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PILOT EVALUATION OF AN ADVANCED HINGELESS ROTOR XV-15 SIMULATION

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FOREWORD

This report was prepared by Boeing Vertol Company for the National Aeronautics and Space Administration, Ames Research Center, under Contract NAS2-8048-4R. The contract was administered by NASA. Mr. Richard J. Abbott was the Contract Administrator and Mr. T. Galloway was the Technical Monitor. The Boeing-Vertol Project Manager was Mr. Harold Alexander, and the Project Engineer was Mr. Michael A. McVeigh.

ABSTRACT

Results of a piloted simulation of an Advanced Hingeless Rotor XV-15 Tilt-Rotor Aircraft are presented. The simulator pilot had previous experience flying the NASA-Ames FSAA simulation of the current gimballed rotor NASA/Army XV-15 tilt rotor.

SUMMARY

The report presents the results of a piloted simulation of an Advanced Hingeless Rotor XV-15 Tilt-Rotor Aircraft. The piloted evaluation was made by a pilot from NASA-Ames who had previous experience flying a simulation of the current gimballed rotor NASA/Army XV-15. The evaluation pointed up the need for some modifications to the force feel system in order to provide rapid force trimming during rapid maneuvers. Some additional tailoring of the SCAS system was required to achieve good nap-of-the-earth performance. Overall pilot opinion on the hingeless rotor XV-15 tilt rotor was favorable. The pilot was impressed with the mission potential of the hingeless tilt-rotor aircraft concept and recommends that development of the hingeless tilt-rotor concept be continued.

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1.0 INTRODUCTION

The work reported in this document was undertaken as part of a more extensive program which has as its objective the flight test demonstration of a NASA-Army XV-15 Tilt-Rotor Research Aircraft which will be modified by replacing the current gimballed rotor with a larger diameter hingeless rotor fabricated from advanced composite materials. The current NASA-Army tilt rotor research aircraft project is aimed at verifying the feasibility of the tilt-rotor concept through investigation of the performance, stability and handling qualities of the XV-15 tilt rotor. This aircraft utilizes 25-foot gimballed rotors constructed of bonded aluminum honeycomb and stainless steel. Replacement of these rotors by advanced-technology fiberglass/composite hingeless rotors of larger diameter, combined with an advanced integrated fly-by-wire control system, will further enhance the flying qualities, performance, maneuverability and rotor system fatigue life of the XV-15.

During 1976 a mathematical simulation model was developed in order to study the performance and control requirements of the NASA/Army XV-15 tilt-rotor aircraft equipped with Boeing 26-foot diameter hingeless rotors and fly-by-wire controls. Using the model, a piloted simulation was conducted to determine the handling qualities of the aircraft in hover, transition and airplane flight. The results of that study are reported in Reference 1.

The present work reports on a further piloted evaluation session using a pilot from NASA-Ames who had experience flying the FSAA simulation of the existing XV-15 aircraft. Because the visiting pilot was unfamiliar with the Boeing-Vertol simulation facility a baseline simulation of a familiar aircraft (a CH-47 Chinook) was also prepared. Flights were made with the CH-47 to enable the pilot to get a feel for the capabilities and limitations of the simulator. Following the familiarization runs the pilot was switched to the hingeless rotor XV-15 simulation, and a comprehensive program of runs at various flight conditions from hover through high speed cruise was completed.

The following sections present brief discussions on the mathematical models and the simulator configuration. The maneuvers and pilot comments are presented along with some engineering comments. A copy of the report written by the evaluating pilot is included as an appendix.

2.0 MATHEMATICAL MODELS

2.1 BASELINE CH-47C MATH MODEL

A mathematical model of the CH-47C helicopter was used to provide a baseline for pilot familiarization with the Boeing-Vertol simulator system. The model is described in Reference (2). The model as implemented represented the C-Model Chinook at a gross weight of 33,000 pounds.

2.2 ADVANCED HINGELESS ROTOR XV-15 TILT-ROTOR MATH MODEL

The basic mathematical model of the Hingeless Rotor XV-15 is that described in Reference (1). During the preparation period before evaluation by the NASA pilot, the following changes were made to the simulation.

2.2.1 Power Lever

The side-arm-controller type power lever arrangement used in the past simulations was replaced by a collective/power lever similar to that utilized in the NASA/Army XV-15. Evaluation by the Boeing pilot indicated that the collective type power lever was as satisfactory as the side-arm style lever.

2.2.2 Nacelle Control

Nacelle tilt control was changed from a variable rate beep system to a fixed rate control corresponding to that on the existing XV-15. The previous variable rate system permitted the pilot to select any nacelle beep rate from zero up to the maximum capability of the nacelle drive system. It was thought that this feature resulted in improved control. However, piloted evaluation showed that a fixed-rate beep was just as effective.

2.2.3 Cyclic-on-the-Stick

The mathematical model incorporated the preliminary cyclic-on-the-stick system described in Reference (1). This feature was not evaluated during the piloted simulation session reported in this reference. Cyclic-on-the-stick is a rotor loads control method wherein lateral (A_1) and longitudinal (B_1) cyclic pitch is fed to the rotors in response to movement of the pilot's longitudinal stick. The amount of cyclic is a function of stick position and nacelle angle, and is such as to yield an incremental nose down rotor moment for an aft stick displacement. The cyclic input is rate limited (0.5 degrees per second) in order to maintain a smooth variation of pitch control power.

2.2.4 Conversion Guide

A conversion guide, Figure 1, was provided that presented the pilot with information on the aircraft's position in the conversion corridor, as defined by airspeed and nacelle angle, with respect to the aircraft stall boundary and rotor loads/engine torque limit boundaries. The conversion guide mask was mounted on the face of a CRT which was placed to the left of the cab viewing screen as shown in Figure (1). The CRT beam was driven by airspeed (X) and nacelle angle (Y).

2.2.5 Motion Base

During the previous simulation period the Boeing pilot found the cab motion base to be unrealistic. He complained of abrupt washout and recentering motions and exaggerated side force cues. Prior to the simulation period reported herein, much time was spent reworking the motion system gains and time constants in order to improve the motion characteristics. A compensation network was implemented to eliminate a 0.25 second time lag in the response of the cab and visual to pitch inputs. The lag was caused by time frame and trunking delays between the computer and the simulator cab. This delay was most noticeable during hover and low speed flight. The compensation network succeeded in reducing this lag to a level below pilot threshold of perception.

2.2.6 Thrust Management/Governor System

The governor system described in Reference (1) achieved control of rotor RPM by increasing or decreasing collective pitch. During the piloted simulation session reported in Reference (1) governor runaways were encountered in steep descents (>2,000 feet per minute) at low power settings and at high nacelle angles (>70°). Investigation showed that the cause was a change in sign of the slope of the rotor power vs collective curve occurring at low advance ratios and high rotor angles of attack. Thus, retarding the throttle reduced the power available, rotor RPM started to drop and the governor acted to maintain RPM by reducing collective. Normally this would also decrease power required and RPM would stabilize. However, in these flight conditions an <u>increase</u> in collective is required to reduce power. Thus, the governor law "increased collective = increased power required" is violated and the governor runs away.

This deficiency in the governor design was corrected by arranging for a second path in the thrust management system which demands increased fuel flow when the collective required by the governor falls below 0°. The new governor block diagram is presented in Figure 2.

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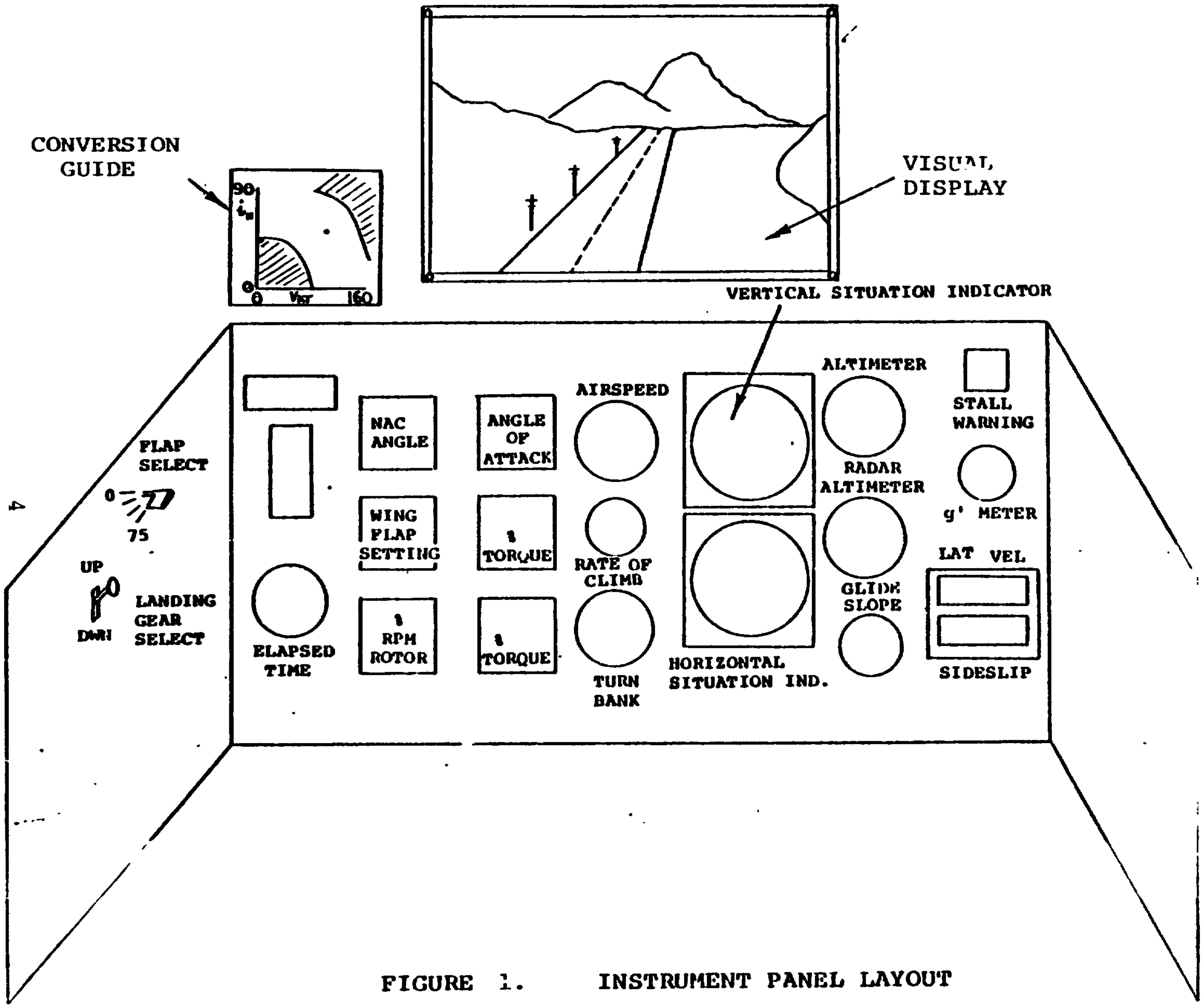
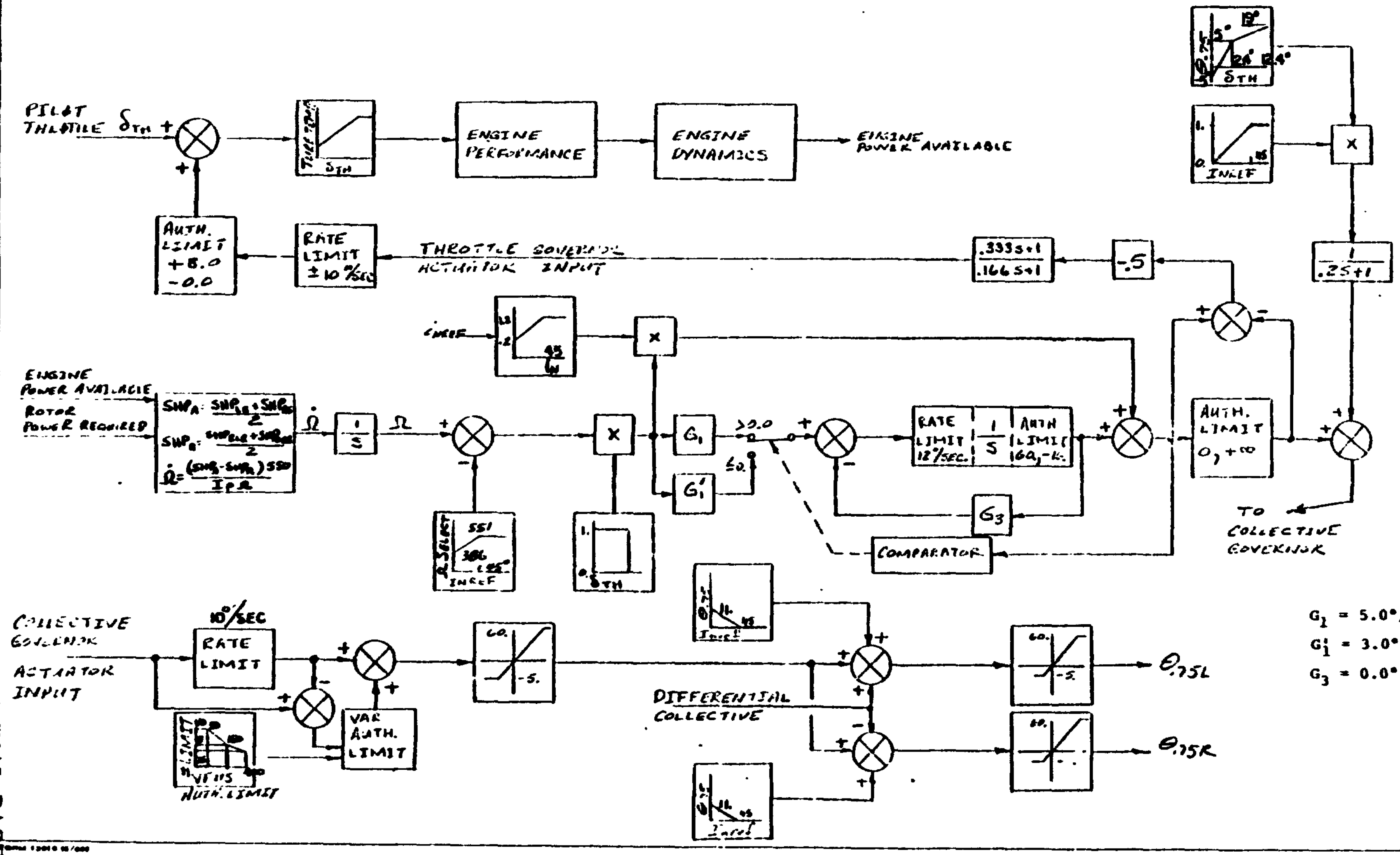


FIGURE 1. INSTRUMENT PANEL LAYOUT



G_1 = 5.0°/SEC/RAD/SEC

G_1' = 3.0°/SEC/RAD/SEC

G_3 = 0.0°/SEC/RAD/SEC

FIGURE 2. THRUST MANAGEMENT/GOVERNOR SYSTEM

2.2.7 Longitudinal and Lateral/Directional SCAS

No fundamental changes were made to the SCAS system on the HTR XV-15 prior to evaluation by the NASA pilot. However, in response to pilot comments during the checkout phase, some of the gains and time constants were adjusted. Additionally, a modification was made to the lateral stick roll beep trim function. In the previous simulation, operation of the lateral beep trim moved the stick laterally. This was changed so that operation of lateral beep repositioned the roll attitude reference in the SCAS.

The revised SCAS diagrams are shown in Figures 3 through 6 and the changes in gains,etc. are indicated.

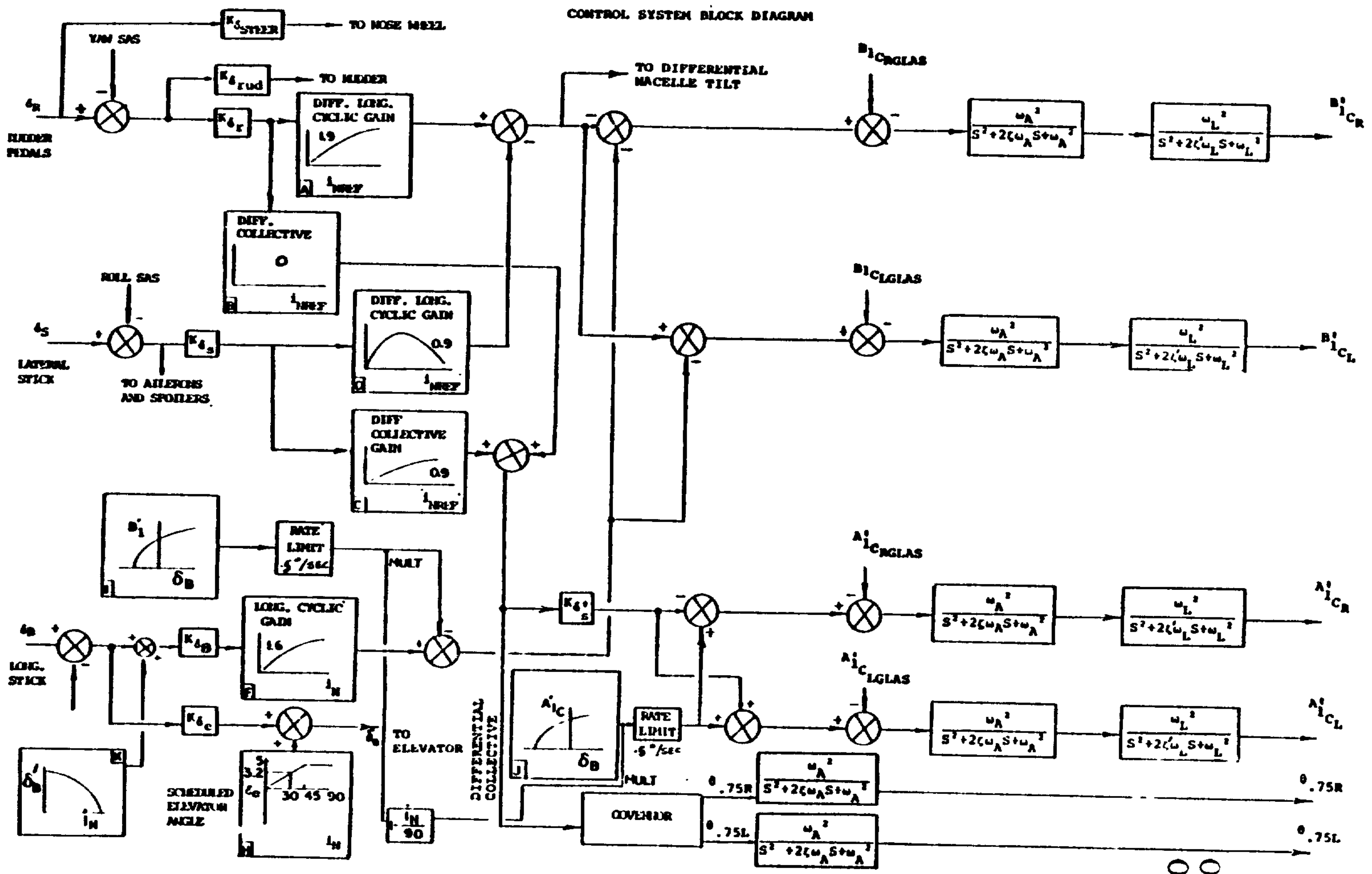


FIGURE 3. CONTROL SYSTEM

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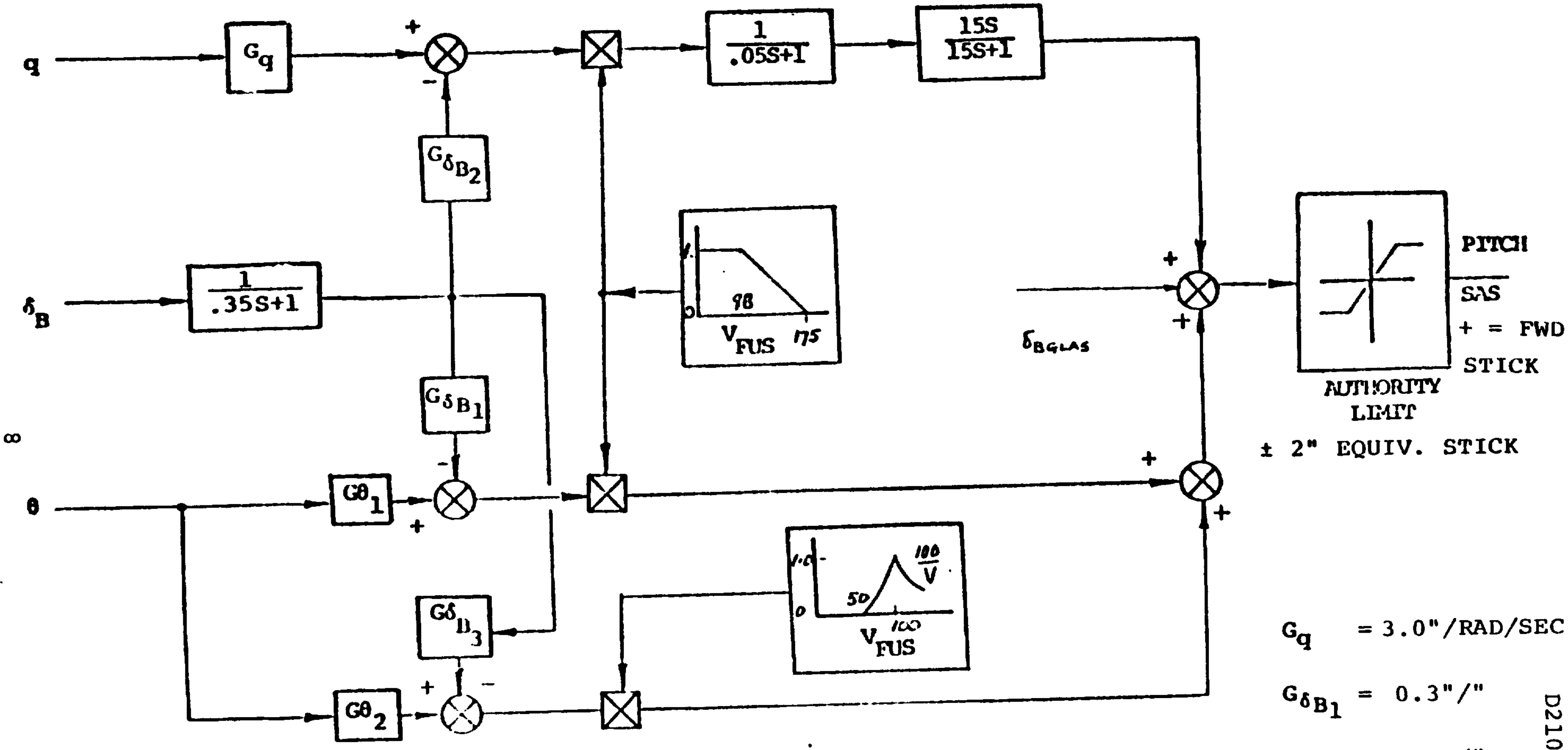

FIGURE 4. LONGITUDINAL SCAS

G_q = 3.0"/RAD/SEC

$G_{\delta_{B_1}}$ = 0.3"/"

$G_{\delta_{B_2}}$ = 0.0"/"

$G\theta_1$ = 8.0"/RAD

$G_{\delta_{B_3}}$ = 0.5"/"

$G\theta_2$ = 6.0"/RAD

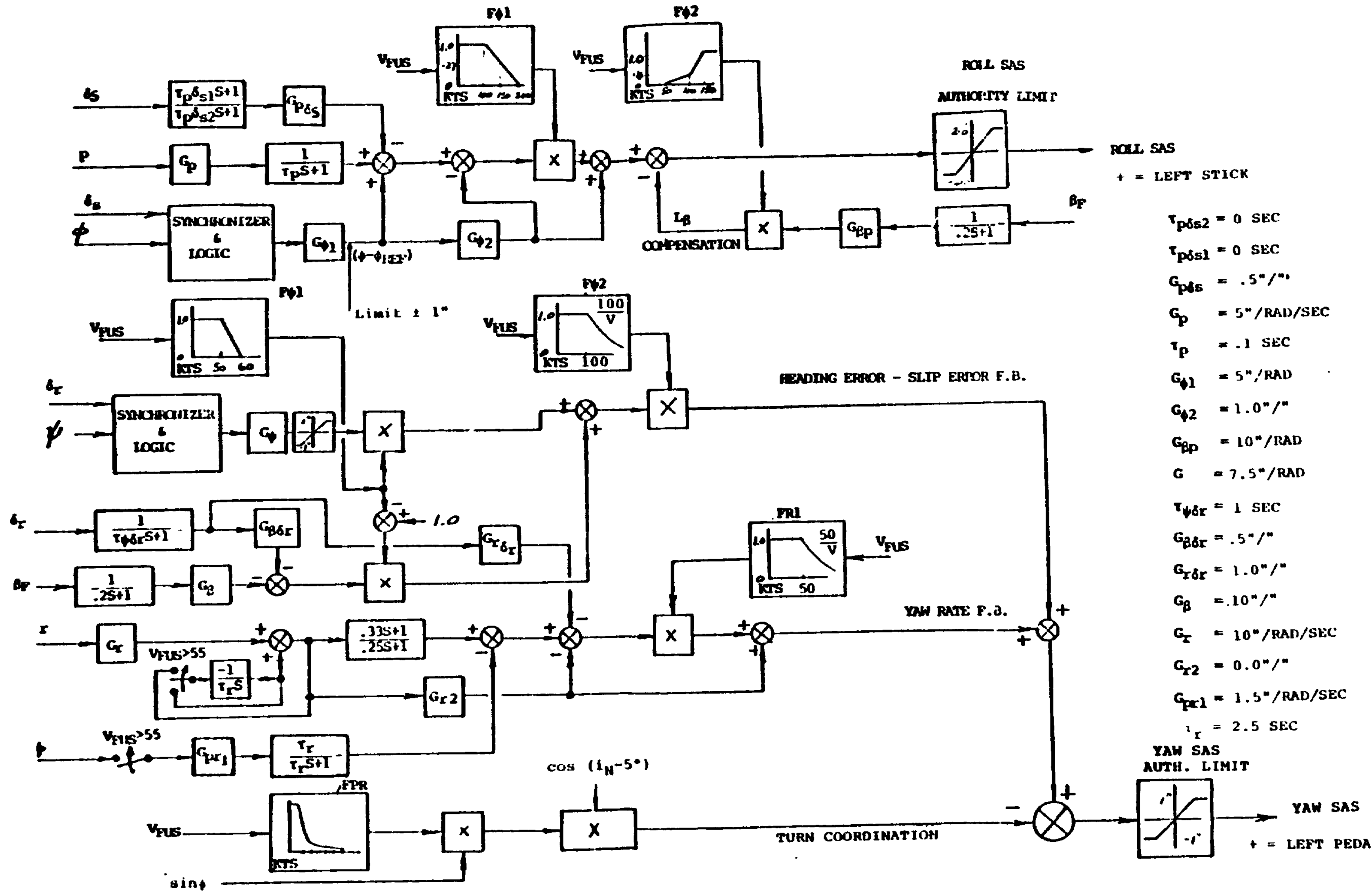

FIGURE 5. LATERAL/DIRECTIONAL SCAS

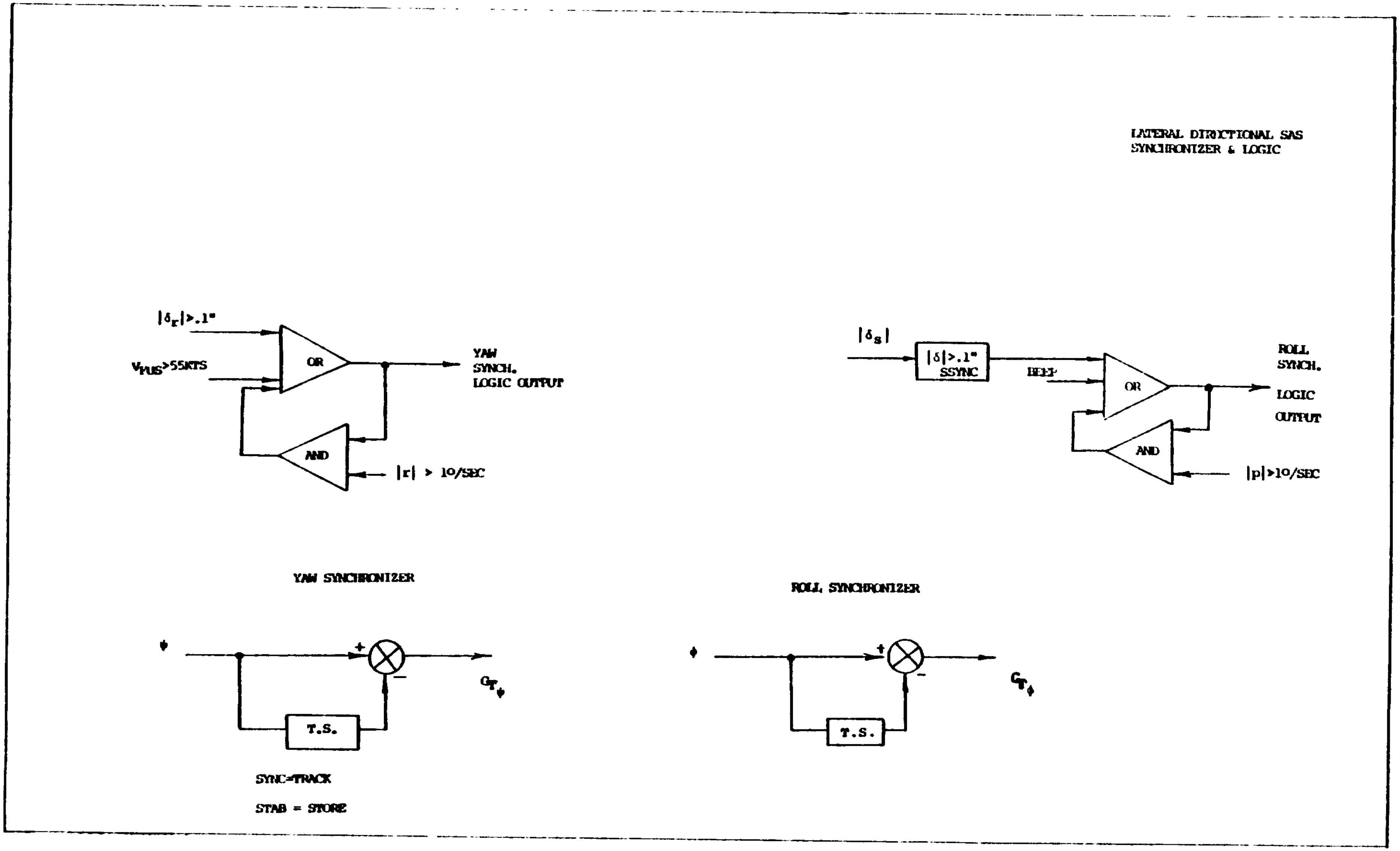

FIGURE 6. LATERAL/DIRECTIONAL SCAS SYNCHRONIZER AND LOGIC

3.0 SIMULATOR DESCRIPTION

The Boeing Vertol simulation facility consists of a 6 degree-of-freedom, small-motion pilot cabin driven by signals from a Xerox Sigma 9 digital computing system. The pilot's cabin is equipped with an adaptable instrument panel, a variable flight control force-feel system, and an out-of-the-window visual display. The visual display is generated by a black-and-white television camera moving over a terrain model. The image is viewed by the pilot through a large collimating lens providing a field of view measuring 38 degrees vertically by 53 degrees azimuthally with 0 degrees depression angle.

3.1 MOTION SYSTEM PERFORMANCE

The limited motion, 6 degrees-of-freedom pilot's cabin has the following performance:

Payload (including pilot)	770 Lbs

Travel Limits (stop-to-stop total):

Vertical	12.7 cm (5 in.)
Longitudinal	
Lateral	
Pitch	13 Degrees
Roll	19 Degrees
Yaw	19 Degrees
Pitch Tilt	26 Degrees

Rate Limits with Zero Acceleration:

Vertical	± 0.66m/s (±26 in./sec.)
Longitudinal	± 1.04m/s (±41 in./sec.)
Lateral	± 0.66m/s (±26 in./sec.)
Pitch	±69 deg./sec.
Roll	±97 deg./sec.
Yaw	±155 deg./sec.

Acceleration Limits for Zero Rates (incremental values):

Vertical	19.63m/s^2 (±64.4 ft./sec.^{2})
Longitudinal	10.79m/s^2 (∓35.4 ft./sec.^{2})
Lateral	8.81m/s^2 (∓28.9 ft./sec.^{2})
Pitch	±248 deg./sec.^{2}
Roll	∓414 deg./sec.^{2}
Yaw	∓745 deg./sec.^{2}

3.2 CONFIGURATION OF PILOT'S CABIN

The cabin of the simulator was configured to represent approximately the layout of the NASA-Army XV-15 aircraft instrument panel and controls. Because the simulator was also being used to evaluate current Company helicopter designs, some compromises had to be made in instrument placement so as to minimize configuration changes when switching back and forth between aircraft models.

4.3 INSTRUMENTS AND CONTROLS

Instruments and primary controls were positioned in the single-seat cabin such that the pilot flew as if from the right seat. Figure 1 shows the instrument panel layout used throughout the simulation and Table 1 details the instruments and ranges. The pilot's force-feel system was programmed to deliver breakout forces and gradients according to those shown in Figures 7a and 7b.

The control stick in the simulator was mechanically limited to +4.8" longitudinally and laterally, and the pedals to ±2.5". A beep force-trim hat switch was mounted on the stick enabling the pilot to zero out stick forces and to make small trim adjustments to the aircraft. Initially beep trim was washed out as a function of dynamic pressure according to the equation: -

$$\text{beep trim rate} = 0.5 - 0.00131q_F \text{ inches per second.}$$

Later in the program this was changed to

$$\text{beep trim rate} = 0.5 - .000605q_F \text{ inches per second}$$

in order to achieve more rapid trimming.

A magnetic brake, operated by a button on the stick, was provided to simultaneously zero out stick and pedal forces. This feature was introduced for evaluation purposes only since the existing XV-15 does not have a magnetic brake force release. Detents on the lateral stick and pedals were set to ±0.05 inches.

As mentioned in Section 2.0, the power lever was reconfigured to approximate that used in the XV-15. A sketch of the power lever is shown in Figure 8. The lever commanded the power of both engines and provided collective pitch lead in hover and transition with rotor speed controlled by the governor. Rotor RPM is scheduled with nacelle angle. A thumb switch, loaded-to-center, with detent and breakout was mounted on the head of the power lever and controlled nacelle tilt angle. The power lever had a travel of 10 inches covering the range from flight idle to maximum power.

A flap lever and a landing gear up-down select lever were mounted on the left sidewall of the simulator cabin. The flap lever commanded settings of 0, 20, 40 and 75 degrees only. Flap extend/retract time was fixed at 5 degrees per second. A 4 second cycle time on the landing gear switch was used.

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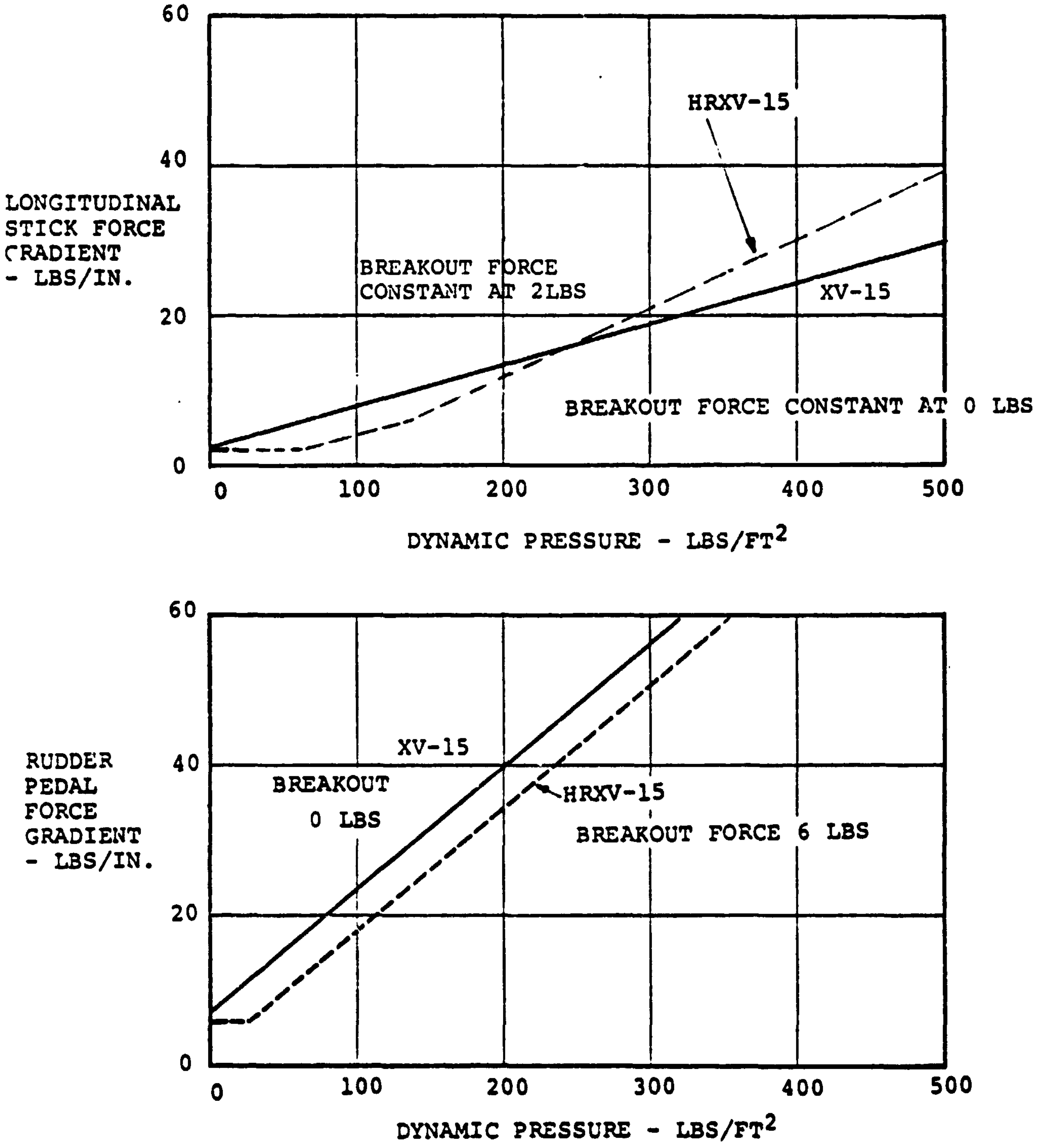

FIGURE 7a. REVISED LONGITUDINAL AND PEDAL FORCE GRADIENTS

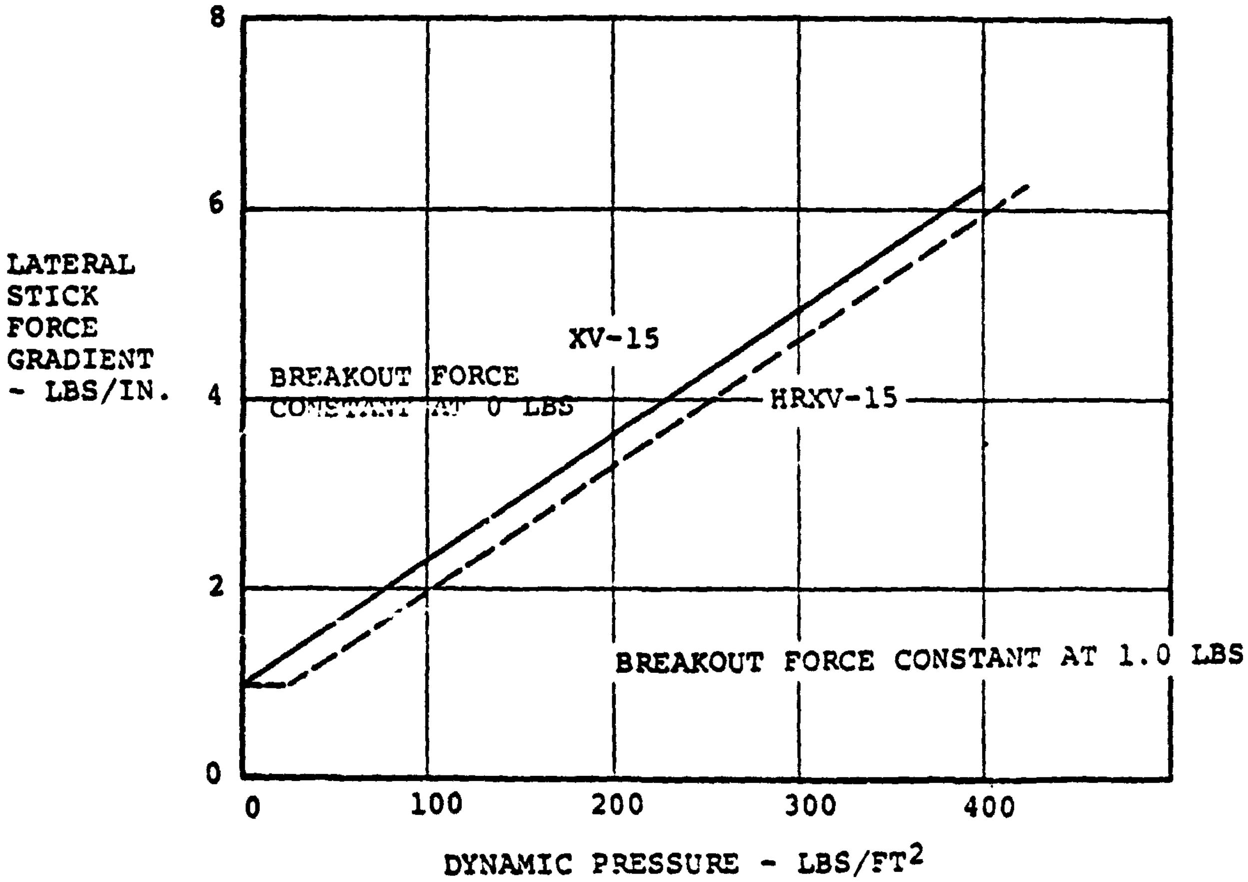

FIGURE 7b. REVISED LATERAL STICK GRADIENT

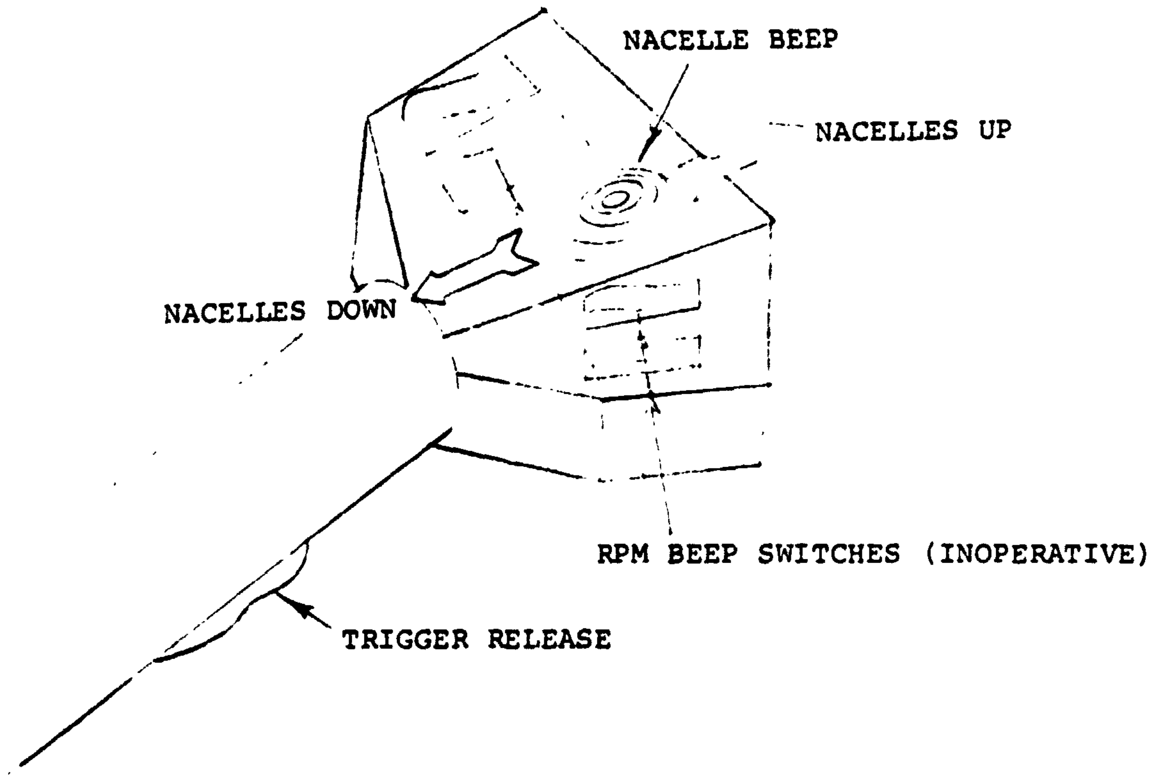

FIGURE 3. SKETCH OF POWER LEVER ARRANGEMENT.

CAB INSTRUMENTATION

Instrument	Range
Vertical Situation Indicator	±90° Pitch and Roll
Horizontal Situation Indicator	±180° Heading
Airspeed	0 → 520 KIAS
Pressure Altimeter	0 → 10,000 Feet
Radar Altimeter	0 → 1,000 Feet
Rate of Climb	± 6,000 Feet/Minute
Turn and Bank	± Needle Widths ± 1-1/2 Ball Widths
'g' Meter	-1, +3 'g'
Nacelle Angle	0 → 120°
Clock	
Sideward Velocity	±40 Knots
Angle of Attack	±20°
Wing Flap Position	0 → 100°
Rotor Speed	0 → 125%
Engine Torque Meters (2)	0 → 125%

PRIMARY FLIGHT CONTROLS

Stick (±4.8" Longitudinal and Lateral)
Pedals (±2.5")
Power Lever (0 → 10")
Nacelle Position Thumb Switch on Power Lever

MISCELLANEOUS EQUIPMENT AND FEATURES

Back Drives to Trim Stick and Pedals while in Initial Condition (I.C.)
Landing Gear Up - Down Switch with Indicator Light
Flap Select Lever 0°, 20°, 40°, 75°
Detent Switches on Spring Cartridges (Pedals & Lateral Stick)
Magnetic Brake on Pedals, Longitudinal and Lateral Controls
Longitudinal and Lateral Beep Force Trim on Stick
Power Lever Null Meter
Toe Brakes
Specified Force Feel System

TABLE 1. HINGELESS ROTOR XV-15 PILOT STATION FEATURE SUMMARY.

4.0 PILOTED SIMULATION

The piloted evaluation was conducted by LTC T. Wright during the period 16 through 20 May 1977. Colonel Wright has logged a substantial amount of time in the NASA/Army XV-15 simulation at NASA-Ames. Approximately 15 hours of productive simulator flying was accomplished - 12 hours on the Advanced Hingeless Rotor XV-15 and the remaining three hours on the CH-47 familiarization simulation.

4.1 EVALUATION OF BASELINE CH-47C SIMULATION

The pilot was briefed on the CH-47C simulation, the cab configuration, flight controls, instrumentation and the layout of the terrain model. A period of flight familiarization followed during which the pilot became accustomed to the cab procedures and the limits of the terrain model. The CH-47 simulated was the C-model which is equipped with Pitch Stability Augmentation (PSA). The pilot had no flight experience in the C-model and was unfamiliar with PSA. The system was switched off, and with PSA inoperative, the pilot stated that the handling was more like that of the B-model Chinook. Cab motion cues, with the exception of side force, were found to be weak, especially in the vertical axis. Sideforce cues in response to pedal inputs were satisfactory. Overall pilot opinion of the fidelity of the Chinook simulation was very favorable.

4.2 EVALUATION OF ADVANCED HINGELESS ROTOR XV-15 SIMULATION

The pilot's report on the HTRXV-15 simulation is presented as an appendix. A detailed table of runs made at selected flight configurations is presented in Table 2. Pilot and engineering comments on the various maneuvers are included in this Table. The following additional comments on the piloted evaluation may be made.

- The effect of the cyclic-on-the-stick system for loads control on handling qualities does not appear to be noticeable by a pilot. This system was switched in and out during successive runs without provoking any pilot comment.

- The changes made to the rotor governor to prevent collective runaway were successful. No governor failures were encountered when flying high rate of descent, low power approaches. Rotor rpm was held with prescribed tolerances.

AIRSPEED	NACELLE ANGLE	FLAP SETTING	PITCH SAS	YAW SAS	ROLL SAS	MANEUVER	PILOT COMMENT	REMARKS/ACTION
0··90	90	40	ON	ON	ON	HELO-FLIGHT.	BEEP TRIM RATE A BIT SLOW FOR RAPID STICK FORCE ZEROING. USE OF MAG BRAKE TOO COARSE FOR PRECISE FLYING. LARGE FWD STICK DISPLACEMENTS AND STEEP NOSE DOWN ATTITUDES REQUIRED AT HIGH SPEED (90 KT).	BEEP TRIM RATE WAS 0.5 - .0013q INCHES/SEC. MAG BRAKE ZEROS ALL FORCES AND ALSO DISABLED HEADING AND ATTITUDE HOLD FEATURES OF SAS. THIS WAS ALSO NOTED BY BOEING PILOT. PILOT INHIBITION TO NOSE ATTITUDE MAY BE EXAGGERATED BY LIMITED FIELD OF VIEW.
0	90	40	ON	ON	ON	HOVER AND SIDEWARD FLIGHT.	INITIAL YAW RATE RESPONSE TO PEDAL SLUGGISH. SIDEWARD FLIGHT PRESENTS NO DIFFICULTIES.	
↓	↓	↓				REPEAT.	YAW RESPONSE MUCH BETTER.	CHANGED PEDAL QUICKENING FROM 1/2"/" TO 1"/".
↓	↓	↓	OFF	ON	ON	HOVER-IGE. EVALUATE WITH SAS REMOVED AXIS-BY-AXIS.	EASY TO DEVELOP P.I.O. IN PITCH WITH NO STICK FORCES (MAG BRAKE DEPRESSED). EASIER TO CONTROL WITH STICK FORCES PRESENT.	DEPRESSION OF MAG BRAKE ALSO REMOVED ROLL ATTITUDE HOLD AND HEADING HOLD.
↓	↓	↓	ON	OFF	ON		CONTROLLABLE WITH FFS ON - MARGINAL FORCE FEEL OFF.	WITH FFS OFF (MAG BRAKE DEPRESSED) ROLL HOLD IS INACTIVE CONTRIBUTING TO DIFFICULTIES
↓	↓	↓	ON	ON	OFF		EASY TO DEVELOP ROLL P.I.O.	
↓	↓	↓	OFF	OFF	OFF	HOVER-IGE - ALL SAS OFF.	CONTROLLABLE WITH STICK FORCES PRESENT. DIFFICULT TO CONTROL WITH NO F.F.S.	
0··90	85	40	ON	ON	ON	SLOW ACCEL/ DECEL IN HELO MODE.	PITCH ATTITUDE IMPROVED, BUT STILL REQUIRES CONSIDERABLE FWD STICK.	LONGITUDINAL STICK PICK-OFF GAIN SET AT ZERO.
						REPEAT.	FWD STICK MOTION MORE COMFORTABLE. COMPLAINED OF ATTITUDE HOLD LOSS IF MAG BRAKE USED.	RESET LONGITUDINAL STICK PICK-OFF GAIN TO 0.6"/".
						REPEAT.	MUCH BETTER.	DECOUPLED MAG BRAKE FUNCTION FROM ATTITUDE HOLD FUNCTIONS.

TABLE 2. SIMULATION RUN SUMMARY WITH PILOT AND ENGINEERING COMMENTS

Page 2 of 4

AIRSPEED	NACELLE ANGLE	FLAP SETTING	PITCH SAS	YAW SAS	ROLL SAS	MANEUVER	PILOT COMMENT	REMARKS/ACTION
0	90	40	ON	ON	ON	HOVER-IGE.	PITCH CONTROL IN HOVER MUCH BETTER.	REDUCED LOW SPEED LONGITUDINAL STICK PICK-OFF GAIN TO 0.3 TO IMPROVE CONTROL/SAS HARMONY.
0→160	90→0	40 & 0	ON	ON	ON	RAPID CONVERSION.	EASILY CONVERTED. TECHNIQUE USED WAS TO LEAVE POWER SETTING AT HOVER VALUE. THIS RESULTED IN TORQUE EXCEEDING A.E.O. LEVEL.	POWER LEVER SHOULD BE RETARDED BY PILOT TO PREVENT OVER TORQUING CAUSED BY AUTOMATIC RPM REDUCTION AS NACELLE ANGLE IS BROUGHT BELOW 45°.
0→160	90→0	40	ON	ON	ON	RAPID CONVERSION WITH LEFT ENGINE FAILURE AT 60 KTS i_N = 80°.	NO TRANSIENT IS FELT IN CAB. GOVERNOR HELD RPM AUTOMATICALLY, ONLY EVIDENCE OF ENGINE FAILURE WAS INCREASED TORQUE LEVEL ON REMAINING ENGINE.	TRANSIENT RPM OVERSPEED TO 556 RPM THEN RETURNED TO 551.
0	90	40	ON	ON	ON	SINGLE ENGINE FAILURE FROM HOVER.	NO PROBLEM - INITIAL RATE OF DESCENT 400 FPM. NOSED OVER AND ACCELERATED TO ABOUT 40 KTS THEN CLIMBED OUT ON REMAINING ENGINE.	GOVERNOR FUNCTIONED NORMALLY - AUTOMATICALLY HELD RPM AND SET REMAINING ENGINE TO TOPPING POWER.
80	75	40	ON	ON	ON	RAPID MANEUVERS AT TREETOP LEVEL, S-TURNING BETWEEN TELEGRAPH POLES SPACED = 1000' APART.	CONTROL RESPONSE IN ROLL WAS SLIGHTLY LOW WITH DAMPING ALSO ON LOW SIDE. ROLL-YAW COORDINATION IN SUCH RAPID MANEUVERS NOT GOOD ENOUGH - PEDAL WAS REQUIRED. MANEUVERS WERE, HOWEVER, FAIRLY EASY TO FLY DESPITE LOSING SIGHT OF THE POLES DUE TO FIELD OF VIEW LIMITATIONS ON VISUAL.	TURN COORDINATION FUNCTIONS WERE SELECTED FOR MANEUVERS IN AIRPLANE FLIGHT.
80	75	40	ON	ON	ON	STEEP APPROACHES AT LOW POWER SETTINGS.	RESPONSE TO REDUCED THROTTLE WAS SOME NOSE DOWN PITCH AND RATE OF DESCENT BUILT UP TO 3000 FT/MIN. - RPM HELD STEADY. - RECOVERY BY INCREASED THROTTLE FOUND RATE OF DESCENT VERY SENSITIVE TO THROTTLE MOVEMENT.	AT LOW THROTTLE POSITIONS COLLECTIVE SENSITIVITY IS GREATER THAN AT HIGH SETTINGS.

TABLE 2. SIMULATION RUN SUMMARY WITH PILOT AND ENGINEERING COMMENTS (CONTINUED)

Page 3 of 4

AIRSPEED	NACELLE ANGLE	FLAP SETTING	PITCH SAS	YAW SAS	ROLL SAS	MANEUVER	PILOT COMMENT	REMARKS/ACTION
80	75	40	ON	ON	ON	REPEAT.	SENSITIVITY REDUCED - MORE ACCEPTABLE. EVEN WITH WING STALL AT HIGH RATE OF DESCENT DOES NOT LOSE RPM GOVERNING - VERY GOOD.	REDUCED COLLECTIVE SENSITIVITY TO THROTTLE POSITION AT LOW THROTTLE SETTINGS.
80	75	40	OFF	OFF	OFF	EVALUATE SAS-OFF.	DIFFICULT TO CONTROL IN PITCH - TENDENCY TO P.I.O. - ESPECIALLY WITH FORCES OFF. MORE MANAGEABLE WITH STICK F.F.S ON.	
160	0	40 & 0	ON	ON	ON	LOW SPEED CRUISE EVALUATION.	TENDENCY TO P.I.O. IN ROLL. LATERAL STICK BEEP TRIM RATE TOO SLOW FOR GOOD TRIMMING. LOWERING FLAPS TO 40° IMPROVES ROLL AXES DAMPING AND CONTROL POWER.	PILOT TENDED TO FLY WITH MAG BRAKE BUTTON DEPRESSED. I.E., NO STICK FORCES. LATERAL BEEP TRIM RATE WAS 0.1 RAD/SEC
						REPEAT.	TENDENCY TO P.I.O. IN ROLL AXIS MUCH REDUCED. MORE RESPONSIVE IN ROLL AND BETTER DAMPED.	INCREASED ROLL DAMPING IN AIRPLANE MODE. INCREASED LATERAL STICK PICK OFF GAIN AND REMOVED LAG. INCREASED LATERAL BEEP TRIM RATE TO 0.15 RAD/SEC
240	0	0	ON	ON	ON	HIGH SPEED CRUISE EVALUATION.	LONGITUDINAL STICK BEEP TRIM RATE NOT FAST ENOUGH. PITCH CONTROL IS SENSITIVE. TURN COORDINATION: 1/4 BALL IN RAPID TURN ENTRIES. WELL COORDINATED OTHERWISE.	
						REPEAT.	PITCH TRIM MUCH BETTER. HANDLES WELL IN CRUISE.	CHANGED LONGITUDINAL BEEP TRIM RATE TO 0.5 - $.000605q_F$.
160	0	0	OFF	ON	ON	AXIS-BY-AXIS SAS-OFF EVALUATION IN LOW SPEED CRUISE.	PITCH AXIS IS NOW SENSITIVE. DIFFICULT TO CONTROL WITH NO STICK FORCES (MAG BRAKE DEPRESSED).	
↓	↓	↓	ON	OFF	ON		DO NOT NOTICE ABSENCE OF SAS.	

TABLE 2. SIMULATION RUN SUMMARY WITH PILOT AND ENGINEERING COMMENTS (CONTINUED)

Page 4 of 4

AIRSPEED	NACELLE ANGLE	FLAP SETTING	PITCH SAS	YAW SAS	ROLL SAS	MANEUVER	PILOT COMMENT	REMARKS/ACTION
160	0	0	ON	ON	OFF		ROLL AXIS SENSITIVE WITH SOME ROLL/YAW COUPLING.	
0→160	90→0	40→0	OFF	OFF	OFF	RAPID CONVERSION, SAS-OFF.	VERY DIFFICULT TO CONVERT RAPIDLY SAS-OFF. WORKLOAD HIGH. DEFINITELY A 2 PILOT OPERATION.	
0→160	90→0	40	ON	ON	ON	RAPID CONVERSION, SAS-ON, WITH A 5 FPS RMS GUST SPECTRUM.	NO PROBLEM. PRESENCE OF GUSTY AIR BARELY NOTICEABLE.	
80	75	40	ON	ON	ON	APPROACH AND LANDING WITH A 15 KNOT LEFT CROSSWIND.	NO PARTICULAR DIFFICULTIES HERE. LINING UP WITH THE RUNWAY MORE DIFFICULT BECAUSE OF COMBINATION OF CROSSWIND AND LIMITED ROOM FOR MANEUVER ON TERRAIN MODEL.	

TABLE 2. SIMULATION RUN SUMMARY WITH PILOT AND ENGINEERING COMMENTS (CONCLUDED)

5.0 CONCLUSIONS AND RECOMMENDATIONS

A piloted evaluation of an Advanced Hingeless Rotor XV-15 Tilt-Rotor Aircraft was made by a NASA pilot who had previous flight experience in the current XV-15 simulation on the NASA-Ames FSAA simulator. The following conclusions and recommendations are based on the results of the simulation.

1. Overall SCAS-on flying qualities are reasonably acceptable. More work is required, however, to improve turn coordination in rapid nap-of-the-earth type maneuvers. Also more damping and control power should be provided in the roll axis for this mode of operation.
2. Some SCAS tailoring appears desirable in the pitch axis to eliminate a tendency toward P.I.O. at nacelle angles between 70° and 90° at low airspeeds.
3. Conversions and reconversions, SAS-on, are very easy to accomplish. Pilot vigilance must be maintained, however, to avoid overtorquing. Automatic means of preventing this should be investigated.
4. The force-feel trim system requires improvement.
5. With the modified governor system no governor failures were encountered during high rate of descent low speed approaches. Also with the new governor, single engine failures were easily managed by the pilot.
6. A substantial amount of collective-to-pitch coupling exists in the helicopter mode. This may be exaggerated by the rotor math model equations and will be investigated.
7. The coupling of nacelle tilt with pitch attitude, due to the large pitch damping provided by the hingeless rotors, should be reduced by feeding forward nacelle tilt rate into the SAS.

6.0 REFERENCES

1. McVeigh, M. A.; "Preliminary Simulation of an Advanced Hingeless Rotor XV-15 Tilt-Rotor Aircraft", NASA CR-151950, December 1976.

2. Egan, C., et al; "Full Flight Envelope Math Model for 347/HLH Control System Analysis - Control Document", Boeing Vertol Company Report D301-10148-1, July 1972.

APPENDIX

The following pages present the NASA pilot's written report on his evaluation of the Advanced Hingeless Rotor XV-15 Simulation at Boeing Vertol.

NASA-AMES FOF:211-3
Moffett Field, California
May 26, 1977

MEMORANDUM for Tom Galloway, Tilt Rotor Project Manager

From: LTC T. K. Wright

Subject: Trip Report - Travel to Boeing Vertol, Philadelphia, PA, 16-20 May 1977

Purpose - To perform preliminary simulation by a Government research pilot of an advanced hingeless rotor for the XV-15 tilt-rotor aircraft.

Simulation Time - Approximately 15 hours

Scope -
- Hover - IGE/OGE
- Slow speed flight (Nacelle Tilt 75°-90°)
- Conversion (Nacelle Tilt 90°-0° and 0°-90°)
- Cruise - Airplane Mode
- Accelerations/Decelerations
- Nap of the earth flight
- Stalls
- Rapid Descents
- Crosswind approaches
- SAS failure analysis

General:

a. A CH-47 math model was utilized to check the validity of simulation and was found to be as valid as any simulation this pilot has flown.

b. The simulation had only black and white video and a nudge base motion system, but was surprisingly good for most of the simulation tasks required. It compared favorably to the recent simulation flown by this pilot of the XV-15 simulation on the FSAA simulator at Ames Research Center.

c. The flight control system was a fly-by-wire system which incorporated damping and/or control quickening as required in all flight control axes (pitch-roll-yaw) and utilized roll attitude hold and yaw heading hold below 50 kts and yaw zero degree sideslip control above 50 kts. A force feel system was utilized with a force trim release button that instantaneously reduced cyclic and pedal forces to zero when depressed. Trim rate motors were also provided to reduce trim forces to zero on all three flight control axes.

d. Unless otherwise specified the following handling qualities discussion is with all stability systems functioning.

Hover:

a. Handling characteristic variations between IGE & OGE were not discernible in simulation.

b. During Hands off hovering flight in smooth air the aircraft maintained a steady fixed attitude in all axes. A small lateral translational oscillation occurred at times but was most probably due to a visual simulation computer update error.

c. In the Hover mode (up to 50 kts fwd speed) when the force trim release button was pushed, two elements of stability augmentation were lost; i.e., heading hold and roll attitude hold. Roll attitude required moderate pilot compensation to control in this mode and heading control became very difficult due to large yaw discursions requiring constant pedal movement to control the yaw axis. By changing the logic so that these two stability modes were not lost when the force trim button was depressed the handling qualities in a hover were greatly improved.

Slow Speed Flight:

a. At Nacelle angles of 90° it is extremely difficult to command forward speed. Large longitudinal displacements are required (up to full stick deflection was required on some longitudinal control sensitivities tested) to obtain a constant altitude acceleration. A 15° nose down aircraft attitude was required to maintain 90 kts forward speed. The combination of large longitudinal stick deflections with the resulting large stick forces and large nose down aircraft attitude was disconcerting to the pilot and resulted in slow accelerations to 90 kts forward speed due to the pilots hesitancy to use the control required to put the aircraft in the proper attitude for forward acceleration.

b. At a Nacelle angle of 85°, a 10° nose down attitude is required at 90 kts forward speed and is not as disconcerting to the pilot.

c. Experience showed that the quickest and easiest way to control acceleration or deceleration in slow speed flight was by use of nacelle tilt to command both the speed desired and the resulting level aircraft attitude (75° nacelle tilt gives a level attitude at about 80 kts).

d. Collective to pitch and nacelle tilt to pitch coupling are large in slow speed flight where the nacelle angles are greater than 70° of tilt. Pilot induced oscillations could easily be induced when too rapid a rate of collective or nacelle tilt was utilized while at these helicopter nacelle angles for slow speed flight.

e. Turn coordination is difficult at slow speeds. At speeds above 50 kts the heading hold function of SAS changes to attempt to maintain sideslip at zero degrees. At the slower speeds (up to 90 kts), sideslip was experienced during turns and was especially uncomfortable during rapid control reversals. Tailoring of this SAS characteristic would be necessary to provide good handling qualities in the slow speed flight regime.

f. Control forces were hard to trim to zero in slow speed flight. Pressing of the force trim button degraded handling qualities appreciably and trimming individual control axes, with the rate trim systems provided, was time consuming and required too much of the pilots attention. An instantaneous control force release system that does not degrade handling qualities is a must for slow speed helicopter modes of flight.

Nap of the earth flight:

a. A slow speed nap of the earth course was developed to compare the handling qualities of this rigid rotor simulation to those recently conducted at Ames on the XV-15.

b. The rigid rotor nap of the earth handling quality characteristics were very similar to those observed while flying the recent XV-15 simulation at Ames.

c. Two handling quality characteristics need improvement to provide a good maneuverable nap of the earth aircraft; i.e.,

(1) Increased roll control power to provide for a method of more rapidly commanding desired bank angles and,

(2) Improved turn coordination to prevent large sideslip angles from developing when doing rapid control reversals.

Accelerations/Decelerations:

a. Accelerations/Decelerations were difficult to accomplish in the helicopter mode (90° nacelle angle) due to the large aircraft pitch attitude change requirements. (15° Nose down for acceleration and 15° Nose up for deceleration.)

b. Accelerations/Decelerations were not performed utilizing nacelle angle as a control but this method or a combination of nacelle tilt and aircraft attitude change would probably produce a better method of changing airspeed rapidly close to the ground.

Conversions:

a. A conversion corridor indicator was provided to show stall boundaries and stress limits and provided an easily readable tool for the pilot during rotor conversions.

b. Conversion from helicopter mode to airplane mode was a very simple operation and basically required the movement of only one control (nacelle tilt). The power lever could be left at the setting for OGE hover. By moving the nacelle tilt control at the rate that permits maintaining a level attitude to stay within the conversion corridor, pilot workload was minimal.

c. Automatic changing of rotor RPM is provided during the final few degrees of nacelle tilt and as currently configured created a power management problem. As RPM was changing automatically, torque would rise beyond limit values for the transmission drives. A limit control of some type is a must to prevent over torquing of the transmission drive systems during conversion.

d. Conversion from airplane mode to helicopter mode is not difficult but is not as simple as forward conversions because power management is more difficult due to a non linearity in power requirements. It is difficult to slow the aircraft from Vmax to 160 kts to enter the conversion corridor due to what feels like a clean configuration and since speed brakes are not provided very low power settings must be utilized in slowing the aircraft. Power management during conversion from the airplane to the helicopter mode is required to change the power from the low power settings during airplane deceleration to the higher power settings required at slow speed flight and it is very easy to slide back into the stall area of the conversion corridor before getting the nacelles tilted to the helicopter mode.

Stalls:

a. Stalls were inadvertently tested during conversions at low power settings, and the characteristic airplane stall mode occurred. Nose drop (loss of pitch control) was followed very shortly by slight wing drop (loss of aileron control).

b. Recovery from stall was easy if it was started immediately upon recognition of the stall.

c. Recovery from deeper stalls were not possible due to simulator visual limitations.

Airplane Mode:

a. Final conversion to the airplane mode occurs at approximately 160 kts. Between speeds of 160 kts and 240 kts the aircraft handles very well with the following exceptions.

b. At speeds below approximately 170 kts, with the flaps up, a noticeable reduction in roll damping occurs and it is possible for the pilot to induce a roll oscillation at these speeds. By placing the flaps at 40° this PIO tendency is considerably reduced.

c. Turn coordination is a problem in the airplane mode just as it is in the slower flight and conversion modes. Rapid roll reversals produce undesirable side forces that are difficult for the pilot to eliminate with pedal control.

Single Engine failures:

a. Single engine failures did not produce undesirable handling qualities.

b. A possibility of overtorquing of transmission/drive systems could occur if a failure occurred at a high power setting because the good engine automatically assumes the load that was previously commanded for both engines.

c. In OGE Hover a rate of descent of approximately 400 fpm occurred with a single engine failure. This descent could be stopped within approximately 100 ft of altitude loss by flying forward to an airspeed of 40 kts or greater where level flight could be maintained.

Minimum power descents:

a. Minimum power descents, up to 4000 fpm rate of descent were checked to determine engine governor characteristics. No problems of engine governing or governor disconnect were observed.

b. A problem of pitch attitude control occurred during these tests. A large amount of collective to pitch attitude coupling exists in this aircraft at nacelle angles used for approaches to land. This coupling triggers large pitch changes when the collective is lowered to start the approach. The collective sensitivity is very high at the lower collective settings, resulting in even larger observations of collective to pitch coupling during descents. The longitudinal control sensitivity was made high to allow for better command of pitch attitude control for accelerations and decelerations in the helicopter mode. This resulted in an easy to trigger, difficult to stop pilot induced oscillation when attempting to control pitch attitude during descents and approaches. A better tailoring of these control characteristics is a must to prevent pilot induced oscillations in the pitch axes at helicopter speeds and helicopter nacelle angles (70°-90°).

Crosswind Approaches:

a. Crosswind approaches in both smooth and gusty air at 20 kts of crosswind were flown with no difficulty. A comfortable yaw control margin appeared to remain.

b. Yaw control power was checked and it appeared sluggish when large yaw angles were needed due to heavy damping by the SAS. When the SAS gains were changed yaw control power appeared satisfactory.

SAS failure analysis:

a. The aircraft was flown throughout its operational flight envelope with the SAS OFF and was found to be controllable.

b. It is possible to produce pilot induced oscillations that can diverge if the pilot does not diligently keep all perturbations to small values throughout the flight envelope. The critical areas are as follows:

   (1) At slow speeds (up to 90 kts), with the nacelle angles between 70° and 90°, pitch is the most difficult axis to control, especially when rapid collective and/or nacelle tilt rates are experienced.

   (2) At nacelle tilt angles of less than 70°, roll damping is low and roll attitude is difficult to control. In this regime of flight from airspeeds between 90 kts and 240 kts, turn coordination is also critical. A slight inattention to turn coordination results in a side force and sideslip which couples with roll and can easily cause a roll divergence when an attempt is made to center the ball.

c. Attempts were made to fly with SAS OFF and with the force trim depressed to relieve all control forces. This was difficult but possible to accomplish in the helicopter mode; and impossible to accomplish in the conversion and airplane modes at nacelle tilt angles less than 70°. This was due to the difficulty in controlling roll oscillations and in controlling sideslip.

d. A trim system that allows trimming of control forces to zero, instantaneously in the helicopter mode and with a rate trimmer in the airplane mode, but that does not allow the pilot to remove control gradients in the airplane mode is essential.

Summary:

a. In slow speed flight in the helicopter mode (Nacelle 70°-90°) pitch attitude is difficult to control precisely and P.I.O. can result with the currently tailored SAS system.

b. Heading control is difficult in a hover if heading hold is disengaged.

c. Turn coordination is difficult at all speeds.

d. Roll attitude control is difficult at all speeds when roll attitude hold is disengaged.

e. Accelerations/Decelerations are difficult and require excessive aircraft pitch attitudes if the nacelle angle is held fixed.

f. Nacelle tilt and collective coupling to the pitch axis are large in the helicopter mode (Nacelle 90°-70°).

g. A force trim system that allows instantaneous zeroing of control forces in the helicopter mode within degrading handling qualities is a necessity.

h. Increased roll control power and improved turn coordination are necessary for nap of the earth flight.

i. Conversions and deconversions are easy and are greatly facilitated by use of the conversion corridor indicator.

j. Improved power management automatic controls are necessary during conversion to prevent transmission/drive train overtorque.

k. Yaw to roll coupling degrades handling qualities at nacelle angles below 70° and airspeeds above 90 knots.

l. Roll damping appears low in the airplane mode and is the most difficult axes to control.

m. Single engine failures do not degrade handling qualities.

n. The aircraft is controllable with SAS OFF but is difficult to fly and would probably be limited to flight in this regime for training or in an emergency situation only.

Conclusions:

a. A few of the problems found during this simulation could be the result of the rigid rotor characteristics, i.e.,

   (1) Acceleration/Deceleration characteristics in helicopter mode.

   (2) Nacelle Tilt to pitch; and collective to pitch coupling in the helicopter mode.

   (3) Longitudinal PIO tendency during approaches.

b. Most of the problems appear to be control and/or SAS tailoring problems with the possibility that simulation problems exist that indicate a problem which may not exist in the actual flight hardware.

c. This pilot was generally impressed with the mission potential of the rigid rotor tilt rotor aircraft concept and feels that the simulation model presented was of good quality for this point in the life cycle development.

Recommendations:

Continue development of the rigid-rotor tilt rotor concept.

T. K. Wright

cc:
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