

IMC into the adequate region. Of particular note, though was an HQR=6 evaluation with attitude command control response and pilot commentary provided by most pilots in IMC. Two issues were identified by the simulation evaluations: 1) configuration control in the form of the late landing gear call necessitated by the 90 knot landing gear deployment limit, and 2) the rapid series of nacelle moves just prior to the landing decision point. These handling qualities deficiencies are worthy of being addressed. Three-degree flight paths are used as the standard for conventional aircraft glide slopes, including standard instrument landing systems (ILS). Furthermore, the noise reductions recorded during the flight test for this approach profile were substantial. Aircraft design should address the landing gear deployment limit. The rapid series of nacelle moves and deceleration produced the desired concentration of noise near the landing area, but led to high workload. Further development of the guided approach profile and suitable control features, including the use of automation such as a coupled flight director or automated nacelle movement may achieve the desired result.

Rapid decelerations combined with a steep final approach angle as tested with FP-17 are not recommended. Noise differences between FP-15 and -17 were insignificant in the flight test.

Drag flap use should be investigated further for use with noise abatement approaches.

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