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Generic Airplane Model Concept and Four Specific Models Developed for Use in Piloted Simulation Studies

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ABSTRACT

A generic airplane model concept was developed to allow configurations with various agility, performance, handling qualities, and pilot vehicle interface to be generated rapidly for piloted simulation studies. The simple concept allows stick shaping and various stick command types or modes to drive an airplane with both linear and nonlinear components. Output from the stick shaping goes to linear models or a series of linear models that can represent an entire flight envelope. The generic model also has provisions for control power limitations, a nonlinear feature. Therefore, departures from controlled flight are possible. Note that only loss of control is modeled, the generic airplane does not accurately model post departure phenomenon. The model concept is presented herein, along with four example airplanes. Agility was varied across the four example airplanes without altering specific excess energy or significantly altering handling qualities. A new feedback scheme to provide angle-of-attack cueing to the pilot, while using a pitch rate command system, was implemented and tested.

INTRODUCTION

Airplane designs begin with the definition of their mission and therefore what capabilities will be needed. In order to write an overall performance definition and requirements for accomplishing the mission or missions, tradeoffs must be made. Many of the requirements and their impact on other parts of the mission can be determined with rigorous or empirical data. These include cruise speed, range, payload, etc. Other requirements such as handling qualities and pitch and roll performance are not as easily bounded. They are harder to determine due to the dependence on human pilots and constantly changing requirements due to the introduction of new weapons, systems, and threat aircraft. Handling qualities and pitch and roll performance guidelines are available for various classes of airplanes in MIL-SPEC 1797A (ref. 1). These guidelines were developed from either rigorous studies or empirical data and are currently valid only at relatively low angles of attack and for conventional maneuvers. The guidelines are always open for refinement as technology improves and sometimes drastically changes the performance available or required for a particular class of airplanes. In order to develop new design guidelines valid across a broader flight envelope or in new environments, testing with various configurations is required. Therefore the need exists to have an easy way to test airplanes with different capabilities and handling qualities. However, development of full airplane configurations, even in simulation, is very time consuming. In order to speed up this process a generic airplane concept was developed for use in the Highly-Agile Vehicle Versus Two (HAVV-TWO) program conducted at NASA Langley Research Center. The generic airplane concept should be useful for performance and handling qualities research for follow-on studies and other programs as well.

The generic airplane model concept allows rapid development of configurations with various agility, handling qualities, and performance. The concept is very simple and allows stick shaping and various stick command types or modes to be implemented. Output from the stick shaping goes to linear models or a series of linear models that can represent an entire flight envelope. It also provides for control power limitations, a nonlinear feature. Therefore, departures from controlled flight are possible. Note that only loss of control is modeled, the generic airplane does not accurately model post departure phenomenon. Herein, the model concept is presented along with four example airplanes. Agility was varied across the four example airplanes without altering specific excess power or significantly altering handling qualities. A new feedback scheme to provide α cueing to the pilot, while using a pitch rate command system, was implemented and tested.

NOMENCLATURE

Symbols

A	Coefficient on second order term in parabola, deg/(sec * in^2)
B	Coefficient on first order term in parabola, deg/(sec * in)
C_D	Total drag coefficient
C_{D_0}	Baseline drag coefficient
$C_{D_{Mach}}$	Mach effect on drag coefficient
C_L	Total lift coefficient
C_{L_0}	Baseline lift coefficient
$C_{L_{max}}$	Maximum lift coefficient
C_X	Axial force coefficient
C_Y	Side force coefficient
C_Z	Normal force coefficient
g	Gravity, 32.2 ft/sec^2
I_{xx},I_{yy},I_{zz}	Moments of inertia about the X, Y ,and Z body axes respectively, slug-ft^2
I_{xz}	Product of inertia in xz frame, slug-ft^2
LTOT	Rolling moment, ft-lbs
MTOT	Pitching moment, ft-lbs
NTOT	Yawing moment, ft-lbs
n_x	Load-factor along longitudinal axis, positive forward, g
n_y	Load-factor along lateral axis, positive right, g
n_z	Load-factor along vertical axis, positive up, g

p	Body axis roll rate, deg/sec or rad/sec
$\dot{p}$	Body axis roll acceleration, deg/sec^2 or rad/sec^2
P_s	Specific excess power, ft/sec
p_w	Wind axis roll rate, deg/sec
q	Body axis pitch rate, deg/sec or rad/sec
$\dot{q}$	Body axis pitch acceleration, deg/sec^2 or rad/sec^2
q_{cmd}	Commanded pitch rate, deg/sec
$q_{cmd\text{-}max}$	Maximum commanded pitch rate for a given flight condition, deg/sec
r	Body axis yaw rate, deg/sec or rad/sec
$\dot{r}$	Body axis yaw acceleration, deg/sec^2 or rad/sec^2
s	Laplace variable, sec^{-1}
SB_{Gain}	Speed brake effectiveness gain
Slope	$\frac{dq_{cmd}}{d\delta_{sp}}$ at $\delta sp = 0$, deg/(sec * in)
$t_{\Delta\phi_w=90°}$	Time to wind axis bank angle change of 90°, sec
u	Body axis longitudinal velocity, ft/sec
$\dot{u}$	Body axis longitudinal acceleration, ft/sec^2
v	Body axis lateral velocity, ft/sec
$\dot{v}$	Body axis lateral acceleration, ft/sec^2
w	Body axis vertical velocity, ft/sec
$\dot{w}$	Body axis vertical acceleration, ft/sec^2
α	Angle of attack, deg.
β	Sideslip angle, deg.
$\Delta C_{D_{SB}}$	Drag coefficient increment due to speed brake deflection

$\Delta C_{L_{SB}}$ Lift coefficient increment due to speed brake deflection

$\Delta\phi_w$ Wind axis bank angle change, deg

δ_{SB} Speed brake deflection, deg

δ_{sp} Pilot stick position, inches, (positive ≡ nose-up ≡ aft)

$\delta_{sp\text{-}max}$ Maximum pilot stick position, inches

θ Euler pitch angle, deg or rad

ϕ Euler bank angle, deg or rad

ψ Euler heading or yaw angle, deg or rad

Abbreviations

A/B Afterburner (max thrust)

CAP Control Anticipation Parameter

CGI Computer Generated Image

CHR Cooper-Harper Rating

CRT Cathode Ray Tube

DMS Differential Maneuvering Simulator

EQM Equations of Motion

HARV High-Alpha Research Vehicle

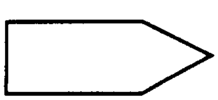
HUD Heads-up display

m.a.c. Mean aerodynamic chord

MATV Multi-Axis Thrust Vectoring

PLA Power lever angle

On block diagrams in Appendix C and D conventional symbology is used and all variables are defined in Appendix E and F. The following designations are given for nonstandard symbols:



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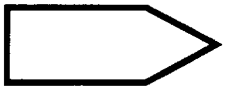

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DESCRIPTION OF FACILITIES

The simulation was conducted using the NASA Langley Differential Maneuvering Simulator (DMS). The DMS is a fixed-base simulator with the capability of simulating two airplanes as they maneuver relative to each other and the earth. A wide-angle visual display is provided for each pilot inside two 40-foot-diameter projection spheres. Each sphere encloses a cockpit, airplane-image projection systems, and a Computer Generated Image (CGI) sky-Earth-Sun projection system (fig. 1). Each pilot is provided a projected image of his opponent's airplane, giving range and attitude cues. Reference 2 contains a detailed, although not current, description of the DMS.

Figure 1. NASA Langley Differential Maneuvering Simulator (DMS).

The DMS is driven by a real-time digital simulation system built around a CONVEX 3800 computer. Dynamics of the generic airplane were calculated using six-degree-of-freedom rigid body equations of motion with an 40 Hz frame rate. Overall transport delay of the system is around 110 milliseconds.

Figure 2 is a photograph showing the cockpit and visual scene. Each cockpit incorporated three CRT heads-down displays and a heads-up display (HUD) with a computer-driven gunsight representative of current fighter aircraft equipment. Displays similar to F-18 displays were provided to the pilot for this work.

A movable center stick was provided for pitch and roll commands from the pilot. A McFadden Control Loader system was used to provide artificial stick feel. The four airplanes herein used longitudinal force gradient and dynamic characteristics like those of an F-18. Longitudinal force gradient was 7 lb. per inch with a 2 lb. breakout force. Lateral stick force gradient was 3 lb. per inch with a 2 lb. breakout force. Symmetrical longitudinal stick travel of ±4 inches was used but is not like an F-18. Lateral stick travel was ±3 inches, like an F-18.

Figure 2. Photograph of DMS cockpit.

GENERIC AIRPLANE MODEL CONCEPT

A simplified block diagram characterizing the generic airplane concept is shown in figure 3. The generic airplane ultimately uses the full six degree-of-freedom equations of motion (EQM) requiring angular accelerations, inertias, thrust, and lift, drag, and side force inputs from the airplane model. Therefore, in addition to defining the components of the generic airplane shown in figure 3, an engine model, and lift, drag, and side force models must be provided to whatever complexity is desired.

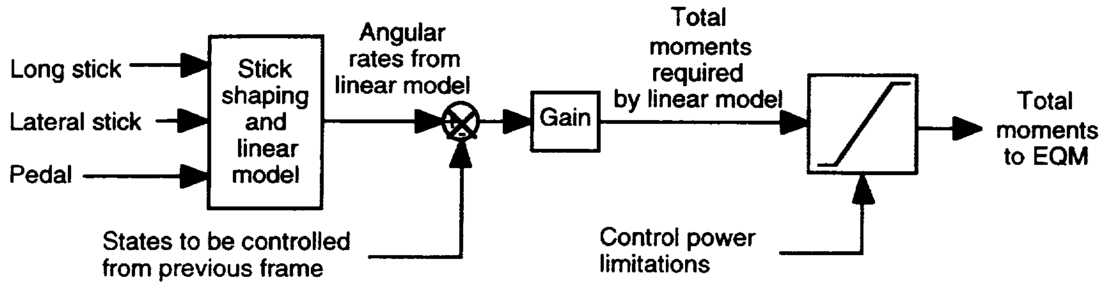

Figure 3. Simplified block diagram of generic airplane concept.

The equations of motions used by the generic airplane are given below.

$$\dot{u} = rv - wq + (n_x - \sin(\theta))g$$

$$\dot{v} = wp - ur + \left(n_y + \sin(\phi)\cos(\theta)\right)g$$

$$\dot{w} = uq - vp - (n_z - \cos(\phi)\cos(\theta))g$$

$$\dot{p} = \frac{LTOT - qr\left(I_{zz} - I_{yy}\right) + pqI_{xz} + \left(NTOT - pq\left(I_{yy} - I_{xx}\right) - qrI_{xz}\right)\frac{I_{xz}}{I_{zz}}}{I_{xx} - \frac{I_{xz}^2}{I_{zz}}}$$

$$\dot{q} = \frac{MTOT - pr(I_{xx} - I_{zz}) + I_{xz}\left(r^2 - p^2\right)}{I_{yy}}$$

$$\dot{r} = \frac{NTOT - pq\left(I_{yy} - I_{xx}\right) + I_{xz}(\dot{p} - qr)}{I_{zz}}$$

The generic airplane structure consists of stick shaping to provide the desired commands to a linear model followed by non-linear components. Stick shaping can take any form with the output to the linear model being the desired value the aircraft state is to match. The linear model can range from the very simple, short period and roll mode, to the full state space matrix. The overall airplane is made to follow the linear model by subtracting the airplane rates from the linear model rates and multiplying by a gain resulting in the total moments required to match the linear model in one iteration. Therefore, during very dynamic maneuvering, the actual airplane is one time step behind the linear model. Otherwise the linear model will be followed exactly unless angular acceleration requirements exceed the control power available as shown in figure 3. These control power limitations can be ignored entirely, i.e., use a perfect linear model, or modeled to any level of complexity. When control power limitations are encountered the linear model is not followed and controllability is sacrificed. The control power limits prevent maneuvering where control power is not available without having to develop linear models across and entire envelope of angles of attack, dynamic pressure, and thrust available combinations. The control power limitations can take many forms. In the examples given herein, control power limits are computed based on maximum and minimum aerodynamic coefficients for roll, pitch, and yaw and angle of attack, dynamic pressure, wing area, wing span, and mean aerodynamic cord. For this study control power limits of the two airplanes with post stall agility also included thrust level and maximum pitch and yaw thrust vectoring angles in the control power limits. The most agile example also assumed larger aerodynamic yaw and roll control power at high-α. The level of yaw control used would be possible by utilizing advanced aerodynamic controls such as moveable forebody strakes (ref. 3)

FOUR EXAMPLE GENERIC AIRPLANES

General Description and Components

Four example generic airplanes representing various agility levels of current or future fighter aircraft are presented below. The four airplanes vary only in agility levels (pitch and roll performance) and were used in a one versus two air combat study conducted at NASA Langley Research Center. The four airplanes generally represent the following: 1) an airplane with a 26° angle-of-attack (α) limit, representative of an F-16, MiG-29, or Su-27; 2) an airplane with roll control up to 35° α and pitch control up to 60° α, representative of an F/A-18; 3) an airplane with roll and pitch control up to 70° α, representative of the F-16 MATV, F/A-18 HARV, or X-31 and; 4) an airplane with roll and pitch control up to 90° α, representative of a more agile aircraft that could potentially be built based on recently proven technologies. All four airplanes are based on the same generic airplane structure and are intended to have the same overall features. Pilot vehicle interface, in terms of what the stick commands, and mode selections are the same. All four aircraft have the same conventional performance, i.e., turn rate versus g and energy bleed rates, within their respective α envelope. Similarity of handling qualities was maintained as consistent as possible with the exception of maximum pitch and roll rates across the four airplanes common flight envelopes. Therefore, the four airplanes had common features only differing in the commanded angular acceleration and associated stick sensitivity differences for large amplitude high-rate maneuvers. Also, associated with the varying angular acceleration requirements, the four configurations had different control power limits. With only these differences, thrust, weight, inertias, lift, drag and side force data were the same for all four aircraft (Table I).

Wing area (ft^2)	600
Wing span (ft)	43
m.a.c. (ft)	17
Weight (lb)	45,000
I_{xx} (slugs ft^2 / sec)	27,000
I_{yy} (slugs ft^2 / sec)	123,936
I_{zz} (slugs ft^2 / sec)	211,000
I_{xz} (slugs ft^2 / sec)	-2,971

Table I. Geometrical and mass properties of the four generic airplanes.

The lift, drag, and side force coefficients used for the four airplanes were based on an F/A-18. Coefficient buildup equations used for C_L and C_D are given below and a complete listing of the data for the C_L and C_D build-up equations as well as C_Y are given in Appendix A. C_L and C_D for the configurations with the speed brake retracted are shown in figure 4 and 5.

(1) $$C_L = C_{L_0} + SB_{Gain} * \Delta C_{L_{SB}} * \frac{\delta_{SB}}{60}, \quad \text{where } SB_{Gain} = 1.0$$

(2) $$C_D = C_{D_0} * C_{D_{Mach}} + SB_{Gain} * \Delta C_{D_{SB}} * \frac{\delta_{SB}}{60}, \quad \text{where } SB_{Gain} = 1.0$$

(3) $$C_X = C_L * \sin\alpha - C_D * \cos\alpha$$

(4) $$C_Z = -C_L * \cos\alpha - C_D * \sin\alpha$$

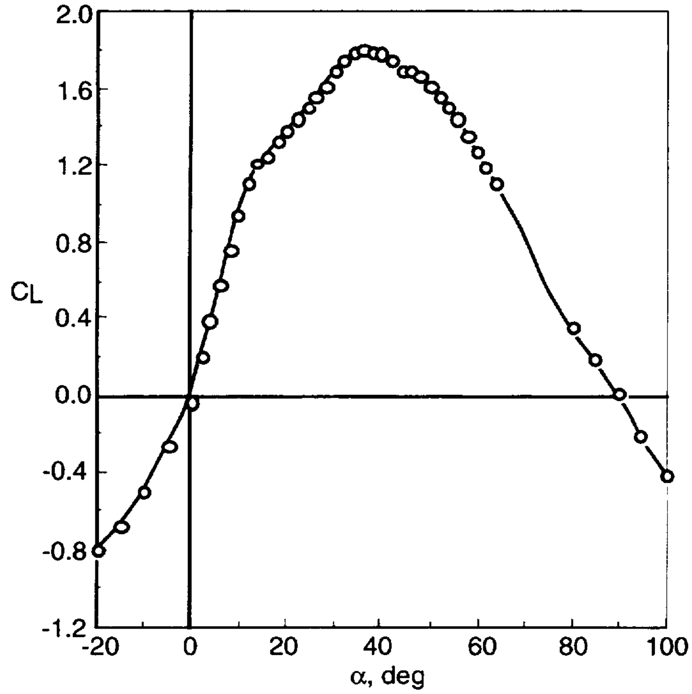

Figure 4. Lift coefficient for the four generic airplanes as a function of α.

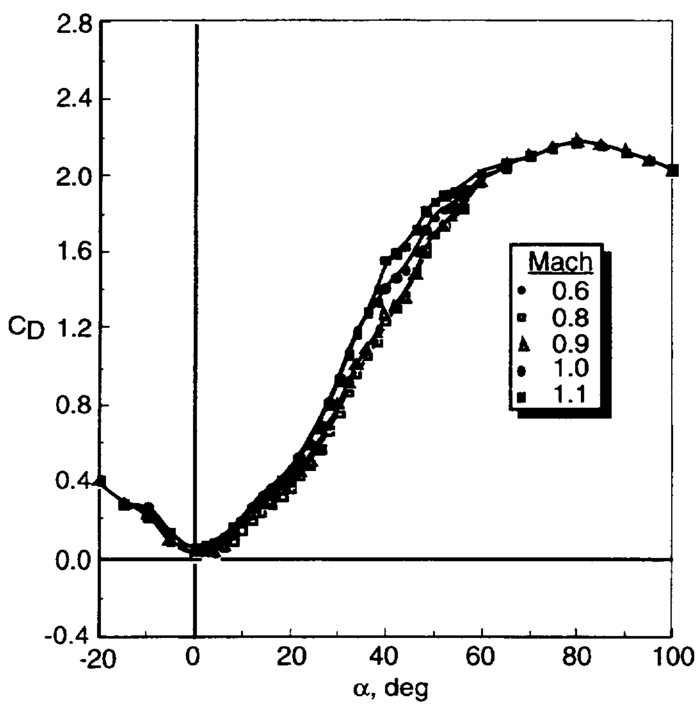

Figure 5(a). Subsonic and transonic drag coefficient for the four generic airplanes as a function of α and Mach number.

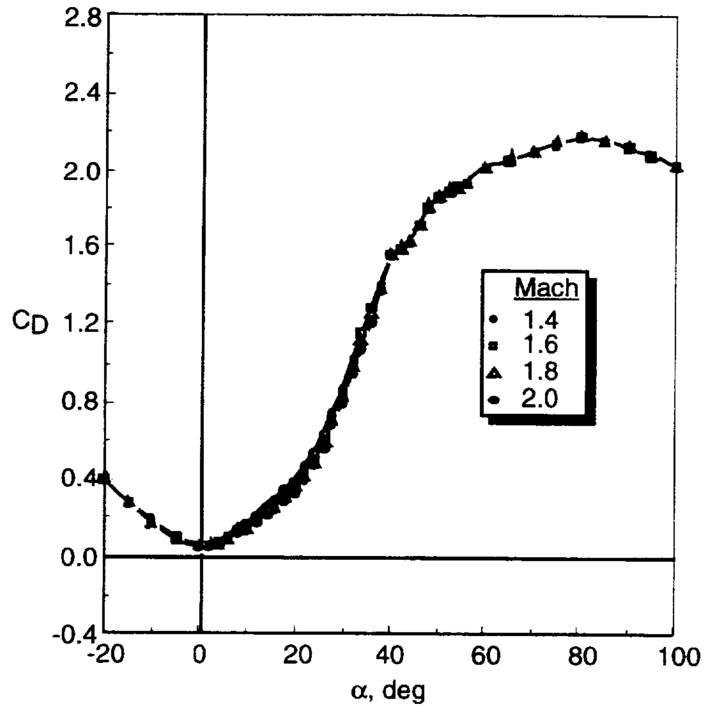

Figure 5(b). Supersonic drag coefficient for the four generic airplanes as a function of α and Mach number.

A model of the General Electric F110-GE-129 afterburning turbofan engine was used during these studies. Net thrust values were modeled as functions of throttle setting (PLA), Mach number, and altitude (see Appendix B). Figure 6 shows net thrust versus Mach number and altitude for selected power settings. A first order lag between throttle movement and net thrust response with a time constant of 1 second was used to simulate engine spool-up/spool-down time. Each aircraft was equipped with two of these engines. Figure 7 shows turn rate versus Mach number, for $\alpha < 35°$ (approximately $C_{L_{max}}$), achievable by the generic airplanes based on aerodynamic characteristics. Maximum sustained g based on aerodynamic characteristics and thrust available($P_s = 0$) is also presented.

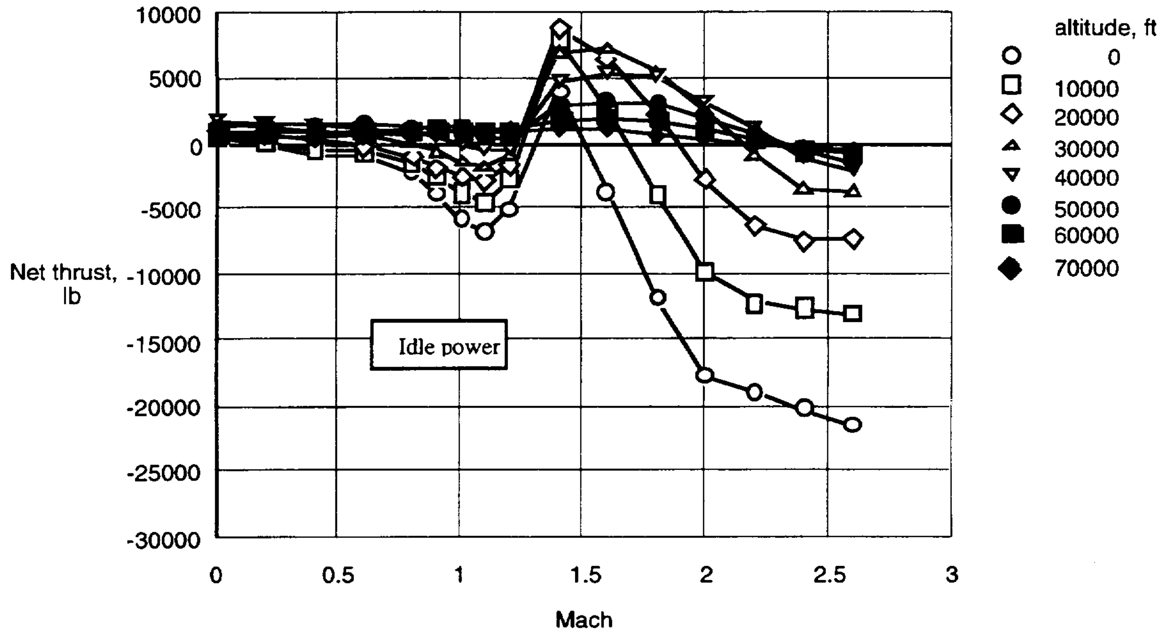

Figure 6(a). Net thrust versus Mach and Altitude for two engines at idle power.

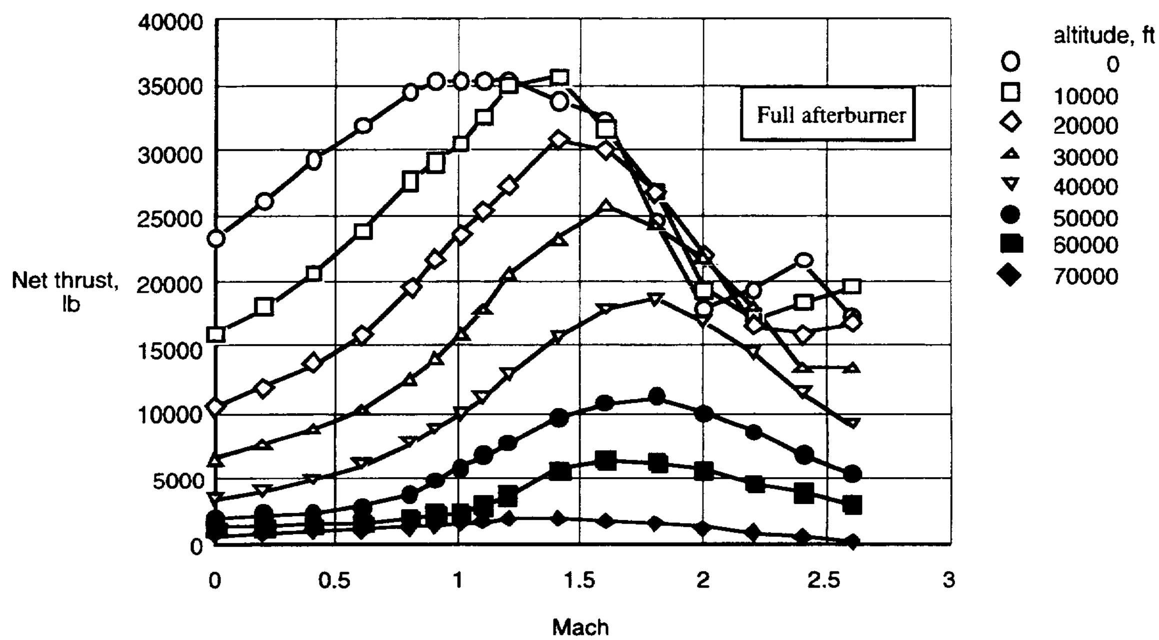

Figure 6(b). Net thrust versus Mach and Altitude for two engines at maximum power.

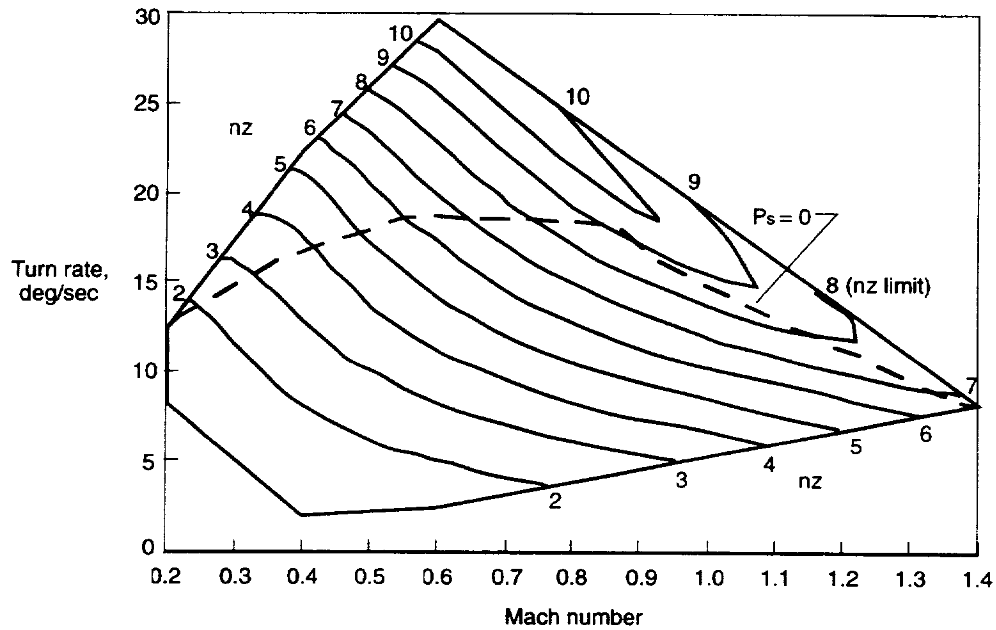

Figure 7(a). Turn rate vs. Mach and maximum sustained turn rate vs. Mach ($P_S = 0$) at an altitude of 5,000 feet.

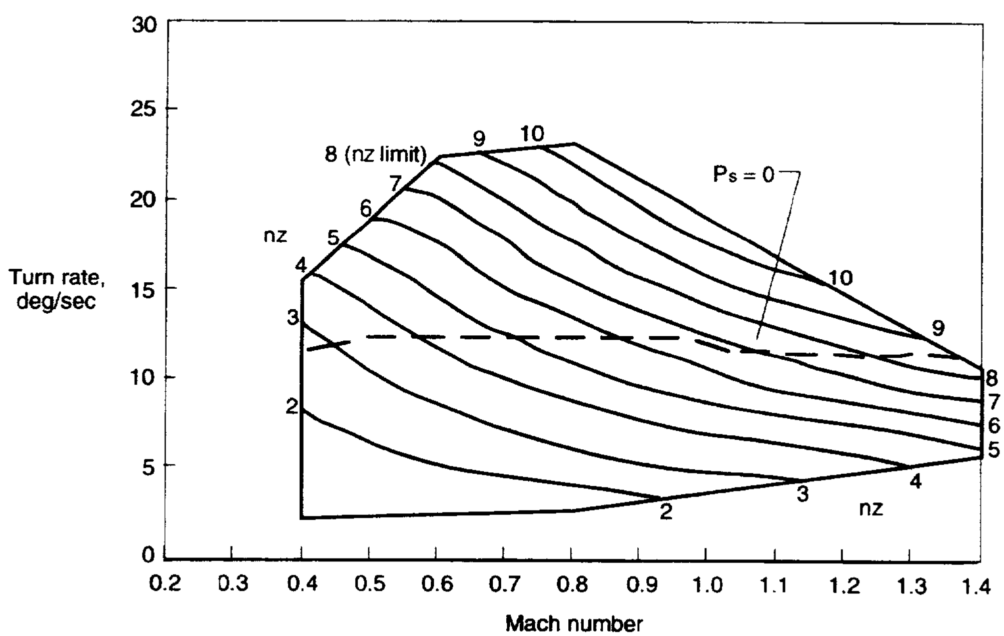

Figure 7(b). Turn rate vs. Mach and maximum sustained turn rate vs. Mach ($P_S = 0$) at an altitude of 15,000 feet.

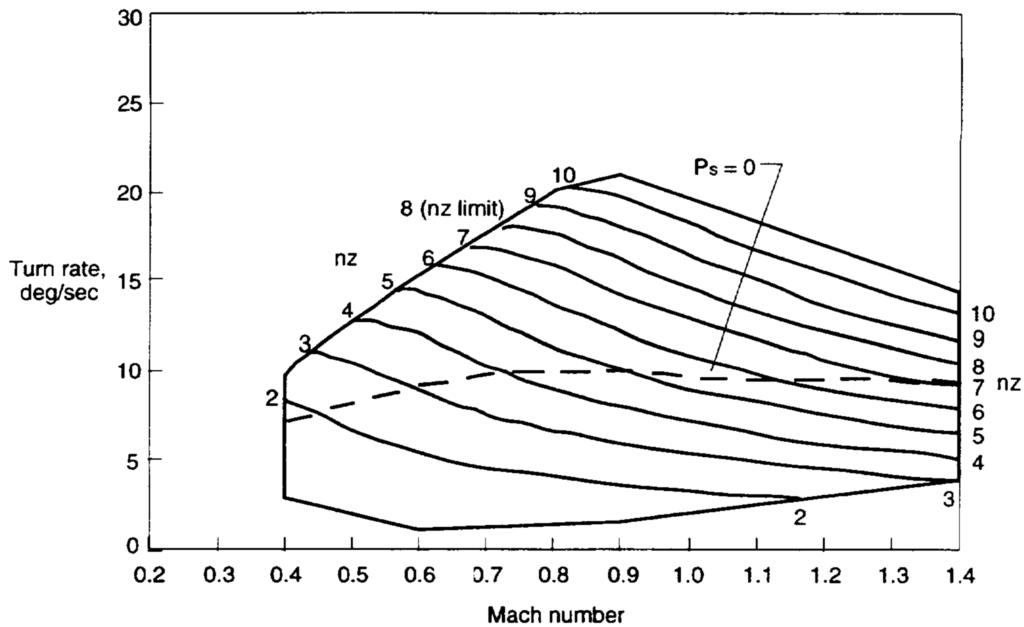

Figure 7(c). Turn rate vs. Mach and maximum sustained turn rate vs. Mach ($P_S = 0$) at an altitude of 25,000 feet.

Longitudinal Axis

Complete block diagrams for the longitudinal axis are shown in Appendix C. The diagrams were the same for all four airplanes with variables inside the diagrams changing to produce the various pitch agility levels. Appendix E lists the data corresponding to the longitudinal axis diagrams. Note that most data was the same for all three airplanes providing similar overall characteristics.

Longitudinal stick was implemented to command body axis pitch rate and angle-of-attack feedback was used to provide artificial α cueing through the stick. The n_Z artificial feel option shown on the diagrams was disabled for the generic airplanes described herein. In order to maintain pitch rate command symmetry and maintain the stick position for zero pitch-rate command, α feedback did not alter the pitch rate command stick shaping. Rather it moved the zero stick force position forward so the zero pitch rate and zero stick force position did not correspond (fig. 8). This meant that with near zero pitch rate, if α was increased through 30°, the stick would move forward to hold α at 30° unless the pilot applied back pressure. Also, the stick force required to hold constant pitch rate would increase as α went through 30°. This feature coupled with an aural tone alerted the pilot to α increases above $\alpha = 30°$. Moving the zero force position rather than the zero rate position also meant that the pilot could always get zero rate at the same stick position.

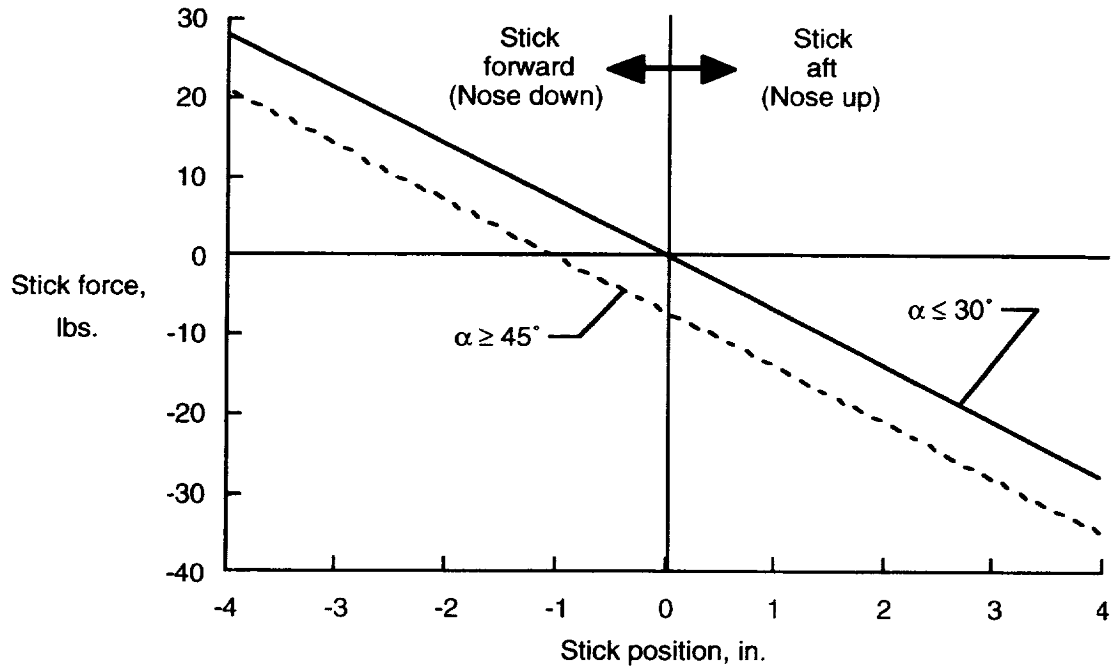

Figure 8. Stick force versus stick position.

A dynamic parabolic stick shape was used to provide different commanded maximum rates at maximum stick deflection while maintaining near constant stick gradient (deg/sec/in) around zero commanded rate. The parabolic stick shape is defined in equation 5 below. Each maximum commanded rate desired requires a different value of A and B.

(5) $$q_{cmd} = \delta_{sp}\left(A\left|\delta_{sp}\right| + B\right),$$

For $\delta_{sp} \geq 0$,

(6) $$q_{cmd} = \left(A\,\delta_{sp}^2 + B\,\delta_{sp}\right),$$

Then,

(7) $$\frac{dq_{cmd}}{d\delta_{sp}} = 2A\,\delta_{sp} + B.$$

Equations 6 and 7 yield two equations and two unknowns. Then defining the stick gradient at zero stick deflection and the maximum commanded rate provides two points. Solving for A and B using the two defined points yields:

(8) $$B = \text{Slope at } \delta_{sp} = 0$$

and

(9) $$A = \frac{1}{\delta_{sp-max}}\left(\frac{q_{cmd\text{-}max}}{\delta_{sp-max}} - Slope\right).$$

Therefore,

(10) $$q_{cmd} = \delta_{sp}\left(\left(\frac{1}{\delta_{sp-max}}\left(\frac{q_{cmd\text{-}max}}{\delta_{sp-max}} - Slope\right)\right)\left|\delta_{sp}\right| + Slope\right)$$

The stick shaping (equation 10) provided variations in the maximum-rate command as a function of angle of attack and thrust level, while maintaining similar stick gradients for tracking when the stick was near zero deflection (see Appendix C and E).

The commanded pitch rate is then limited by n_z and α limiters. An n_z limit of 8 g's was used for all four example airplanes. Two α limits were available in airplanes 2, 3, and 4. One limited α to approximately 26° and the other to an α corresponding to the maximum pitch authority for the airplane. Airplane 1 always had the 26° α limit. The 26° limit could prevent entry into the post stall α region, helping with energy management. The higher α limit could be selected when needed to allow post stall maneuvering when desired. Angle-of-attack limit selection was made via a button on the stick, referred to as the "agility switch." Note that the realized α limit is not necessarily equal to the α limit given in the diagram. The desired α limits can only be obtained by iterating on the α limit values in the control law diagrams.

The stick force bias, dynamic parabolic stick shaping, and limiters make up the longitudinal stick shaping. The pitch rate command then goes to the linear model. The examples used only the short period mode. Frequency and damping were computed based on α, $\bar{q}$, and the control anticipation parameter (CAP) (ref. 4). Output from the linear model was compared to the airplanes pitch rate during the previous frame and pitch rate due to kinematic coupling. The result was multiplied by a gain to provide the pitch acceleration required to follow the linear model. The gain was set such that the linear model would be followed exactly. Pitch moment requirement was then passed through a limiter with limits computed based on aerodynamic and thrust vectoring control power available.

Varying the commanded pitch rate and linear model yielded an airplane with performance variations across a defined flight envelope. The control power limits, as implemented, add a high degree of realism without adding the complication of providing linear models for all possible flight conditions.

Lateral/Directional Axis

Complete block diagrams for the lateral/directional axis are shown in Appendix D. The diagrams were the same for all four airplanes with only the values of the variables inside the diagrams changing. Appendix F lists the data corresponding to the lateral/directional axis diagrams. Note that most data was the same for all four airplanes providing similar overall characteristics.

Lateral stick commanded stability axis roll rate and rudder pedals were not used. The lateral stick used a dynamic parabolic stick shaping scheme, like the one described above for the longitudinal stick. The stick shaping provided maximum rate command variations as a function of angle of attack and thrust level, while maintaining a similar stick gradient (deg/sec/in) for tracking (when the stick was near zero deflection). The stability axis roll rate command from the stick was then split into body axis roll and yaw commands. Sideslip feedback was added to the roll and yaw commands to counter sideslip buildup due to gravity effects and control power limits in either axis. The roll and yaw commands then pass through a first order filter representing the roll mode. The roll mode time constant varied with angle of attack to provide near level one handling qualities across the angle of attack envelope. The data used for the roll mode time constants originally came from references 1 and 5.

Output from the linear models was compared to the roll and yaw rates of the airplane. As in the longitudinal axis the result was multiplied by a gain to yield roll and yaw accelerations required to match the linear model. Then the roll and yaw accelerations were limited based on aerodynamic and thrust vectoring control power available.

Agility of Example Airplanes

In this paper, agility refers to pitch and roll performance. The four agility levels modeled are for: 1) an airplane with a 26° α limit, representative of an F-16, MiG-29, or Su-27; 2) an airplane with roll control up to 35° α and pitch control up to 60° α, representative of an F/A-18; 3) an airplane with roll and pitch control up to 70° α, representative of the F-16 MATV, F/A-18 HARV, or X-31 and; 4) an airplane with roll and pitch control up to 90° α, representative of a more agile aircraft that could potentially be built based on recently proven technologies. Note that airplane 1 is the same as airplane 2 with the exception of the 26° α limit. The 26° α limit was achieved by disabling the agility switch (AGSW always false).

Maximum wind axis roll rate and time to bank through a wind axis bank angle change are shown in figures 9 and 10 below. The values shown are from a 1-g trim condition at 25000 feet. Maximum thrust was selected and after engine spool-up time, maximum lateral stick was applied and held until $\Delta\phi_W \geq 90°$. Roll performance between airplanes 1 and 2 is identical up through the 26° α limit. The roll performance of airplane 2 drops off rapidly at α's greater than 25°, whereas airplanes 3 and 4 maintain good roll performance throughout their available α range.

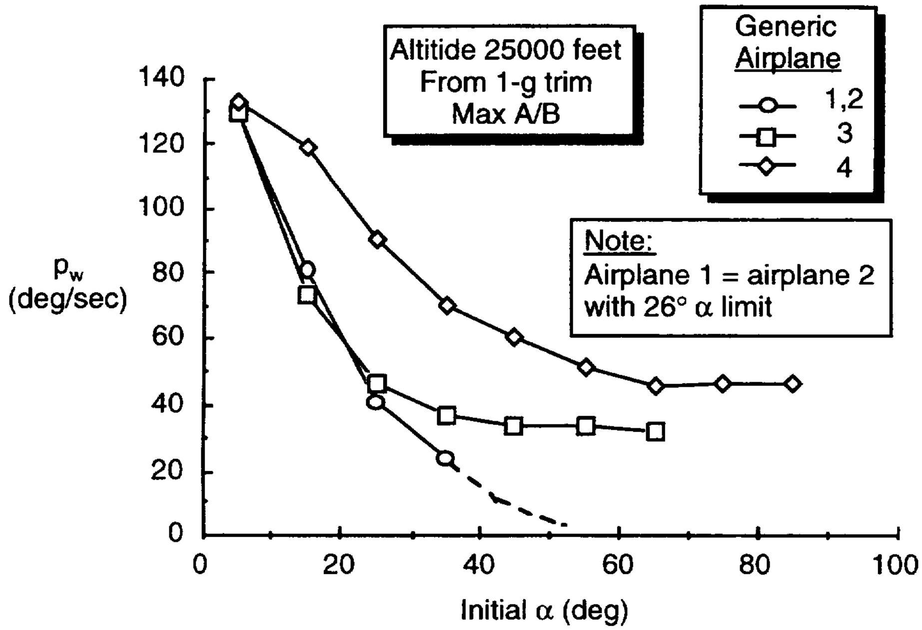

Figure 9. Maximum wind axis roll rate achieved during roll through 90° bank angle change.

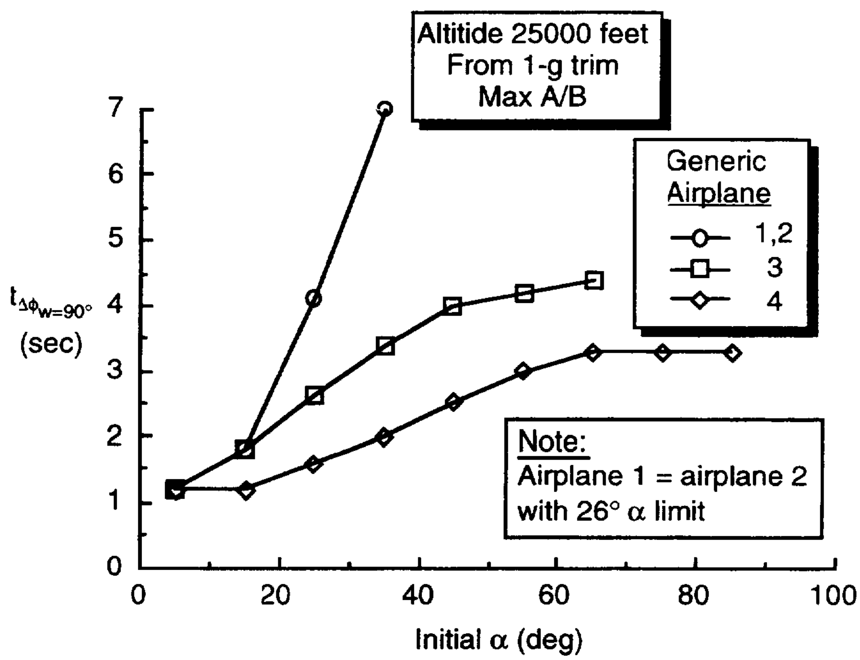

Figure 10. Time to bank through wind axis bank angle change of 90°.

Maximum pitch rate and acceleration are shown in figures 11 and 12 below. The values shown are from a 1-g trim condition at 25000 feet. Maximum thrust was selected and after engine spool-up time, maximum longitudinal stick was applied and held. The pitch model of airplanes 1 and 2 are the same with the exception of the α limit. Pitch performance for $\alpha > 5°$ was reduced due to the α limiter with a limit of 26°. All four airplanes have pitch performance similar to airplane 1 when the Agility Switch is off.

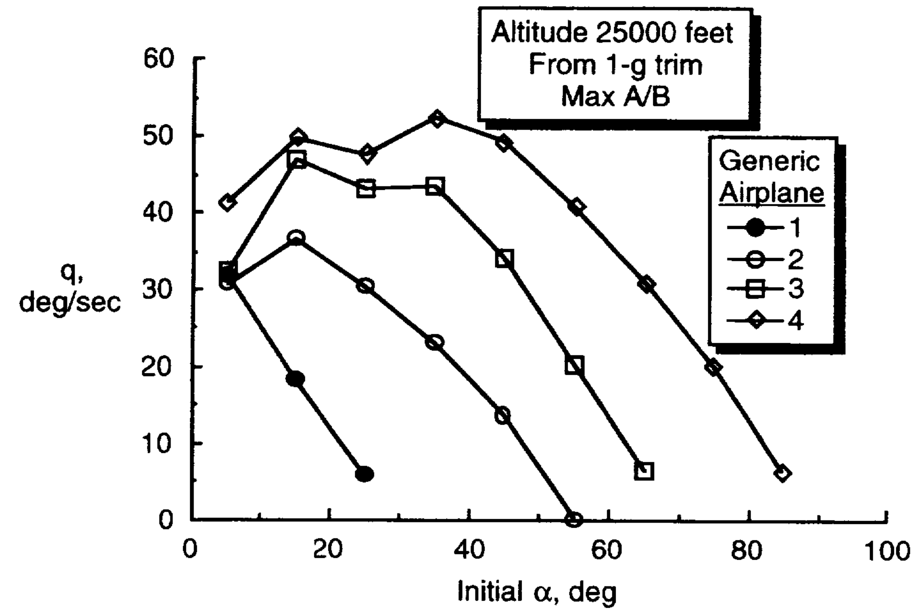

Figure 11. Maximum pitch rate achieved from 1-g trim at maximum power.

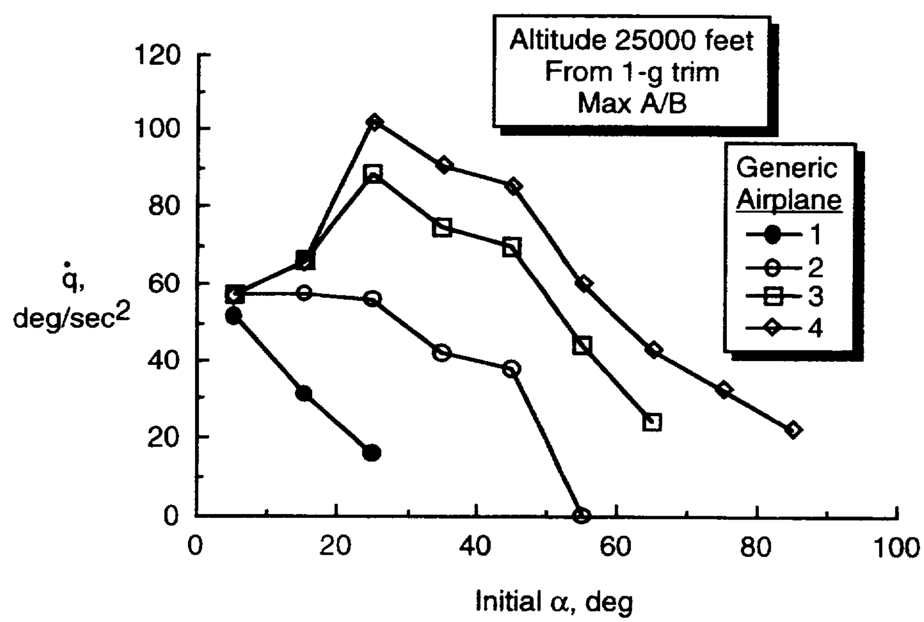

Figure 12. Maximum pitch acceleration achieved from 1-g trim at maximum power.

Handling Qualities of the Example Airplanes

Handling qualities is not the emphasis of this paper nor was it the emphasis of the HAVV-TWO program for which the generic airplane model was originally developed. Therefore, results from previous studies were used to determine the desired frequency and damping for the short period and the roll mode time constant as well as stick sensitivity for small inputs. A very brief overview follows but detailed results are not presented herein..

A brief handling qualities investigation was made using two pilots and the maneuvers discussed in reference 6. Cooper-Harper ratings (CHR) (ref. 7 and fig. 13) were taken for all the maneuvers with airplanes 2, 3, and 4. Virtually all CHRs were either 3 or 4 with the configurations presented herein. A few ratings of 2 and 5 were received as well. Pilot comments during the evaluation were intentionally few. Basically the pilots were ask to point out any glaring problems, i.e., those that would impact the HAVV-TWO results. Based on the comments a few changes to the original generic airplane set up were made resulting in the models described herein. Comments made on the stick implementation referred to some minor difficulties with tracking in the vicinity of 30° α where the stick force biasing started. Otherwise the results were good. During the air combat maneuvering some pilots were initially puzzled when they occasionally lost control of airplane 3 or 4. The loss of control occurred at around 25 knots indicated airspeed or less and was expected.

The longitudinal stick force biasing used herein is unique. It provides stick force feedback to alert the pilot when α goes above 30°. Conventional α feedback schemes, either α command or augmented pitch rate command similar to the one herein, drive the zero pitch rate stick position back as α increases. During acquisitions with the conventional approaches many pilots complain about hunting for the proper stick position because it is constantly moving. It was hoped that this scheme would eliminate that problem. This investigation was not through enough to yield a definitive answer. Indications are that gross acquisitions do not suffer from the "hunting for a stick position" phenomena. However, some mild annoyances were noted when tracking in the vicinity of 30° α where the stick force biasing starts.

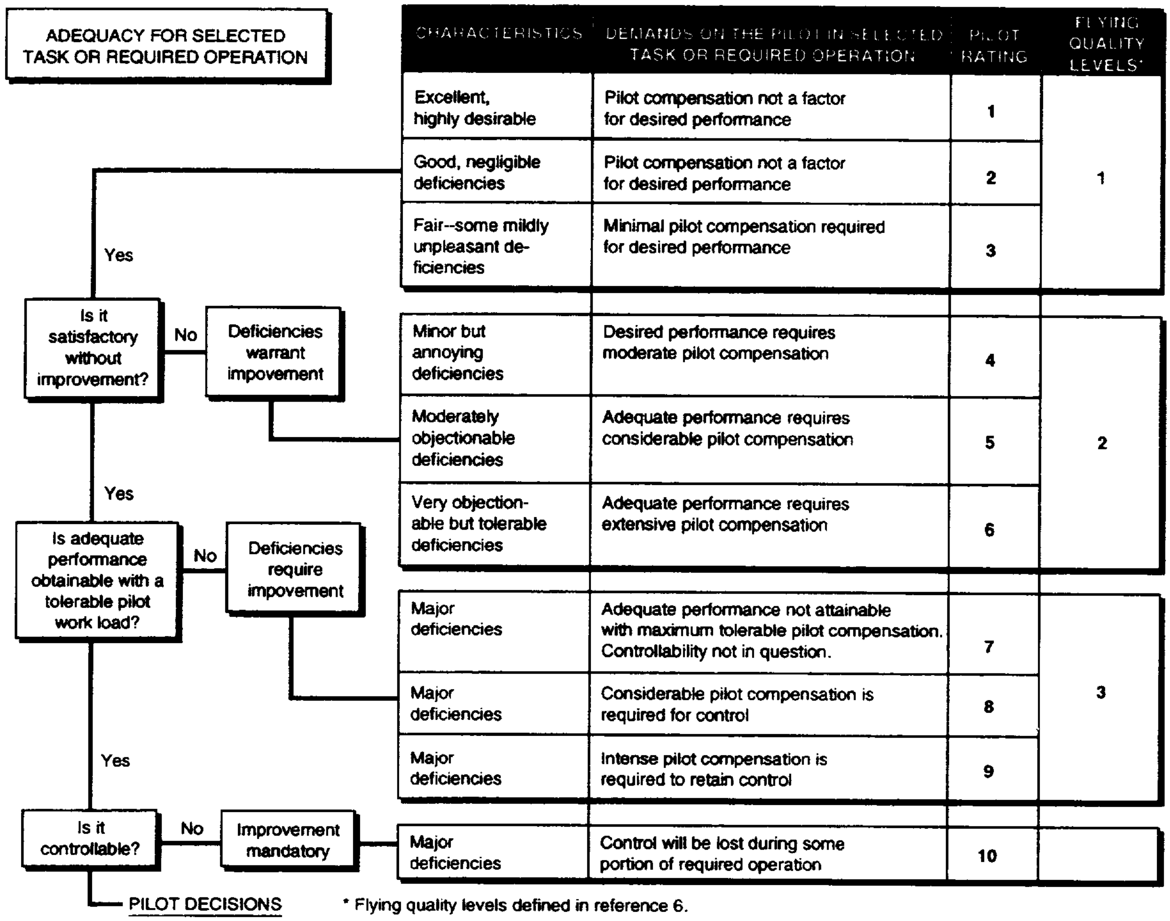

Figure 13. Cooper-Harper rating scale.

CONCLUSIONS

A generic airplane model concept was developed to allow configurations with various agility, performance, handling qualities, and pilot vehicle interface to be generated rapidly for piloted simulation studies. The simple concept allows stick shaping and various stick command types or modes to drive an airplane with both linear and nonlinear components. Output from the stick shaping goes to linear models or a series of linear models that can represent an entire flight envelope. The generic model also has provisions for control power limitations, a nonlinear feature. Therefore, departures from controlled flight are possible. Note that only loss of control is modeled, i.e., the generic airplane does not accurately model post departure phenomenon. The model concept is presented herein, along with four example airplanes. Agility was varied across the four example airplanes without altering specific excess energy or significantly altering handling qualities. A new feedback scheme to provide α cueing to the pilot, while using a pitch rate command system, was implemented and tested.

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APPENDIX A - LIFT, DRAG, and SIDE FORCE DATA

C_{L_0}

α

-180.	-175.	-170.	-165.	-160.	-155.	-150.
-145.	-140.	-135.	-130.	-125.	-120.	-115.
-110.	-105.	-100.	- 95.	- 90.	- 85.	- 80.
-75.	- 70.	- 65.	- 60.	- 55.	- 50.	- 45.
-40.	- 35.	- 30.	- 25.	- 20.	- 15.	- 10.
-5.	0.	2.	4.	6.	8.	10.
12.	14.	16.	18.	20.	22.	24.
26.	28.	30.	32.	34.	36.	38.
40.	42.	44.	46.	48.	50.	52.
54.	56.	58.	60.	62.	64.	80.
85.	90.	95.	100.	105.	110.	115.
120.	125.	130.	135.	140.	145.	150.
155.	160.	165.	170.	175.	180.	

-0.21000	0.05000	0.47000	0.83000	1.03000	1.06000	1.10000
1.09000	1.14000	1.13000	1.11000	1.05000	0.96000	0.85000
0.70000	0.56000	0.40000	0.24000	0.06000	-0.22000	-0.38000
-0.53000	-0.67000	-0.82000	-0.94000	-1.07000	-1.16000	-1.22000
-1.22000	-1.19000	-1.08000	-0.95000	-0.81000	-0.68000	-0.50000
-0.27000	-0.04000	0.20962	0.38512	0.57315	0.75845	0.92992
1.08813	1.19320	1.24308	1.31153	1.36873	1.43473	1.49446
1.54916	1.61239	1.68580	1.74871	1.78719	1.80406	1.79315
1.78187	1.73584	1.68482	1.69021	1.66237	1.61107	1.55468
1.49809	1.42964	1.34925	1.25725	1.17181	1.09641	0.35000
0.18000	0.00000	-0.22000	-0.42000	-0.57000	-0.76000	-0.91000
-1.04000	-1.16000	-1.25000	-1.34000	-1.38000	-1.40000	-1.42000
-1.40000	-1.34000	-1.22000	-0.93000	-0.56000	-0.21000	

$\Delta C_{L_{SB}}$

Mach	α						
	4.	0.	4.	8.	12.	16.	20.
	24.	28.	32.	36.	40.		
0.2	-0.04800	-0.04800	-0.05100	-0.05600	-0.06800	-0.08000	-0.08600
	-0.08800	-0.08200	-0.07800	-0.07700	-0.07900		
0.6	-0.06060	-0.06030	-0.06050	-0.05960	-0.05480	-0.04180	-0.03190
	-0.03410	-0.04700	-0.05930	-0.06660	-0.06840		
0.8	-0.08430	-0.08460	-0.08430	-0.08190	-0.07710	-0.06820	-0.06080
	-0.06500	-0.08900	-0.09930	-0.10310	-0.10330		
0.9	-0.11170	-0.11140	-0.11020	-0.10790	-0.10060	-0.09830	-0.10260
	-0.10990	-0.11770	-0.12400	-0.12680	-0.12610		
1.2	-0.08340	-0.08570	-0.09200	-0.09830	-0.10460	-0.11190	-0.11620
	-0.12100	-0.12230	-0.12300	-0.12330	-0.12400		

C_{D_0}

α

-180.	-175.	-170.	-165.	-160.	-155.	-150.
-145.	-140.	-135.	-130.	-125.	-120.	-115.
-110.	-105.	-100.	- 95.	- 90.	- 85.	- 80.
-75.	- 70.	- 65.	- 60.	- 55.	- 50.	- 45.
-40.	- 35.	- 30.	- 25.	- 20.	- 15.	- 10.
-5.	0.	2.	4.	6.	8.	10.
12.	14.	16.	18.	20.	22.	24.
26.	28.	30.	32.	34.	36.	38.
40.	42.	44.	46.	48.	50.	52.
54.	56.	60.	65.	70.	75.	80.
85.	90.	95.	100.	105.	110.	115.
120.	125.	130.	135.	140.	145.	150.
155.	160.	165.	170.	175.	180.	

0.06000	0.06000	0.03000	0.17000	0.33000	0.42000	0.54000
0.65000	0.83000	0.99000	1.17000	1.33000	1.47000	1.62000
1.72000	1.84000	1.92000	2.00000	2.03000	1.98000	1.94000
1.90000	1.84000	1.77000	1.65000	1.58000	1.44000	1.30000
1.12000	0.93000	0.73000	0.56000	0.40000	0.28000	0.21860
0.08020	0.02054	0.02303	0.03041	0.05252	0.09145	0.13827
0.19069	0.23660	0.27236	0.31605	0.35909	0.41843	0.48126
0.56488	0.66105	0.76210	0.86997	0.96809	1.05733	1.13371
1.23370	1.30621	1.37484	1.49704	1.61027	1.68975	1.74090
1.79161	1.82929	1.96500	2.04000	2.10000	2.14000	2.17000
2.15500	2.12500	2.08000	2.03000	1.97000	1.94000	1.82000
1.68000	1.54000	1.40000	1.24000	1.07000	0.90000	0.75000
0.60000	0.44000	0.28000	0.12000	0.00001	0.06000	

$C_{D_{Mach}}$

Mach				α			
	-180.	-175.	-170.	-165.	-160.	-155.	-150.
	-145.	-140.	-135.	-130.	-125.	-120.	-115.
	-110.	-105.	-100.	- 95.	- 90.	- 85.	- 80.
	-75.	- 70.	- 65.	- 60.	- 55.	- 50.	- 45.
	-40.	- 35.	- 30.	- 25.	- 20.	- 15.	- 10.
	-5.	0.	5.	10.	15.	20.	25.
	30.	35.	40.	45.	50.	55.	60.
	65.	70.	75.	80.	85.	90.	95.
	100.	105.	110.	115.	120.	125.	130.
	135.	140.	145.	150.	155.	160.	165.
	170.	175.	180.				
0.8	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000
	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000
	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000
	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000
	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000
	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000
	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000
	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000
	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000
	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000
	1.00000	1.00000	1.00000				
0.9	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000
	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000
	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000
	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000
	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.05581
	1.17830	1.22224	1.39270	1.33234	1.11170	1.09401	1.03592
	1.04872	1.04182	1.03233	0.98150	0.99715	1.00000	1.00000
	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000
	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000
	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000
	1.00000	0.00000	1.00000				
1.0	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000
	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000
	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000
	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000
	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.22347
	1.45168	2.06855	2.05579	1.41449	1.34078	1.28957	1.24461
	1.24301	1.23746	1.14919	1.07953	1.05508	1.03119	1.01137
	1.00245	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000
	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000
	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000
	1.00000	0.00000	1.00000				
1.1	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000
	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000
	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000
	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000
	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.17658
	1.45636	2.48466	2.24158	1.36416	1.27664	1.26002	1.21065
	1.21655	1.21258	1.26078	1.15598	1.10256	1.06150	1.02901
	1.00735	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000
	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000
	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000
	1.00000	0.00000	1.00000				

$C_{D_{Mach}}$

Mach	α						
	-180.	-175.	-170.	-165.	-160.	-155.	-150.
	-145.	-140.	-135.	-130.	-125.	-120.	-115.
	-110.	-105.	-100.	- 95.	- 90.	- 85.	- 80.
	-75.	- 70.	- 65.	- 60.	- 55.	- 50.	- 45.
	-40.	- 35.	- 30.	- 25.	- 20.	- 15.	- 10.
	-5.	0.	5.	10.	15.	20.	25.
	30.	35.	40.	45.	50.	55.	60.
	65.	70.	75.	80.	85.	90.	95.
	100.	105.	110.	115.	120.	125.	130.
	135.	140.	145.	150.	155.	160.	165.
	170.	175.	180.				
1.4	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000
	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000
	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000
	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000
	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	0.87008
	1.22052	2.54695	2.08964	1.16415	1.09240	1.09642	1.11942
	1.14568	1.19203	1.26078	1.15598	1.10256	1.06150	1.02901
	1.00735	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000
	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000
	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000
	1.00000	0.00000	1.00000				
1.6	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000
	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000
	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000
	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000
	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	0.72659
	1.11767	2.50150	2.03483	1.07489	0.98853	1.00641	1.06691
	1.12957	1.20249	1.26078	1.15598	1.10256	1.06150	1.02901
	1.00735	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000
	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000
	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000
	1.00000	0.00000	1.00000				
1.8	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000
	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000
	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000
	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000
	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	0.76197
	1.10238	2.49138	1.97441	0.99577	0.94042	0.96701	1.02898
	1.09120	1.16427	1.26078	1.15598	1.10256	1.06150	1.02901
	1.00735	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000
	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000
	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000
	1.00000	0.00000	1.00000				
2.0	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000
	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000
	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000
	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000
	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	0.79735
	1.08354	2.40899	1.83878	0.93718	0.89230	0.92761	0.99105
	1.05283	1.12604	1.26078	1.15598	1.10256	1.06150	1.02901
	1.00735	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000
	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000
	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000
	1.00000	0.00000	1.00000				

$\Delta C_{D_{SB}}$

Mach	α = -4.	0.	4.	8.	12.	16.	20.	24.	28.	32.	36.	40.
0.2	0.03700	0.03400	0.03100	0.02800	0.02500	0.01800	0.01000	0.00000	0.00200	0.00200	-0.00100	-0.00500
0.6	0.05260	0.04390	0.03570	0.02810	0.02200	0.01610	0.01070	0.00460	-0.00030	-0.00230	-0.00360	-0.00380
0.8	0.05820	0.04670	0.03550	0.02550	0.01680	0.01000	0.00430	-0.00050	-0.00410	-0.00660	-0.00770	-0.00790
0.9	0.06360	0.05030	0.03800	0.02620	0.01520	0.00730	0.00090	-0.00370	-0.00700	-0.00850	-0.00900	-0.00920
1.2	0.06180	0.04820	0.03570	0.02360	0.01190	0.00190	-0.00550	-0.01010	-0.01160	-0.01260	-0.01260	-0.01280

c_Y

β				α			
	0.	5.	10.	15.	20.	25.	30.
	35.	40.	45.	50.	55.	60.	65.
	70.	75.	80.	85.	90.	95.	100.
	105.	110.	115.	120.	125.	130.	135.
	140.	145.	150.	155.	160.	165.	170.
	175.	180.					
0.	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000
	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000
	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000
	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000
	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000
	0.0000000	0.0000000					
2.	-0.0383486	-0.0374986	-0.0366486	-0.0280000	-0.0109000	-0.0163000	-0.0178000
	-0.0174000	-0.0253486	-0.0173486	-0.0183486	-0.0203486	-0.0143486	-0.0193486
	-0.0243486	-0.0258486	-0.0273486	-0.0283486	-0.0293486	-0.0283486	-0.0273486
	-0.0258486	-0.0243486	-0.0193486	-0.0143486	-0.0203486	-0.0183486	-0.0173486
	-0.0253486	-0.0174000	-0.0178000	-0.0163000	-0.0109000	-0.0280000	-0.0366486
	-0.0374986	-0.0383486					
4.	-0.0736971	-0.0717971	-0.0698971	-0.0548000	-0.0269000	-0.0321000	-0.0383000
	-0.0350000	-0.0466971	-0.0396971	-0.0326971	-0.0386971	-0.0346971	-0.0426971
	-0.0506971	-0.0536971	-0.0566971	-0.0566971	-0.0566971	-0.0566971	-0.0566971
	-0.0536971	-0.0506971	-0.0426971	-0.0346971	-0.0386971	-0.0326971	-0.0396971
	-0.0466971	-0.0350000	-0.0383000	-0.0321000	-0.0269000	-0.0548000	-0.0698971
	-0.0717971	-0.0736971					
6.	-0.1130457	-0.1059457	-0.0988457	-0.0829000	-0.0456000	-0.0472000	-0.0623000
	-0.0534000	-0.0710457	-0.0650457	-0.0550457	-0.0650457	-0.0700457	-0.0735457
	-0.0770457	-0.0825457	-0.0880457	-0.0865457	-0.0850457	-0.0865457	-0.0880457
	-0.0825457	-0.0770457	-0.0735457	-0.0700457	-0.0650457	-0.0550457	-0.0650457
	-0.0710457	-0.0534000	-0.0623000	-0.0472000	-0.0456000	-0.0829000	-0.0988457
	-0.1059457	-0.1130457					
8.	-0.1493943	-0.1393443	-0.1292943	-0.1120000	-0.0756000	-0.0665000	-0.0874000
	-0.0724000	-0.0943943	-0.0903943	-0.0813943	-0.0963943	-0.1043943	-0.1043943
	-0.1043943	-0.1108943	-0.1173943	-0.1148943	-0.1123943	-0.1148943	-0.1173943
	-0.1108943	-0.1043943	-0.1043943	-0.1043943	-0.0963943	-0.0813943	-0.0903943
	-0.0943943	-0.0724000	-0.0874000	-0.0665000	-0.0756000	-0.1120000	-0.1292943
	-0.1393443	-0.1493943					
10.	-0.1867429	-0.1736929	-0.1606429	-0.1450000	-0.1140000	-0.0902000	-0.1140000
	-0.0927000	-0.1197429	-0.1177429	-0.1137429	-0.1307429	-0.1327429	-0.1332429
	-0.1337429	-0.1392429	-0.1447429	-0.1422429	-0.1397429	-0.1422429	-0.1447429
	-0.1392429	-0.1337429	-0.1332429	-0.1327429	-0.1307429	-0.1137429	-0.1177429
	-0.1197429	-0.0927000	-0.1140000	-0.0902000	-0.1140000	-0.1450000	-0.1606429
	-0.1736929	-0.1867429					

APPENDIX B - THRUST DATA

Thrust PLA = 18.0

Altitude	Mach						
	0.00	0.20	0.40	0.60	0.80	0.90	1.00
	1.10	1.20	1.40	1.60	1.80	2.00	2.20
	2.40	2.60					
0.	464.0080	-7.4890	-872.3450	-867.5340	-2318.1021	-3997.8770	-5794.7051
	6773.5210	-5011.8589	4099.3770	-3850.7671	-11679.162	-17626.292	-18912.361
	-20198.430	-21484.498					
10000.	553.2610	132.6380	-477.3980	-685.9230	-1612.8571	-2589.8130	-3852.4089
	4488.2378	-2821.8740	8014.9209	2328.4131	-3951.9810	-9833.4092	-12168.657
	-12591.415	-13014.173					
20000.	940.4450	686.3310	360.0700	-176.6700	-1022.1380	-1747.7540	-2505.1550
	2872.5649	-1612.2371	8713.6484	6546.2451	2272.0950	-2762.2759	-6448.0952
	-7477.2549	-7459.3599					
30000.	1511.4070	1264.0660	970.6410	591.1440	-9.5410	-575.2170	-1368.7740
	1799.9210	-858.5840	6976.8389	7322.2529	5387.0469	2511.1389	-920.1070
	-3558.7361	-3794.9309					
40000.	1821.3571	1608.6630	1395.9680	1130.9000	771.1490	469.0990	-275.1740
	-567.5340	-539.7970	4837.3442	5305.9541	5112.6738	3305.4990	1026.1300
	-1135.4780	-2144.4500					
50000.	1266.2030	1336.1500	1406.9180	1477.6851	1299.9390	1157.5870	758.3430
	549.2860	320.1160	2988.0520	3228.4170	3073.4221	1942.5870	604.8690
	-679.3950	-1287.2310					
60000.	790.6230	832.7460	889.1510	961.4820	1084.6880	1187.1990	1210.9580
	1151.0890	1091.2190	1838.0861	1942.6580	1811.0830	1109.7880	313.6150
	-439.3880	-800.2260					
70000.	500.6690	527.9160	563.1670	608.7680	685.7330	748.2620	765.9180
	853.2010	967.5780	1132.3840	1080.2720	701.9100	297.3500	-133.8040
	-377.5750	-541.0000					

Thrust PLA = 52.0

Altitude	Mach						
	0.00	0.20	0.40	0.60	0.80	0.90	1.00
	1.10	1.20	1.40	1.60	1.80	2.00	2.20
	2.40	2.60					
0.	7342.8369	7388.4849	7414.0088	8614.5674	8371.5049	8030.7559	5574.2139
	5135.9180	4213.8838	4100.0840	-3850.4690	-11577.996	-17626.562	-18912.546
	-19038.152	-19163.757					
10000.	5022.0449	5061.8672	5066.0449	6211.8569	6542.2930	6548.2100	4940.8809
	4677.5762	4669.5811	8014.7788	2327.7639	-3951.7959	-9832.8379	-12168.465
	-12590.774	-12237.094					
20000.	3332.2419	3354.8391	3350.0381	4157.5068	4555.9951	4768.6792	3966.7251
	4095.9839	4118.9800	9384.6113	6545.9971	2272.0029	-2761.9980	-6447.3608
	-7477.5278	-7459.4878					
30000.	2157.0750	2173.6379	2165.9641	2687.9109	2934.0320	3076.2219	2667.9619
	2925.9480	3249.7781	7615.5200	7987.2861	5841.0771	2653.4080	-842.9890
	-3558.8611	-3794.7891					
40000.	1871.2980	1672.1851	1433.4290	1671.3850	1816.8621	1890.2440	1628.3920
	1781.5900	2038.6320	5222.0400	5717.8511	5548.0352	3566.1030	1205.8680
	-934.0380	-2144.6489					
50000.	1413.5750	1479.7460	1585.2390	1516.1090	1277.2377	1157.8020	964.3350
	1049.9740	1203.1080	3218.4519	3483.2480	3345.4189	2106.4670	695.2920
	-544.7240	-1287.1219					
60000.	898.5670	938.6590	995.1420	1068.2240	1212.7791	1312.7690	1306.0100
	1186.4370	1050.8630	1976.1840	2106.1440	1897.1210	1211.2330	363.6920
	-352.6170	-799.7410					
70000.	582.3760	609.1960	644.6570	693.6930	782.8220	843.0420	835.6560
	922.7750	1042.7330	1212.8929	1095.7190	681.5520	245.9880	-166.1030
	-384.6520	-540.8580					

Thrust PLA = 87.0

Altitude	Mach						
	0.00	0.20	0.40	0.60	0.80	0.90	1.00
	1.10	1.20	1.40	1.60	1.80	2.00	2.20
	2.40	2.60					
0.	13932.8408	14686.2734	15715.1933	16569.6054	16658.0937	16485.6816	13603.3144
	12246.2880	10461.3417	4222.2261	-3749.7400	-11586.330	-17558.166	-18831.300
	-18954.314	-19077.328					
10000.	9656.9990	10213.6201	11047.3466	11887.9394	12978.4404	13380.2236	12147.0097
	11705.9833	11293.0107	8179.1792	2430.9141	-3802.3521	-9758.1377	-12112.753
	-12545.606	-12166.140					
20000.	6393.8862	6790.2109	7373.6270	8075.3862	8952.3467	9599.0830	9395.4941
	10267.9521	10389.4101	9531.5059	6716.6641	2379.1641	-2638.9180	-6400.9072
	-7432.6182	-7413.1689					
30000.	4069.3560	4328.1348	4711.1572	5176.3530	5834.8389	6283.3179	6289.7051
	7057.7568	7940.3252	8751.3867	8347.6328	5995.7612	2754.3279	-760.8440
	-3511.8311	-3752.8000					
40000.	2536.6250	2691.3530	2907.7061	3199.4500	3670.6960	3968.3911	3975.3679
	4449.0020	5066.8252	6170.8159	6344.2739	5685.5952	3654.6411	1276.6440
	-905.5820	-2119.7090					
50000.	1574.6630	1669.4120	1804.3710	1976.1160	2286.0081	2471.5559	2472.6121
	2776.8301	3173.9360	3812.2180	3876.1790	3431.0500	2159.8770	738.5330
	-523.1630	-1271.0000					
60000.	986.1500	1043.6169	1125.7371	1233.9670	1430.2750	1559.6270	1559.2841
	1737.1230	1972.6610	2346.3621	2356.2810	1900.2910	1230.1570	389.7140
	-339.1090	-789.7550					
70000.	626.7820	663.8060	716.8530	783.7240	906.6360	993.3660	990.1210
	1092.4900	1233.5880	1257.3580	1029.3120	681.4740	245.8000	-165.7640
	-384.6520	-540.8580					

Thrust PLA = 94.0

Altitude	Mach 0.00	0.20	0.40	0.60	0.80	0.90	1.00	1.10
0.	15755.8896	16872.7285	18215.0683	19241.7597	19445.6640	19613.6464	16951.4023	15513.9033
10000.	10766.8935	11604.3310	12729.3271	14132.4785	15782.6425	16303.1103	15144.3916	14953.1054
20000.	7077.0718	7637.3540	8408.0586	9427.8496	10996.3837	12027.1728	12087.0986	12811.2578
30000.	4500.6001	4864.8599	5381.0562	6005.9419	7085.3672	7822.0088	8408.5250	8995.0410
40000.	2786.9250	3009.4170	3305.0740	3700.4709	4393.4648	4864.3350	5013.8652	5619.3208
50000.	1726.9010	1855.9351	2031.2679	2253.5371	2672.4541	2961.5000	3049.3621	3427.1970
60000.	1081.5510	1159.0350	1264.8540	1402.4170	1647.6200	1818.4640	1861.6000	2082.1650
70000.	688.2580	737.8860	804.5870	889.6430	1041.7860	1147.1840	1173.1520	1298.9390

Altitude	Mach 1.20	1.40	1.60	1.80	2.00	2.20	2.40	2.60
0.	13897.7255	8098.6851	49.3020	-8001.5308	-14298.760	-15572.480	-15807.542	-14639.762
10000.	14717.6435	11635.4648	5781.9199	-571.9440	-6874.2300	-9405.8467	-9885.0332	-9597.2520
20000.	13108.5966	12575.2753	9771.6768	5288.5859	49.4140	-4101.6812	5230.9600	-5236.0142
30000.	10139.3720	10947.3378	10882.0527	8348.9785	5129.1680	1367.0420	1505.0699	-2033.7321
40000.	6381.9990	7667.0688	8029.1392	7410.2231	5291.8311	2807.9109	392.8410	-850.6100
50000.	3906.0459	4695.9321	4882.5171	4454.0581	3130.1680	1653.7970	250.6320	-515.6140
60000.	2375.9299	2863.0859	2943.4390	2461.6021	1756.8669	774.6520	90.6260	-348.0140
70000.	1468.3170	1489.2520	1273.3960	895.6370	471.3520	53.8100	-196.1930	-399.8340

Thrust PLA = 110.5

Altitude	Mach 0.00	0.20	0.40	0.60	0.80	0.90	1.00
0.	20214.6855	22346.7832	24698.6035	26784.7792	28736.6992	28999.4589	27581.6445
10000.	13840.8320	15437.2470	17360.2792	19803.6464	22801.9082	24050.8984	24644.2617
20000.	9078.1436	10142.8271	11508.5087	13284.9228	15961.8203	17695.3203	18863.3847
30000.	5752.5908	6433.4502	7361.9038	8450.0244	10329.7744	11590.2880	12609.9658
40000.	3054.9490	3483.4189	4208.2368	5167.8369	6377.5098	7180.6338	7852.2202
50000.	1845.8459	2004.0310	2214.7429	2487.7930	3266.1919	3943.4961	4636.3740
60000.	1154.4670	1249.6440	1376.9871	1542.6820	1833.6840	2036.4160	2128.4319
70000.	732.7560	793.4270	873.8200	975.3390	1156.7780	1281.9100	1337.4310

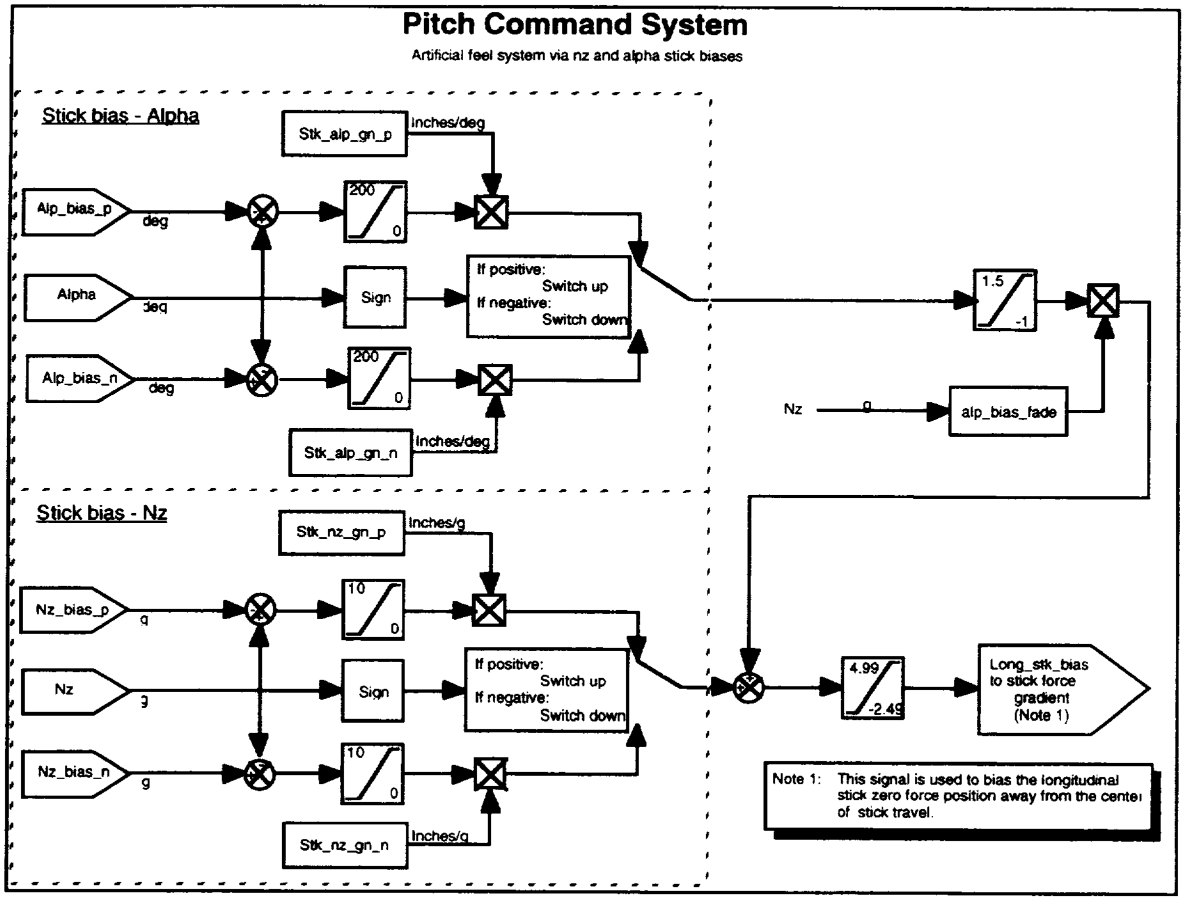
Altitude	Mach 1.10	1.20	1.40	1.60	1.80	2.00	2.20	2.40	2.60
0.	27027.6582	26486.1386	24078.0019	19348.9003	11369.1650	4406.7681	4197.8838	3988.9995	3780.1152
10000.	26056.4746	27382.6054	26090.3984	21504.5781	15677.3945	8764.8906	6106.6240	5976.4380	6551.2861
20000.	20330.8730	21713.7675	23875.6679	22468.5019	18859.0273	13623.2490	8536.2314	7328.8530	7437.4438
30000.	14235.2792	15602.5129	18336.9804	20041.7343	18424.5019	15996.2724	12077.2851	7643.4961	7507.1758
40000.	8893.9902	10160.4121	12427.8769	13975.6757	14299.9228	12650.6191	10252.6933	7327.8350	5159.7178
50000.	5372.8188	6170.2061	7573.1509	8456.7305	8569.2461	7514.9341	6109.5381	4409.4268	3099.8330
60000.	2481.1699	3042.3821	4439.0581	5054.9458	4794.4468	4275.9941	3231.2480	2495.2070	1767.7010
70000.	1488.2159	1685.8190	1738.2100	1553.9871	1216.2690	841.8610	455.6900	188.5620	-125.4800

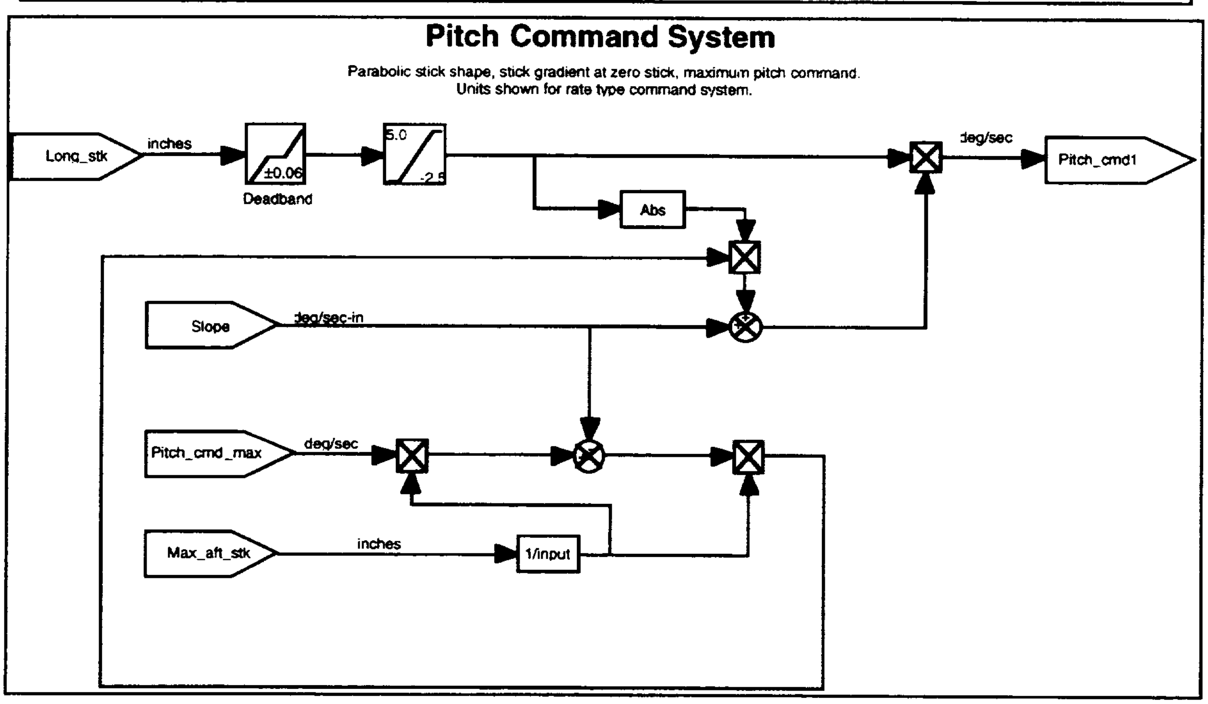
Thrust PLA = 130.0

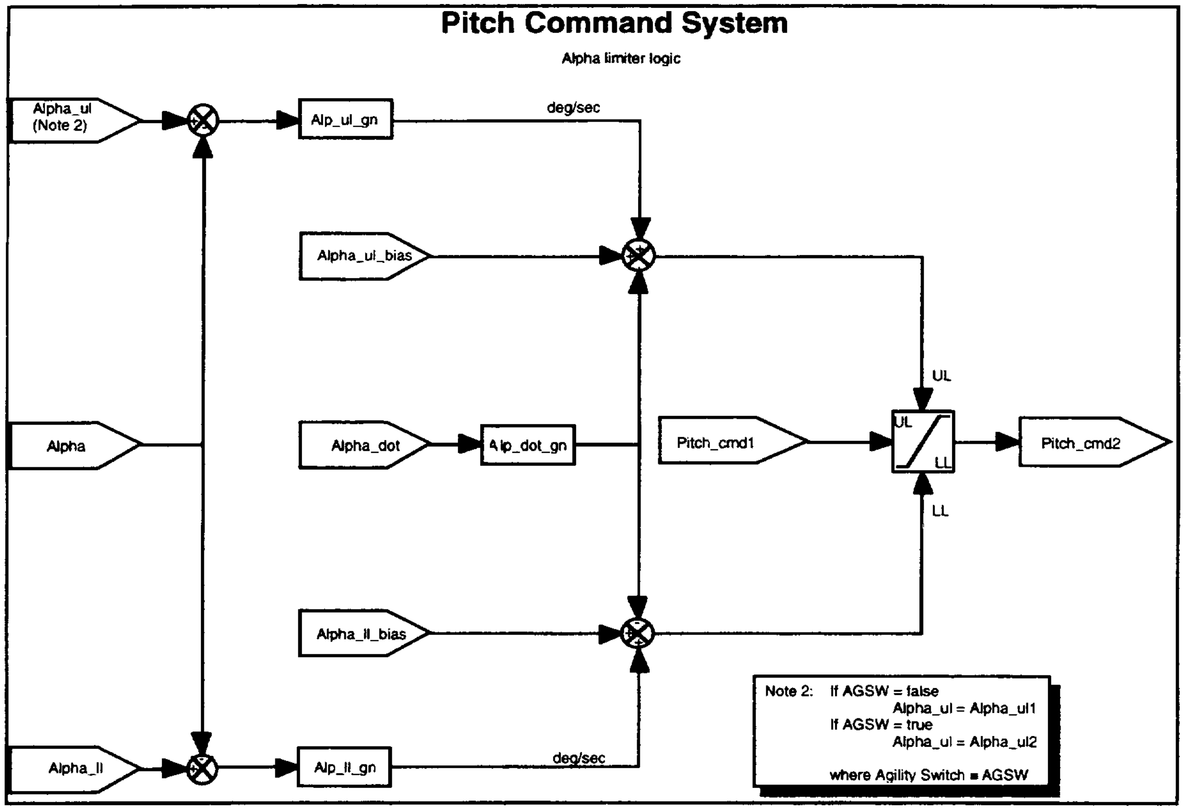
Altitude	Mach 0.00	0.20	0.40	0.60	0.80	0.90	1.00
0.	23453.1855	26245.6464	29388.4589	31922.7402	34514.0468	35210.7851	35199.0195
10000.	16085.9765	18142.5000	20719.9062	23907.2988	27732.5644	29149.0019	30575.2734
20000.	10559.8085	11924.7822	13761.1660	16047.3164	19514.9550	21710.5449	23694.0742
30000.	6690.3091	7564.4541	8794.9697	10224.0166	12665.8242	14261.6679	15908.5410
40000.	3425.3721	4009.8000	4997.2939	6243.8032	7826.8081	8829.4209	9920.4492
50000.	2020.0070	2244.1780	2468.3491	2824.7920	3895.5029	4847.6489	5936.8711
60000.	1261.2260	1378.3320	1532.1260	1732.6820	2081.6699	2322.3770	2466.4351
70000.	798.9010	872.8910	969.4390	1094.7280	1310.6420	1457.2620	1545.7570

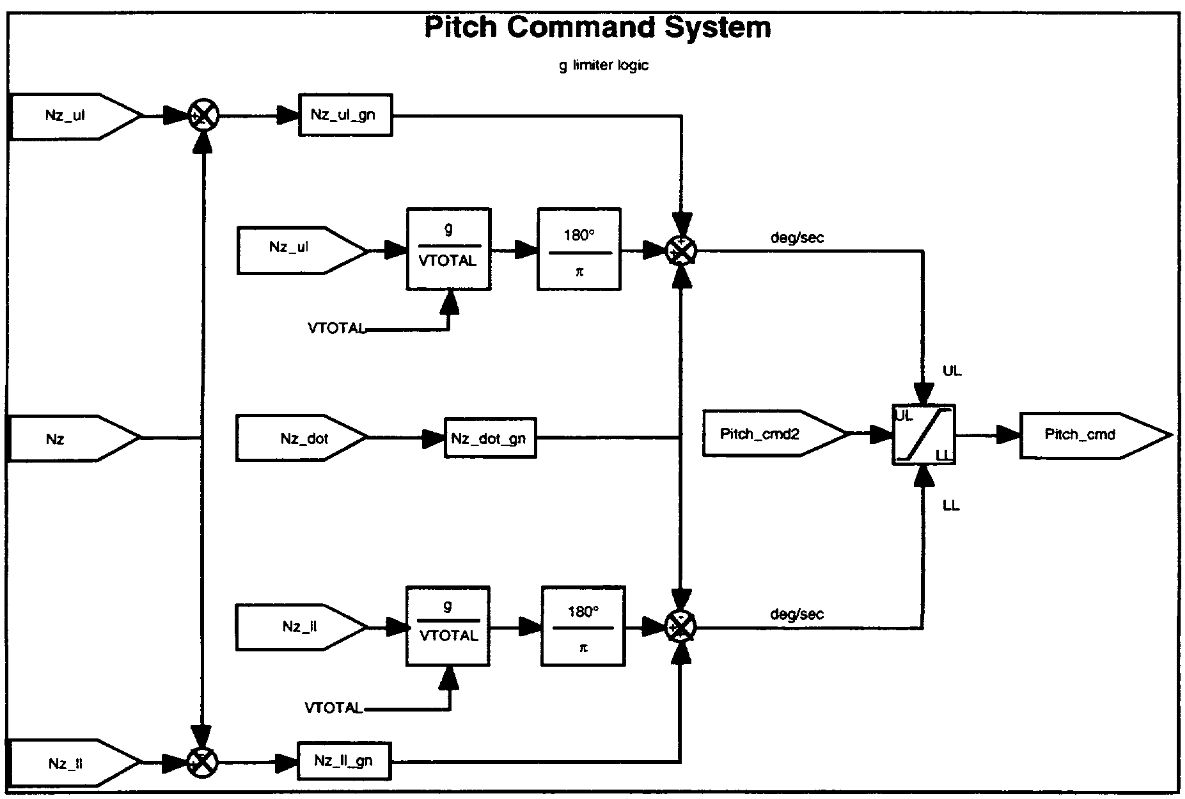
Altitude	Mach 1.10	1.20	1.40	1.60	1.80	2.00	2.20	2.40	2.60
0.	35274.2148	35450.0351	33759.4960	32451.5703	24683.2753	18023.8828	19441.6835	21524.2636	17347.6132
10000.	32644.4296	34941.6210	35705.9843	31629.3242	26934.0507	19460.4843	17236.1171	18493.4511	19710.9980
20000.	25542.7578	27388.4589	30875.3085	30073.5214	26860.9355	22137.1328	16739.8300	16084.3662	16820.9785
30000.	17999.3515	20650.3340	23301.3164	25898.1679	24385.4316	21818.4414	18124.4453	13575.5263	13553.7412
40000.	11278.0693	12892.6611	15795.4677	17939.1718	18648.3183	16914.9960	14471.3750	11541.8261	9170.3076
50000.	6822.0830	7846.0469	9637.0684	10859.7431	11204.6611	10095.6083	8675.6836	6981.0288	5536.4922
60000.	2980.7529	3741.5291	5704.1240	6491.5640	6324.4648	5772.1929	4727.3081	4004.7759	3207.9819
70000.	1727.4790	1959.0060	1994.6169	1880.8530	1582.9620	1245.3300	882.0930	606.2170	214.7040

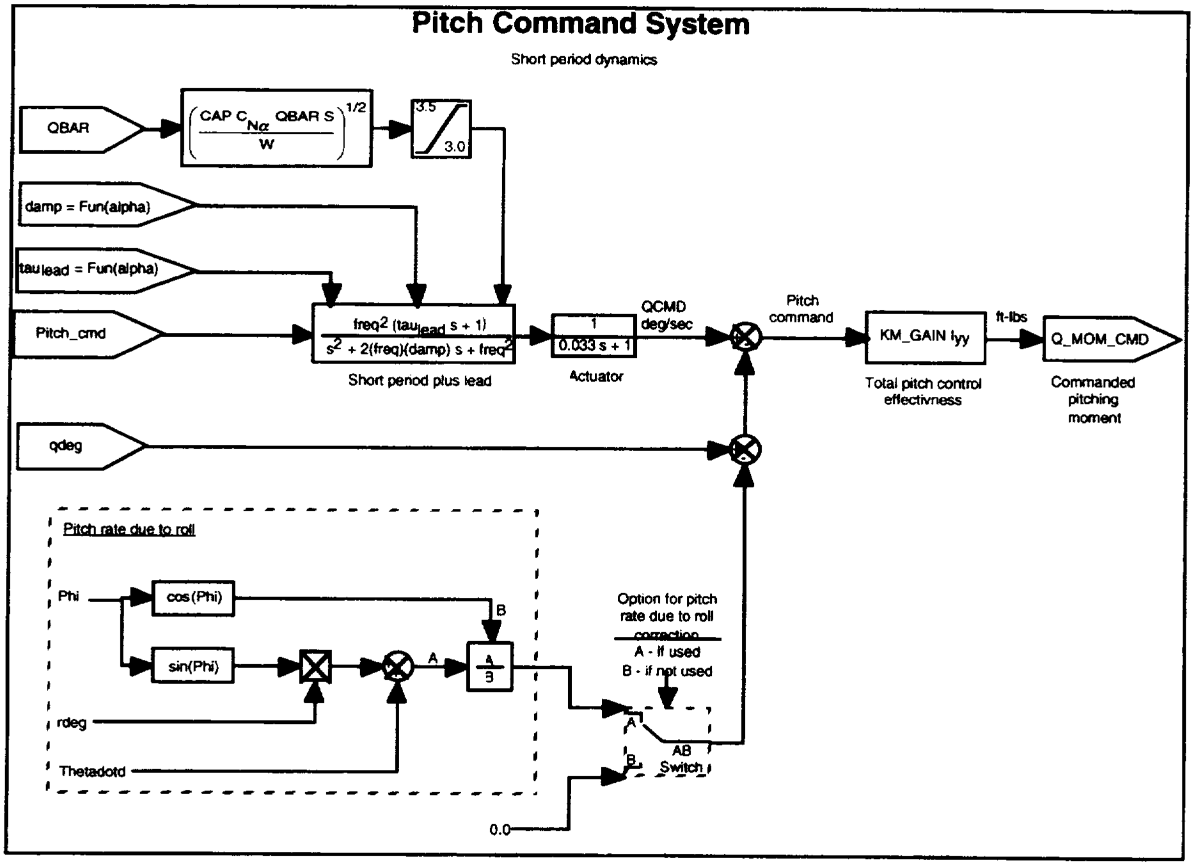
APPENDIX C - PITCH COMMAND SYSTEM BLOCK DIAGRAMS

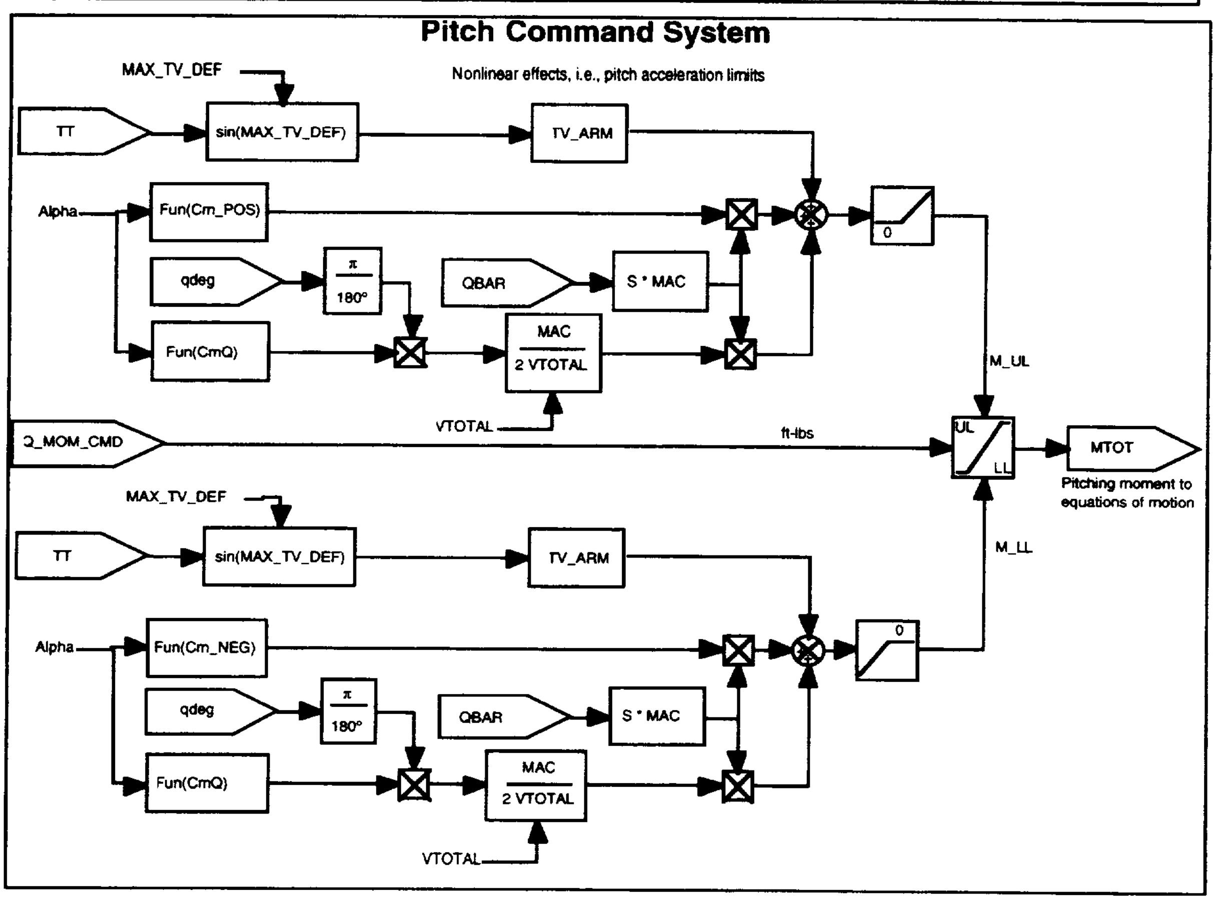




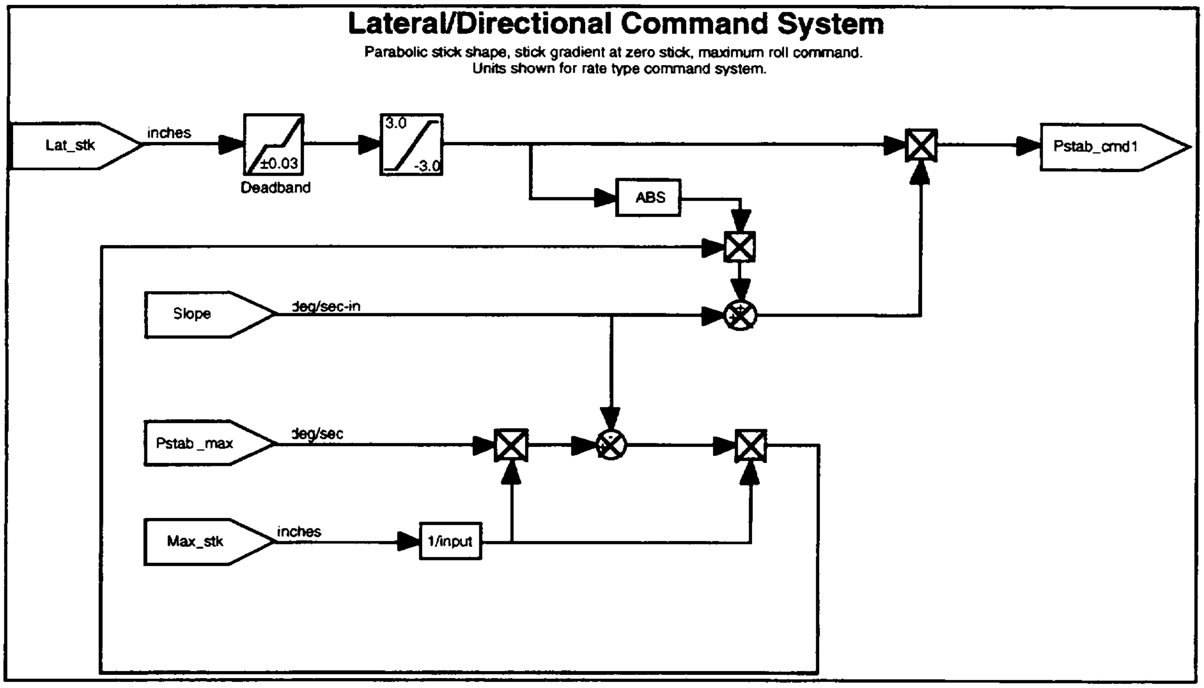

Pitch Command System
Alpha limiter logic
Alpha_ul (Note 2)
Alp_ul_gn
deg/sec
Alpha_ul_bias
UL
Alpha
Alpha_dot
Alp_dot_gn
Pitch_cmd1
UL
LL
Pitch_cmd2
LL
Alpha_ll_bias
Note 2: If AGSW = false
Alpha_ul = Alpha_ul1
If AGSW = true
Alpha_ul = Alpha_ul2
where Agility Switch = AGSW
Alpha_ll
Alp_ll_gn
deg/sec

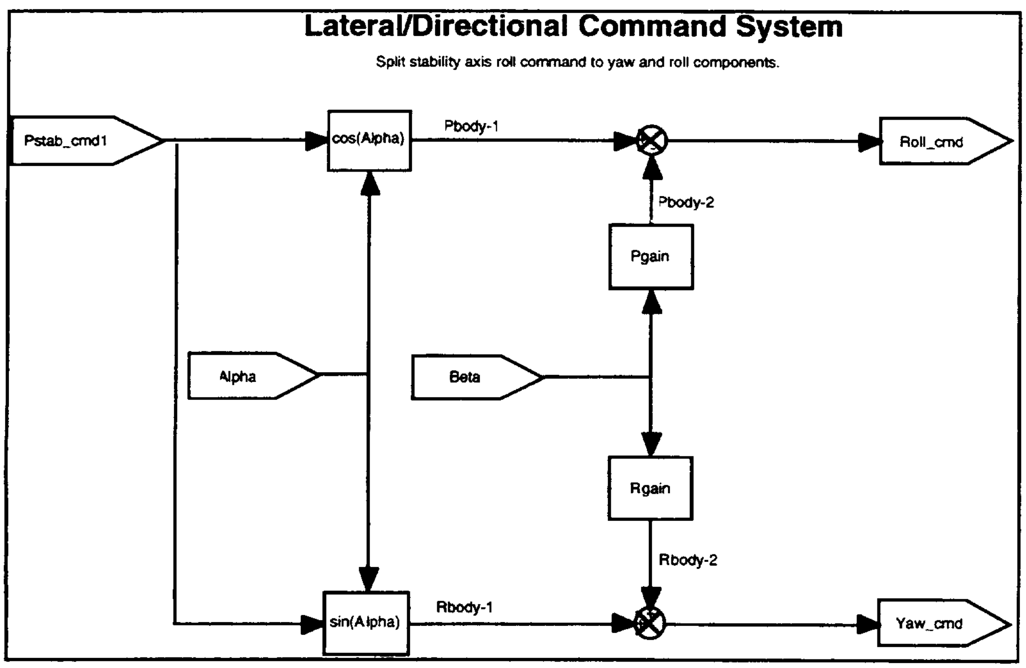

Pitch Command System
g limiter logic
Nz_ul
Nz_ul_gn
Nz_ul
g
VTOTAL
180°
π
deg/sec
VTOTAL
UL
Nz
Nz_dot
Nz_dot_gn
Pitch_cmd2
UL
LL
Pitch_cmd
LL
Nz_ll
g
VTOTAL
180°
π
deg/sec
VTOTAL
Nz_ll
Nz_ll_gn

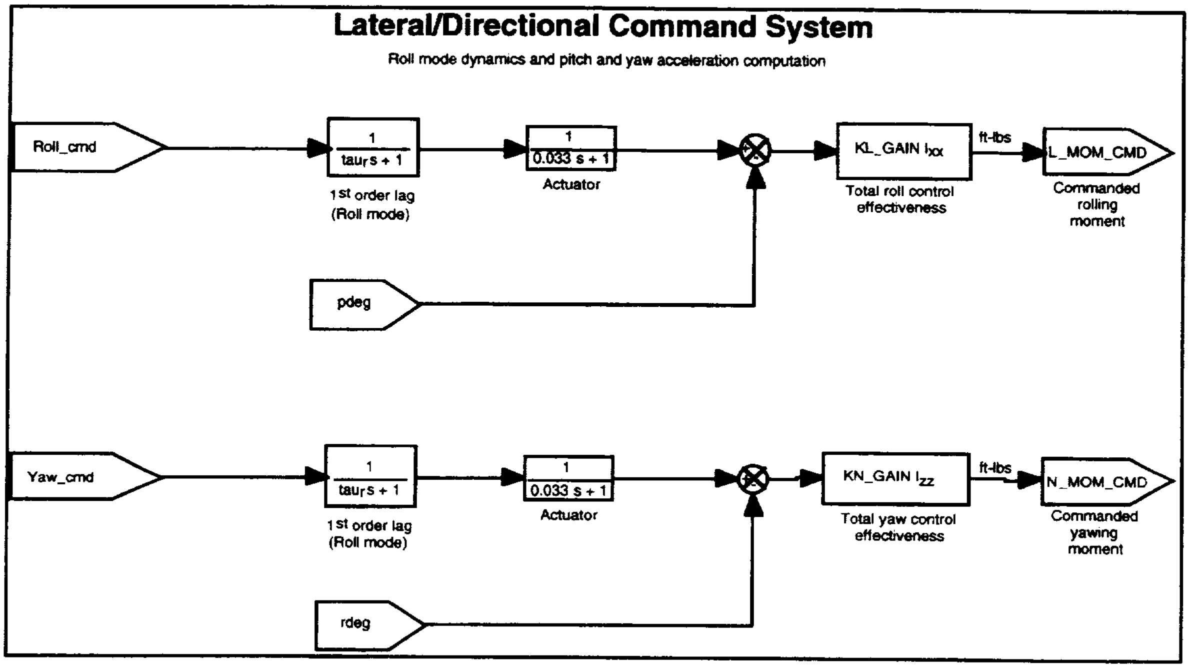

Pitch Command System
Short period dynamics
QBAR
CAP C Nα QBAR S / W ^1/2
3.5
3.0
damp = Fun(alpha)
taulead = Fun(alpha)
Pitch_cmd
freq2 (taulead s + 1) / s2 + 2(freq)(damp) s + freq2
Short period plus lead
1 / 0.033 s + 1
Actuator
QCMD deg/sec
Pitch command
KM_GAIN Iyy
Total pitch control effectivness
ft-lbs
Q_MOM_CMD
Commanded pitching moment
qdeg
Pitch rate due to roll
Phi
cos(Phi)
sin(Phi)
rdeg
Thetadotd
A
B
A / B
Option for pitch rate due to roll correction
A - If used
B - if not used
AB Switch
0.0

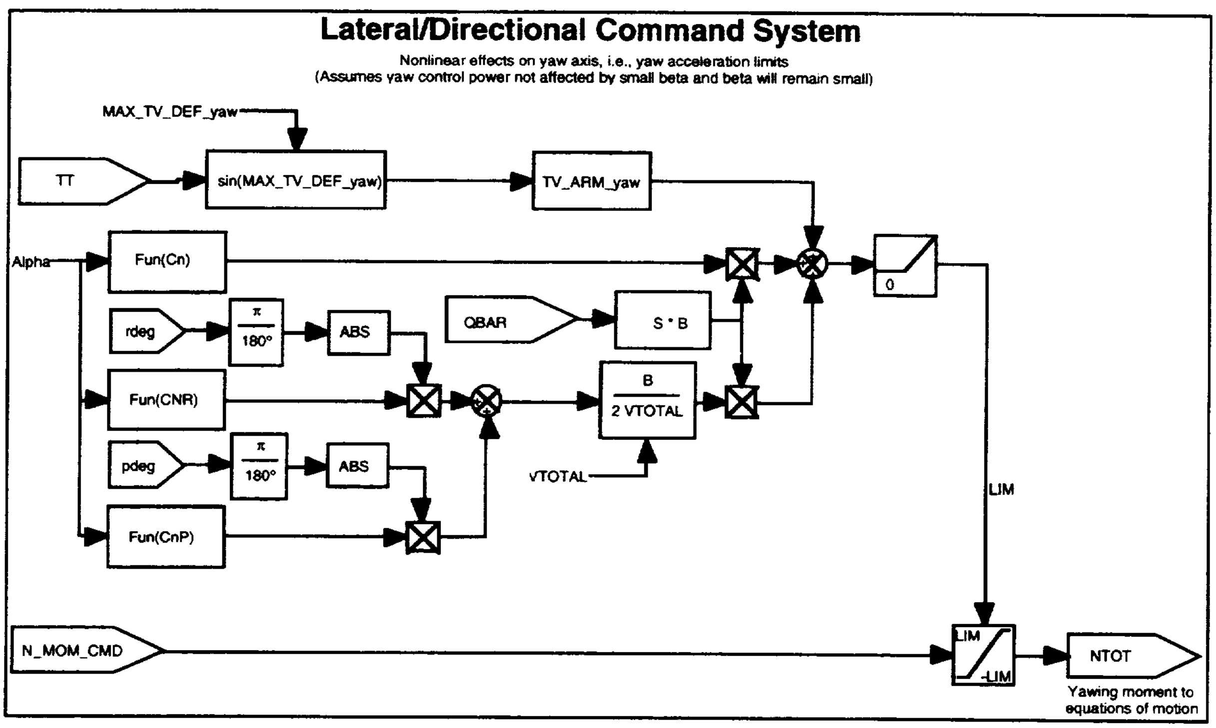

Pitch Command System
Nonlinear effects, i.e., pitch acceleration limits
MAX_TV_DEF
TT
sin(MAX_TV_DEF)
TV_ARM
Alpha
Fun(Cm_POS)
qdeg
π / 180°
QBAR
S * MAC
Fun(CmQ)
MAC / 2 VTOTAL
VTOTAL
0
M_UL
Q_MOM_CMD
ft-lbs
UL
LL
MTOT
Pitching moment to equations of motion
M_LL
MAX_TV_DEF
TT
sin(MAX_TV_DEF)
TV_ARM
Alpha
Fun(Cm_NEG)
qdeg
π / 180°
QBAR
S * MAC
Fun(CmQ)
MAC / 2 VTOTAL
VTOTAL
0

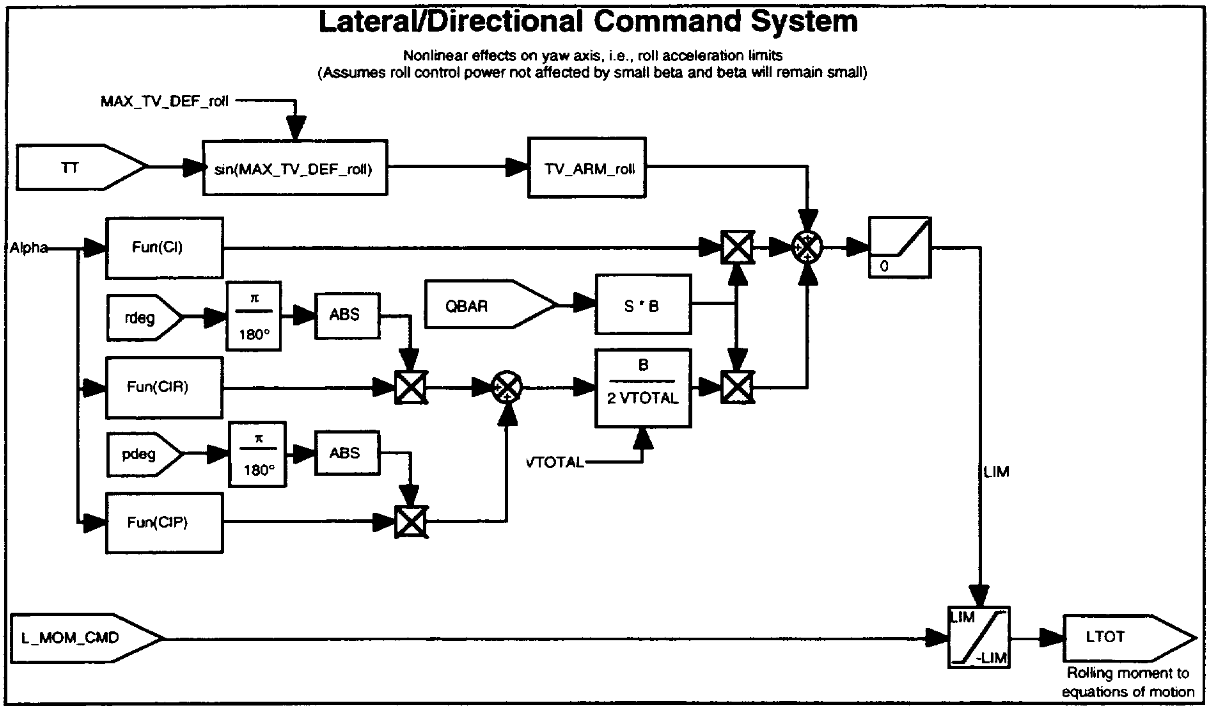
APPENDIX D - LATERAL/DIRECTIONAL COMMAND SYSTEM BLOCK DIAGRAMS






Lateral/Directional Command System
Roll mode dynamics and pitch and yaw acceleration computation
Roll_cmd
1
taurs + 1
1st order lag
(Roll mode)
1
0.033 s + 1
Actuator
KL_GAIN Ixx
Total roll control effectiveness
ft-lbs
L_MOM_CMD
Commanded rolling moment
pdeg
Yaw_cmd
1
taurs + 1
1st order lag
(Roll mode)
1
0.033 s + 1
Actuator
KN_GAIN Izz
Total yaw control effectiveness
ft-lbs
N_MOM_CMD
Commanded yawing moment
rdeg


Lateral/Directional Command System
Nonlinear effects on yaw axis, i.e., yaw acceleration limits
(Assumes yaw control power not affected by small beta and beta will remain small)
MAX_TV_DEF_yaw
TT
sin(MAX_TV_DEF_yaw)
TV_ARM_yaw
Alpha
Fun(Cn)
0
rdeg
π
180°
ABS
QBAR
S * B
Fun(CNR)
B
2 VTOTAL
pdeg
π
180°
ABS
VTOTAL
Fun(CnP)
LIM
N_MOM_CMD
LIM
-LIM
NTOT
Yawing moment to equations of motion


Lateral/Directional Command System
Nonlinear effects on yaw axis, i.e., roll acceleration limits
(Assumes roll control power not affected by small beta and beta will remain small)
MAX_TV_DEF_roll
TT
sin(MAX_TV_DEF_roll)
TV_ARM_roll
Alpha
Fun(Cl)
rdeg
π
180°
ABS
QBAR
S * B
Fun(ClR)
B
2 VTOTAL
pdeg
π
180°
ABS
VTOTAL
Fun(ClP)
0
LIM
L_MOM_CMD
LIM
-LIM
LTOT
Rolling moment to
equations of motion

APPENDIX E - LONGITUDINAL DATA

- *Only given if different from A/C #1 and 2.

Variable or Constant	Units	Description	Lon. A/C #1 and 2 Value or (x,y) pair	Lon. A/C #3* Value or (x,y) pair	Lon. A/C #4* Value or (x,y) pair
Alpha	deg	Angle of attack	external input		
Alpha_dot	deg/sec	Angle of attack rate	external input		
Alpha_dot_gn	sec	Gain on alpha_dot feedback in alpha limiter	0.1		
Alpha_ll	deg	Alpha lower limit in alpha limiter	-20		
Alpha_ll_bias	deg/sec	Alpha lower limit bias in alpha limiter	0.0		
Alpha_ll_gn	deg/sec/deg	Alpha lower limit gain in alpha limiter	2.0		
Alpha_ul1	deg	Alpha upper limit in alpha limiter. AGSW = false	30		
Alpha_ul2	deg	Alpha upper limit in alpha limiter. AGSW = true	55.0	70.0	90.0
Alpha_ul_bias	deg/sec	Alpha upper limit bias in alpha limiter	0.0		
Alpha_ul_gn	deg/sec/deg	Alpha upper limit gain in alpha limiter	2.0		
Alp_bias_n	deg	Alpha negative bias in stick feel system. Determines minimum alpha for neutral stick.	-10.0		
Alp_bias_p	deg	Alpha positive bias in stick feel system. Determines maximum alpha for neutral stick.	30.0		
CAP	$1/g\text{-}sec^2$	Control anticipation parameter	1		
CMDTYP	Logical	Command system, i.e., feedback used. Current options are "pitch rate (2)" and "alpha-dot (1)"	Pitch rate		

CmQ	non-dimensional	Pitch damping coefficeint	Alpha,CmQ -20,-5 0,-5 20,-5 30,-6 40,-10 50,-1 90,-5		
Cm_NEG	non-dimensional	Maximum nose down aerodynamic pitching moment coefficient	Alpha, Cm_neg -20,-.18 -5,-.20 0,-.25 10,-.32 45,-.1 60,-.35 90,-.65		
Cm_POS	non-dimensional	Maximum nose up aerodynamic pitching moment coefficeint	Alpha, Cm_pos -20,.28 -5,.28 0,0.24 20,.28 40,.24 60,0.0 90,-.2		
$C_{N\alpha}$	1/rad	Derivative of normal force coefficient with α	3.78		
damp		Short period damping. Function of alpha.	Alpha,damp -20,1.0 -5,1.4 5, 1.4 20, 1.0 30, 1.0 45, 1.0 60, 1.0 90, 1.0		

freq	rad/sec	Short period frequency. Based on CAP with imposed upper and lower limits. (For now)	$\left[CAP\left(\frac{C_{N_\alpha}\bar{q}S}{W}\right)\right]^{0.5}$; lower limit = 3.0 upper limit = 3.5		
alp_bias_fade	non-dimensional	Fades out alpha stick bias between $n_z = 4.0$ and 6.0.	nz,Fun(alp_bias_fade) -10.0,0.0 -6.0,0.0 -4.0,1.0 4.0,1.0 6.0,0.0 10.0,0.0		
I_{yy}	slugs-ft^2	Pitching moment of inertia	123936		
KM_GAIN	$\frac{rad}{deg \cdot sec}$	Pitch control surface gain	.35		
Long_stk	in	Longitudinal stick position. Use F-18 force feel, dynamics, and range.	external input		
MAC	ft	Mean aerodynamic cord	17		
Max_aft_stk	in		4.0		
MAX_TV_DEF	deg	Maximum available thrust vectoring angle	0	10	20
MTOT	ft-lbs	Pitching moment produced by all control surfaces to equations of motion	output		
Nz	g	Load factor	external input		
Nz_bias_n	g	n_z negative bias in stick feel system. Combines with NZ_BIAS_P to drive n_z to 1.0 with stick fixed.	1.0		
Nz_bias_p	g	See NZ_BIAS_N	1.0		
Nz_dot	g/sec	Load factor rate	external input		
Nz_dot_gn	deg/sec/g/sec	nz dot gain on nz limiter	1.5		
Nz_ll	g	nz lower limit in nz lmiter	-3.0		

Nz_ll_gn	deg/sec/g	nz lower limit gain in nz limiter	3.5		
Nz_ul	g	nz upper limit in nz limiter	8.0		
Nz_ul_gn	deg/sec/g	nz upper limit gain in nz limiter	3.5		
Phi	radians	Euler bank angle	External input		
Pitch_cmd_max	deg/sec	Maximum pitch command available. Function of alpha.	Alpha, Pitch_cmd_max -20,50 -5,70 5,70 20,50 30,40 60,25 70,25 90,25	Alpha, Pitch_cmd_max -20,70 -5,80 5,80 20,70 30,60 60,35 70,25 90,25	Alpha, Pitch_cmd_max -20,70 -5,80 5,80 20,70 30,60 60,50 70,50 90,50
QBAR	lb/ft2	Dynamic pressure	extermal input		
qdeg	deg/sec	Body axix pitch rate	external input		
rdeg	deg/sec	Body axis yaw rate	External input		
S	ft2	Wing area	600		
Slope	deg/sec-in	Slope of stick gradient at zero stick deflection. Determines (can be used to adjust) stick sensitivity during tracking.	Alpha,slope -20,3 -5,3 5,3 20,3 30,3 45,3 60,3 90,3		
Stk_alp_gn_n	in/deg	Determines inches stick zero force position will move when ALPHA_BIAS_N > ALPHA	-0.2		
Stk_alp_gn_p	in/deg	Determines inches stick zero force position will move when ALPHA_BIAS_P < ALPHA	0.2		

Stk_nz_gn_n	in/g	Determines inches stick zero force position will move when NZ_BIAS_N > nz	-2.5/3.0		
Stk_nz_gn_p	in/g	Determines inches stick zero force position will move when NZ_BIAS_P < nz	5.0/8.0		
tau_{lead}	sec	Lead term required to get level 1 handling qualities at high alpha according to McDonnell Douglas Aerospace work (ref. 5).	Alpha,tau_{lead} -20,0 -5,0 5,0 20,0 30,0.5 45,0.5 60,0.5 90,0.5		
Thetadotd	deg/sec	Euler pitch angle rate	External input		
TT	lb	Total thrust from both engines	Extermal input		
TV_ARM	ft	Thrust vectoring moment arm	20		
W	lb	Airplane weight	45,000		

APPENDIX F - LATERAL/DIRECTIONAL DATA

- *Only given if different from A/C #1 and 2.

Variable or Constant	Units	Description	Lon. A/C #1 and 2 Value or (x,y) pair	L/D A/C #3* Value or (x,y) pair	L/D A/C #4* Value or (x,y) pair
ABS		Absolute value function	-----		
Alpha	deg	Angle of attack	external input		
B	ft	Wing span	43		
Beta	deg	Angle of sideslip	external input		
Cl	non-dimensional	Maximum available rolling moment coefficient (roll control power)	alpha,Cl 0,.063 10,.06 30,.03 45,.015 90,.002		
ClP	non-dimensional	Roll damping due to roll coefficient	alpha,ClP 0,-.41 10,-.4 20,-.22 35,-.45 45,-.02 60,-.25 90,-.3		
ClR	non-dimensional	Roll damping due to yaw coefficient	alpha,ClR 0,.08 20,.25 35,.35 50,.12 90,.05		

Cn	non-dimensional	Maximum available yawing moment coefficient (yaw control power)	alpha,Cn 0,.037 10,.037 30,.02 60,.018 90,.013		alpha,Cn 0,.037 10,.037 30,.04 50,.08 90,.02
CnP	non-dimensional	Yaw damping due to roll coefficient	alpha,CnP 0,-.02 15,-.01 30,.03 40,.01 50,.06 60,-.14 67,-.02 75,-.1 90,0		
CnR	non-dimensional	Yaw damping due to yaw coefficient	alpha,CnR 0,-.17 20,-.19 40,-.3 55,-.22 70,-.01 90,-.25		
I_{xx}	slugs-ft^2	Roling moment of inertia	27,000		
I_{xz}	slugs-ft^2	Product of inertia	-2,971		
I_{zz}	slugs-ft^2	Yawing moment of inertia	211,000		
KL_GAIN	$\frac{rad}{deg \cdot sec}$	Roll control surface gain	0.35		
KN_GAIN	$\frac{rad}{deg \cdot sec}$	Yaw control surface gain	0.35		
Lat_stk	in	Lateral stick position. Use F-18 force feel, dynamics, and range.	external input		
LTOT	ft-lbs	Rolling moment produced by all control surfaces to equations of motion	output		
Max_stk	inches	Maximum stick deflection	3.0		

MAX_TV_DEF_roll	deg	Maximum available roll thrust vectoring angle	0		
MAX_TV_DEF_yaw	deg	Maximum available yaw thrust vectoring angle	0	10	20
NTOT	ft-lbs	Yawing moment produced by all control surfaces to equations of motion	output		
pdeg	deg/sec	Body axis roll rate	external input		
Pgain	rad/sec-deg	Beta_feedback gain on roll rate	4		
Pstab_max	deg/sec	Maximum stability axis roll rate. Fun(alpha)	Idle power alpha,pstab 0,180 5,180 15,90 25,30 35,20 45,2 60,2 90,2 Mil power alpha,pstab 0,180 5,180 15,90 25,30 35,20 45,2 60,2 90,2	Idle power alpha,pstab 0,180 5,180 15,90 25,30 35,20 45,2 60,2 90,2 Mil power alpha,pstab 0,180 5,180 15,90 25,55 35,45 45,45 60,40 90,40	Idle power alpha,pstab 0,180 5,180 15,90 25,30 35,20 45,2 60,2 90,2 Mil power alpha,pstab 0,180 5,180 15,160 25,120 35,95 45,90 60,60 90,60
QBAR	lb/ft2	Dynamic pressure	external input		
rdeg	deg/sec	Body axis yaw rate	external input		
Rgain	rad/sec-deg	Beta_feedback gain on yaw rate	3		
S	ft2	Wing area	600		

Slope	deg/sec-in	Slope of stick gradient at zero stick deflection. Determines (can be used to adjust) stick sensitivity during tracking.	alpha,slope 0,3 5,3 30,3 45,3 60,3 90,3		
Tau_r	sec	Roll mode time constant	alpha,taur 0,0.4 30,0.4 45,1.2 90,1.2	alpha,taur 0,0.4 30,0.4 45,1.2 90,1.2	alpha,taur 0,0.4 30,0.4 45,1.2 90,1.2
TT	lb	Total thrust from both engines	extermal input		
TV_ARM_roll	ft	Thrust vectoring moment arm for roll axis	0		
TV_ARM_yaw	ft	Thrust vectoring moment arm for yaw axis	20		
VTOTAL	ft/sec	Total true velocity	extermal input		
W	lb	Airplane weight	45,000		

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13. ABSTRACT *(Maximum 200 words)*

A generic airplane model concept was developed to allow configurations with various agility, performance, handling qualities, and pilot vehicle interface to be generated rapidly for piloted simulation studies. The simple concept allows stick shaping and various stick command types or modes to drive an airplane with both linear and nonlinear components. Output from the stick shaping goes to linear models or a series of linear models that can represent an entire flight envelope. The generic model also has provisions for control power limitations, a nonlinear feature. Therefore, departures from controlled flight are possible. Note that only loss of control is modeled, the generic airplane does not accurately model post departure phenomenon. The model concept is presented herein, along with four example airplanes. Agility was varied across the four example airplanes without altering specific excess energy or significantly altering handling qualities. A new feedback scheme to provide angle-of-attack cueing to the pilot, while using a pitch rate command system, was implemented and tested.

14. SUBJECT TERMS
flight dynamics; high angle of attack, flying qualities, piloted simulation, superagility, model development

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