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January 1992

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Summary

This paper describes a mathematical model of a tilt-wing aircraft that was used in a piloted, six-degree-of-freedom flight simulation application. Two types of control systems developed for the math model are discussed: a conventional, programmed-flap wing-tilt control system and a geared-flap wing-tilt control system. The primary objective was to develop the capability to study tilt-wing aircraft. Experienced tilt-wing pilots subjectively evaluated the model using programmed-flap control to assess the quality of the simulation. The math model was then applied to study geared-flap control to investigate the possibility of eliminating the need for auxiliary pitch-control devices (such as the horizontal tail rotor or tail jet used in earlier tilt-wing designs). This investigation was performed in the moving-base simulation environment, and the vehicle responses with programmed-flap and geared-flap control were compared. The results of the evaluation of the math model are discussed.

Introduction

Interest in tilt-wing V/STOL (vertical/short takeoff and landing) aircraft concepts has recently been renewed in both government and industry (refs. 1-3). The preliminary results of NASA's High-Speed Rotorcraft Program have indicated that tilt wings are competitive concepts for high-speed missions (at least in the opinion of two of the four study contractors) (ref. 4). Factors that have contributed in varying degrees to the reemergence of tilt wings in the aerospace community include advances in technology, such as materials, thrust/power systems, and fly-by-wire control systems; state-of-the-art augmentation and optimization techniques to yield improved handling qualities; and superior performance characteristics for missions requiring a vertical takeoff capability with no significant hover time. These factors warranted the development of the capability within NASA to study tilt-wing aircraft, and the mathematical model described in this paper was developed for that purpose.

Several tilt-wing aircraft have been built and flown with significant success. The first tilt-wing aircraft to success-fully convert from hover to forward flight and back was the Vertol VZ-2, in 1958. The VZ-2 had empennage-mounted pitch and yaw fans and differential propeller collective for control in hover and in low-speed flight. Differential flaperons, stabilizer incidence, and rudder were used for fixed-wing control in conventional forward flight (with the pitch and yaw fans active in all flight modes). This vehicle marked the beginning of more than a decade of improved tilt-wing and related V/STOL designs.

Other tilt wings that were built and flown include the Hiller X-18, the Vought/Hiller/Ryan XC-142, and the Canadair CL-84. Both the XC-142 and the CL-84 were eminently successful, with both aircraft completing military operational demonstration programs. Both used a tail rotor for low-speed pitch control, and large chord flaps programmed with wing incidence for conversion. Yaw control was accomplished with differential flaperons in hover and low-speed flight. The last tilt wing to fly was the CL-84, more than 15 years ago.

This paper presents an overview of a mathematical model for a generic tilt-wing aircraft, and the model's application to a piloted simulation that was conducted on the NASA Ames Vertical Motion Simulator (VMS) in September 1990 (fig. 1). The primary objective of the simulation was to develop the capability to study tilt-wing aircraft in hover, low-speed, and conversion flight conditions. The math model incorporates two types of control systems: a conventional, programmed-flap wing-tilt control system (similar to that employed by the XC-142 and CL-84) and a geared-flap wing-tilt control system (patented by G. B. Churchill, U.S. Patent Number 3029043, April 10, 1962). The results of the piloted simulation have been published (ref. 5); the complete math model and the control laws will be published in separate NASA reports.

Symbols

i_w	wing incidence, deg
$I_{(\ )}$	mass moments of inertia, slug-ft^2
K_β	propeller blade pitch lead gain, deg/in.
Q_E	engine torque, ft-lb
u,v,w,p,q,r	aircraft body axis states, ft/sec or rad/sec
X,Y,Z,L,M,N	aircraft forces and moments, lb or ft-lb
$Y_{(\ )},L_{(\ )},N_{(\ )}$	lateral-directional derivatives, 1/sec or 1/sec^2
β	sideslip angle, rad
β_{lead}	propeller blade pitch lead command, rad
$\delta_{(\ )}$	pilot or control input, in. or deg
Ω	propeller rotational speed, rad/sec

Mathematical Model

The mathematical model described in this section is based on experimental and analytical work initiated in 1957 to support the development of the geared-flap control system (refs. 6 and 7). The geared-flap system uses the flap in a servo mode to control the wing incidence relative to the

fuselage. This system can generate large wing accelerations, velocities, and displacements; therefore, a math model of sufficient complexity is required to accurately assess aircraft performance, stability, and handling qualities. The work initiated in 1957 was refined and expanded over the years, and the math model described in this paper reflects this work. The model also incorporates work performed as recently as May 1990. The complete math model includes nonlinear longitudinal aerodynamics, complex engine/propeller dynamics, coupled-body equations of motion (relative fuselage and wing/propeller motion about a common pivot), and simplified lateral-directional dynamics. The model is of sufficient complexity to assess any class of tilt-wing aircraft with either geared-flap control or the more benign programmed-flap control. Thus it is a very useful and general analytical tool.

The strength of this math model is that it has a complete longitudinal-mode representation that is suitable for studies in hover, low-speed, and conversion flight conditions. However, there are three important limitations of the model that have restricted its application: (1) ground effect is not taken into account; (2) a simplified lateral-directional mode was incorporated; and (3) the model is not designed for high speeds. Therefore, the application of this model was confined to an "out of ground effect" environment for only longitudinal-mode flight conditions at hover, low speed, and conversion.

The complete math model is a conglomerate of separately identifiable, but related, components. Those components are shown in figure 2, and are discussed in the following subsections.

Lateral-Directional Mode

The original work, initiated in 1957, upon which this math model is based, considered only longitudinal degrees of freedom. A pilot would be able to fly in the X-Z plane only if the original model were used for a piloted simulation. Therefore, the decision was made to expand the model to include a lateral-directional mode so that a pilot could maneuver the aircraft. To facilitate the study of longitudinal-mode handling qualities, the aircraft was given desirable lateral-directional control and response characteristics that were uncoupled from the longitudinal mode. The idea was to let the pilot have what he or she thought was a realistic aircraft without compromising the basic research objectives of the simulation: the study of longitudinal-mode handling qualities of a tilt-wing aircraft with programmed-flap and geared-flap control.

The lateral-directional mode is represented by a simple rate-command model. There are two pilot inputs to this

portion of the model: lateral stick and pedals. Estimated stability derivatives multiplied by lateral-directional states are fed back and summed with the rate-commanded inputs, as shown in figure 3. Side force, rolling moment, and yawing moment are calculated based on values of mass and estimated inertia, and then resolved by rigid-body equations of motion to ultimately obtain the lateral-directional states p, r, and v.

The control inputs are multiplied by a roll response gain (deg/sec/in. of stick deflection) and a yaw response gain (deg/sec/in. of pedal at hover and degrees of sideslip/in. of pedal in airplane mode). The roll- and yaw-rate responses are simple first-order lags. Dutch roll is obtained by incorporating sideslip effects, which are washed out at low forward speeds. Stability derivatives and inertias were calculated from first-order estimates, and were then slightly modified during the simulation because of pilot comments. Complex nonlinear aerodynamics and effects of wing motion were not incorporated into the lateral-directional mode. This is obviously a simplistic approach, but it is also effective in decreasing the number of potential distractions.

Longitudinal Mode

The longitudinal mode of the math model is shown in figure 4. There are two pilot inputs to this portion of the model: longitudinal stick and wing tilt. These parameters are used as inputs to the control laws that produce a wing-tilt acceleration command or a flap position command as an output. Programmed-flap and geared-flap control laws provide a means by which the pilot can control the wing; thus they are identified as wing-tilt control laws. The two outputs from the control laws, however, command up to five inputs to the longitudinal aerodynamics (i_w, δ_f, δ_t, δ_e, and δ_{tj}). The longitudinal aerodynamic forces and moments subsequently calculated are a function of these five inputs as well as the four longitudinal mode states that are ultimately generated. The forces and moments are identified as either the tilting-system or the nontilting-system forces and moments. The tilting system comprises the thrust/power systems and the wing. The nontilting system comprises the fuselage, landing gear, empennage, and tail jet. Both the tilting-system and the nontilting-system forces and moments are resolved using the coupled-body equations of motion to produce longitudinal aircraft states, identified as $\dot{u}$, $\dot{w}$, $\dot{q}$, and i_w. Note that pitch rate feedback was employed for both control systems, but that the programmed-flap and geared-flap control laws are otherwise unaugmented.

Coupled-body considerations– The classical rigid-body equations of motion were modified to account for coupled-body motion of the tilting system and the

nontilting system. These modified equations resolve the longitudinal aerodynamic forces and moments in order to generate longitudinal aircraft states about the total system center of gravity (CG). The coupled-body equations of motion are based on the independent calculation of the accelerations of the tilting-system CG and the nontilting-system CG relative to a reference frame fixed in space. These accelerations are then summed and resolved for the longitudinal-translational and rotational aircraft states. Conceptually, the coupled-body motion can also be thought of as the motion of the total system CG relative to a reference frame fixed in space. Rapid wing movements can be obtained easily with geared-flap control, and therefore wing rate and acceleration effects also have to be considered. These effects are pronounced because the tilting-system mass is a large percentage of the total mass of the aircraft. The geometry that defines the position of the total-system CG relative to the tilting-system CG and the nontilting-system CG is shown in figure 5.

Thrust/power system– The thrust/power system is an extremely important part of the tilt-wing math model, and the dynamics involved are critical for realistically representing the aircraft's response to a throttle input. A means by which pilots avoid stall and alleviate stick shaking caused by buffeting is to apply throttle during the conversion process. The aircraft's response to a throttle input greatly affects its handling qualities, because propeller forces and moments factor directly into the tilting-system forces and moments, and also directly affect the local wing-flow conditions.

The thrust/power system dynamics are representative of a turboshaft that drives propellers that are mounted below the wing and inclined to the wing-chord reference line. These dynamics consist of three major elements, as shown in figure 6: (1) the engine; (2) the governor; and (3) the propeller. The throttle generates an input to the engine and a propeller blade-pitch lead command. That blade-pitch lead command is summed with a blade-pitch command that is based on governed propeller rotational speed and then fed into the propeller along with engine torque. The thrust/power system dynamics are shown as a separate degree of freedom in propeller rotational speed; however, the propeller forces and moment affect, and are affected by, the longitudinal aerodynamics, indicating a strong physical coupling between the longitudinal aircraft states and the thrust/power system dynamics.

Aerodynamics–

Propeller· The propeller produces thrust, normal force, hub moment, and torque calculated in the thrust axis frame with the origin at the hub (propeller center of rotation). The normal force acts parallel to the propeller

disk, and the thrust vector is perpendicular to it, along the thrust axis. The hub moment is depicted as a positive pitching moment, and it is affected by wing-tilt and aircraft pitching rates, and wing circulation. Propeller torque is used only in the thrust/power system calculations previously described. Propeller side force and yawing moment are not considered because the left wing propellers are counterrotating to the right wing propellers, and they are ideally considered to have the same rotational speeds and blade pitch angles, and are not affected by lateral-directional flow.

The forces and moment are calculated using conventional expressions and nondimensional coefficients similar to those found in the literature. Obviously, a unique feature of a tilt-wing aircraft is that large propeller angles of attack are generated. This effect is factored into the nondimensional coefficients for thrust, normal force, hub moment, and power (for torque). Nonlinear data was used to generate values for the thrust and power coefficients; however, the normal force and hub moment coefficients were calculated using curve-fit expressions that are a function of a total propeller activity factor (ref. 8). All of these coefficients are functions of propeller blade pitch angle, advance ratio, and propeller angle of attack.

Wing/flap system: The calculation of wing lift, drag, and pitching moment is somewhat involved. The methodology introduces an augmentation factor, a ratio of wing immersed area to total wing area, and ratios of free-stream-to-slipstream dynamic pressure and free-stream-to-ideal-slipstream dynamic pressure directly into the calculation of the wing lift, drag, and pitching moment.

The augmentation factor and the ratios are functions of slipstream velocity, equivalent angle of attack, and proximity of the propeller relative to the wing quarter-chord. Slipstream velocities and equivalent angles of attack are obtained by a vector summation of the free-stream velocity and the propeller-induced velocity. The induced velocity is assumed to be uniformly distributed and is calculated using momentum theory. The induced-velocity calculation is based on the resultant force (equal to the sum of the thrust and the normal force) and the inclination of the resultant force to the propeller disk and the horizon.

Three-dimensional wing coefficients are used in the calculations of wing lift, drag, and pitching moment. These coefficients are defined for angles of attack between $-180°$ and $180°$, and for flap angles between $-0.25°$ and $60°$. The values of these coefficients do not vary with Mach number, thus wing compressibility effects are not taken into account.

Fuselage and landing gear The method used to calculate fuselage and landing-gear lift, drag, and pitching moment is rudimentary Fuselage lift, drag, and pitching-moment coefficients are linear functions of angle of attack, and the respective forces and moment are produced when multiplied by free-stream dynamic pressure, wing area, and mean chord (for pitching moment). The landing-gear calculations are similar except that they are assumed not to produce lift, and their effects are reduced linearly to zero when the landing gear are retracted.

Horizontal tail: The method used to calculate the aerodynamic forces and moment at the horizontal tail is based on an empirical model developed from two-propeller tilt-wing data in 1967 The horizontal tail lift, drag, and pitching moment are calculated as functions of the respective three-dimensional coefficients, local velocity, and local angle of attack. The local velocity and local angle of attack are, in turn, functions of nominal and slipstream-based tail efficiency functions, downwash angle, and horizontal tail proximity relative to the wake.

The downwash angle, ε, downstream of a propeller-wing-flap system is assumed to be constant (not to change direction); however, position and rate changes of the propeller-wing-flap system are taken into account. The wake geometry is physically defined by Φ_t and χ, as shown in figure 7

Three-dimensional tail coefficients are used in the calculations of lift, drag, and pitching moment. These coefficients are defined for angles of attack between $-180°$ and $180°$, and for elevator angles between $-30°$ and $30°$ The values of these coefficients do not vary with Mach number, thus tail compressibility effects are not taken into account.

Reaction control: The reaction control is a tail jet that provides pitch control to the aircraft in hover, at low speeds, and in conversion, and varies with longitudinal stick position. The pitch moment generated by the tail jet is calculated by multiplying the normalized longitudinal stick position with total aircraft pitch inertia and control power (in units of rad/sec^2). The resulting moment produced by the tail jet provides the type of pitch control common to the XC-142 and the CL-84.

Control Laws

The programmed-flap and geared-flap wing-tilt control systems are described in this section and are shown in figure 8. The longitudinal controls common to all control systems are throttle, flaperons, horizontal tail, elevator,

and tail jet. Lateral-directional control is assumed to be achievable with differential propeller collective, differential flaperons, and rudder The wing is capable of moving from a 2° (horizontal) to a 90° (vertical) wing incidence and beyond for rearward flight. The longitudinal stick controls the horizontal tail incidence, elevator, and tail jet, and is augmented with pitch-rate feedback.

Programmed flap– The programmed-flap control system uses a spring-centered beep switch on the throttle lever to generate a wing reference command. This corresponds to a wing acceleration command that is integrated once and rate-limited with a 0.25-sec time constant. The acceleration physically represents a wing actuator producing a moment about the wing pivot. The rate-limited wing actuator command is integrated once to produce a position. The flaperons are entirely dependent on the position of the wing, or, alternatively stated, the flaperons are programmed relative to the wing position.

The pilot is given the authority to attenuate the flap position using a detented flap lever, which acts as a gain that multiplies the programmed position of the flaperons by values of 0.0 (flap lever full up), 0.2, 0.4, 0.6, 0.8, and 1.0 (flap lever full down).

Geared flap– The geared-flap control system produces a reference command that drives the flaperon position directly, and not in a programmed fashion. A reference command can be generated from the spring-centered beep switch on the throttle, from the longitudinal stick, or from a combination of the two. The first option was studied in the piloted simulation, but the other two were not. The second option is termed wing on the stick. Regardless of the type of pilot control(s) used to generate the wing reference command, a direct wing acceleration command (similar to that of the programmed flap) is generated only if the flaperon position is at a limit, thereby defaulting to a programmed-flap control system if the pilot requires additional authority

Simulated Aircraft

The aircraft simulated on the VMS was generally modeled after a cargo-class aircraft, shown in figure 9. The geometry of this configuration was not optimized for any particular mission or handling-qualities task. The same configuration, however, was used with both programmed-flap and geared-flap control. Some physical characteristics of interest can be found in table 1

Table 1. Physical characteristics of the simulated aircraft

Loading	
Weight	87,000 lb
Thrust-to-weight ratio	1 15
Disk loading	40 lb/ft^2
Wing loading	66 lb/ft^2
Dimensions	
$\bar{c}/D$	0.45
$\bar{c}$	12 ft
Overall length	97 ft
b (wing span)	109 ft
D (propeller diameter)	26 ft
Wing area	1321 ft^2
Locations (aft of aircraft nose, wing down)	
Wing $\bar{c}/4$ location	40 ft
Tilting-system CG location	38.25 ft
Wing pivot location	41.8 ft
Nontilting-system CG location	41.8 ft
Total system CG location	39.8 ft
Masses and inertias	
Wing/prop mass	1510 slug
Fuselage mass	1190 slug
Total mass	2700 slug
$I_X = I_Z$	1,829,500 slug-ft^2
I_Y	418,344 slug-ft^2, wing down
I_Y	453,221 slug-ft^2, wing up

Analysis

An important advantage of geared-flap control is the potential for eliminating the auxiliary pitch control device (tail jet). Formal analyses of geared-flap control were performed by Churchill (refs. 6 and 7), and, more recently, the results of the piloted simulation comparing geared-flap and programmed-flap control showed that the handling qualities were, for the most part, comparable (ref. 5). A complete analysis of the math model described herein is not within the scope of this paper. However, some analysis is presented in this section to illustrate the differences between programmed-flap and geared-flap control. The math model described in this report was developed for handling-qualities studies; the issue at hand relative to handling qualities is whether the mathematical treatment of a tilt-wing aircraft produces a realistic simulation. Experienced tilt-wing pilots subjectively assessed the quality of the simulation, and their comments are also presented in this section.

The longitudinal trim states generated by the math model are shown in figure 10 for both control systems at the same forward speeds and wing-incidence angles. The data were obtained by varying throttle, longitudinal stick, and pitch attitude at a given forward speed and a given wing-incidence angle until a steady-state condition was achieved. It is possible, however, to trim on pitch attitude rather than wing incidence.

A nominal hover condition for the geared-flap system was chosen as a starting point. A wing incidence was defined that produced a nominal pitch attitude within 2° for the geared-flap control system. The programmed-flap system was then trimmed at that wing-incidence angle in hover, and the longitudinal trim states were obtained. This process was repeated (without attempting to define pitch attitude for either control system) at wing incidences of 70° at 10 knots, 50° at 30 knots, and 30° at 60 knots. These flight conditions were chosen arbitrarily to illustrate some differences between the control systems. Note that the longitudinal trim states are not unique, because of the additional degree of freedom introduced by wing incidence.

The throttle positions of the two control systems shown in figure 10 are fairly close, each reflecting a noticeable reduction in the power required to maintain steady state at wing incidence angles less than 70° and forward speeds greater than 10 knots. The differences in longitudinal stick position and pitch attitude between the two control systems are pronounced in hover and at low speed, and tend to approach similar values in conversion. Up to 10% more longitudinal stick is required to trim with programmed-flap than with geared-flap at the same flight conditions (note that the moment produced by the tail jet is a function of longitudinal stick position). The reason for these differences is discussed below.

A comparison of the wing/prop and tail-jet moments about the wing pivot that are required to achieve a trimmed condition for each control system is shown in figure 11 for various speeds and wing-incidence angles. It can be seen that the wing/prop moment of a geared-flap system is considerably less than that of a programmed-flap system at the same flight conditions, thus much less (if any) tail-jet pitching moment is required to trim the geared-flap system.

The reason for the differences in wing/prop moment is quite simple. The flap of a geared-flap system is not programmed as a function of wing incidence, but rather is positioned to create a moment balance about the pivot at a steady-state condition, as shown in figures 12 and 13. Propeller pitching moment about the wing pivot is extremely large and of roughly the same magnitude for each control system. However, the geared-flap wing

pitching-moment contributions are greater than those of the programmed flap because the flaps are deflected. This difference in the pitching-moment contributions accounts for the differences in the associated trim states of the programmed flap and geared-flap control systems previously noted.

Figure 13 shows that propeller and wing moments increase with an increase in forward speed and a decrease in wing incidence. Hub moment and normal force contributions coupled with an increase in wing equivalent angle of attack contribute to this effect, but ultimately tend to wash out as the flight condition approaches that of conventional, fixed-wing aircraft in forward flight. An additional contribution from mechanical pivot moment, characterized as a pivot-moment bias term, was used with the geared-flap control system to provide the additional amount of pitching moment needed to balance the sum of the tilting-system moments about the wing pivot. The wing contributions to pitching moment about the pivot are attenuated by a ratio of wing immersed area to total wing area and ratios of free-stream-to-slipstream dynamic pressure and free-stream-to-ideal-slipstream dynamic pressure.

Obviously, if the flaps of a programmed-flap control system were positioned at the same location as that of the geared-flap system, the pitching moment distributions about the pivot would be the same (except for the pivot-moment bias term). The advantages this would offer to the programmed-flap system would be limited to specific flight conditions and would not be realized in dynamic conditions. For these reasons, and because it would not resemble a conventional control system employed by tilt-wing aircraft such as the XC-142 or CL-84, no attempt was made to optimize the programmed-flap control system. However, the ability to gain the flap position independently was given to the pilot.

The handling-qualities characteristics of the programmed-flap system were evaluated subjectively by an experienced XC-142 pilot and an experienced CL-84 pilot. The XC-142 pilot stated that the "simulation is very good relative to a tilt-wing configuration," and "the addition of moving base to this simulation provides a quantum improvement to realism and fidelity." The CL-84 pilot stated that the "longitudinal acceleration due to wing tilt is about as expected—'it is not crisp'," and "the very large and immediate reduction in power required to maintain level flight with even small forward wing tilt from hover seems unrealistic." All but the last comment were considered favorable about the quality of the math model. The last comment is clearly supported by the data shown in figure 10, as previously discussed.

Concluding Remarks

This report describes a mathematical model of a tilt-wing aircraft employing both programmed-flap and geared-flap wing-tilt control laws. The primary objective of this effort was to develop the capability to study tilt-wing aircraft. This objective was met and subsequently applied to the study of programmed-flap and geared-flap control of a cargo-class aircraft. The math model was subjectively evaluated by experienced tilt-wing pilots in a six-degree-of-freedom motion simulator. The comments relative to the quality of the simulation were positive with one exception, which reflects the fact that the math model is developmental, as are all math models to some extent. Descriptions of the complete math model and the programmed-flap and geared-flap control laws will be published in separate NASA reports. Another piloted simulation experiment is scheduled for September 1991 on the VMS to further investigate geared-flap control and to enhance the capabilities of the math model. These enhancements will improve NASA's capability to study tilt wings and related V/STOL aircraft and to address specific technology issues that government and industry now face.

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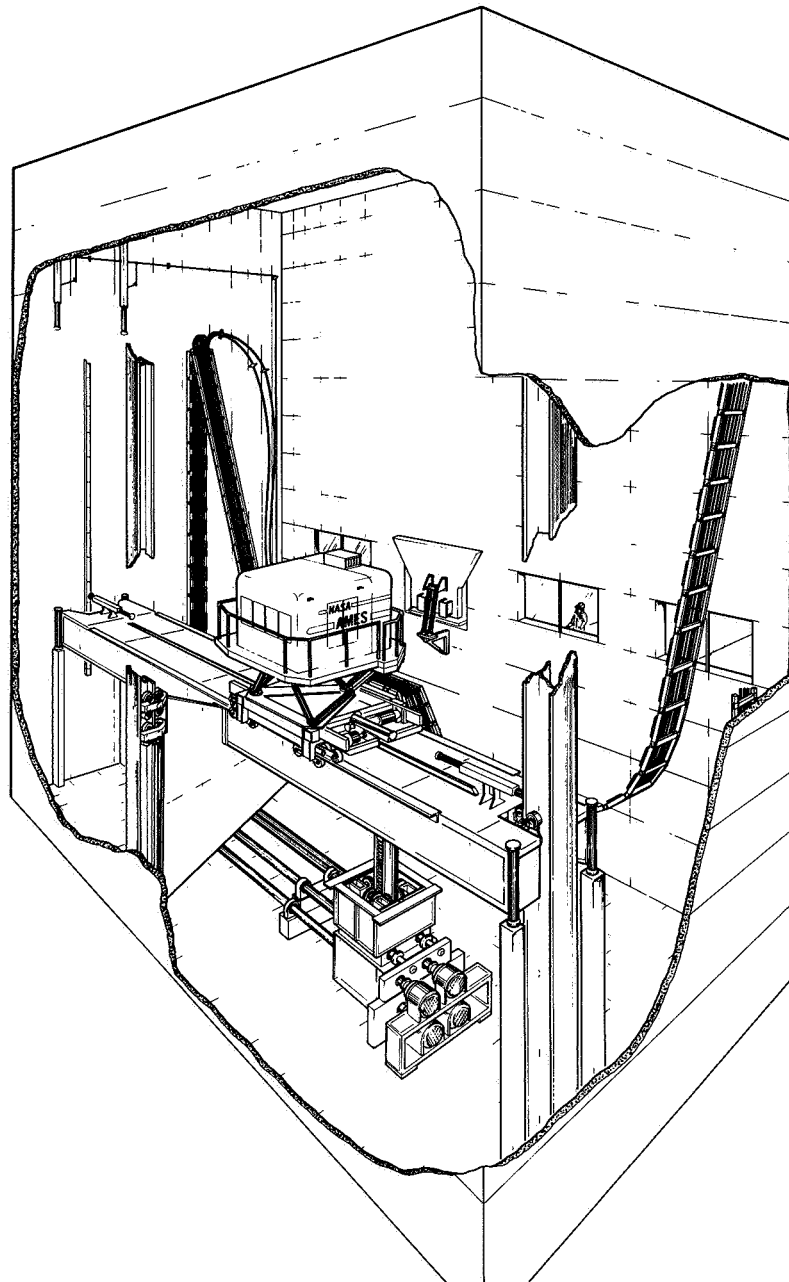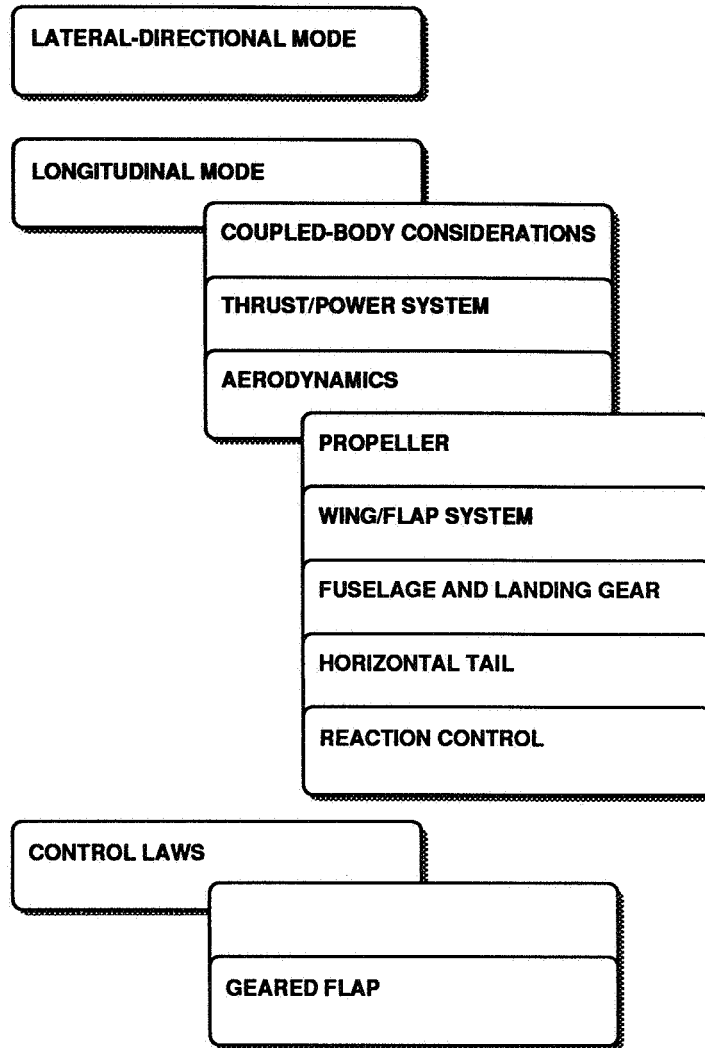
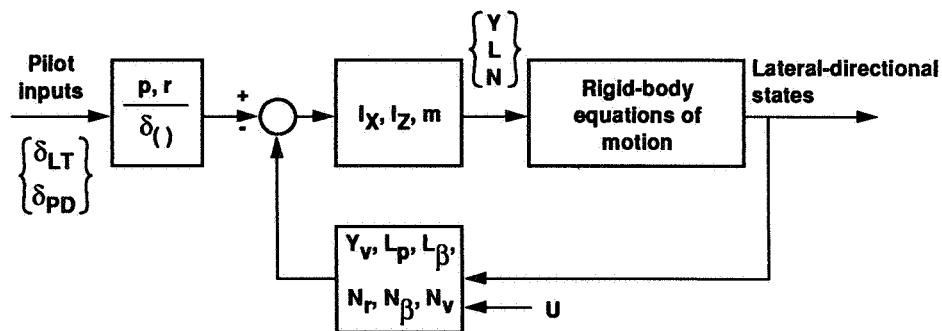Figure 1. The NASA Ames Vertical Motion Simulator (VMS).

LATERAL-DIRECTIONAL MODE

LONGITUDINAL MODE

COUPLED-BODY CONSIDERATIONS

THRUST/POWER SYSTEM

AERODYNAMICS

PROPELLER

WING/FLAP SYSTEM

FUSELAGE AND LANDING GEAR

HORIZONTAL TAIL

REACTION CONTROL

CONTROL LAWS

GEARED FLAP

Figure 2. Math model components.

Pilot inputs

$\left\{ \begin{array}{c} \delta_{LT} \\ \delta_{PD} \end{array} \right\}$

$\dfrac{p, r}{\delta_{()}}$

I_X, I_Z, m

$\left\{ \begin{array}{c} Y \\ L \\ N \end{array} \right\}$

Rigid-body equations of motion

Lateral-directional states

$Y_v, L_p, L_\beta,$

N_r, N_β, N_v

U

Figure 3. Lateral-directional mode.

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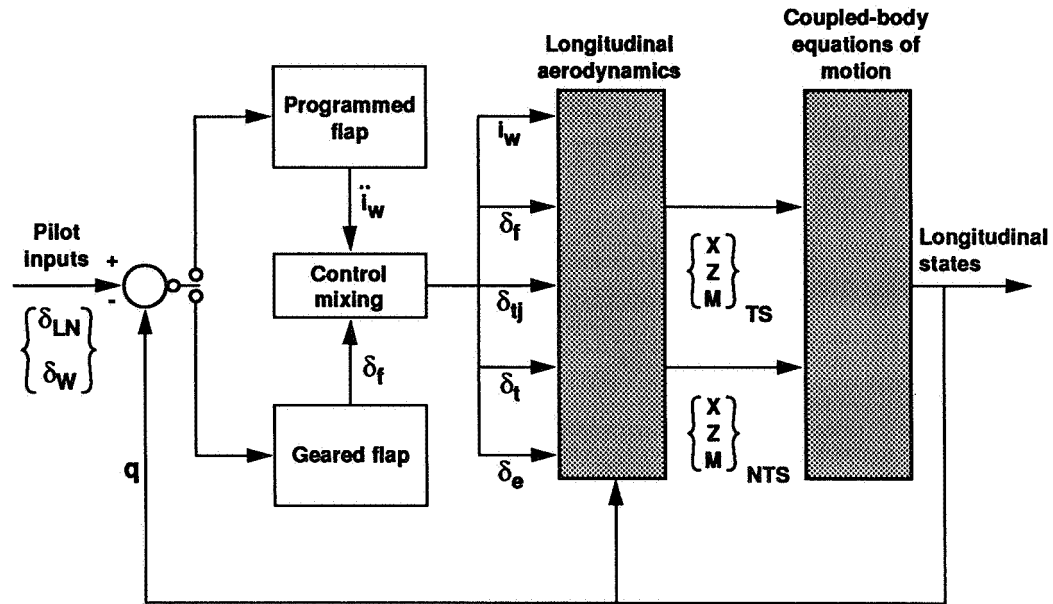
Figure 4. Longitudinal mode.
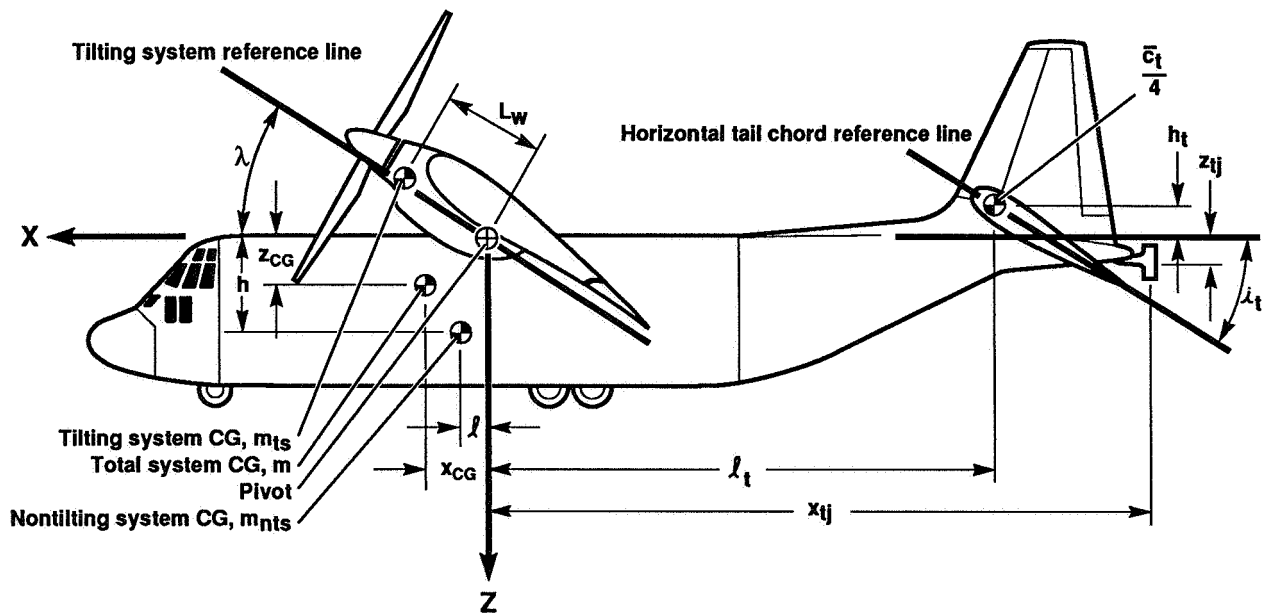
Figure 5. Tilting- and nontilting-system geometry.
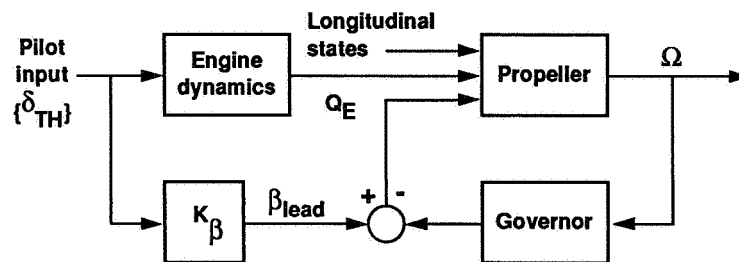
Figure 6. Thrust/power system.
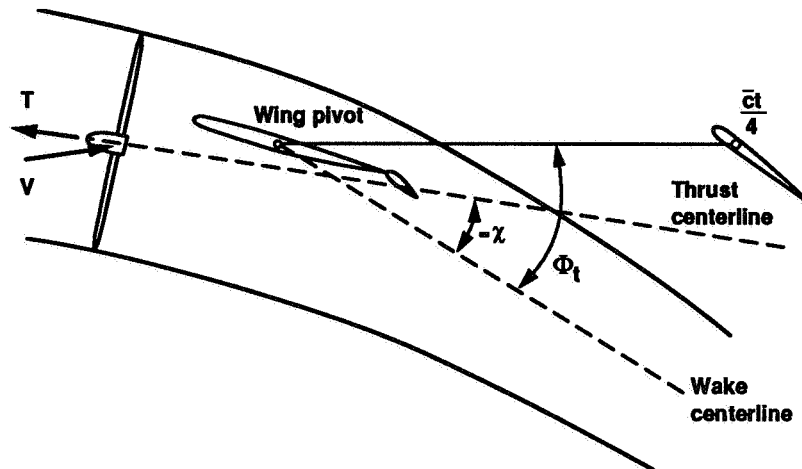
Figure 7. Propeller-wing-flap wake geometry.

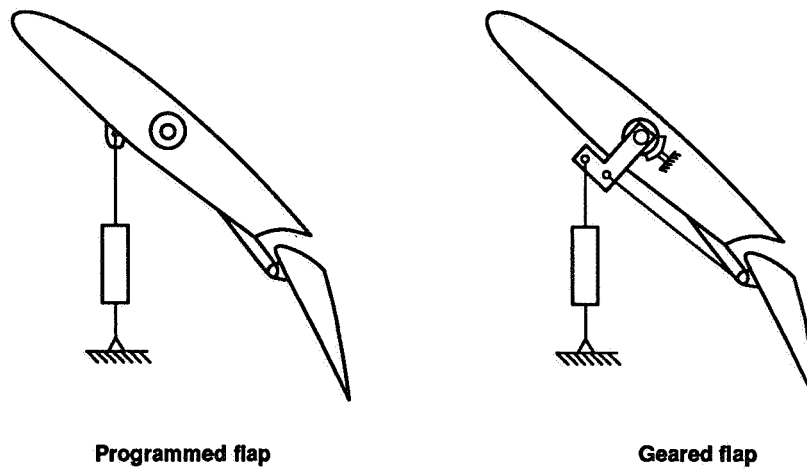Programmed flap   Geared flap

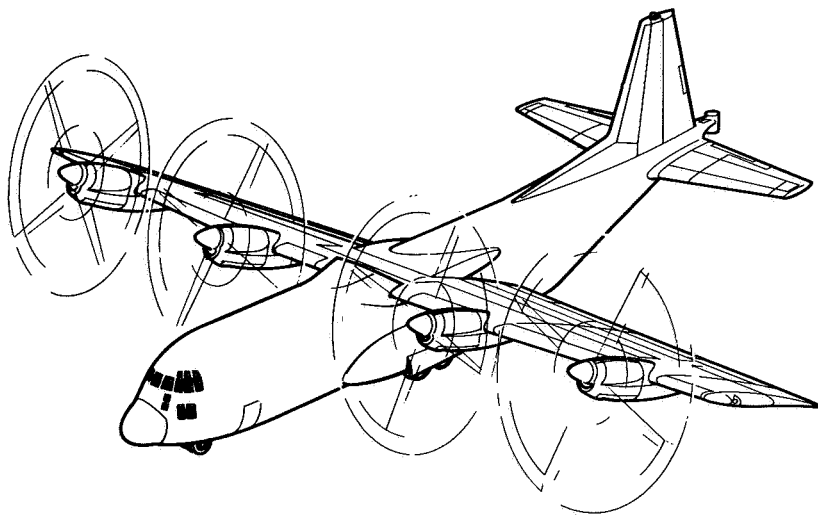Figure 8. Programmed-flap and geared-flap wing-tilt control systems.

Figure 9. Simulated tilt-wing aircraft.

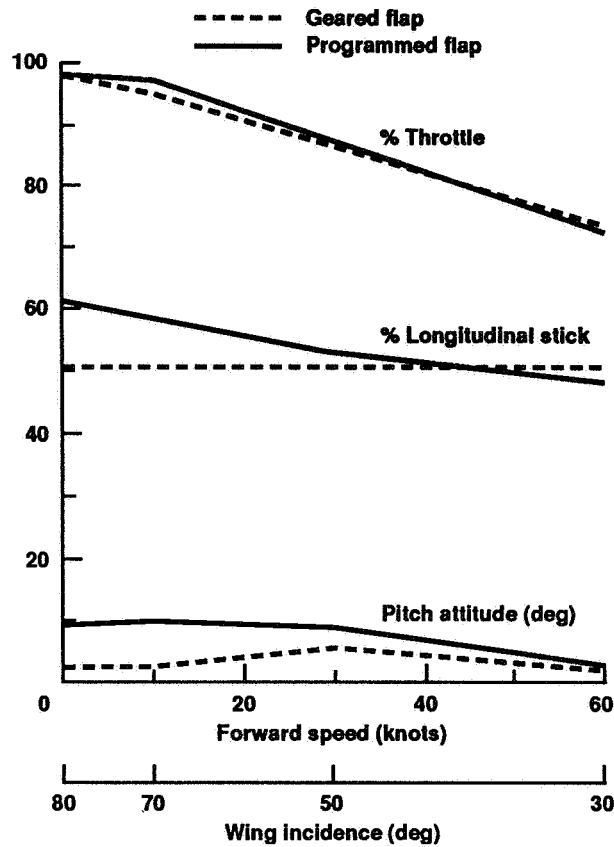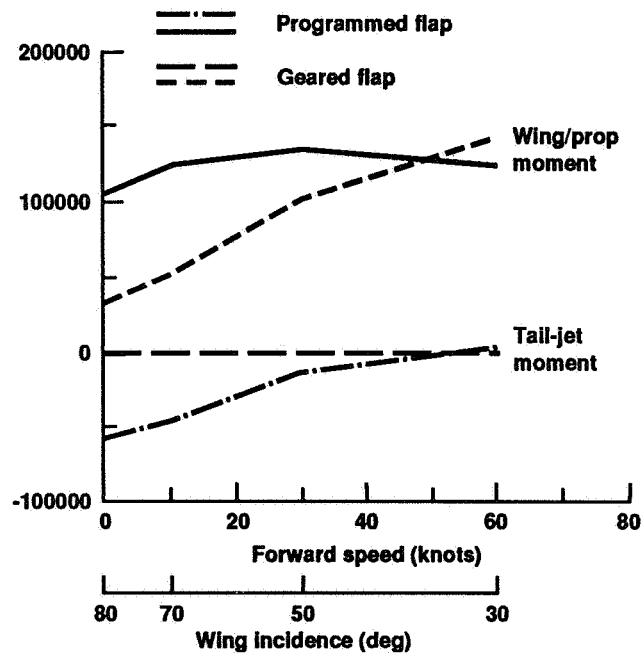*Figure 10. Programmed-flap and geared-flap longitudinal trim states in conversion.*

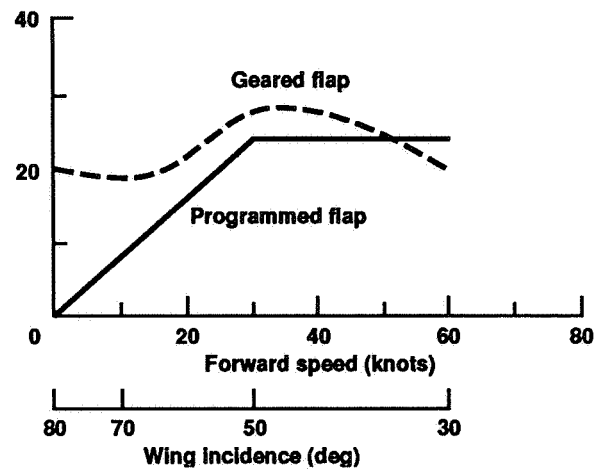*Figure 11. Comparison of wing/prop and tail-jet pivot moment contributions.*

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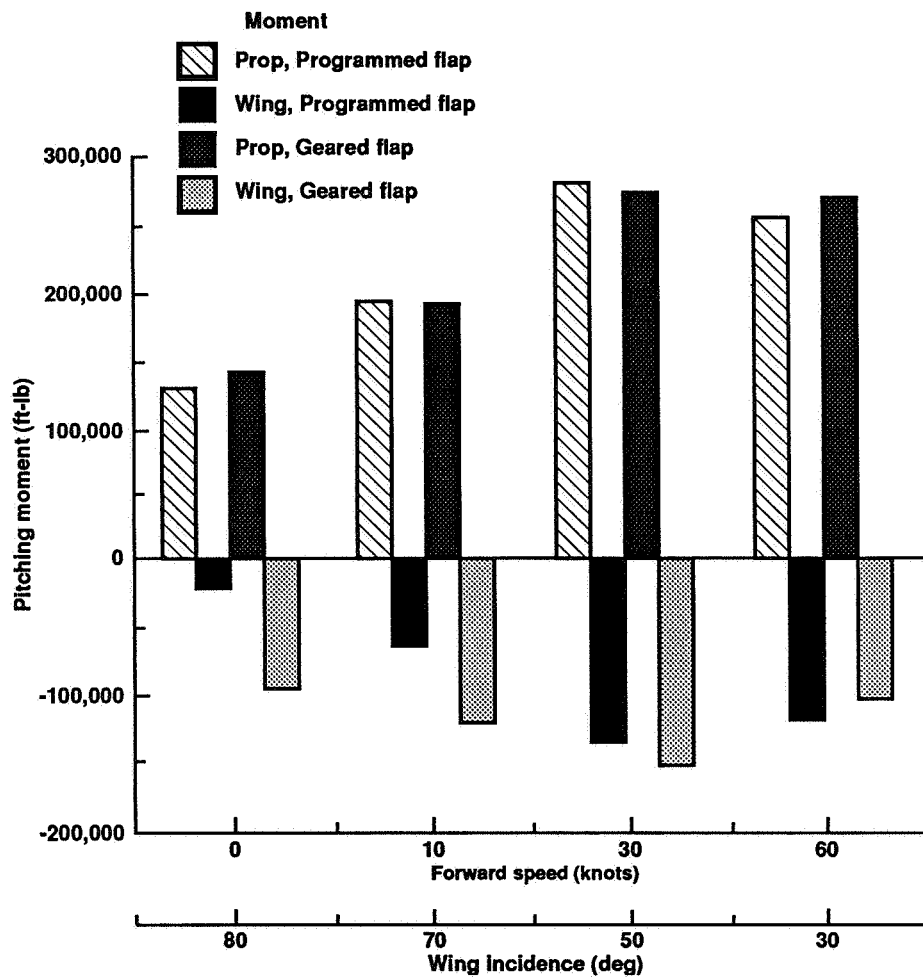*Figure 12. Comparison of flap positions in conversion.*

Figure 13. Comparison of wing and propeller pitching-moment contributions about the wing pivot.

REPORT DOCUMENTATION PAGE

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1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	January 1992	Technical Memorandum

4. TITLE AND SUBTITLE

A Mathematical Model of a Tilt-Wing Aircraft for Piloted Simulation

5. FUNDING NUMBERS

505-61-51

6. AUTHOR(S)

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7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

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8. PERFORMING ORGANIZATION REPORT NUMBER

A-91150

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

National Aeronautics and Space Administration
Washington, DC 20546-0001

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

NASA TM-103864

11. SUPPLEMENTARY NOTES

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12a. DISTRIBUTION/AVAILABILITY STATEMENT

Unclassified — Unlimited
Subject Category 05

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

This paper describes a mathematical model of a tilt-wing aircraft that was used in a piloted, six-degree-of-freedom flight simulation application. Two types of control systems developed for the math model are discussed: a conventional, programmed-flap wing-tilt control system and a geared-flap wing-tilt control system. The primary objective was to develop the capability to study tilt-wing aircraft. Experienced tilt-wing pilots subjectively evaluated the model using programmed-flap control to assess the quality of the simulation. The math model was then applied to study geared-flap control to investigate the possibility of eliminating the need for auxiliary pitch-control devices (such as the horizontal tail rotor or tail jet used in earlier tilt-wing designs). This investigation was performed in the moving-base simulation environment, and the vehicle responses with programmed-flap and geared-flap control were compared. The results of the evaluation of the math model are discussed.

14. SUBJECT TERMS

Tilt wing, Simulation, Mathematical model

15. NUMBER OF PAGES

14

16. PRICE CODE

A02

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified		