NASA Technical Memorandum 110217

Design Specification for a Thrust-Vectoring, Actuated-Nose-Strake Flight Control Law for the High-Alpha Research Vehicle

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Acronyms

AC	aircraft
ANSER	Actuated Nose Strakes for Enhanced Rolling
AOA	angle of attack
CRAFT	Control power, robustness, agility, and flying qualities trade-off
DMS	Differential Maneuvering Simulator
FFCG	feed-forward command generator
HARV	High Alpha Research Vehicle
HBD	horizontal block diagram
I/O	input/output
INS	inertial navigation system
LaRC	Langley Research Center
NASA-0	baseline thrust-vectoring control law
NASA-1A	Advanced thrust-vectoring control law flown during Phase II
OBES	On-Board Excitation System
Phase II	Flight phase (Jan. - Jun. 1994) for evaluating HARV Thrust-Vectoring System
Phase III	Flight phase for evaluating HARV ANSER System
RAM	random access memory
RFCS	Research Flight Control System
S-mode	thrust-vectoring control-law mode
STV-mode	nose-strake plus thrust-vectoring control-law mode
TED	trailing-edge down
TEU	trailing-edge up
TV	thrust vectoring
TV-mode	thrust-vectoring control-law mode
WOW	weight-on-wheels
701E	Pace 701E research flight computer

Chapter 1
General

1.1 Introduction

The main objective of this specification is to document the HARV ANSER Control Laws in sufficient detail for use as a source from which an engineer/programmer can produce computer source code to implement the control laws in flight software. The secondary objective is to provide information on the control laws to assist a controls engineer in understanding the control laws, debugging source code, writing test plans, and analyzing test data.

The ANSER Control Laws were implemented in the Research Flight Control System (RFCS) and flown on the F/A-18 HARV (High Alpha Research Vehicle) after it was modified to install the Actuated Nose Strakes for Enhanced Rolling (ANSER). To meet the operational requirements with the modified HARV, the Control Laws must provide three modes of operation: 1) the TV (thrust-vectoring) mode for use with thrust vectoring when the nose strakes are not being used in a closed-loop manner; 2) the S (strake) mode for use when the strakes are in use, but yaw thrust vectoring is not, and 3) the STV (strake/thrust vectoring) mode for use when both strakes and yaw thrust vectoring are in use. Pitch thrust vectoring is used in all three modes. The TV mode is used during "Program-a-Strake" operation. "Program-a-Strake" operation involves deploying the nose strakes to pre-determined positions in an open-loop manner to obtain strake aerodynamic data while the pilot controls the aircraft using the ANSER Control Laws.

The nose strakes are primarily a directional control effector and have little effect in the pitch axis. Thus, the ANSER Longitudinal Control Law is based on the NASA-1A Longitudinal Control Law (ref. 1.1), but some modifications have been incorporated as a result of NASA-1A flight test results. The ANSER Lateral/Directional Control Law design effort used the NASA-1A Lateral/Directional Control Law design as a starting point. This design was modified as discussed in Chapters 3 and 4 to accommodate the nose strakes and provide the three modes of operation. Even though the ANSER Longitudinal Control Law design was thoroughly evaluated during the design of the NASA-1A Control Laws, the ANSER Longitudinal and Lateral/Directional Control Laws were extensively evaluated as a integrated all-axis control law in piloted simulation using the Langley Differential Maneuvering Simulator (DMS) during the ANSER design phase. Langley and Dryden research test pilots were used in the formal DMS piloted evaluation, and Langley engineering pilots have also flown the control laws in the DMS. Throughout the design and evaluation process, control law performance was continually compared with the HARV control design guidelines.

During the design and linear analysis phase extensive use was made of MATRIX$_X$®, Version 7.24, and MATRIX$_X$® with SystemBuild™ Workstation Versions 2.04 and 2.4. From the SystemBuild™ implementation the control laws were encoded in FORTRAN using the MATRIX$_X$® FORTRAN AutoCode™ Generator Versions 2.21 and 2.23. This FORTRAN AutoCode™ was then implemented in batch and piloted HARV simulations for control law evaluation. The ACSL batch simulation hosted on the VAX 3200's operating under VAX/VMS V5.5 and on the Unix-basedSun SPARCstation 10 and the piloted simulation in the DMS were based on Dryden's F-18 HARV batch simulation, Releases 1 through 13.

Detailed specifications for the ANSER control laws are presented in subsequent chapters of this document: Chapter 2 describes the Longitudinal Control Law, Chapter 3 describes the Lateral/Directional Feedback Control Law, and Chapter 4 describes Pseudo Controls portion of the Lateral/Directional Control Law. These chapters contain block diagrams, input/output lists, and MATRIX$_X$® SystemBuild™ diagrams. Chapter 3 also contains a discussion of the design technique used for the Lateral/ Directional Feedback Control Law and a functional description of the control law. A similar detailed discussion for the Longitudinal Control Law is contained in reference 1.2. Chapter 5 defines the interface between the ANSER Control Law and other flight software in the form of input and output lists, including outputs for diagnostic purposes only. In these chapters some references are made to the NASA-0 Control Law. NASA-0 refers to the Research Flight Control System developed by McDonnell Douglas and flown on the HARV during Phase II flight tests.

The basic up-and-away control law defined by this specification is the same for implementation in simulation and in flight code. However, implementation in real-time flight code requires some functions, such as ARM and ENGAGE, that are not relevant to the control law's basic performance and are not included in the specification. Likewise, some features used in simulation, such as a facility for linear model computation, are also not included. In a few cases, elements that are applicable only to simulation or to flight code are so noted in the text.

1.2 NASA-1A Implementation

An earlier version of the ANSER Control Laws, designated NASA-1A Control Laws, was flight tested on the HARV during the Phase II flights. During Phase II the aircraft was not equipped with nose strakes, so the control laws operated only in the TV mode. The parts of the Lateral/Directional Control Law that are used only in the S mode or the STV mode are clearly marked in Chapters 3 and 4. These parts were not implemented in the NASA-1A flight code.

Results of the NASA-1A flight tests led to some modifications to the original ANSER Control Law design to improve performance. Those modifications are included in the control laws defined by this specification.

1.3 Reference

1.1 Ostroff, Aaron J.; Hoffler, Keith D.;and Proffitt, Melissa S.: *High-Alpha Research Vehicle (HARV) Longitudinal Controller: Design, Analyses and Simulation Results*, NASA TP 3446, July 1994.

1.2 Ostroff, Aaron J.; and Proffitt, Melissa S.: *Longitudinal-Control Design Approach for High-Angle-of-Attack Aircraft.* NASA TP 3302, Feb. 1993.

Chapter 2
Longitudinal Control Law
Version 151

2.1 Functional Description

The ANSER Longitudinal Controller is composed of a feed-forward command generator (FFCG) and a feedback controller that was designed using a Variable Gain Output Feedback technique (refs. 2.1 to 2.4). The feedback controller is a direct digital design based upon a sample rate of 80 Hz and is implemented in incremental form. Feedback variables are pitch rate, angle of attack, and normal acceleration, and the controls are horizontal stabilator and pitch thrust vectoring. Scaling parameters for the variable feedback gains are a function of angle of attack, impact pressure, static pressure, and some combinations. Flaps (leading and trailing edge) are scheduled as in the basic F/A-18 Controller. The objective of the FFCG is to relate pilot commands into equivalent commands to the feedback controller. Both the FFCG and the feedback controller are combined and implemented for multi-rate use. Flap logic, feedback gains, angle-of-attack (AOA) selection logic, sine(AOA), and cosine(AOA) are implemented at a slower rate of 40 Hz. For a more complete functional description of the Longitudinal Controller, see references 2.3 and 2.4.

2.2 Implementation

The Longitudinal Control Law was implemented in two subroutines, USR18V151 and USR19V151, using the MATRIX$_X$® FORTRAN AutoCode™ generator. The definition and units of all inputs and outputs for these subroutines are described in Section 2.3 in Tables 2.1 through 2.6 for the INPUTS, OUTPUTS, and STATES (trimming coefficients). Symbols shown in the second column of these tables are those used in the MATRIX$_X$® FORTRAN AutoCode™. The horizontal flow charts in Section 2.4 show the complete longitudinal controller. Variable names in the flow charts match the variable names in the FORTRAN AutoCode™ implementation. In case of discrepancies between documentation sources such as number of significant figures in constants, AutoCode™ is the defining source. AutoCode™ and the horizontal block diagrams should agree in these cases. Figure 2.1(a) (for USR18V151) has three colums of stored gains labled "DEFAULT", "GAINSET1, and "GAINSET2". These are for DIAL-A-GAIN use where each set of gains will be used separately for evaluation during specified flight maneuvers, with the DEFAULT set used initially. DIAL-A-GAIN refers to the flight software logic by which the pilot can select any one of three sets of gains for the Longitudinal Control Law.

2.3 Input/Output Lists

Table 2.1 - Subroutine **USR18V151** - INPUTS

NO	AUTO CODE SYMBOL	DEFINITION
1	AOAP	Angle-of-attack PROBE (deg)
2	AOAINS	Angle-of-attack INS (deg)
3	QCFILTER2	10 rad/sec filtered impact pressure (lb/ft^2)
4	PS	Static Pressure (lb/ft^2)
5	RI	Pressure ratio - (QCFILTER2/PS)
6	TRMMING	Trim flag (real): 0.0 = Operate 1.0 = Trim

Table 2.2 - Subroutine **USR18V151** - OUTPUTS

NO	AUTO CODE SYMBOL	DEFINITION
1	TEFSC1	Collective trailing-edge-flap command (deg)
2	LEFSC1	Collective leading-edge-flap command (deg)
3	AOA	Angle-of-attack faded between probe and INS (deg)
4	FGI	Fader gain input for AOA (used to initialize fader gain state)
5	GTILY1	Feedback gain (proportional) for angle-of-attack
6	GTILY2	Feedback gain (proportional) for pitch rate
7	GTILY3	Feedback gain (proportional) for load factor
8	GTILU1	Feedback gain for filter
9	GTILZ1	Feedback gain for integrator
10	RHON1	1st variable gain-schedule parameter
11	RHON2	2nd variable gain-schedule parameter
12	RHON3	3rd variable gain-schedule parameter
13	RHON4	4th variable gain-schedule parameter
14	RHON5	5th variable gain-schedule parameter
15	RHON6	6th variable gain-schedule parameter
16	COSALF	Cosine of AOA
17	SINALF	Sine of AOA

Table 2.3 - Subroutine **USR18V151** - STATES (1)

NO	FORCING FUNCTION	EQUATION - TRIM
X(2)	Y(4) - FGI	X(2) = 0.8888889*Y(4)
X(3)	Y(3) - AOA	X(3) = 0.9844237*Y(3)
X(4)	Y(3) - AOA	X(4) = 0.9689441*Y(3)

(1) There are a total of 4 states which are updated within AutoCode™. State coefficients 2 to 4 are only used when the controller is trimming and are calculated for a sampling period of 0.025 second. If desired, these states can still be updated externally, X(I)=XD(I).

Table 2.4 - Subroutine **USR19V151** - INPUTS

NO	AUTO CODE SYMBOL	DEFINITION
1	PSTICK	Pitch stick (inch)
2	PTRIM	Pitch trim (inch)
3	OBES_LONST	OBES (1) longitudinal stick
4	AOA	Angle-of-attack faded between probe and INS (deg)
5	Q	Pitch rate (deg/sec)
6	NZ	Normal acceleration (g) - positve along negative z-axis
7	QCFILTER1	2.5 rad/sec filtered impact pressure (lb/ft^2)
8	QCFILTER2	10 rad/sec filtered impact pressure (lb/ft^2)
9	PS	Static Pressure (lb/ft^2)
10	GTILY1	Feedback gain (proportional) for angle-of-attack
11	GTILY2	Feedback gain (proportional) for pitch rate
12	GTILY3	Feedback gain (proportional) for load factor

Table 2.4 - Concluded

NO	AUTO CODE SYMBOL	DEFINITION
13	GTILU1	Feedback gain for filter
14	GTILZ1	Feedback gain for integrator
15	VT	True airspeed (ft/sec)
16	COSALF	Cosine of angle-of-attack
17	SINALF	Sine of angle-of-attack
18	COSTHE	Cosine of the pitch angle
19	SINTHE	Sine of the pitch angle
20	COSPHI	Cosine of the roll angle
21	DELSTM	Stabilator, and pitch jet commanded position for trim (deg)
22	TRMMING	Trim flag (real): 0.0 = Operate 1.0 = Trim
23	OBE_COLLECTIVE _STABI.LATOR _CMD	OBES collective stabilator command (deg)
24	OBE_PITCH _VANE_CMD	OBES pitch thrust vectoring command (deg)

(1) OBES - On-Board Excitation System - Provides computer-generated commands to control surfaces and control system

Table 2.5 - Subroutine **USR19V151** - OUTPUTS

NO	AUTO CODE SYMBOL	DEFINITION
1	SBPAC1	Collective stabilator command (deg)
2	TVSC	Pitch thrust vectoring command (deg)
3	PSGTOT	Total stick command (inch)
4	YCMD	Command to the feedback control
5	AOATR	Estimated angle-of-attack trim
6	DY	Error in regulated variable
7	DELY	Error in regulated variable limited to max of 5.0. Used by pilot to trim stick position.
8	QCOMP	Compensated pitch-rate (deg/sec)
9	QCOMP1	Gravity compensation in pitch-rate signal
10	VBRK1	Rate command for stabilator
11	UK1	Control variable for stabilator command (deg)
12	UME11	Feedforward control variable (deg/sec)
13	KCGT	Feedforward gain

Table 2.6 - Subroutine **USR19V151** - STATES (1)

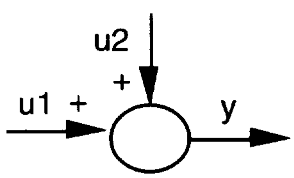
NO	FORCING FUNCTION	EQUATION - TRIM
X(8)	Y(12) - QCOMP1	X(8) = .8421053*Y(12)
X(9)	U(5) - Q	X(9) = 1.3459*U(5)
X(10)	U(5) - Q	X(10) = 1.3459*U(5)
X(11)	U(6) - NZ	X(11) = 18.656716*U(6)
X(12)	U(6) - NZ	X(12) = 18.656716*U(6)
X(13)	U(6) - NZ	X(13) = .4326*U(6)
X(14)	U(6) - NZ	X(14) = .4326*U(6)
X(15)	U(6) - NZ	X(15) = .4326*U(6)
X(16)	U(9) - PS	X(16) = .4326*U(9)
X(17)	Y(1) - SBPAC1	X(17) = .993785*Y(1)

(1) There are a total of 17 states which are updated within AutoCode™. State coefficients 8 to 17 are only used when the controller is trimming and are calculated for a sampling period of 0.0125 second. During trim states 1 to 7 are updated by setting X(I)=XD(I), and after trim all states are updated using this equation.

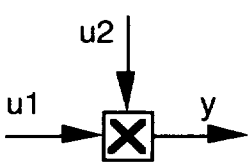
2.4 Block Diagram

A complete block diagram of the Longitudinal Control Law is shown in figure 2.1. The following subsection describes special flow chart notation, special inputs that are needed, and certain calculations that may not be obvious from the flow charts.

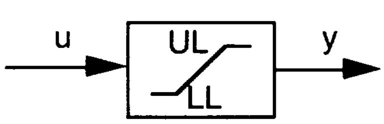
2.4.1 Flow Chart Notation



The diagram above represents a summer where y = u1 + u2..

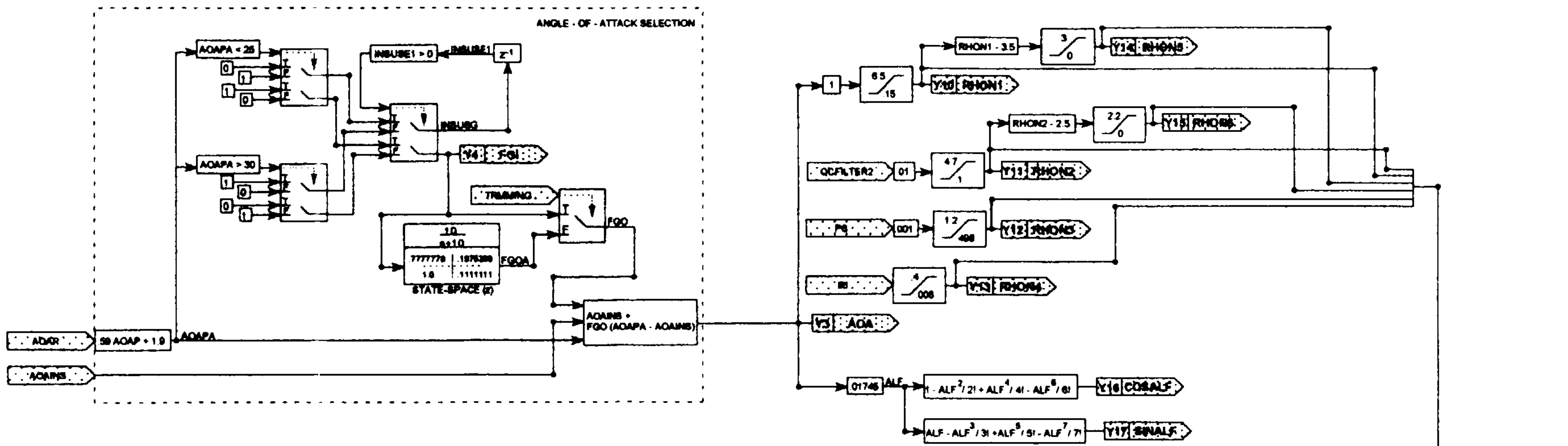


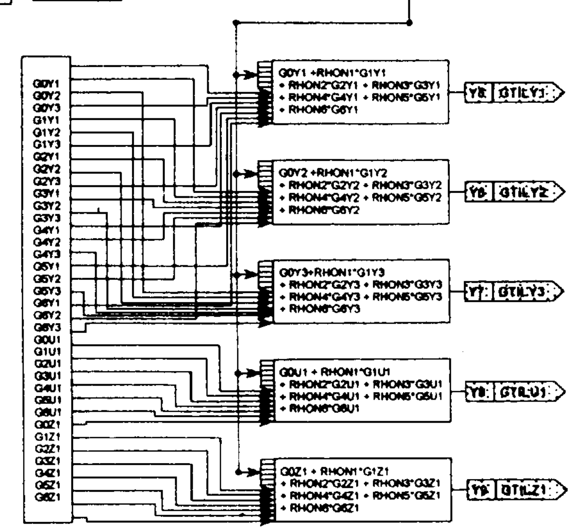
The diagram above represents a multiplier where y = u1 * u2.



The diagram above represents a limiter with lower limit LL and upper limit UL as

$y = u \quad \text{if } LL \leq u \leq UL$
$y = LL \text{ if } u < LL$
$y = UL \text{ if } u > UL.$





	GAINSET 0	GAINSET 1	GAINSET 2
G0Y1	-14.62	-17.326	-10.62846
G0Y2	-21.71	-19.275	-25.47208
G0Y3	0.0	0.0	-5.316923
G1Y1	-1.4749	-1.4639	-1.216533
G1Y2	-1.2367	-1.611	-1.086538
G1Y3	0.0	0.0	-10.29744
G2Y1	-2.466	-1.5186	-3.517264
G2Y2	-16.247	-17.52	-12.79536
G2Y3	0.0	0.0	-16.77676
G3Y1	3.4317	2.3982	4.427750
G3Y2	3.2854	4.6636	.8636643
G3Y3	0.0	0.0	.2945739
G4Y1	40.219	42.866	33.58884
G4Y2	53.075	53.056	51.69084
G4Y3	0.0	0.0	38.94163
G5Y1	.17419	1.2816	-1.570699
G5Y2	-1.6711	-1.7377	-.8436691
G5Y3	0.0	0.0	50.16061
G6Y1	3.2363	2.502	4.566806
G6Y2	13.286	14.376	9.149627
G6Y3	0.0	0.0	24.26147
G0U1	20.305	19.383	21.93404
G1U1	.07942	.22329	-.04226651
G2U1	13.484	13.492	12.73723
G3U1	-6.632	-6.5514	-6.763256
G4U1	11.232	12.366	9.869692
G5U1	1.9031	1.5969	1.776999
G6U1	.52047	.46165	1.537797
G0Z1	-12.771	-4.9819	-30.80272
G1Z1	-1.6904	-.43126	-4.576894
G2Z1	2.1457	-1.3299	14.64501
G3Z1	-5.969	-3.0343	-16.06921
G4Z1	-43.338	-43.036	-37.45262
G5Z1	5.2069	-.50778	19.06181
G6Z1	3.7968	4.9062	-8.766835

LONGITUDINAL CONTROLLER

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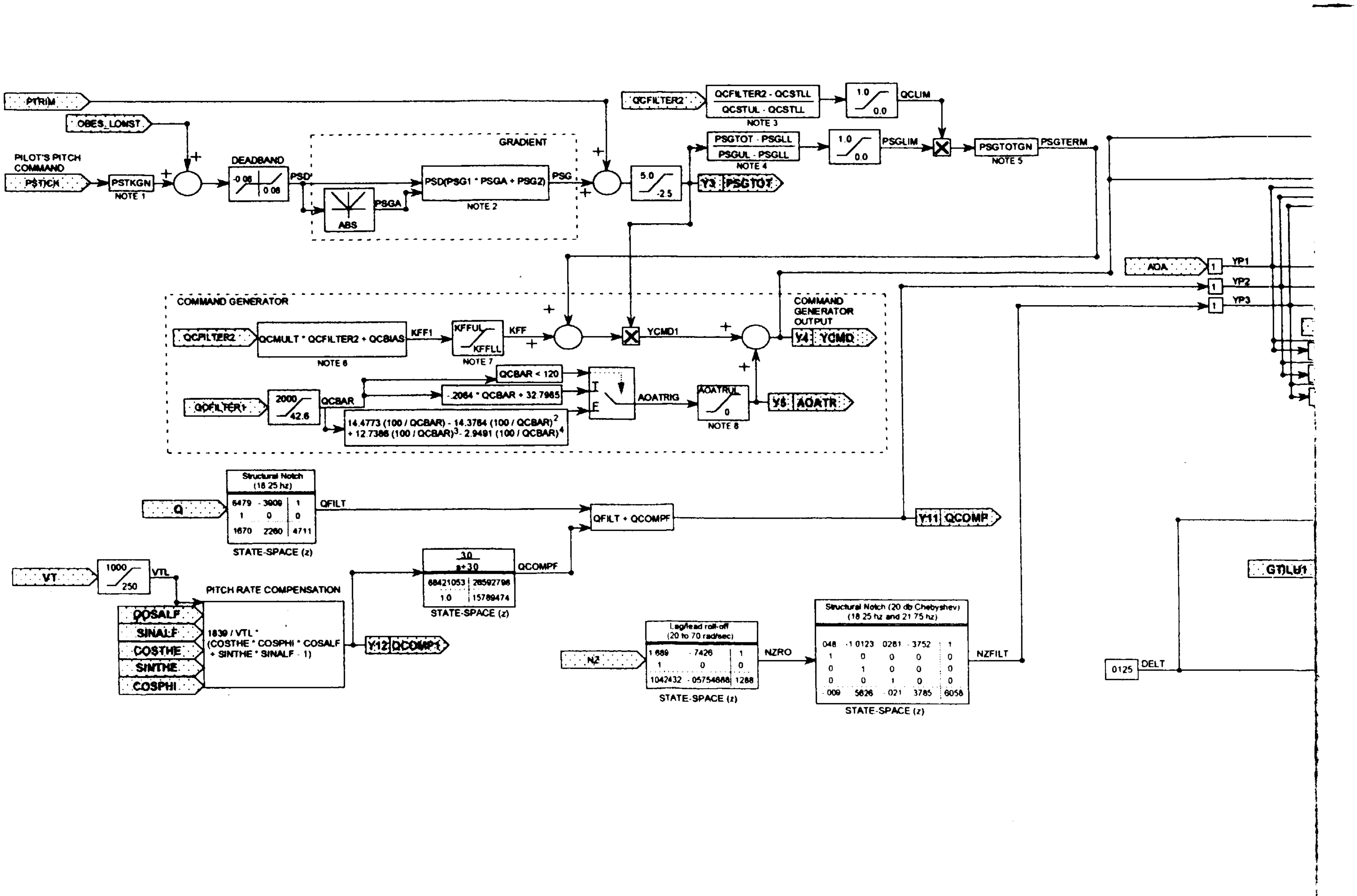
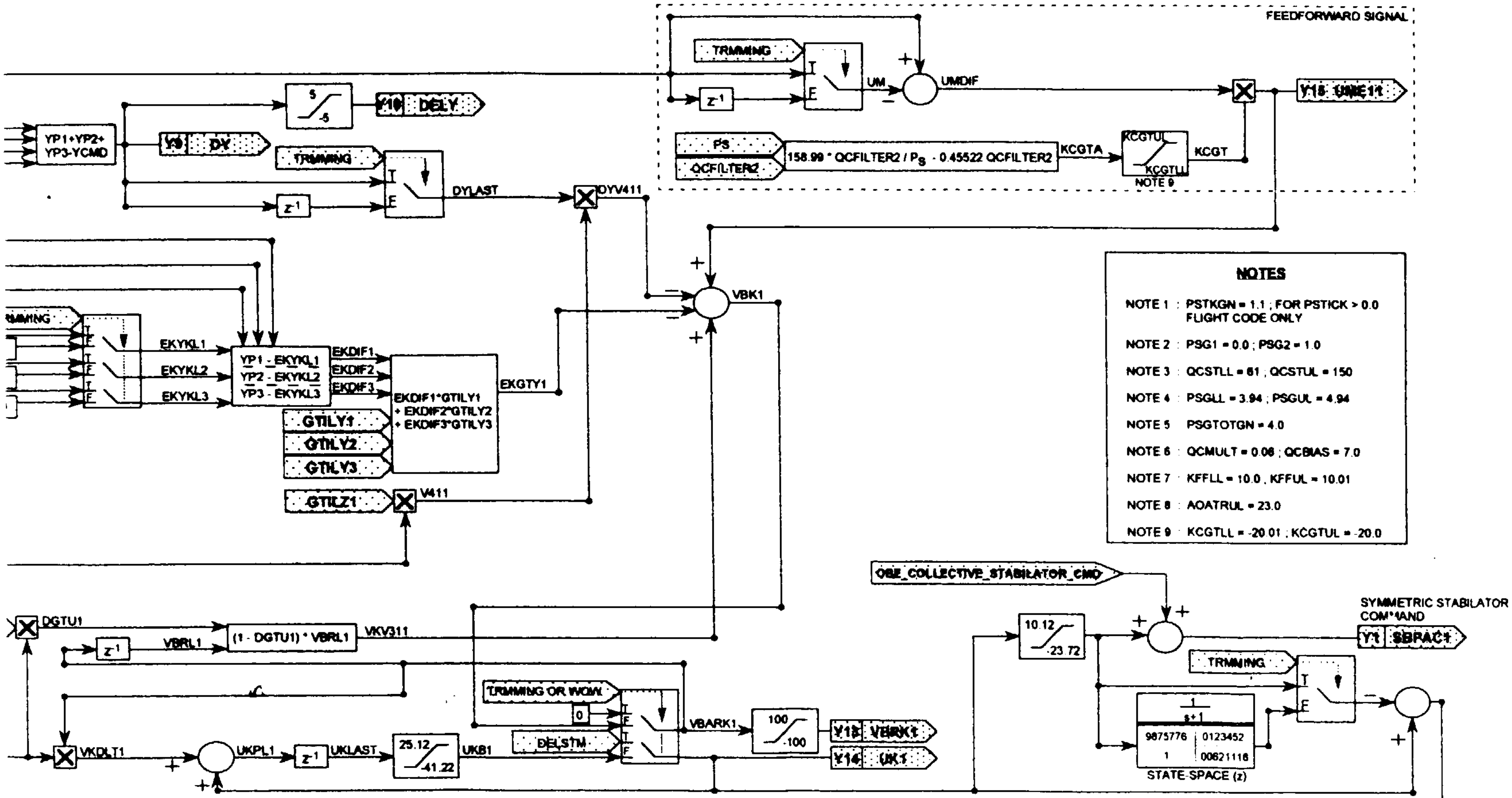
Figure 2.1 (a)


PTRIM
OBES_LONST
PILOT'S PITCH COMMAND
PSTICK
PSTKGN
NOTE 1
DEADBAND
-0.06
0.06
PSD'
GRADIENT
ABS
PSGA
PSD(PSG1 * PSGA + PSG2)
NOTE 2
PSG
5.0
-2.5
Y3 PSGTOT
QCFILTER2
QCFILTER2 - QCSTLL
QCSTUL - QCSTLL
NOTE 3
1.0
0.0
QCLIM
PSGTOT - PSGLL
PSGUL - PSGLL
NOTE 4
PSGLIM
PSGTOTGN
NOTE 5
PSGTERM
AOA
YP1
YP2
YP3
COMMAND GENERATOR
QCMULT * QCFILTER2 + QCBIAS
NOTE 6
KFF1
KFFUL
KFFLL
NOTE 7
KFF
YCMD1
COMMAND GENERATOR OUTPUT
Y4 YCMD
QCFILTER1
2000
42.6
QCBAR
QCBAR < 120
.2064 * QCBAR + 32.7985
14.4773 (100 / QCBAR) - 14.3764 (100 / QCBAR)^2 + 12.7388 (100 / QCBAR)^3 - 2.9491 (100 / QCBAR)^4
T
F
AOATRIG
AOATRUL
0
NOTE 8
Y5 AOATR
Q
Structural Notch (18 25 hz)
6479 - 3909 1
1 0 0
1670 2260 4711
STATE-SPACE (z)
QFILT
QFILT + QCOMPF
Y11 QCOMP
VT
1000
250
VTL
PITCH RATE COMPENSATION
COSALF
SINALF
COSTHE
SINTHE
COSPHI
1839 / VTL * (COSTHE * COSPHI * COSALF + SINTHE * SINALF - 1)
Y12 QCOMP1
30
s+30
68421053 28592798
1.0 15789474
STATE-SPACE (z)
QCOMPF
NZ
Lag/lead roll-off (20 to 70 rad/sec)
1 689 - 7426 1
1 0 0
1042432 - 05754688 1288
STATE-SPACE (z)
NZRO
Structural Notch (20 db Chebyshev) (18 25 hz and 21 75 hz)
048 -1 0123 0281 - 3752 1
1 0 0 0 0
0 1 0 0 0
0 0 1 0 0
- 009 5626 - 021 3785 6058
STATE-SPACE (z)
NZFILT
0125
DELT
GTILT1



LONGITUDINAL CONTROLLER

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Figure 2.1(b)

FIGURE 2.1(c)

LONGITUDINAL CONTROLLER - FLAPS

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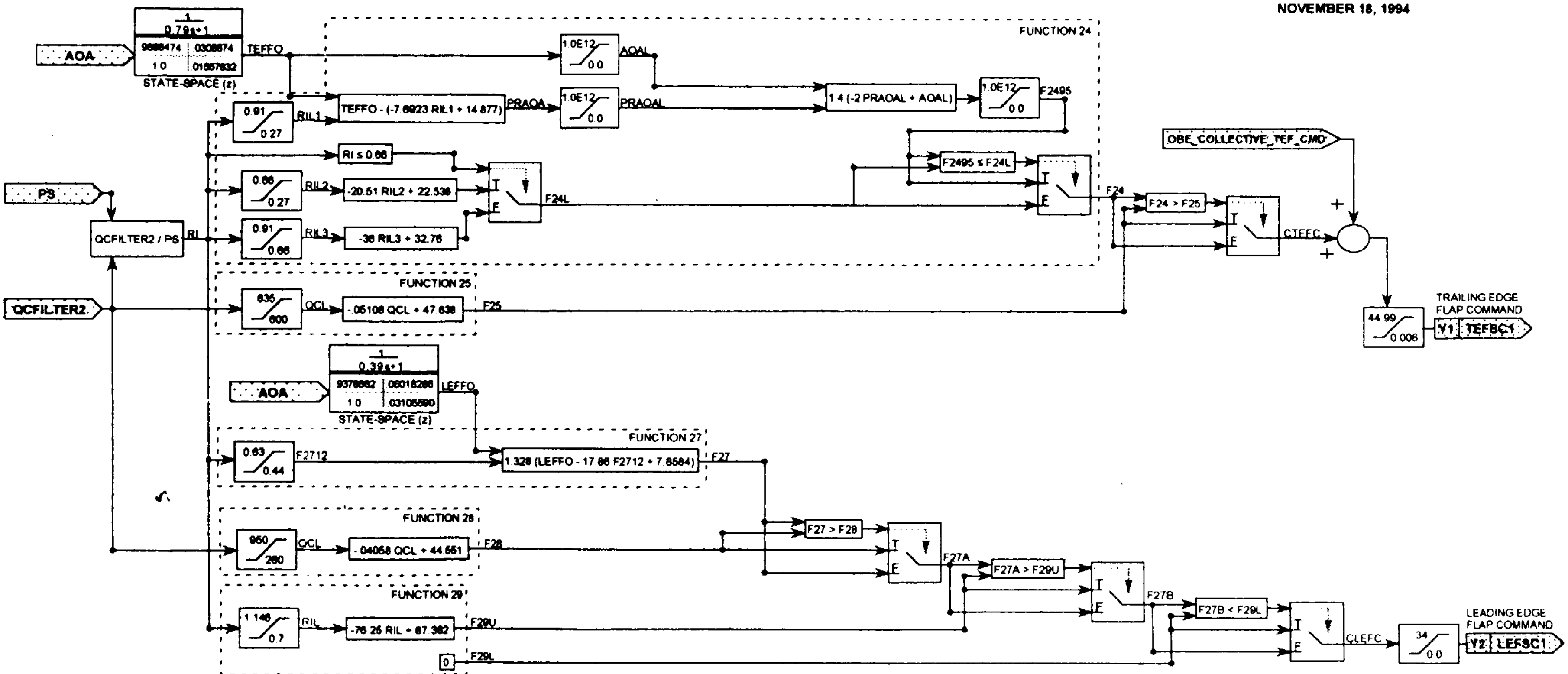
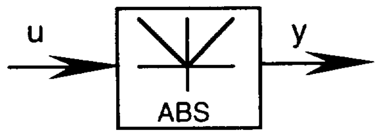
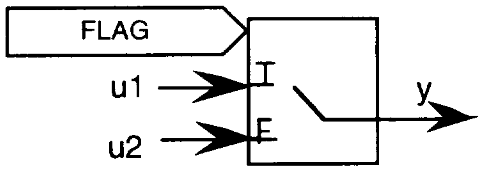
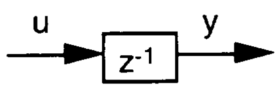




The diagram above represents an absolute value condition where y = | u |.



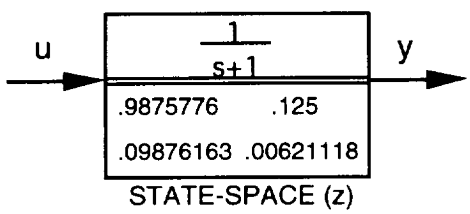
The diagram above represents a logical IF, THEN, ELSE statement.
If FLAG is TRUE y = u1, ELSE y = u2.



The diagram above represents a dynamic element for a one sample period time delay as

$$x_{k+1} = u_k$$
$$y_k = x_k$$

where the subscript k represents the sample number.



The diagram above represents a dynamic element with one state. The continuous transfer function is shown on top and the discrete state-space representation is shown on the bottom. The discrete version is to be used in the code as shown in the example

$$x_{k+1} = 0.9875776\, x_k + 0.125\, u_k$$
$$y_k = 0.09876163\, x_k + 0.00621118\, u_k$$

where the subscript k represents the sample number. The approach used to calculate dynamic filters is shown in a later section.

2.4.2 *Calculated Inputs Required*

VT	Total airspeed (ft/sec) - calculated as in NASA-0 [(1)]
RI	Pressure ratio (N/D) - calculated as in NASA-0
COSTHE	Cosine(θ) - computed to an accuracy of $\theta^6/6!$ for $\theta = \pm 90°$.
SINTHE	Sin(θ) - computed to an accuracy of $\theta^7/7!$ for $\theta = \pm 90°$.
COSPHI	Cosine(ϕ) - computed to an accuracy of $\phi^8/8!$ for $\phi = \pm 180°$.
PTRIM	Pitch stick trim input (inch) - calculated as in NASA-0.

[(1)] NASA-0 is the HARV Control Law designed by McDonnell Aircraft Company and Dryden Flight Research Center and flight tested during Phase II.

2.4.3 *Approach to Calculation of Dynamic Filters*

Given a discrete dynamic equation

$$x_{k+1} = \phi\, x_k + \gamma\, u_k$$
$$y_k = C\, x_k + D\, u_k$$

Procedure:

1. Initialize state x_k to zero on first pass.

$$x_k = 0.$$

2. If the controller is in trim condition (TRMMING is TRUE), calculate the initial condition for the state as

$$x_k = (1 - \phi)^{-1}\, \gamma\, u_k$$

3. Calculate the output equation

$$y_k = C\, x_k + D\, u_k$$

4. Calculate the dynamic equation

$$x_{k+1} = \phi\, x_k + \gamma\, u_k$$

5. Update the state x_k

Documentation supplied with the horizontal flow charts includes tables of STATES that contain the trim coefficients ($(1 - \phi)^{-1}\, \gamma$) for each of the appropriate filter states and the input u_k (forcing function) that should be used.

2.4.4 *Technique for Engage*

Prior to engaging the RFCS, the flag TRMMING should be TRUE. During this condition, the rate-command loop is opened, and the state is set to zero. In addition, the rate-to-position integrator loop is also opened, and the 701E stabilator command is passed in to set the integrator state. Except for potential time delays, the control command from the RFCS will always be the same as the 701E command, including when the weight-on-wheels (WOW) flag is TRUE. When ENGAGE occurs, the flag TRMMING is set to FALSE. This puts the control system into the operational configuration.

2.5 References

2.1 Halyo, Nesim; Moerder, D.D.; Broussard, J.R.; and Taylor, D.B.: *A Variable-Gain Output Feedback Control Design Methodology.* NASA CR-4226, March 1989.

2.2 Ostroff, A. J. : High-Alpha Application of Variable-Gain Output Feedback Control. *Journal of Guidance, Control, and Dynamics*, Pages 491-497, Volume 15, Number 2, March-April 1992.

2.3 Ostroff, Aaron J.; and Proffitt, Melissa S.: *Longitudinal-Control Design Approach for High-Angle-of-Attack Aircraft*, NASA TP-3302, February 1993.

2.4 Ostroff, Aaron J.; Hoffler, Keith D.;and Proffitt, Melissa S.: High-Alpha Research Vehicle (HARV) Longitudinal Controller: Design, Analyses and Simulation Results, NASA TP 3446, July 1994.

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CHAPTER 3
Lateral/Directional Feedback Control Law
Version 151

3.1 Functional Description

The ANSER Lateral/Directional Control Law is an innovative control augmentation system for the HARV flight test vehicle. This control law was developed utilizing the Pseudo Controls and CRAFT design methods, which are currently being researched at NASA LaRC (refs.3-1, 3-2). Pseudo Controls is a nonlinear control blending strategy which translates roll and yaw commands into an optimum combination of control surface and thrust vectoring control deflections which provide maximum stability-axis roll and yaw moments. The CRAFT control design method is used to compute measurement feedback gains. It is a combination of Direct Eigenspace Assignment (ref. 3-3) and a graphical approach for optimizing robustness, agility, and flying qualities requirements, while simultaneously respecting the available aircraft control power. The combination of CRAFT and Pseudo Controls facilitated production of a lateral/directional control law which provides good flying qualities, system robustness, and maximum agility within the constraints of the available control power and flying qualities requirements.

Figure 3.0 shows a functional diagram of the ANSER Lateral/Directional Control Law. Pilot inputs to the control law are stability-axis roll rate through lateral stick deflections and "conventional" yaw command through pedal deflections. Pilot inputs are modified and shaped before being multiplied by input gains and summed with feedback signals which have been passed through structural filters and multiplied by CRAFT feedback gains. The feedback measurements are body-axis roll rate, body-axis yaw rate, lateral acceleration, and sideslip rate. The sum of pilot inputs and feedback measurements produce stability-axis roll and yaw acceleration commands, or Pseudo Control commands, vlat and vdir. These lateral and directional commands are distributed by Pseudo Controls into the optimum blend of control deflections. The controls being used are aileron, rudder, differential stabilator, yaw thrust vectoring, and nose strakes. The ANSER control law does not use differential leading and trailing edge flaps. Roll thrust vectoring is not used, but a capability exists to use this control if desired.

Within the Pseudo Controls portion of the control law body angular rates and nominal inertial characteristics are used to provide inertial coupling compensation. Thrust vectoring management is also provided within Pseudo Controls. Thrust vectoring is engaged based on its control moment producing capabilities relative to that of the aerodynamic controls. As the available aerodynamic moment decreases, the thrust vectoring increases to "fully on" at the point where the available aerodynamic moment is equal to the available thrust vectoring moment. When the available aerodynamic moment is twice the available thrust vectoring moment, the thrust vectoring is turned off. Vane relief is also provided to reduce paddle heating; whenever sufficient aerodynamic control moment is available to replace yaw thrust-vectoring control, thrust vectoring is faded out.

The ANSER lateral-directional control law has three modes of operation. These modes allow the selection of one of three combinations of traditional aero controls (aileron, rudder, and differential stabilator), yaw thrust vectoring, and differential forebody strakes as lateral-directional control effectors. These three modes are : yaw thrust vectoring mode (TV), strake mode (S), and strake plus yaw thrust vectoring mode (STV). TV mode utilizes the traditional aero controls and yaw thrust vectoring. S mode utilizes the traditional aero controls and differential forebody strakes. STV mode utilizes all the control power available - the traditional aero controls plus yaw thrust vectoring and differential forebody strakes. All three modes include pitch thrust vectoring.

3.2 Implementation

A complete horizontal block diagram (HBD) of the Lateral/Directional Feedback Control Law is shown in figure 3.1.

3.3 Specification Description

The following sections present the details of the software specification including equations and graphical depictions of the functions to be implemented. Some brief narrative on the operation of each element of the specification and the assignment of each element to a module is given as well. Dynamics specifications are presented in the z-plane on the HBD and in the s-plane in the text. Continuous-domain dynamics were discretized using a Tustin transformation at 80 Hz.

Since this control law was primarily developed using the SystemBuild™ feature of MATRIX$_X$® and FORTRAN code was primarily produced using the MATRIX$_X$® Autocode™ Generator, the following description of the control law uses names corresponding to the Super-Blocks and AutoCode subroutines created with these design tools. For clarity, variable names are identical in the Super blocks, AutoCode subroutine modules, and the horizontal block diagram, except as noted.

For organizational purposes the control law description and the HBD are divided into the following groups of elements which are considered separately.

3.3.1 Lateral Stick Command Path - Figure 3.2
3.3.2 Pedal Command Path - Figure 3.3
3.3.3 Feedback Signal Path - Figure 3.4
3.3.4 Command Summation Block - Figure 3.5
3.3.5 Pseudo Controls Interface and Command Limiting - Figures 3.6 and 3.7
3.3.6 Mode Switching Logic - Figure 3.8

A complete description of Pseudo Controls is given in Chapter 4.

Notes describing how to hardwire or modify the ANSER lateral-directional control law to operate in the TV mode only are given in italics at the end of the following sections :

3.3.1.7 Stick Command Gain
3.3.3.6 Strake Deployment Compensation
3.3.5.1 Pseudo Controls Interface
3.3.5.2 Control Effector Command Limits
3.3.6 Mode Switching Logic
3.4 Control Law Inputs and Outputs

The corresponding control law elements are highlighted in Figures 3.2-3.7 by bold boxes.

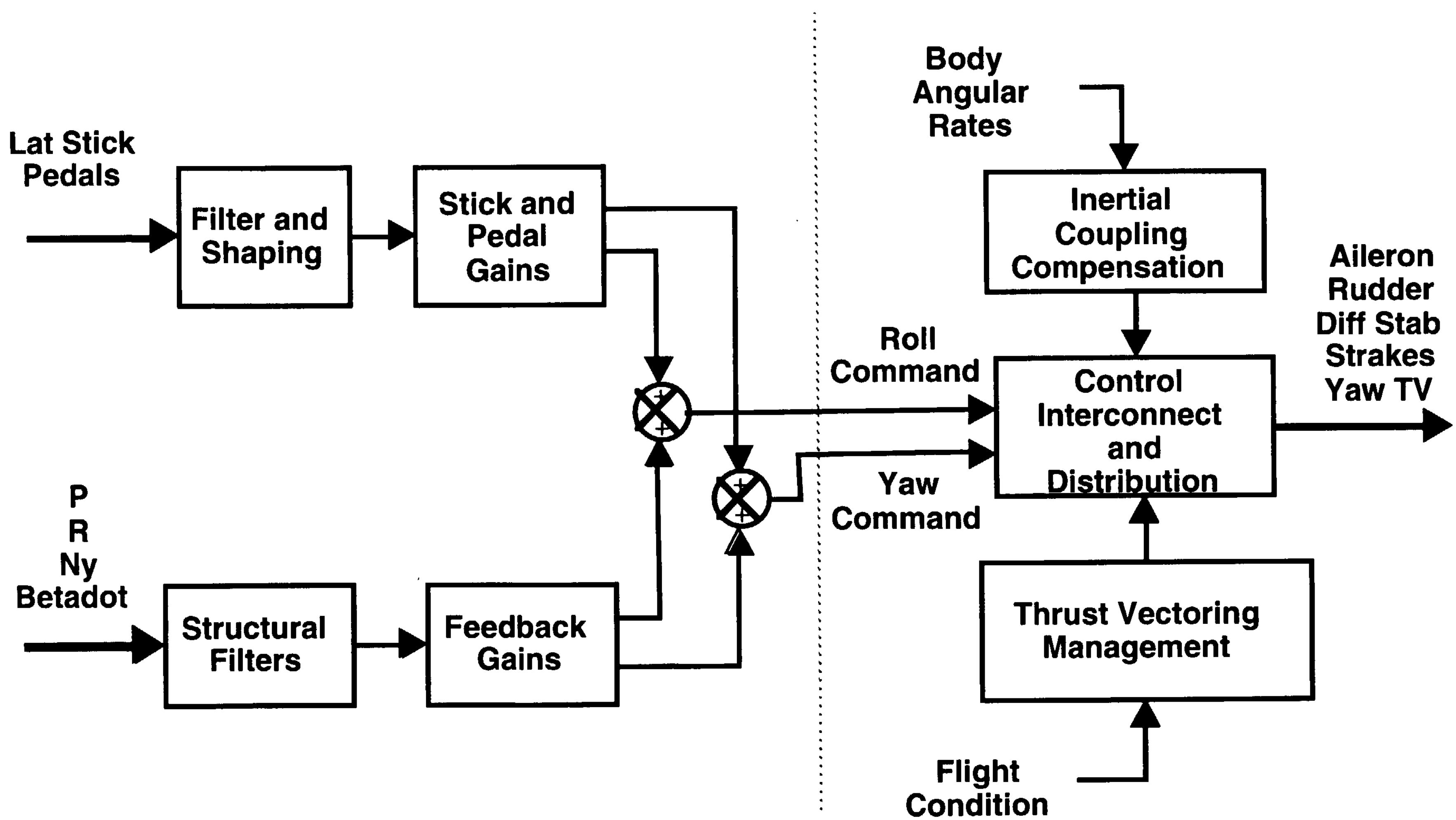


Figure 3.0 - Control Law Overview

3.3.1 Lateral Stick Command Path

The Lateral Stick Command Path is given in Figure 3.2.

3.3.1.1 Lateral Stick Deadband and Shaping Function

The external lateral stick input is assumed to be bounded to ±3.0 inches. Lateral stick external input is first passed through a deadband and shaping function. The deadband and shaping function are chosen to provide appropriate stick characteristics to the pilot. The deadband is set to ±0.025 inches.

The parabolic shape function is

Output = (1.0 - 0.75*(1.0 - 0.3361*ABS(Input)))*0.3361*Input

The shape function normalizes the stick input. The output is bounded to ±1.0. A comparison of the ANSER and NASA-1A lateral stick parabolic shape functions is given in figure 3.2.1.

3.3.1.2 Stick Coordination

Stick-coordination elements are provided to compensate for the lack of coordination occurring due to different actuation rates available on the ailerons and rudders. This compensation provides a rate limit, and the feedforward element is added to improve the roll rate response. The rate limit is 0 to maximum lateral stick in 0.25 seconds.

3.3.1.3 Stick Dynamic Limiter and Roll Trim

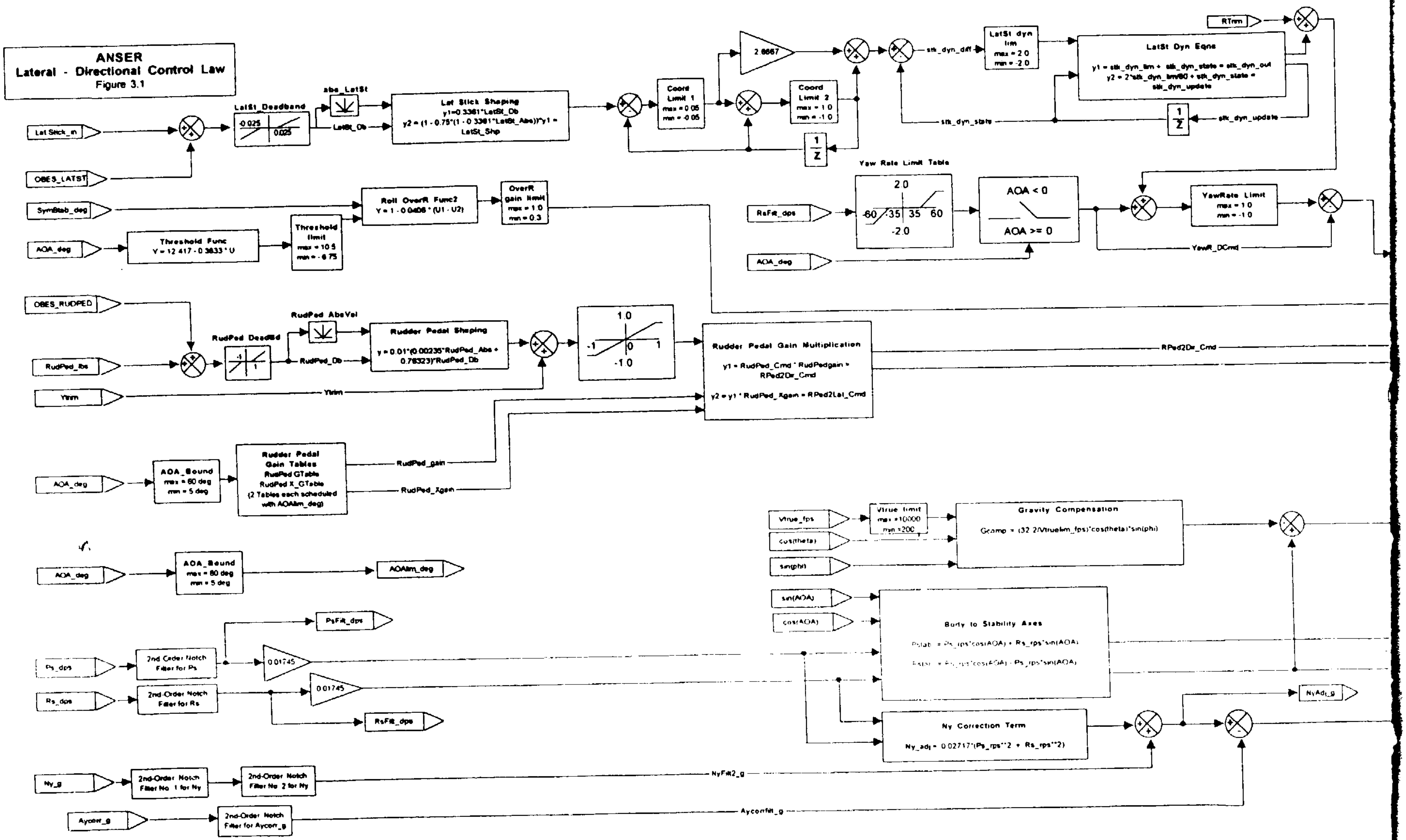
These elements are designed to reduce sideslip excursions that can occur during aggressive recoveries from maximum performance rolls where a large stick deflection is used. Functionally these elements allow stick deflections up to 70 percent of full throw to be passed directly with larger deflections having the signal passed through a first order lag. *This element should be disabled for the ANSER flight test. This can be done by changing the internal limit variable from +/-0.7 to +/-2.0.*

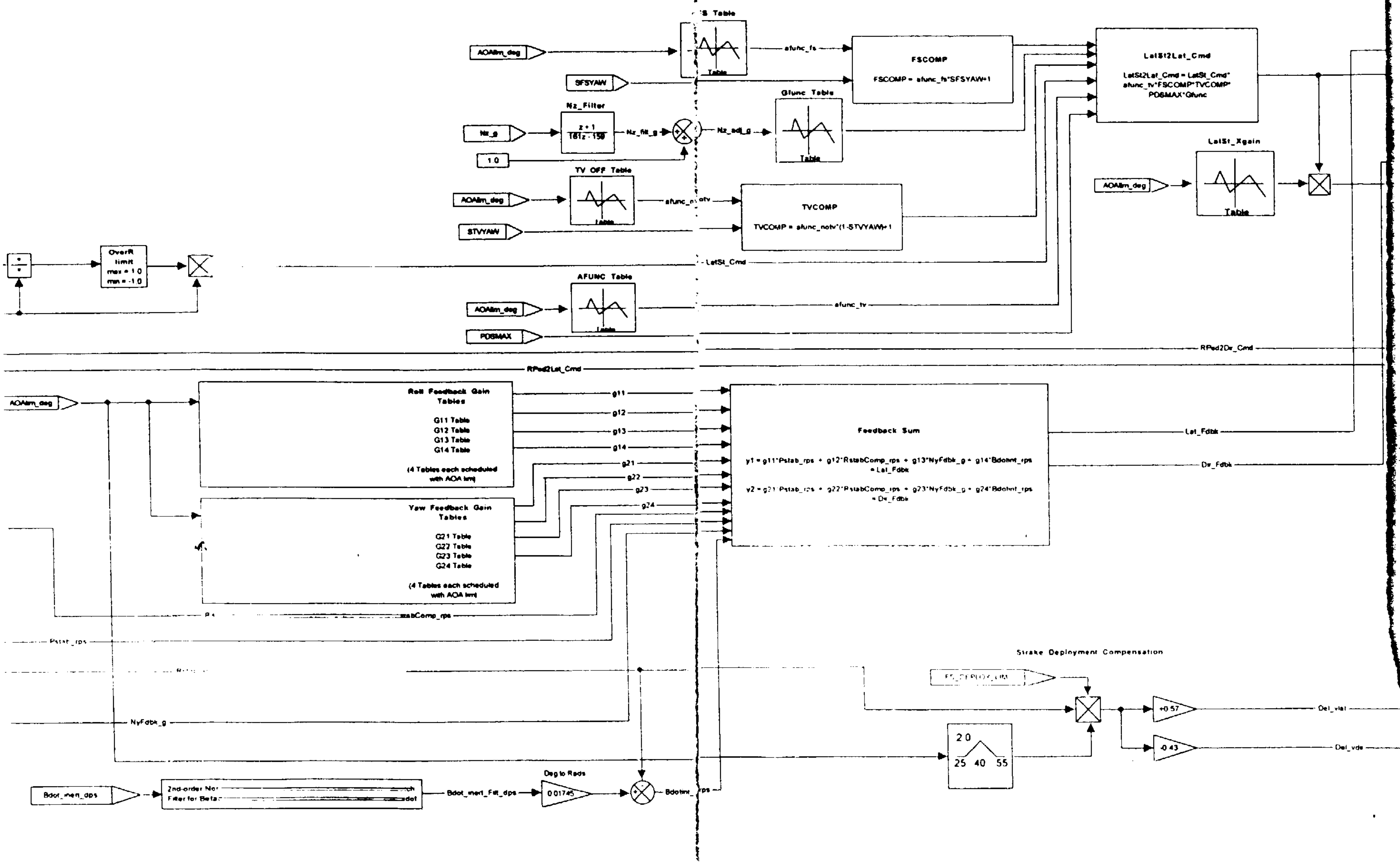
Roll Trim is added to the signal after the stick dynamic limiter. The external roll trim input is assumed to be bounded to ±0.5 (nondim).

3.3.1.4 Yaw Rate Limiter

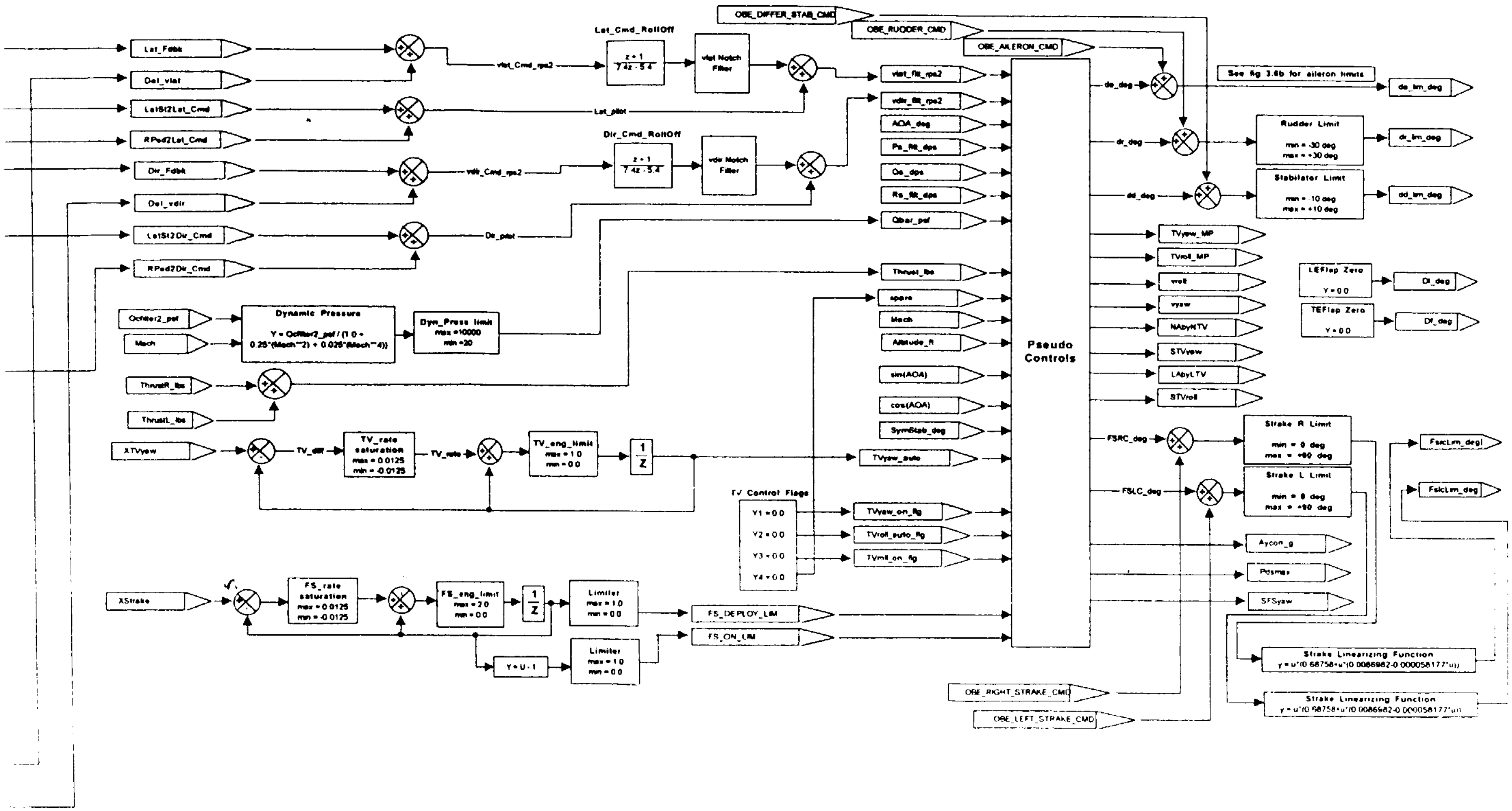
Excessive yaw rates, beyond that required for coordinated rolling, may be produced with thrust vectoring. To prevent excessive rates a yaw-rate limiter is incorporated into the stick command path. These elements monitor body-axis yaw rate Rs_dps (sensed yaw rate) and begin reducing stability-axis roll commands in the stick path when Rs_dps exceeds 35 deg/sec according to the table below. Additional reduction is applied as yaw rate increases in magnitude according to the Yaw Rate Limit Table below, and maximum reduction is attained when Rs reaches 60 deg/sec. The yaw-rate limiting is not applied when AOA is negative.

ANSER
Lateral - Directional Control Law
Figure 3.1

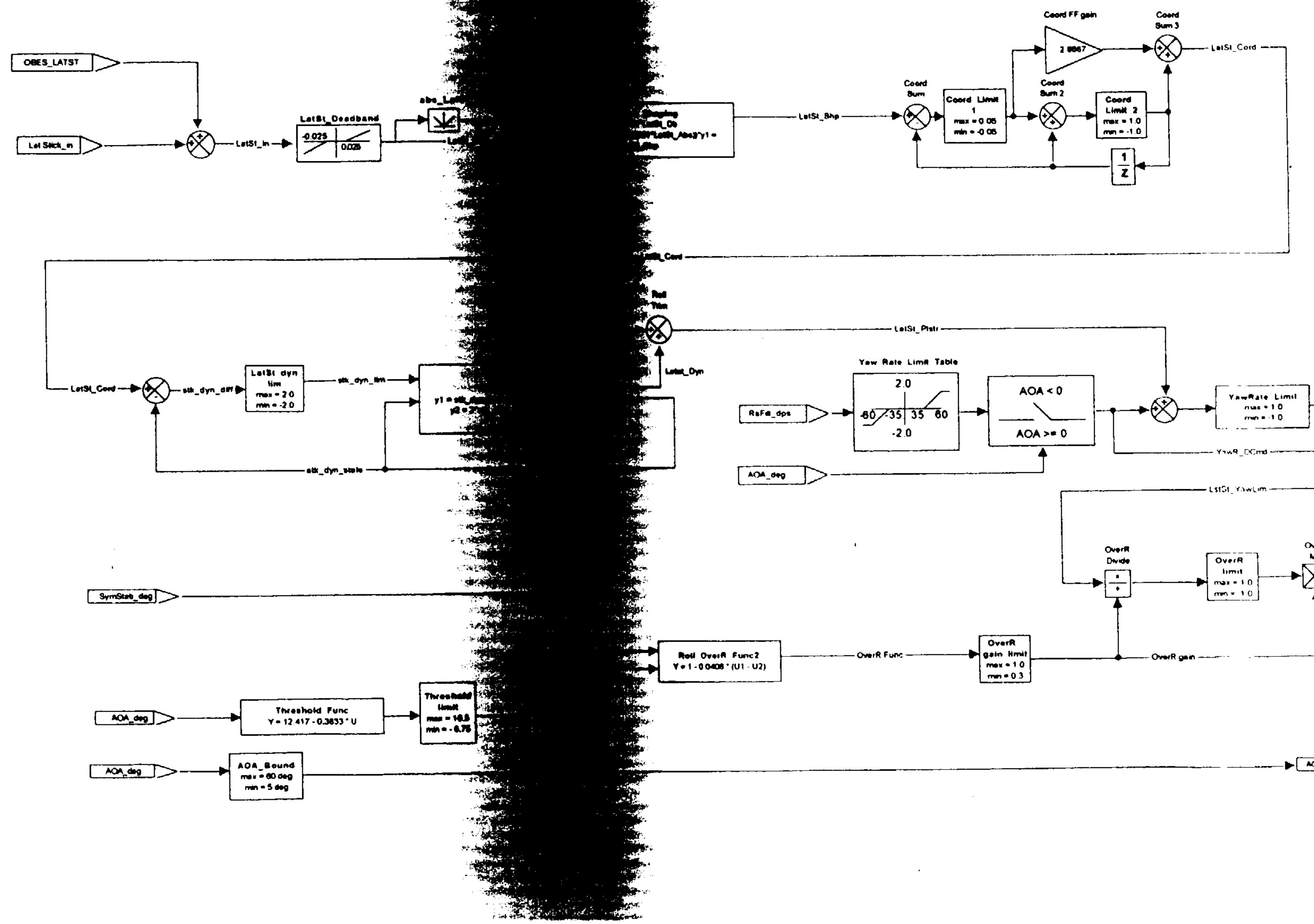


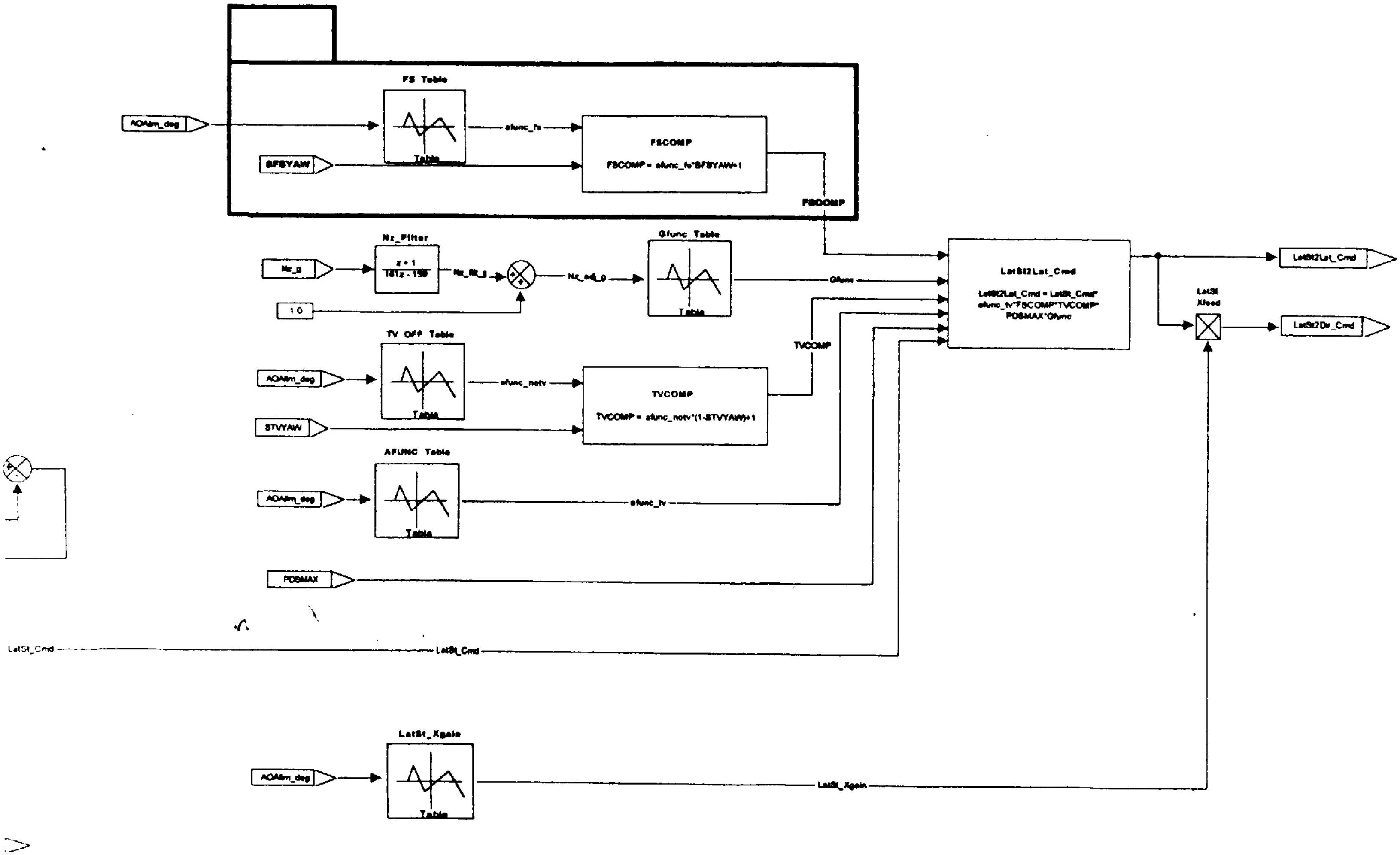


AOAlim_deg
SFSYAW
Nz_g
Nz_Filter
z + 1
T61z - 150
Nz_filt_g
1.0
Nz_adj_g
Gfunc Table
Table
afunc_fs
FSCOMP
FSCOMP = afunc_fs*SFSYAW+1
TV OFF Table
STVYAW
TVCOMP
TVCOMP = afunc_notv*(1-STVYAW)+1
LatSt_Cmd
AFUNC Table
afunc_tv
PDSMAX
LatSt2Lat_Cmd
LatSt2Lat_Cmd = LatSt_Cmd*afunc_tv*FSCOMP*TVCOMP*PDSMAX*Gfunc
LatSt_Xgain
OverR limit max = 1.0 min = -1.0
RPed2Dr_Cmd
RPed2Lat_Cmd
Roll Feedback Gain Tables
G11 Table
G12 Table
G13 Table
G14 Table
(4 Tables each scheduled with AOA lim)
Yaw Feedback Gain Tables
G21 Table
G22 Table
G23 Table
G24 Table
(4 Tables each scheduled with AOA lim)
g11
g12
g13
g14
g21
g22
g23
g24
Feedback Sum
y1 = g11*Pstab_rps + g12*RstabComp_rps + g13*NyFdbk_g + g14*Bdotinrt_rps = Lat_Fdbk
y2 = g21*Pstab_rps + g22*RstabComp_rps + g23*NyFdbk_g + g24*Bdotinrt_rps = Dr_Fdbk
Lat_Fdbk
Dr_Fdbk
Pstab_rps
NyFdbk_g
Bdot_inert_dps
2nd-order Not Filter for Beta
Bdot_inert_Filt_dps
Deg to Rads
0.01745
Strake Deployment Compensation
20
25 40 55
+0.57
-0.43
Del_vlat
Del_vde


Lat_Fdbk
Del_vlat
LatSt2Lat_Cmd
RPed2Lat_Cmd
Dir_Fdbk
Del_vdir
LatSt2Dir_Cmd
RPed2Dir_Cmd
Lat_Cmd_RollOff
vlat_Cmd_rps2
vlat Notch Filter
Lat_pilot
Dir_Cmd_RollOff
vdir_Cmd_rps2
vdir Notch Filter
Dir_pilot
Qcfilter2_psf
Mach
Dynamic Pressure
Y = Qcfilter2_psf / (1.0 + 0.25*(Mach^2) + 0.025*(Mach^4))
Dyn_Press limit
max =10000
min =20
ThrustR_lbs
ThrustL_lbs
XTVyaw
TV_diff
TV_rate saturation
max = 0.0125
min = -0.0125
TV_rate
TV_eng_limit
max = 1.0
min = 0.0
TV Control Flags
Y1 = 0.0
Y2 = 0.0
Y3 = 0.0
Y4 = 0.0
XStrake
FS_rate saturation
max = 0.0125
min = -0.0125
FS_eng_limit
max = 2.0
min = 0.0
Limiter
max = 1.0
min = 0.0
Y = U - 1
FS_DEPLOY_LIM
FS_ON_LIM
OBE_DIFFER_STAB_CMD
OBE_RUDDER_CMD
OBE_AILERON_CMD
vlat_filt_rps2
vdir_filt_rps2
AOA_deg
Ps_filt_dps
Qs_dps
Rs_filt_dps
Qbar_psf
Thrust_lbs
spare
Mach
Altitude_ft
sin(AOA)
cos(AOA)
SymStab_deg
TVyaw_auto
TVyaw_on_flg
TVroll_auto_flg
TVmil_on_flg
Pseudo Controls
da_deg
dr_deg
dd_deg
See fig 3.6b for aileron limits
da_lim_deg
Rudder Limit
min = -30 deg
max = +30 deg
dr_lim_deg
Stabilator Limit
min = -10 deg
max = +10 deg
dd_lim_deg
TVyaw_MP
TVroll_MP
vroll
vyaw
NAbyNTV
STVyaw
LAbyLTV
STVroll
LEFlap Zero
Y = 0.0
Dl_deg
TEFlap Zero
Y = 0.0
Df_deg
FSRC_deg
FSLC_deg
Strake R Limit
min = 0 deg
max = +90 deg
Strake L Limit
min = 0 deg
max = +90 deg
FsrcLim_degl
FslcLim_deg
Aycon_g
Pdsmax
SFSyaw
Strake Linearizing Function
y = u*(0.68758+u*(0.0086982-0.000058177*u))
OBE_RIGHT_STRAKE_CMD
OBE_LEFT_STRAKE_CMD

ANSER
Lateral Stick Command Path
Figure 3.2





AOAlim_deg
BFSYAW
FS Table
Table
afunc_fs
FSCOMP
FSCOMP = afunc_fs*BFSYAW+1
FSCOMP
Nz_g
Nz_Filter
z + 1
161z - 159
Nz_filt_g
1.0
Nz_off_g
Gfunc_Table
Table
Gfunc
TV OFF Table
Table
afunc_notv
TVCOMP
TVCOMP = afunc_notv*(1-STVYAW)+1
STVYAW
TVCOMP
AFUNC Table
Table
afunc_tv
PDSMAX
LatSt_Cmd
LatSt_Cmd
LatSt2Lat_Cmd
LatSt2Lat_Cmd = LatSt_Cmd*
afunc_tv*FSCOMP*TVCOMP*
PDSMAX*Gfunc
LatSt
Xfeed
LatSt2Lat_Cmd
LatSt2Dir_Cmd
LatSt_Xgain
Table
LatSt_Xgain

Yaw Rate Limit Table

Body Yaw Rate (deg/sec)	Gain
-100.0	-2.0
-60.0	-2.0
-35	0.0
35.0	0.0
60.0	2.0
100.0	2.0

3.3.1.5 Roll Override

Roll-override elements are designed to compensate against pitch-out during rapid rolls. Commanded symmetric stabilator deflection is monitored and compared against a threshold function which is a function of AOA. When the symmetric stabilator becomes saturated, the lateral stick command is reduced 70 percent.

3.3.1.6 Nz Filter and Adjustment

The sensed Nz signal is passed through a filter to attenuate noise in the signal.

Nz Filter

Continuous Form :

$$\frac{1}{s + 1}$$

Discrete Form (direct Tustin):

One (+1) is added to the filtered Nz signal to yield load factor.

3.3.1.7 Stick Command Gain

The lateral-stick-to-lateral-command gain (pds_max) is a function of available body roll and yaw control moments. The command gain is calculated in Pseudo Controls. Four functions (AFUNC, TV OFF, FS ON,and GFUNC) adjust the command gain for changes in control mode (TV,S, or STV) , angle of attack, and load factor. These functions are defined by the following tables. Values between design points are determined by linear interpolation.

ANSER AFUNC Table

Angle of Attack (deg)	Gain
5.0	1.16
10.0	1.24
15.0	1.4
20.0	1.7
25.0	1.9
30.0	1.7
35.0	1.16
40.0	1.16
45.0	1.04
50.0	1.16
60.0	1.16

TV Off Table

Angle of Attack (deg)	Gain
0.0	0.0
5.0	0.0
15.0	-0.3
35.0	-0.3
45.0	-0.1
55.0	0.0
100.0	0.0

FS Table

Angle of Attack (deg)	Gain
0.0	0.15
17.0	0.15
32.0	0.15
90.0	0.15

GFUNC Table

Load Factor (g)	Gain
0.0	1.0
1.5	1.0
3.5	0.35
9.0	0.35

Note: The FS Table is not required for operation in the TV mode. To hardwire for TV-mode-only operation set control law inputs XTVYAW = 1.0 and XSTRAKE = 0.0. To reduce code size for TV-mode-only operation delete the FS Table, FSCOMP calculation and set FSCOMP = 1.0.

3.3.1.8 Lateral Stick Cross-Gain

The lateral-stick-to-directional-command gains are functions of angle of attack. Values between design points are determined by linear interpolation. Gain values at design points are given in the following tables.

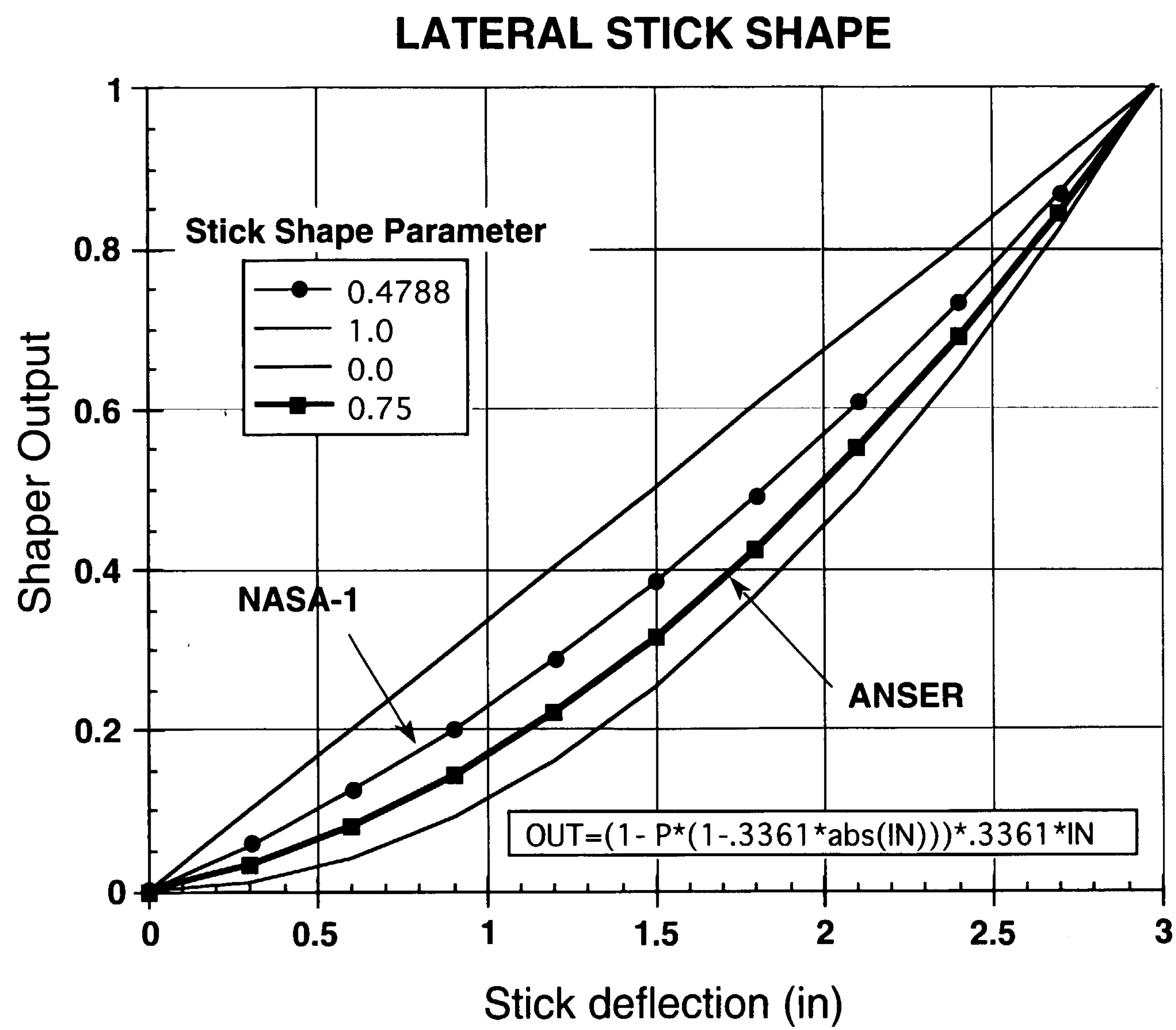


Figure 3.2.1- ANSER Lateral Stick Shape

Angle of Attack (deg)	Gain
5.0	-0.0209
10.0	-0.0575
15.0	-0.1044
20.0	-0.1259
25.0	-0.1560
30.0	-0.2107
35.0	-0.2398
40.0	-0.1318
45.0	-0.2427
50.0	-0.3768
55.0	-0.1769
60.0	-0.1453

3.3.2 Pedal Command Path

The Pedal Command Path is given in Figure 3.3.

3.3.2.1 Pedal Deadband, Shaping Function, and Yaw Trim

The deadband and shaping function are chosen to provide appropriate pedal characteristics to the pilot. The external pedal input is assumed to be bounded to ±100.0 pounds. The deadband is set to ±1.0 pounds. The parabolic shape function is the same as in NASA-0.

Output = 0.01*(2.34838e-03*ABS(Input) + 0.763225)*Input

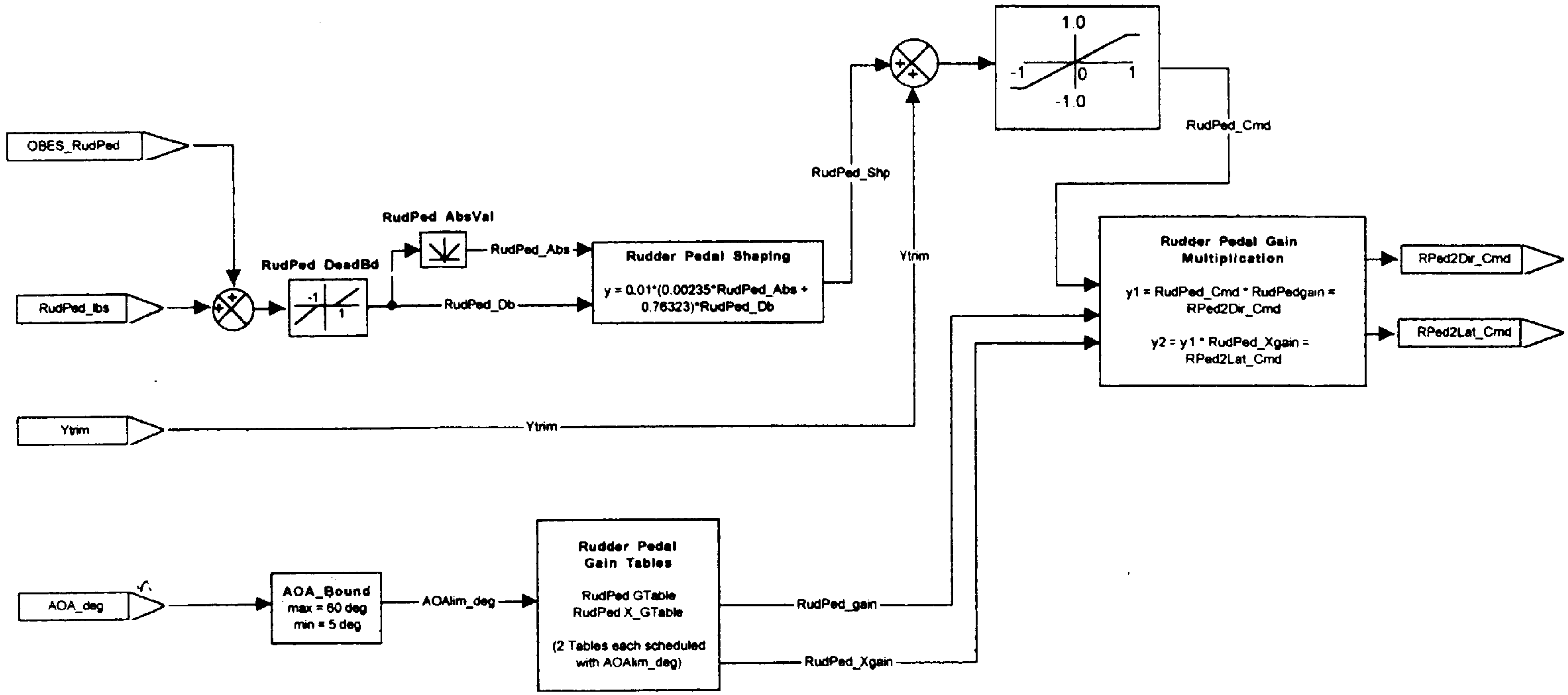
The Yaw Trim signal is added after the pedal shaping function. The external yaw trim input is assumed to be bounded to ±0.33 (nondim). After addition of the yaw trim, the signal is limited to ±1.0.

3.3.2.2 Pedal Command Gain

The pedal directional command gains are functions of angle of attack. Values between design points are determined by linear interpolation. Gain values at design points are given in the following tables.

Angle of Attack (deg)	Gain
5.0	0.26
10.0	0.29
15.0	0.30
20.0	0.37
25.0	0.41
30.0	0.27
35.0	0.18
40.0	0.22
45.0	0.27
50.0	0.23
55.0	0.23
60.0	0.19

ANSER
Pedal Command Path
Figure 3.3



3.3.2.3 Rudder Pedal Cross-Gain

The rudder-pedal-to-lateral-command gains are functions of angle of attack. Values between design points are determined by linear interpolation. Gain values at design points are given in the following tables. (These gains have been set to zero to improve handling qualities as a result of pilot comments during flight testing of the NASA-1A Control Law.)

Angle of Attack (deg)	Gain
5.0	0.0
10.0	0.0
15.0	0.0
20.0	0.0
25.0	0.0
30.0	0.0
35.0	0.0
40.0	0.0
45.0	0.0
50.0	0.0
55.0	0.0
60.0	0.0

3.3.3 Feedback Signal Path

The Feedback Signal Path is shown in Figure 3.4.

3.3.3.1 Filtering, Transformation, and Compensation of Sensed Roll and Yaw Rates

Sensed body-axis roll and yaw rates are converted from (deg/sec) to (rad/sec) and passed through second-order notch filters to suppress structural modes.

Ps Notch Filter

Continuous Form:

$$\frac{s^2 + 2(0.08)(80)s + (80)^2}{s^2 + 2(0.7)(80)s + (80)^2}$$

Discrete Form:
(Tustin transform, warped to ω=87.0 rad/sec, ζ_n=0.096, ζ_d=0.84)

$$\frac{0.6338z^2 - 0.6376z + 0.5392}{z^2 - 0.6376z + 0.1730}$$

Rs Notch Filter

Continuous Form:

$$\frac{s^2 + 2(0.08)(150)s + (150)^2}{s^2 + 2(0.7)(150)s + (150)^2}$$

Discrete Form:
(Tustin transform, warped to ω=218 rad/sec, ζ_n=0.16, ζ_d=1.40)

$$\frac{0.4935z^2 + 0.2567z + 0.3628}{z^2 + 0.2567z - 0.1437}$$

After structural filtering, sensed body-axis roll and yaw rates are transformed to stability-axis rates. Gravity compensation terms are calculated and added to stability-axis yaw rate.

3.3.3.2 Ny Filtering and Offset Correction

The sensed Ny signal is passed through two notch filters to attenuate structural mode responses .

Ny Notch Filter No. 1

Continuous Form:

$$\frac{s^2 + 2(0.04)(58)s + (58)^2}{1.4s^2 + 2(0.7)(58)s + (58)^2}$$

Discrete Form:

$$\frac{0.56592338z^2 - 0.82529534z + 0.53667645}{z^2 - 1.21087437z + 0.48817887}$$

Ny Notch Filter No. 2

Continuous Form:

$$\frac{s^2 + 2(0.08)(100)s + (100)^2}{2s^2 + 2(0.7)(100)s + (100)^2}$$

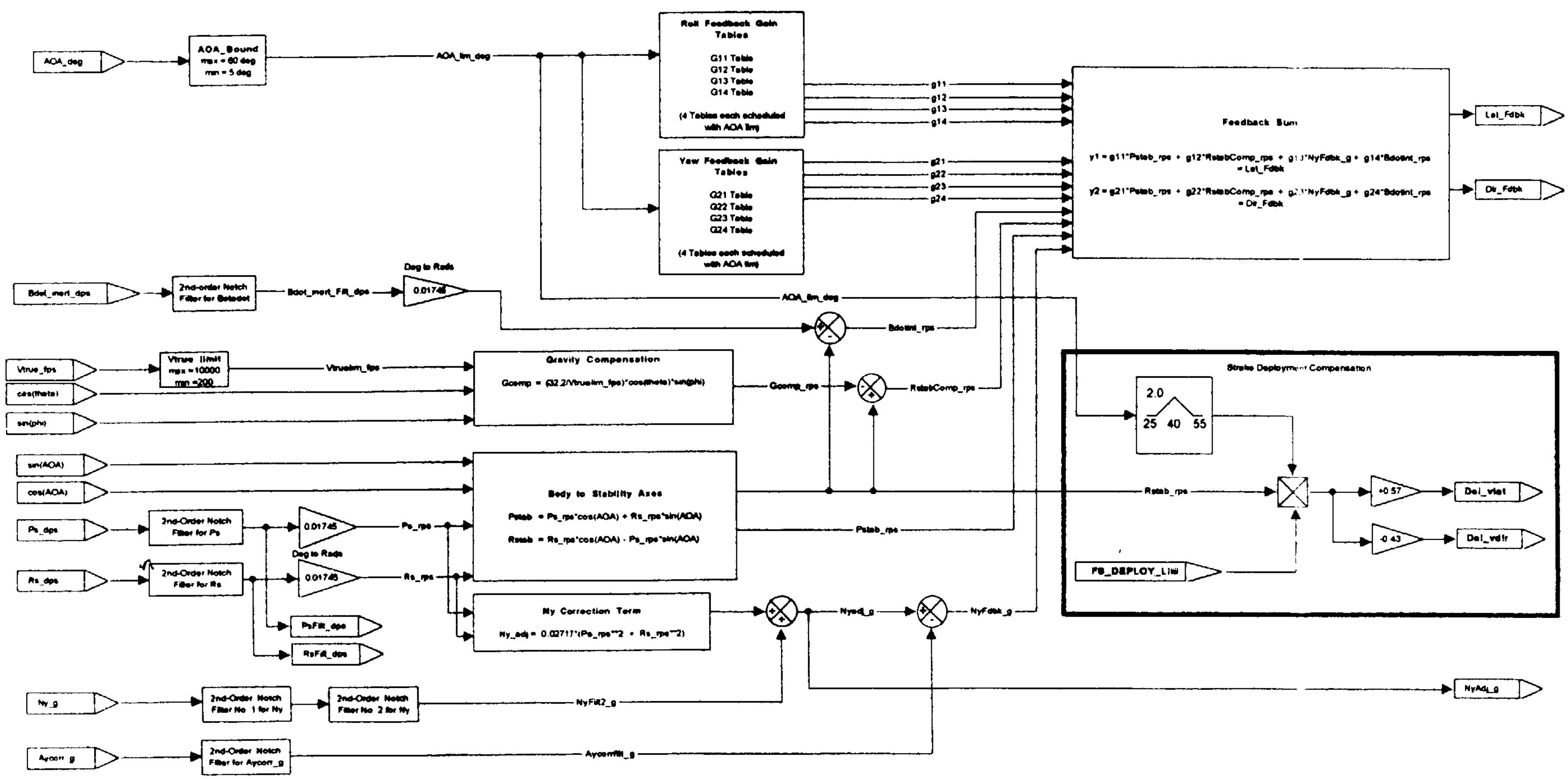
Discrete Form:

$$\frac{0.463336853z^2 - 0.27160128z + 0.39797629}{z^2 - 0.83807435z + 0.42781789}$$

A correction term is added to the filtered Ny to compensate for the sensor being located off axis.

Nyadj_g = Nyfilt_g + 0.02717*(Pbody_rps**2 + Rbody_rps**2)

ANSER
Feedback Signal Path
Figure 3.4



where Pbody_rps and Rbody_rps are structurally filtered body roll rate and body yaw rate in (rad/sec), respectively.

3.3.3.3 Ny Interference Correction

A correction term is calculated in Pseudo Controls to compensate for interference introduced by commanded yaw thrust vectoring and differential strake deflections into the measured lateral acceleration (Ny) signal. This term is output from Pseudo Controls through the Pseudo Controls interface. The interference correction is passed through a notch filter to suppress structural modes.

Ny-Interference Correction Notch Filter

Continuous Form:

$$\frac{s^2 + 2(0.35)(25)s + (25)^2}{s^2 + 2(0.70)(25)s + (25)^2}$$

Discrete Form (direct Tustin):

$$\frac{0.9120z^2 - 1.5695z + 0.7361}{z^2 - 1.5695z + 0.6481}$$

The filtered interference correction term is subtracted from the offset corrected Ny signal.

Nyfdbk_g = Nyadj_g - Aycorrfilt_g

3.3.3.4 Betadot Feedback Signal

The inertial component of sideslip rate is converted from (deg/sec) to (rad/sec) and passed through a second-order notch filter to suppress structural modes.

Continuous Form:

$$\frac{s^2 + 2(0.1)(80)s + (80)^2}{s^2 + 2(0.7)(80)s + (80)^2}$$

Discrete Form:
(Tustin transform, warped to ω=87.0 rad/sec, ζ_n=0.12, ζ_d=0.84)

$$\frac{0.6456z^2 - 0.6376z + 0.5274}{z^2 - 0.6376z + 0.1730}$$

The betadot feedback signal is calculated by subtracting stability-axis yaw rate (in units of rad/sec) from the filtered inertial sideslip-rate signal.

3.3.3.5 Roll and Yaw Feedback Gain Tables

The roll and yaw feedback gains are functions of angle of attack. Values between design points are determined by linear interpolation. Gain values at design points are given in the following tables.

Roll Feedback Gain Table

AOA (deg)	Pstab	Rstab	Ny	Betadot
5	-0.6112	-0.7420	-0.0019	-0.3825
10	-1.3001	-0.9917	-0.1014	-0.1852
15	-1.5267	-0.8051	-0.0005	-0.6436
20	-2.0934	-1.4072	-0.6063	-1.2320
25	-2.2762	-1.1051	0.3622	-1.1257
30	-1.4900	-1.7434	0.1121	-1.2376
35	-1.1466	-1.9652	0.5000	-0.9062
40	-1.0211	-1.3905	1.0000	-0.4289
45	-0.9574	-0.2758	-0.6353	-1.0400
50	-0.8741	-0.5382	-0.2759	-0.9231
55	-0.7002	-0.3071	-0.0952	-0.4048
60	-0.6523	0.0633	0.0109	0.1267

Yaw Feedback Gain Table

AOA (deg)	Pstab	Rstab	Ny	Betadot
5	-0.0524	0.1184	0.0524	1.7372
10	-0.0122	0.1826	0.0607	1.7539
15	0.0857	0.2316	0.0600	1.5931
20	0.2006	0.3522	0.2004	1.9451
25	0.2903	0.4131	0.0183	2.1152
30	0.1704	0.7166	-0.0254	1.6765
35	0.1384	0.7926	-1.0000	1.3411
40	-0.0608	0.4468	-1.5258	1.2669
45	0.3635	0.1073	-0.2938	1.5237
50	0.3420	0.3262	0.2016	1.3646
55	0.1152	0.2536	0.1606	1.0613
60	0.0801	0.2048	0.0698	0.7430

3.3.3.6 Strake Deployment Compensation

The symmetric strake deployment induces a reduction in system roll damping at high angles of attack. To compensate for this reduction, terms are multiplied by stability axis yaw rate then added to the lateral and directional command channels when the strakes are symmetrically deployed. The function AOASW adjusts the compensation as a function of angle of attack. This function is defined by the following table. Values between design points are determined by linear interpolation.

AOASW Table

Angle of Attack (deg)	Value
0.0	0.0
25.0	0.0
40.0	2.0
55.0	0 .0
90.0	0.0

Note: The Strake Deployment Compensation is not required for operation in the TV mode. To hardwire for TV-mode-only operation set control law inputs XTVYAW = 1.0 and XSTRAKE = 0.0. To reduce code size for TV-mode-only operation delete AOASW function; delvlat and delvdir calculations.

3.3.4 Command Summation Block

The Command Summation Block is given in Figure 3.5.

3.3.4.1 Lateral Command Summation and Filtering

The lateral feedback command and lateral strake-deployment-compensation command are summed to yield the total lateral feedback command. This signal is passed through second-order notch and first-order roll-off filters to suppress structural modes and high-frequency noise.

Lateral Command Structural Filter

Continuous Form:

$$\frac{\left(\frac{s}{140}\right)^2 + 2(0.74)\left(\frac{s}{140}\right) + 1}{\left(\frac{s}{40}\right)^2 + 2(0.60)\left(\frac{s}{40}\right) + 1}$$

Discrete Form (direct Tustin):

$$\frac{0.1834z^2 - 0.0281z + 0.0282}{z^2 - 1.3761z + 0.5596}$$

Lateral Command Roll-Off Filter

Continuous Form :

$$\frac{25}{s+25}$$

Discrete Form (direct Tustin):

$$\frac{z+1}{7.4z-5.4}$$

After filtering, the total lateral feedback command is summed with the lateral pilot command to yield the lateral command.

3.3.4.2 Directional Command Summation and Filtering

The directional feedback command and directional strake-deployment-compensation command are summed to yield the total directional feedback command. This signal is passed through second-order notch and first-order roll-off filters to suppress structural modes and high-frequency noise.

Directional Command Structural Filter

Continuous Form:

$$\frac{\left(\frac{s}{140}\right)^2 + 2(0.74)\left(\frac{s}{140}\right) + 1}{\left(\frac{s}{40}\right)^2 + 2(0.60)\left(\frac{s}{40}\right) + 1}$$

Discrete Form (direct Tustin):

$$\frac{0.1834z^2 - 0.0281z + 0.0282}{z^2 - 1.3761z + 0.5596}$$

Directional Command Roll-Off Filter

Continuous Form :

$$\frac{25}{s + 25}$$

Discrete Form (direct Tustin):

$$\frac{z + 1}{7.4z - 5.4}$$

After filtering, the total directional feedback command is summed with the directional pilot command to yield the directional command.

3.3.5 Pseudo Controls Interface and Command Limiting

Pseudo Controls translates the lateral and directional commands into an optimum combination of control surface and thrust vectoring control deflections which provide maximum stability-axis roll and yaw moments. The control blending and distribution is a function of flight condition. The Pseudo Controls Interface is given in Figure 3.6. A complete description of Pseudo Controls is given in Chapter 4.

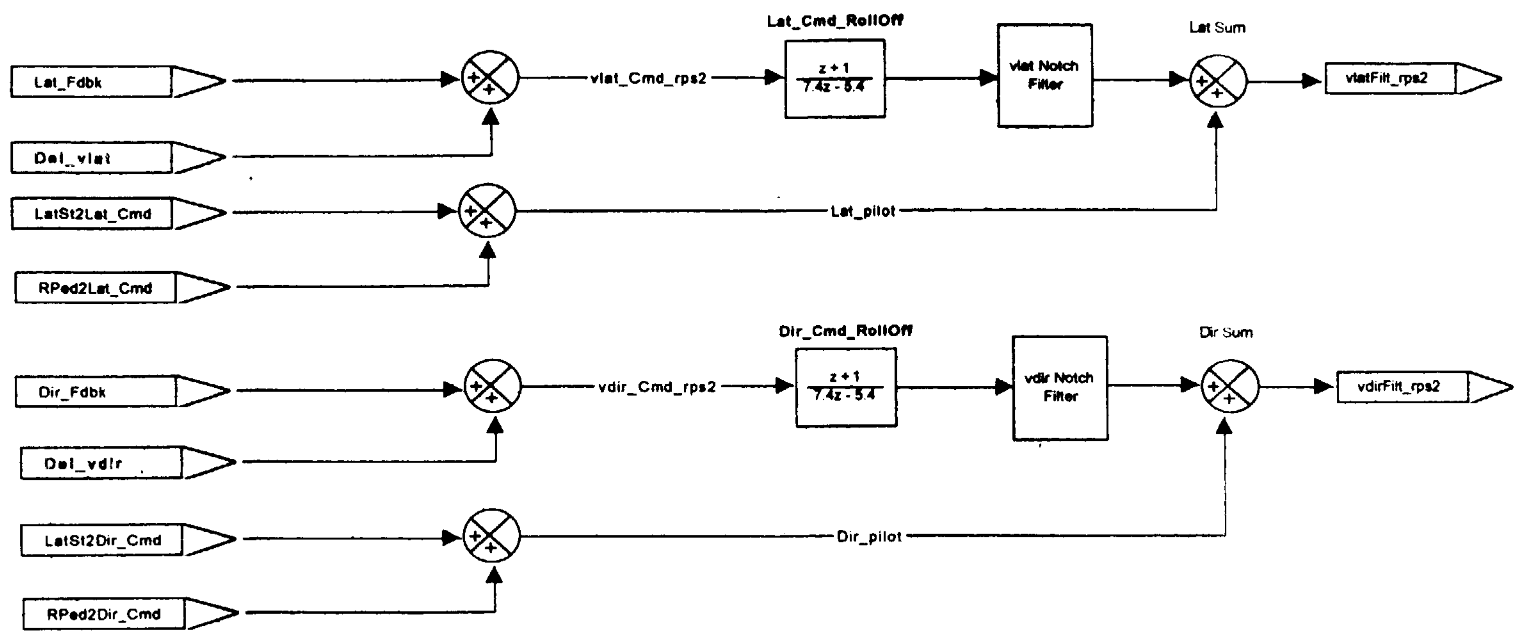
3.3.5.1 Pseudo-Controls Interface

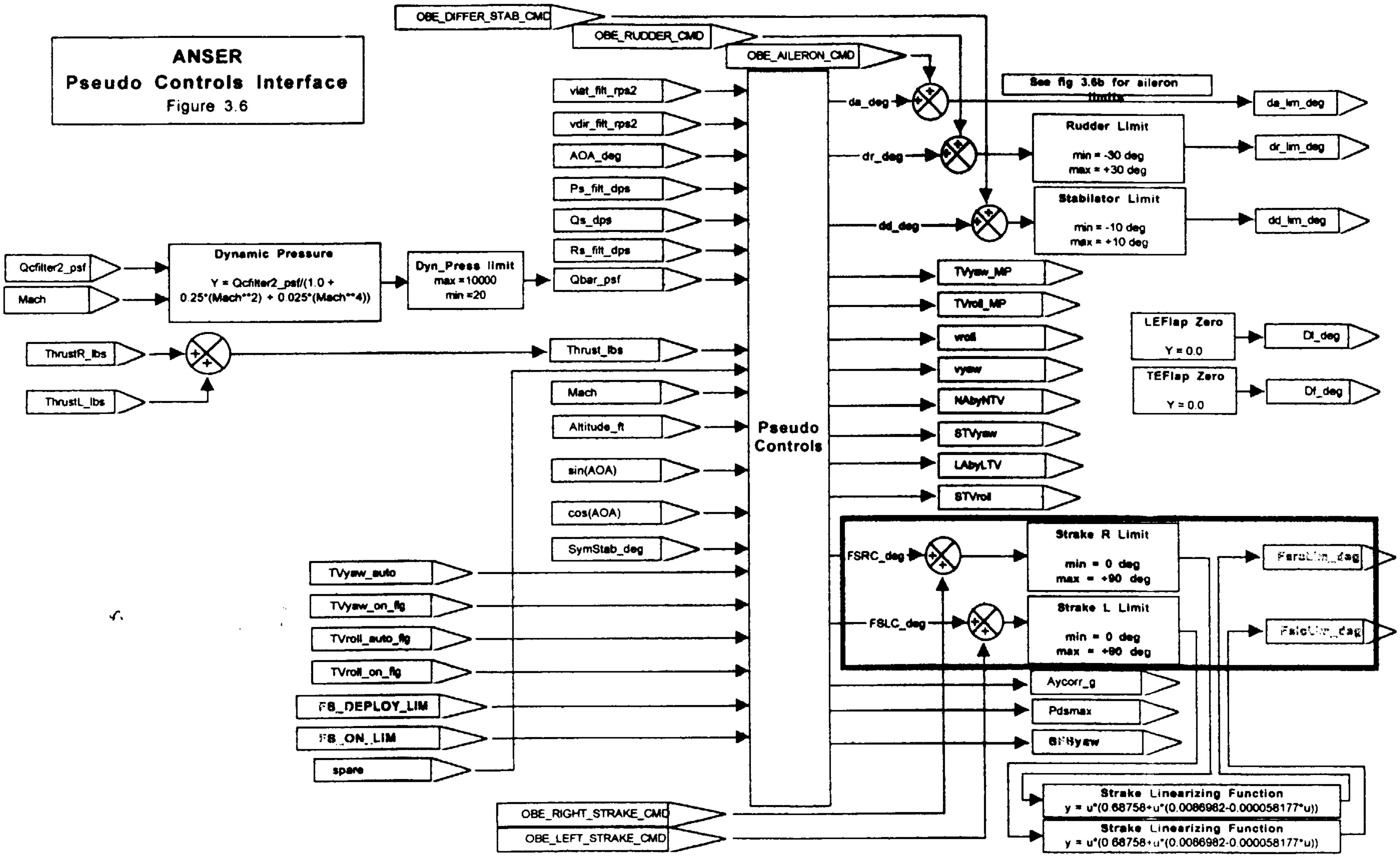
The Pseudo Controls module has 20 inputs, 16 outputs, and 3 states.

Inputs

No.	AC Variable	Description
1	VLAT_FILT_RPS2	Filtered Lateral Command (rad/sec2)
2	VDIR_FILT_RPS2	Filtered Directional Command (rad/sec2)
3	AOA_DEG	Angle of Attack (deg) (from Long cont. law)
4	PS_FILT_DPS	Filtered Body Axis Roll Rate (deg/sec)
5	QS_DPS	Body Axis Pitch Rate (deg/sec)
6	RS_FILT_DPS	Filtered Body Axis Yaw Rate (deg/sec)
7	QBAR_PSF	Dynamic Pressure (psf)
8	THRUST_LBS	Total Engine Thrust (lbs)
9	SPARE	Not Used
10	MACH	Mach Number (nondim)
11	H_FT	Altitude (ft)

ANSER
Command Summation Block
Figure 3.5





ANSER
Pseudo Controls Interface
Figure 3.6

Inputs (Continued)

No.	AC Variable	Description
12	SINAOA	Sine of AOA (nondim)
13	COSAOA	Cosine of AOA (nondim)
14	SYMSTAB_DEG	Commanded Sym Stabilator Deflection (deg)
15	TVYAW_AUTO	PsC Yaw Thrust Vectoring Control Flag (nondim)
16	TVYAW_ON_FLG	PsC Yaw Thrust Vectoring Control Flag (=0) (nondim)
17	TVROLL_AUTO_FLG	PsC Roll Thrust Vectoring Control Flag (=0) (nondim)
18	TVROLL_ON_FLG	PsC Roll Thrust Vectoring Control Flag (=0) (nondim)
19	FS_DEPLOY_LIM	PsC Strake Symmetric Deployment Control Flag (nondim)
20	FS_ON_LIM	PsC Differential Strake Control Flag (nondim)

Outputs

No.	AC Variable	Description
1	DA_DEG	Differential Aileron Deflection (deg)
2	DR_DEG	Rudder Deflection (deg)
3	DD_DEG	Differential Stabilator Deflection (deg)
4	TVYAW_MP	Yaw Thrust Vectoring Command (nondim)
5	TVROLL_MP	Roll Thrust Vectoring Command (nondim)
6	VROLL	Roll Pseudo Control (nondim)
7	VYAW	Yaw Pseudo Control (nondim)
8	NABYNTV	Yaw Moment Available (nondim)
9	STVYAW	Yaw Thrust Vectoring Engage (nondim)
10	LABYLTV	Roll Moment Available (nondim)
11	STVROLL	Roll Thrust Vectoring Engage (nondim)
12	FSRC_DEG	Right Strake Deflection (deg)
13	FSLC_DEG	Left Strake Deflection (deg)
14	AYCORR_G	Lateral Accelerometer Correction (g)
15	PDSMAX	Lateral Stick Command Gain (nondim)
16	SFSYAW	Differential Strake Engage (nondim)

Roll thrust vectoring (Output 5) is not used, but a capability exists to use this control if desired. Outputs 6 through 11 are internal lateral/directional-control-law variables used for performance monitoring and system diagnostics.

Note: To hardwire for TV-mode-only operation set control law inputs XTVYAW = 1.0 and XSTRAKE = 0.0. Setting XSTRAKE to zero sets Pseudo Control inputs FS_DEPLOY_LIM and FS_ON_LIM to 0.0. When these Pseudo Controls inputs are zero, Pseudo Controls will not use the forebody strakes as a control effector . Pseudo Controls outputs FSRC_DEG, FSLC_DEG, and SFSYAW will be zero.

3.3.5.2 Control Effector Command Limits

The aerodynamic controls are position limited. The aileron is limited to ±25.0 degrees. The rudder is limited to ±30.0 degrees. The differential stabilator is limited to ±10. degrees. The right and left strake commands are each limited to 0.0 to +90.0 degrees. The yaw thrust-vectoring signal is a Mixer/Predictor command and is not limited.

Note: The right and left strake command deflection limits are not required for operation in the TV mode. To hardwire for TV-mode-only operation set control law inputs XTVYAW = 1.0 and XSTRAKE = 0.0. To reduce code size for TV-mode-only operation delete left and right deflection limits and set strake deflection outputs to 0.0.

3.3.5.3 Aileron Trailing-Edge-Down Deflection Limit

The trailing-edge-down deflection of the left and right ailerons are limited at high angle of attack to reduce potential problems due to adverse yaw. The aileron trailing-edge-down deflection limit is given in Figure 3.7. The limit is a function of angle of attack. Below 30 degrees AOA the trailing-edge-down deflection is not limited. The trailing-edge-down deflection is limited to 25 degrees at 30 degrees AOA and decreases linearly to a limit of 8 degrees at 55 degrees AOA. Above 55 degrees AOA the trailing-edge-down deflection is limited to 8 degrees. However, if the OBES[1] is engaged, the trailing-edge-down deflection is limited to 25 degrees at all angles of attack.

3.3.5.4 Strake Linearizing Function

A third-order-polynomial linearizing function is included after the strake command limiter to correct for a nonlinearity in the strake actuator transfer function.

3.3.6 Mode Switching Logic

The Mode Switching Logic is shown in figure 3.8.

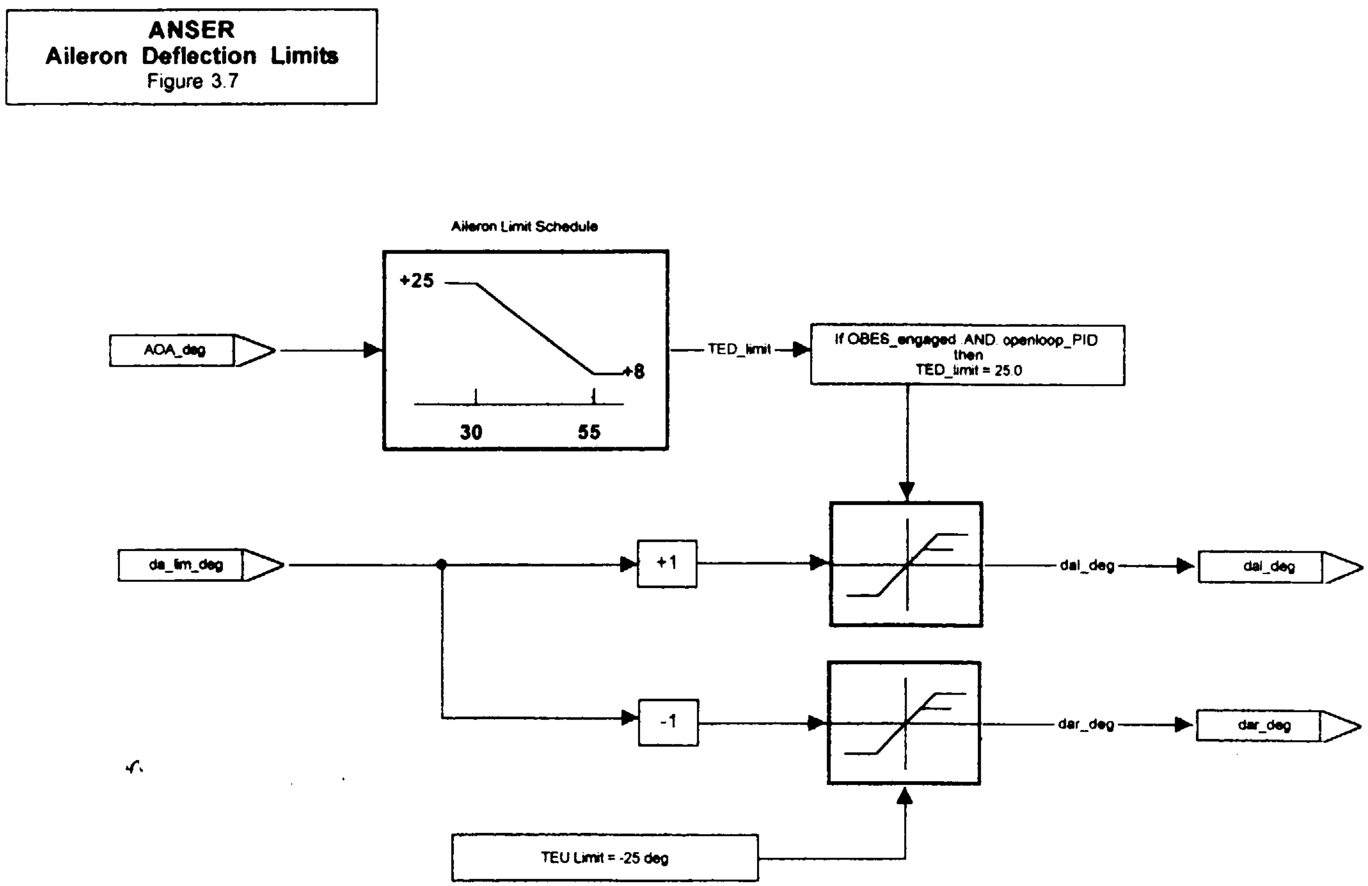
The mode switching logic performs two functions. First, the logic translates external mode-control inputs into internal control-law mode-control variables. Secondly, it prevents abrupt changes in control mode by ramping in changes over a specified period of time. Changes in the yaw thrust vectoring are ramped in over one second. Changes in the forebody strake are ramped in over two seconds (symmetric strake deployment during the first second, differential strake deflections during the remaining second)

The mode switching is controlled by the external input signals XSTRAKE and XTVYAW (Inputs 18 and 27, respectively). Input values for XTVYAW and XSTRAKE to engage the different control law modes are given in the following table.

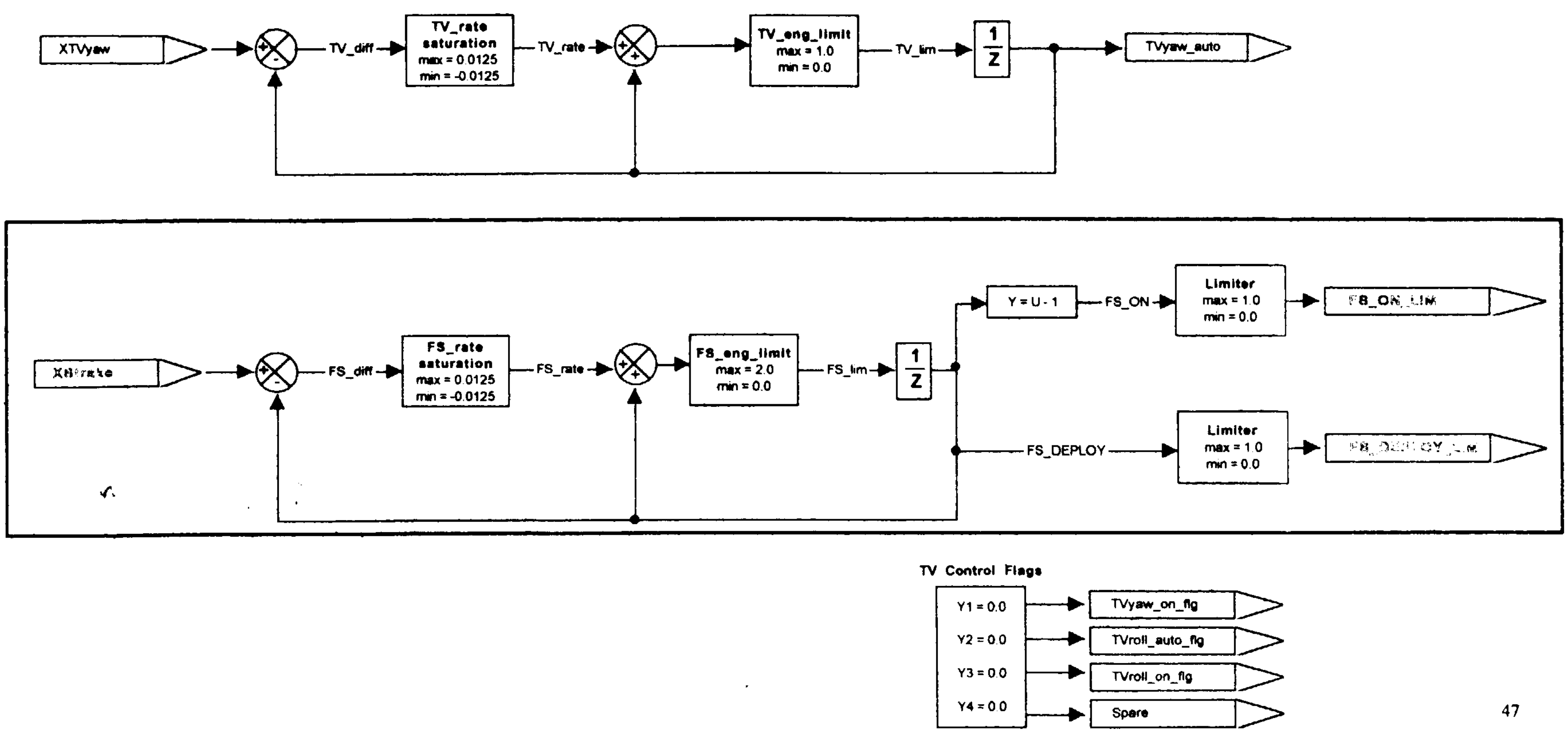
Mode	XTVYAW	XSTRAKE
TV	1.0	0.0
S	0.0	2.0
STV	1.0	2.0

Note: The forebody strake switching logic is not required for operation in the TV mode. To hardwire for TV-mode-only operation set control law inputs XTVYAW = 1.0 and XSTRAKE = 0.0. To reduce code size for TV-mode-only operation, delete forebody strake-switching logic, and set FS_DEPLOY_LIM and FS_ON_LIM to 0.0.

[1] The OBES (On-Board Excitation System) is a software-implemented system to produce precision computer-generated commands for input into the RFCS for accurate control of maneuvers.


ANSER
Aileron Deflection Limits
Figure 3.7
Aileron Limit Schedule
AOA_deg
+25
+8
30
55
TED_limit
If OBES_engaged .AND. openloop_PID
then
TED_limit = 25.0
da_lim_deg
+1
-1
dal_deg
dal_deg
dar_deg
dar_deg
TEU Limit = -25 deg

ANSER
Mode Switching Logic
Figure 3.8



3.4 Control Law Inputs and Outputs

The lateral/directional control law has 32 inputs, 29 outputs, and 32 states.

Inputs

No.	AC Variable	Description
1	LATST_IN	Lateral Stick (in.) (-3 to +3)
2	NY_G	Sensed Lateral Acceleration (g)
3	PS_DPS	Sensed Body Axis Roll Rate (deg/sec)
4	RS_DPS	Sensed Body Axis Yaw Rate (deg/sec)
5	BDOTINERT_DPS	Inertial component of Sideslip Rate (deg/sec)
6	RUDPED_LBS	Rudder Pedal (lbs) (-100 to +100)
7	AOA_DEG**	Angle of Attack (deg)
8	QS_DPS	Sensed Body Axis Pitch Rate (deg/sec)
9	OBES_LATST	OBES lateral stick (nondim) (-1 to +1)
10	QCFILTER2_PSF	Filtered Impact Pressure (psf)
11	COSTHETA	Cosine of INS Theta
12	FGTOTL_LBS	Left Engine Thrust (lbs)
13	FGTOTR_LBS	Right Engine Thrust (lbs)
14	YTRIM	Yaw Trim Input (nondim) (-0.33 to +0.33)
15	RTRIM	Roll Trim Input (nondim) (-0.5 to +0.5)
16	MACH	Mach Number (nondim)
17	H_FT	Altitude (above sea level) (ft)
18	XSTRAKE	Forebody Strake Control Flag (0,1, or 2)
19	NZ_G	Sensed Normal Acceleration (g)
20	SYMSTAB_DEG**	Commanded Sym Stabilator Deflection (deg)
21	VTRUE_FPS	True Velocity (fps) (from Long cont. law)
22	SINPHI	Sine of INS Phi
23	OBES_RudPed	OBES rudder pedal (nondim) (-1 to +1)
24	SINALPHA**	Sine of Alpha
25	COSALPHA**	Cosine of Alpha
26	STKNLG*	Strake Non-Linearity Gearing Switch*
27	XTVYAW	Yaw Vectoring Control Flag (0 or 1)
28	OBE_DIFFER_STAB_CMD†	OBES Differential Stabilator Command (deg)
29	OBE_RUDDER_CMD†	OBES Rudder Command (deg)
30	OBE_AILERON_CMD†	OBES Differential Aileron Command (deg)
31	OBE_RIGHT_STRAKE_CMD†	OBES Right Strake Command (deg)
32	OBE_LEFT_STRAKE_CMD†	OBES Left Strake Command (deg)

* Simulation use only. ** From Longitudinal Control Law

† Not present in all simulations

Outputs

No.	AC Variable	Description
1	DD_LIM_DEG	Differential Stabilator Deflection (deg)
2	DA_LIM_DEG	Differential Aileron Deflection (deg)
3	DL_DEG	Diff Leading Edge Flap Deflection (deg)
4	DF_DEG	Diff Trailing Edge Flap Deflection (deg)
5	DR_LIM_DEG	Differential Rudder Deflection (deg)
6	TVYAW_MP	Yaw Thrust Vector Command (nondim)

Outputs (Continued)

No.	AC Variable	Description
7	VROLL	Roll Pseudo Control (nondim)
8	VYAW	Yaw Pseudo Control (nondim)
9	LAT_CMD_RPS2	Lateral Command (rad/sec2)
10	DIR_CMD_RPS2	Directional Command (rad/sec2)
11	LATST_CMD	Lateral Stick Command (nondim)
12	TVROLL_MP	Roll Thrust Vector Command (nondim)
13	NYADJ_G	Adjusted lateral acceleration (g)
14	RSTABCOR_DPS	Compensated Rstab (deg/sec)
15	FSRC_LIM_DEG	Right Forebody Strake Command (deg)
16	FSLC_LIM_DEG	Left Forebody Strake Command (deg)
17	NABYNTV	Yaw Moment Available (nondim)
18	LABYLTV	Roll Moment Available (nondim)
19	GCOMP_RPS	Gravity Compensation (rad/sec)
20	THRUST_LBS	Total Thrust (lbs)
21	AYCORR_G	Lateral Accelerometer Correction (g)
22	PDSMAX	Lateral Stick Command Gain (nondim)
23	STVYAW	Yaw Thrust Vectoring Engage (nondim)
24	SFSYAW	Differential Strake Engage (nondim)
25	TVYAW_AUTO	PsC Yaw Thrust Vectoring Control Flag
26	FS_ON_LIM	PsC Differential Strake Control Flag
27	FS_DEPLOY_LIM	PsC Strake Symmetric Deployment Control Flag
28	BDOTINERT_DPS	Inertial component of Sideslip Rate (deg/sec)
29	BDOT_DPS	Sideslip Rate (deg/sec)

Outputs 7 through 14 and 17 through 29 are internal Lateral/Directional Control Law variables used for performance monitoring and system diagnostics.

Note : To hardwire for TV-mode-only operation set control law inputs XTVYAW = 1.0 and XSTRAKE = 0.0.

3.5 References

3.1 Lallman, Frederick J.: *Relative Control Effectiveness Technique With Application to Airplane Control Coordination.* NASA TP 2416, April 1985.

3.2 Lallman, Frederick J.: *Preliminary Design Study of a Lateral-Directional Control System Using Thrust Vectoring.* NASA TM 86425, November 1985.

3.3 Murphy, Patick C.and Davidson, John B.: Control Design for Future Agile Fighters. Presented at 1991 AIAA Atmospheric Flight Mechanics Conference, held in New Orleans, LA, August 19-21, 1991. AIAA Paper No. 91-2882, 1991.

3.4 Schmidt, David K.; and Davidson, John B.: Synthesis and Analysis of a Modal Control Law for an Aeroelastic Vehicle. Presented at AIAA Guidance, Navigation, and Control Conference, Snowmass, Colorado. AIAA Paper No. 85-1898. August 1985.

3.5 Davidson, John B.; and Schmidt, David K.: *Flight Control Synthesis for Flexible Aircraft Using Eigenspace Assignment.* NASA CR-178164. June 1986.

Chapter 4
Lateral/Directional Pseudo Controls
Version 151

4.1 General

This chapter contains equations, diagrams, and tables that define the Pseudo Controls portion of the ANSER Lateral/Directional Control Law for the HARV airplane. A development of the Pseudo Controls methodology can be found in reference 4.1, and its application to the lateral/directional control of a high performance fighter can be found in reference 4.2. The methodology described in the references was modified for use in the ANSER Control Law design.

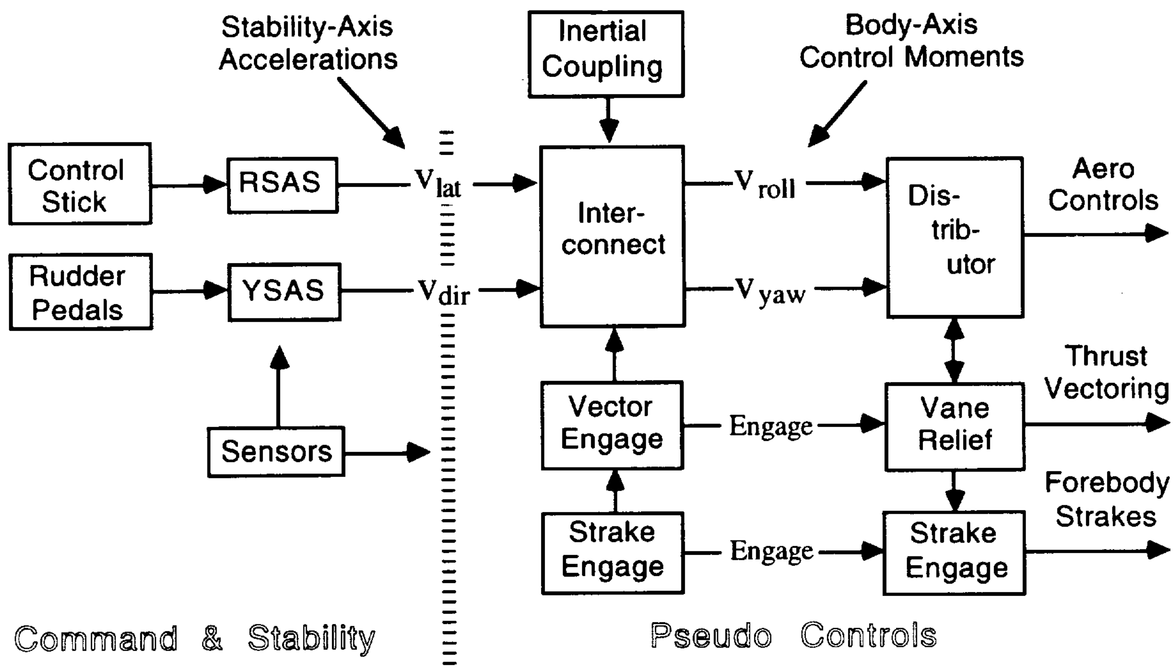
The purpose of Pseudo Controls is to distribute lateral/directional commands in a near-optimal fashion to the appropriate control effectors. A benefit of the technique is that the feedback controller is required to generate fewer outputs (commands), and thus the number of feedback gains is reduced. In the ANSER Pseudo Controls, stability-axis roll and yaw angular acceleration commands from the Lateral/Directional Feedback Control Law are processed to generate deflection commands to the three aerodynamic control surface actuators (aileron, rudder, and differential stabilator), roll and yaw commands to the thrust-vectoring system, and yaw commands to the forebody strakes as in figure 4.1.

This specification includes modifications to the NASA–1A Control Law to include forebody strake controls, a calculation of the available stability-axis roll acceleration, calculations of the interference of forebody strake and yaw thrust-vectoring forces in the lateral accelerometer, and a modification to account for a ± 10 degree limit on differential stabilator commands in the flight computer.

The HARV Pseudo Controls are divided into an Interconnect and a Distributor, and functional block diagrams of these are shown in figures 4.2 and 4.3, respectively (A more comprehensive diagram is presented in section 4.3). The Interconnect converts the stability-axis roll and yaw angular acceleration commands into body-axis roll and yaw angular acceleration commands, provides compensation for inertial coupling, provides compensation for the roll moment produced by yaw thrust vectoring due to the engine nozzle displacement in the z-direction, and outputs roll and yaw commands in the form of Pseudo Control variables. These Pseudo Control variables are the commanded, normalized body-axis roll and yaw moments, that is, the fraction of the available full-scale roll and yaw moments, which are also calculated in the Interconnect as functions of angle of attack, airspeed, altitude, Mach number, and symmetric stabilator deflection. The Interconnect also provides logic to engage the thrust-vectoring controls as a function of engine power and flight condition. Thrust vectoring can be disabled by an external input signal.

The Distributor apportions the roll and yaw commands to the aerodynamic surfaces and to the thrust-vectoring system (Mixer/Predictor) according to the effectiveness of the controls computed as functions of angle of attack and symmetric stabilator deflection and according to the thrust-vectoring engage signal from the Interconnect. To prevent overheating of the thrust-vectoring vanes, the Distributor provides vane-relief logic to transfer slowly-varying and steady-state thrust-vectoring commands to the aerodynamic control surfaces. Thrust vectoring is always used for transient maneuvers when permitted by the yaw thrust-vector engagement logic, and thrust vectoring is used in steady state when the aerodynamic surfaces cannot supply the required moments.

Forebody strake controls are deployed and engaged by setting external control inputs. The yaw moment capability of the strakes is included in the calculation of the yaw Pseudo Control,



Pseudo Controls Distributor

- Coordinate Aero Controls (Ailerons, Rudder, Differential Stabilator)
- Produce Body-Axis Control Moments (Roll and Yaw)
- Augment with Thrust-Vectoring Controls

Pseudo Controls Interconnect

- Crossfeed to Produce Decoupled Lateral & Directional Commands
- Produce Stability-Axis Accelerations (Roll and Yaw)
- Compensate Inertial Coupling

Thrust-Vector Engage – Vane Relief

- Engage Thrust-Vectoring Controls Based on Control Power
- Adjust Interconnect to Maintain Constant Gains
- Transfer Long-Term Thrust-Vectoring Commands to Aero Controls

Strake Engage – Strake Controls

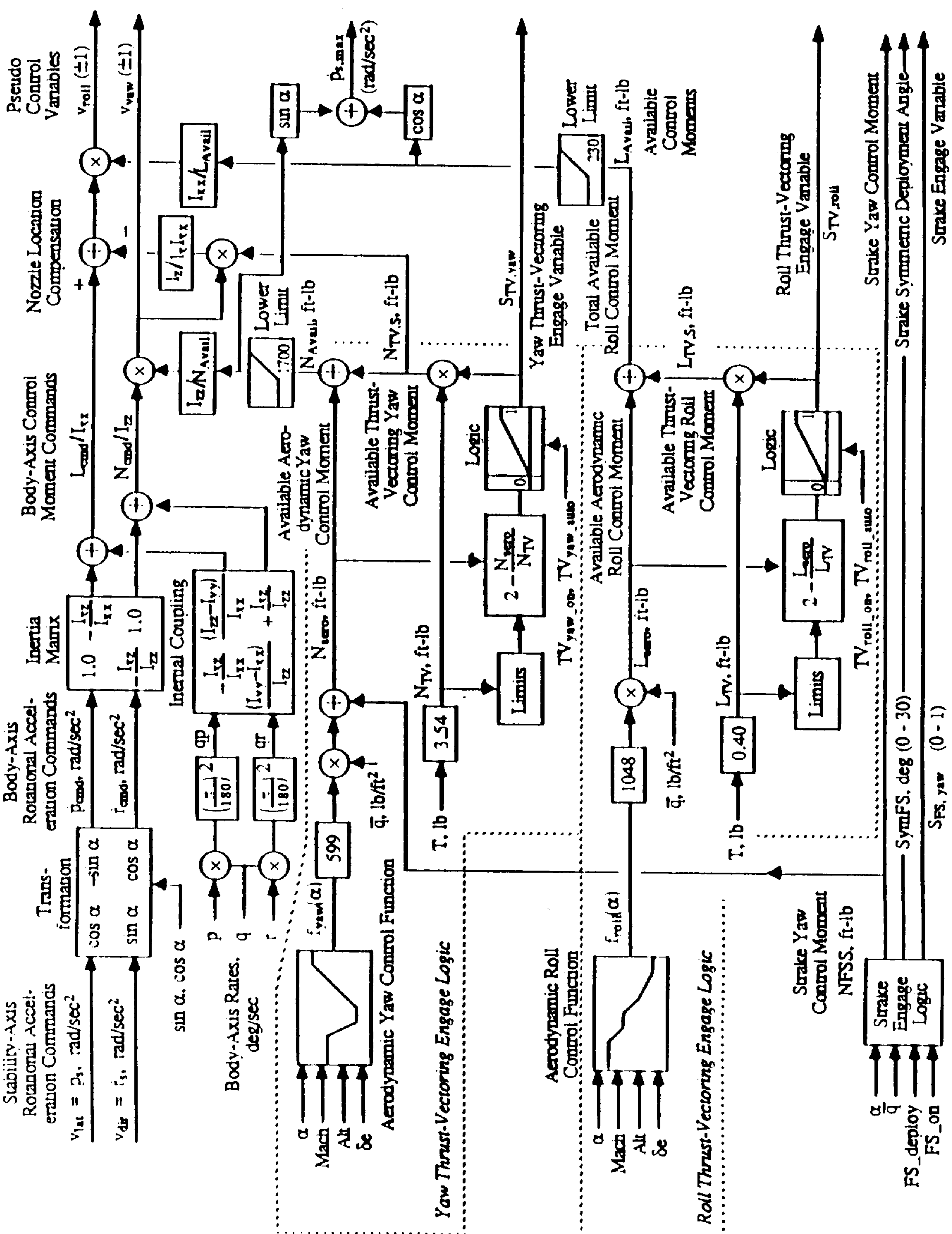
- Integrate Forebody Strakes with Aero and TV Controls

Figure 4.1 – Pseudo Controls – Version 8.1

reducing the deflection commands for the aerodynamic controls and the yaw thrust-vectoring control if it is also engaged.

The Pseudo Controls design was based on the F18 HARV weights and moments of inertia for 60% fuel and wing-tip missiles for altitudes between 10 000 and 50 000 ft and airspeeds between 0.2 and 0.8 Mach. The system operates at a basic 80 Hz rate, but some of the functions operate at 40 Hz or 20 Hz to decrease execution time. Much of the design was implemented using the SystemBuild™ function of MATRIX$_X$®. The resulting Super Blocks were converted to FORTRAN code using the MATRIX$_X$® AutoCode™ Generator. The AutoCode™ was subsequently modified to decrease execution time and reduce memory requirements. The code is organized into a number of modules (subroutines) in order to

Figure 4.2.- Interconnect Functional Diagram



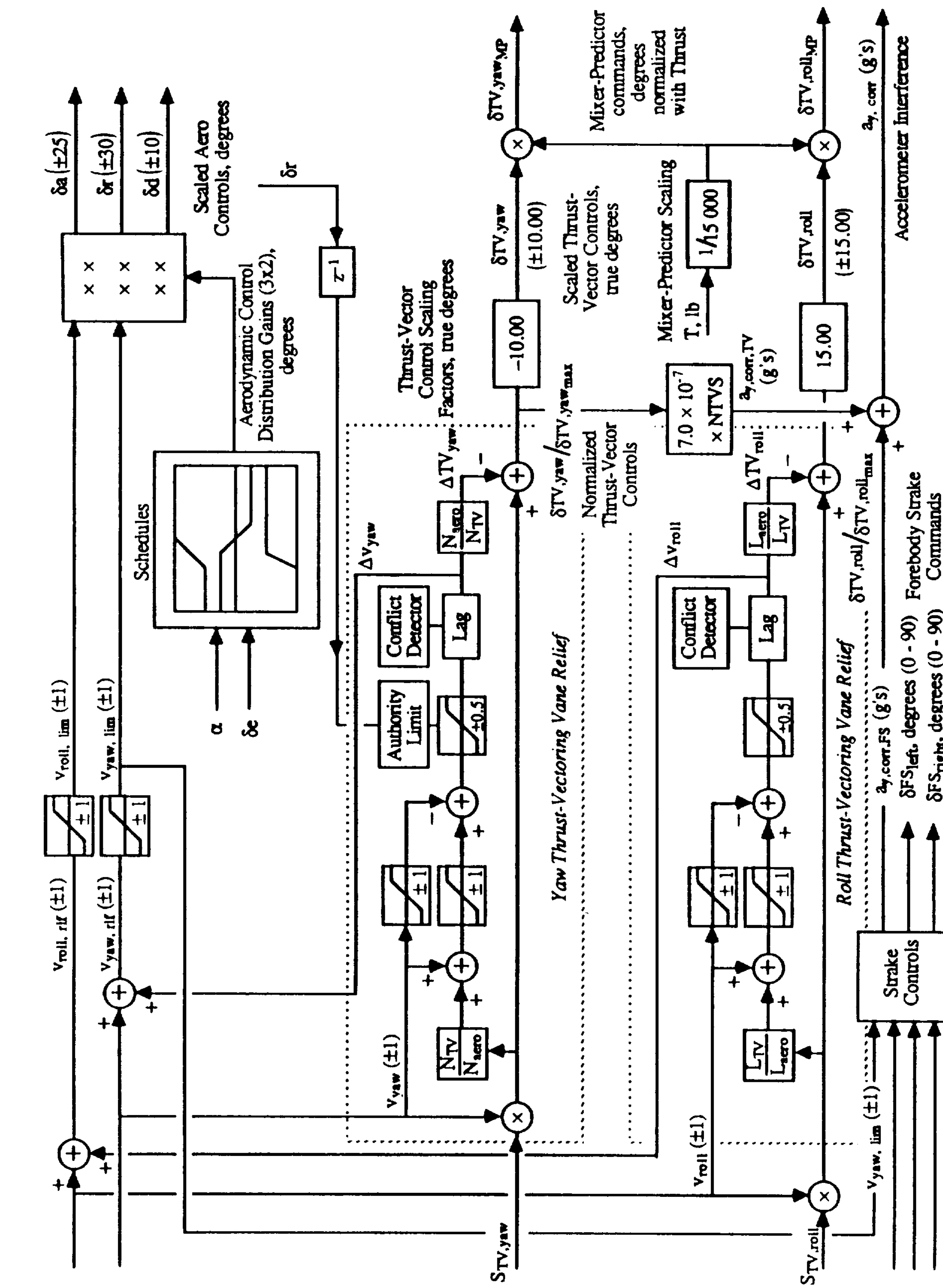


Figure 4.3.- Distributor Functional Diagram

1) collect sections of code together into functional units, 2) facilitate multirate operation, and 3) enable detailed checkout.

The remainder of this section contains a brief description of the modules and the multirate timing for the modules. Section 4.2 contains a detailed description of each module including equations, tables, and diagrams. Section 4.3 contains overall (horizontal) block diagrams and input/output lists for the complete Pseudo Controls System.

4.1.1 Modules

The top-level module of the Pseudo Controls system is named AC_PSEUDO_CONTROLS and is assigned the subroutine name USR39FJL in the LaRC implementation. This module calls the other modules as subroutines except for DX_YAW_VANE_RELIEF (USR54FJL) and DX_ROLL_VANE_RELIEF (USR53FJL) which are called by AC_DISTRIBUTOR (USR38FJL). The modules are listed with brief descriptions below.

Modules

Name	Subroutine	Description
AC_PSEUDO_CONTROLS	USR39FJL	Top level module to convert roll and yaw acceleration commands into control deflection angles.
	USRCKFJL	Multi-phase clock provides signals to enable selected modules at 40 Hz and 20 Hz rates.
DX_FYAW_FUNCTION*	USR33FJL	Calculates available yaw moment coefficient for primary controls.
DX_FROLL_FUNCTION*	USR34FJL	Calculates available roll moment coefficient for primary controls.
DX_DISTRIBUTOR_GAINS*	USR36FJL	Calculates gains to distribute roll and yaw commands among primary controls.
DX_STRAKE_ENGAGE*	USR59FJL	Engagement control for forebody strakes.
DX_YAWTV_ENGAGE*	USR52FJL	Engagement control for yaw thrust-vectoring controls.
DX_ROLLTV_ENGAGE*	USR51FJL	Engagement control for roll thrust-vectoring controls.
DX_INTERCONNECT*	USR35FJL	Interconnects lateral and directional controls to produce roll and yaw controls.
AC_DISTRIBUTOR*	USR38FJL	Distributes roll and yaw controls among primary and thrust-vectoring controls.
DX_YAW_VANE_RELIEF†	USR54FJL	Replaces yaw thrust-vectoring by primary controls when possible.
DX_ROLL_VANE_RELIEF†	USR53FJL	Replaces roll thrust-vectoring by primary controls when possible.
DX_STRAKE_CONTROLS*	USR58FJL	Generates position commands for forebody strakes.

* module called by AC_PSEUDO_CONTROLS † module called by AC_DISTRIBUTOR

4.1.2 Multirate Clock

A multirate clock (USRCKFJL) is used to schedule selected modules at 40 Hz and 20 Hz computation rates. In the FORTRAN implementation this clock is hand-coded and is called by AC_PSEUDO_CONTROLS(USR39FJL) at a 80 Hz rate. The clock repeatedly counts from one (1) to four (4) and sets logical variables that are used to enable each low-rate module at the proper time. The following table gives the execution rates for the modules and indicates the minor cycle frame time(s) for each module.

The clock initializes its internal counter to a value of 1 when 1) an initialization signal is received from AC_PSEUDO_CONTROLS signaling the first time of execution in the LaRC implementation, or 2) the internal counter acquires a number outside the range of 1 to 4. Initialization will also occur if variable memory is zeroed at power-up. Initialization signals are issued to each module for the first four frames in the LaRC implementation for compatibility with the startup procedure used by AutoCode™ v2.21.

Module Timing

Name	Subroutine	Rate, Hz	Frame 1	Frame 2	Frame 3	Frame 4
AC_PSEUDO_CONTROLS	USR39FJL	80	×	×	×	×
	USRCKFJL	80	×	×	×	×
DX_FYAW_FUNCTION	USR33FJL	20	×			
DX_FROLL_FUNCTION	USR34FJL	20		×		
DX_DISTRIBUTOR_GAINS	USR36FJL	20			×	
DX_STRAKE_ENGAGE	USR59FJL	20				×
DX_YAWTV_ENGAGE	USR52FJL	40	×		×	
DX_ROLLTV_ENGAGE	USR51FJL	40		×		×
DX_INTERCONNECT	USR35FJL	80	×	×	×	×
AC_DISTRIBUTOR	USR38FJL	80	×	×	×	×
DX_YAW_VANE_RELIEF	USR54FJL	40	×		×	
DX_ROLL_VANE_RELIEF	USR53FJL	40		×		×
DX_STRAKE_CONTROLS	USR58FJL	80	×	×	×	×

Note that the implementation of the software used at LaRC is written like conventional FORTRAN code with modules calling other modules as subroutines. There are instances of higher-rate modules calling lower-rate modules. Since arguments of the lower-rate modules may be calculated by the higher-rate calling module, the multirate operation is implemented by enabling the subroutine calls depending on the state of the clock. This minimizes the possibility of delays being introduced into the system by a multirate scheduler.

4.2 Module Descriptions

The following sections present the details of the software specification including equations and graphical depictions of the functions to be implemented, some brief narrative on the operation of each element of the specification, and the assignment of each element to a module. The modules are given in the order of their being called. The elements of each module are given in their order of execution.

4.2.1 AC_PSEUDO_CONTROLS (USR39FJL) 80 Hz

4.2.1.1 Update Multirate Clock

The first task of AC_PSEUDO_CONTROLS (USR39FJL) is to call the multirate clock module USRCKFJL. This module repeatedly counts from 1 to 4 and sets logical enable signals that are used to control the execution of the 40 Hz and 20 Hz modules. The following table defines the enable signals.

Module Enable Signals

Module Name	Enable Signal	Rate, Hz	Frame 1	Frame 2	Frame 3	Frame 4
DX_FYAW_FUNCTION	ENBL33	20	True	False	False	False
DX_FROLL_FUNCTION	ENBL34	20	False	True	False	False
DX_DISTRIBUTOR_GAINS	ENBL36	20	False	False	True	False
DX_STRAKE_ENGAGE	ENBL59	20	False	False	False	True
DX_YAWTV_ENGAGE	ENBL52	40	True	False	True	False
DX_ROLLTV_ENGAGE	ENBL51	40	False	True	False	True
DX_YAW_VANE_RELIEF	ENBL54	40	True	False	True	False
DX_ROLL_VANE_RELIEF	ENBL53	40	False	True	False	True

4.2.1.2 Differential Stabilator Authority

Calculate the fraction of the differential stabilator that is available for lateral/ directional control. This fraction varies from 0.0 when the symmetric stabilator command is hardover (–24.0 degrees and +10.5 degrees) to 0.5797 when the symmetric stabilator command is between –14.0 and +0.5 degrees. *This function differs from the NASA–1A specification to account for a ±10 degree limit on differential stabilator commands in the dual-port RAM.*

DE_DEG → DD_AUTH → DD_AUTH

Symmetric Stabilator Command from Longitudinal Control System

to DX_FYAW_FUNCTION DX_FROLL_FUNCTION AC_DISTRIBUTOR

DE_DEG	DD_AUTH	
-27.0	0.0	
-24.0	0.0	← hard-over TEU
-14.0	0.5797	
+0.5	0.5797	
+10.5	0.0	← hard-over TED
+13.5	0.0	

Use piece-wise linear interpolation or equivalent.

4.2.1.3 Subroutine Calls

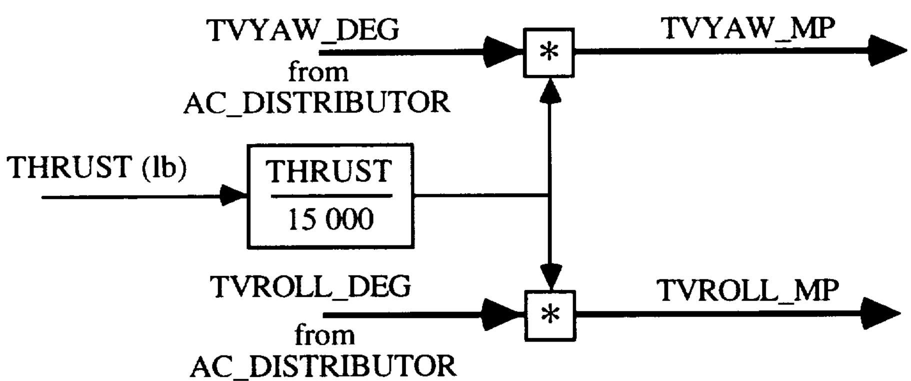
Execute modules (subroutines) depending on multirate clock state.

20 Hz Modules –	Call DX_FYAW_FUNCTION(USR33FJL)	if ENBL33 is true.
	Call DX_FROLL_FUNCTION(USR34FJL)	if ENBL34 is true.
	Call DX_DISTRIBUTOR_GAINS(USR36FJL)	if ENBL36 is true.
	Call DX_STRAKE_ENGAGE(USR59FJL)	if ENBL59 is true.
40 Hz Modules –	Call DX_YAWTV_ENGAGE(USR52FJL)	if ENBL52 is true.
	Call DX_ROLLTV_ENGAGE(USR51FJL)	if ENBL51 is true.
80 Hz Modules –	Call DX_INTERCONNECT(USR35FJL)	each frame.
	Call AC_DISTRIBUTOR(USR38FJL)*	each frame.
	Call DX_STRAKE_CONTROLS(USR58FJL)	each frame.

* DX_YAW_VANE_RELIEF(USR54FJL) and DX_ROLL_VANE_RELIEF(USR53FJL) are called from AC_DISTRIBUTOR(USR38FJL) at 40 Hz.

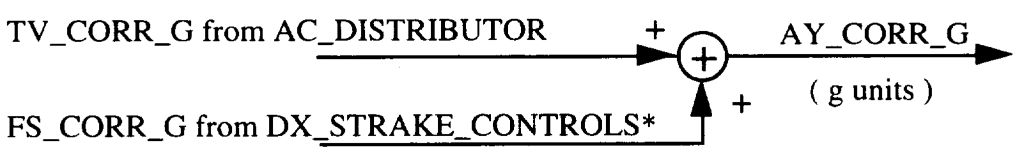
4.2.1.4 Thrust-Vector Scaling

The roll and yaw thrust-vector commands are adjusted by estimated engine thrust (two-engine sum) for compatibility with the scaling of the Mixer/Predictor.



4.2.1.5 Accelerometer Correction

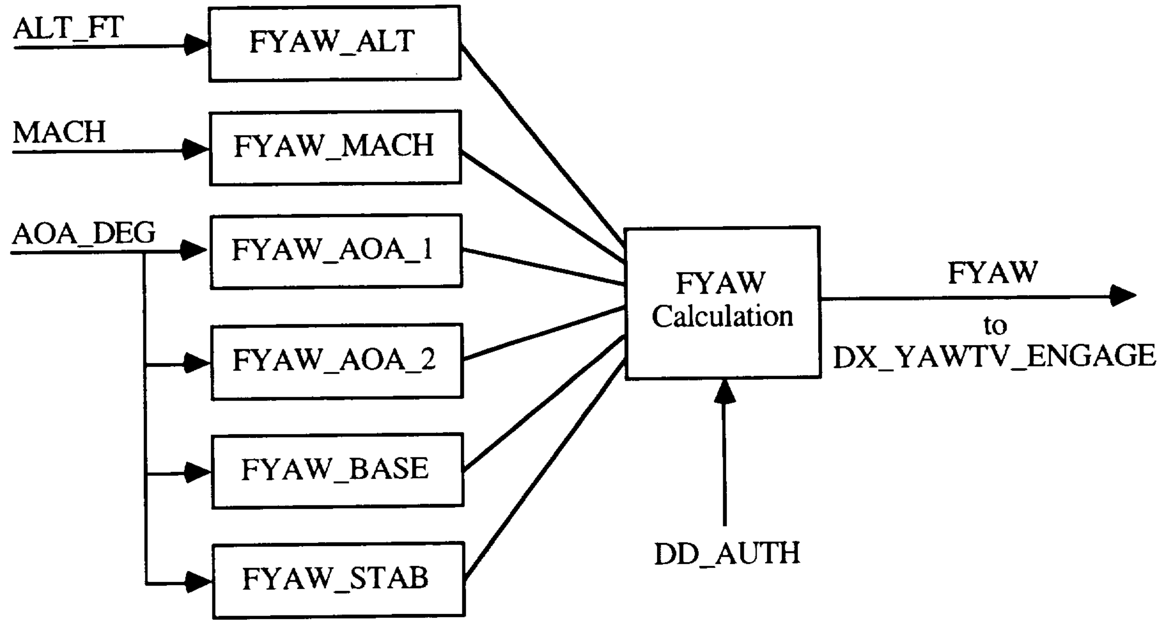
The interference of the research controls in the lateral accelerometer output AY_CORR_G as calculated by summing the interference caused by the forebody strake controls FS_CORR_G and the yaw thrust-vectoring controls TV_CORR_G. The output of the accelerometer may be corrected by subtracting AY_CORR_G from it.



* equals zero for NASA–1A

4.2.2 DX_FYAW_FUNCTION (USR33FJL) 20 Hz

Calculate the effectiveness of the primary aerodynamic controls (ailerons, rudders, and differential stabilator) in producing body-axis yaw moments. The output is the non-dimensional yaw-moment coefficient C_n normalized by 0.04 and corresponds to the Pseudo Control variable VYAW having a value of unity.



FYAW_BASE is the basic fyaw function calculated at Mach 0.2 and altitude 30 000 ft with the symmetric stabilator commanded to the center of its range (–6.75 degrees TEU). FYAW_STAB and DD_AUTH are used to calculate changes caused by variable symmetric stabilator commands. The other functions are used to calculate changes with Mach (0.2 to 0.8) and altitude (10 000 to 50 000 ft).

4.2.2.1 FYAW Tables

ALT_FT	FYAW_ALT
0	0.25
10 000	0.25
30 000	0.15
50 000	0.10
60 000	0.10

MACH	FYAW_MACH
0.0	0.0
0.2	0.0
0.8	1.0
1.0	1.0

AOA_DEG	FYAW_AOA_1
−10.0	1.0
28.0	1.0
42.0	0.0
90.0	0.0

AOA_DEG	FYAW_AOA_2
−10.0	0.0
0.0	0.0
15.0	1.0
20.0	1.0
28.0	0.0
90.0	0.0

AOA_DEG	FYAW_BASE
−10.0	1.0
15.0	1.0
28.0	0.575
37.0	0.575
60.0	1.5
90.0	1.5

AOA_DEG	FYAW_STAB
−10.0	0.085
0.0	0.085
13.0	0.060
22.0	0.0
37.0	0.0
60.0	0.925
90.0	0.925

Output values are held constant for inputs exceeding the table ranges. Use piece-wise linear interpolations or equivalent.

4.2.2.2 FYAW Calculation

Intermediate variables

FYAW_FUN1 = FYAW_ALT * FYAW_AOA_1

FYAW_FUN2 = [FYAW_FUN1 * (1.0 – FYAW_AOA_2)
+ 0.45 * FYAW_AOA_2] * FYAW_MACH

FYAW_FUN3 = (1.0 – DD_AUTH) * FYAW_STAB

Result

FYAW = FYAW_BASE – FYAW_FUN2 – FYAW_FUN3

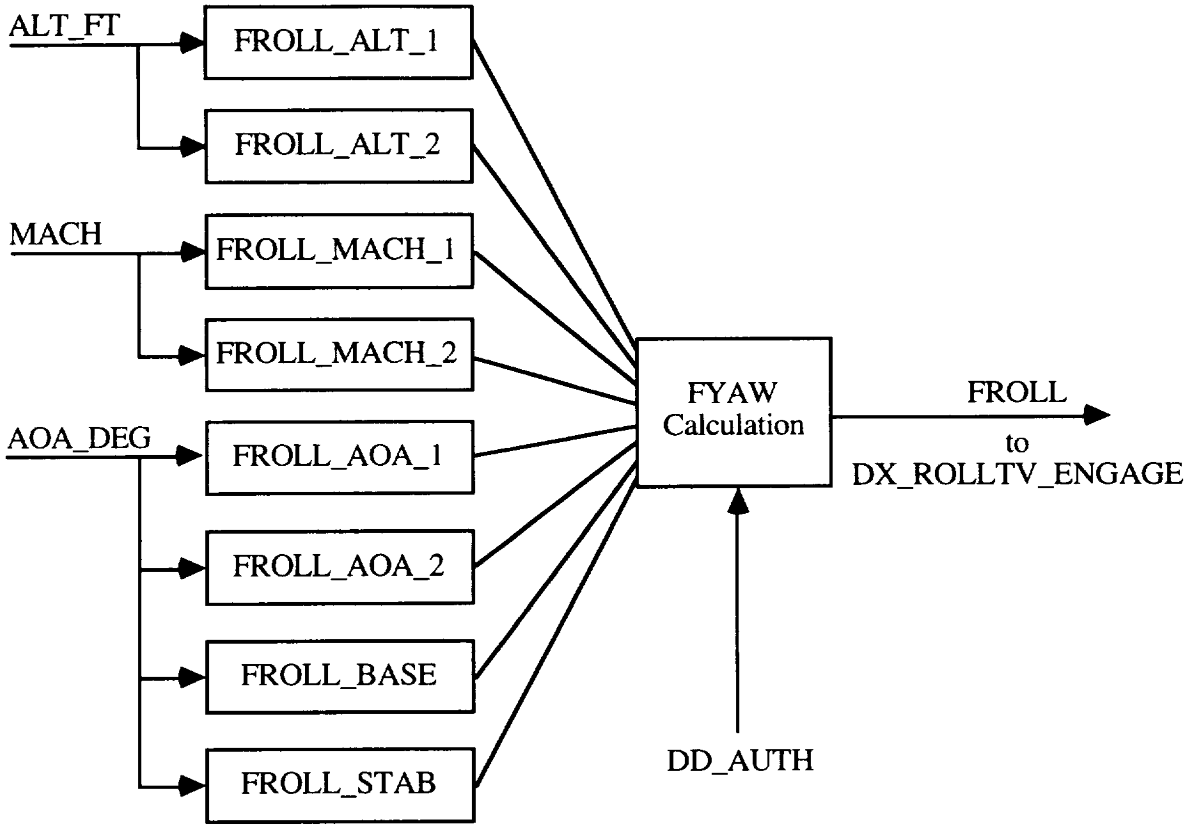
4.2.3 DX_FROLL_FUNCTION (USR33FJL) 20 Hz

Calculate the effectiveness of the primary aerodynamic controls (ailerons, rudders, and differential stabilator) in producing body-axis roll moments. The output is the non-dimensional roll-moment coefficient C_l normalized by 0.07 and corresponds to the Pseudo Control variable VROLL having a value of unity.

FROLL_BASE is the basic froll function calculated at Mach 0.2 and altitude 30 000 ft with the symmetric stabilator commanded to the center of its range (–6.75 degrees TEU). FROLL_STAB and DD_AUTH are used to calculate changes caused by variable symmetric stabilator commands. Changes to FROLL caused by variations of Mach (0.0 to 0.8) and altitude (10 000 to 50 000 ft) are calculated using:

1) FROLL_AOA_1, FROLL_MACH_1, and FROLL_ALT_1
when AOA_DEG < 16 degrees

2) FROLL_AOA_2, FROLL_MACH_2, and FROLL_ALT_2
when AOA_DEG > 16 degrees.



4.2.3.1 FROLL Tables

AOA_DEG	FROLL_AOA_1
-10.0	1.0
7.0	1.0
16.0	0.0
90.0	0.0

MACH	FROLL_MACH_1
0.00	0.0
0.25	0.0
0.80	1.0
1.00	1.0

ALT_FT	FROLL_ALT_1
0	0.443
10 000	0.443
50 000	0.200
60 000	0.200

MACH	FROLL_MACH_2
0.00	0.0
0.20	0.0
0.63	1.0
1.00	1.0

AOA_DEG	FROLL_AOA_2
-10.0	0.0
16.0	0.0
32.0	1.0
44.0	0.2
60.0	0.2
68.0	0.0
90.0	0.0

AOA_DEG	FROLL_BASE
-10.0	1.00
10.0	1.00
20.0	0.64
32.0	0.60
44.0	0.29
60.0	0.14
90.0	0.14

AOA_DEG	FROLL_STAB
-10.0	0.08
8.0	0.08
28.0	0.16
38.0	0.14
54.0	0.00
90.0	0.00

ALT_FT	FROLL_ALT_2
0	0.308
10 000	0.308
50 000	0.262
60 000	0.262

Output values are held constant for inputs exceeding the table ranges. Use piece-wise linear interpolations or equivalent.

4.2.3.2 FROLL Calculation

Intermediate variables

FROLL_FUN1 = FROLL_AOA_1 * FROLL_MACH_1 * FROLL_ALT_1

FROLL_FUN2 = FROLL_AOA_2 * FROLL_MACH_2 * FROLL_ALT_2

FROLL_FUN3 = (1.0 - DD_AUTH) * FROLL_STAB

Result

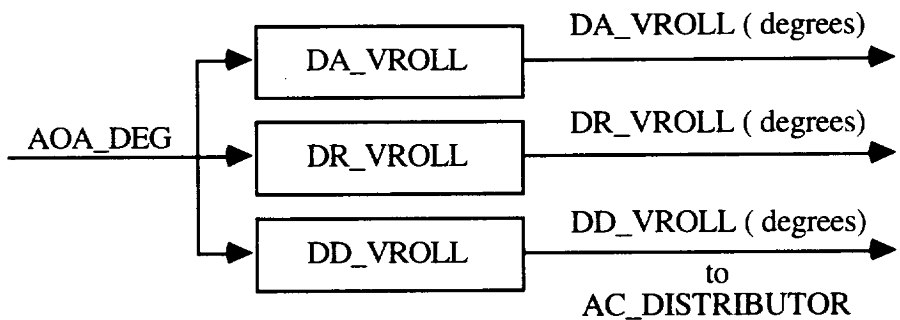
FROLL = FROLL_BASE - FROLL_FUN1 - FROLL_FUN2 - FROLL_FUN3

4.2.4 DX_DISTRIBUTOR_GAINS (USR36FJL) 20 Hz

Calculate the gains used to distribute Pseudo Controls VROLL and VYAW to the primary aerodynamic controls (ailerons, rudders, and differential stabilator). Use piece-wise linear interpolation or equivalent.

4.2.4.1 Roll Distributor Gains

Calculate the distributor gains used to command body-axis roll moments according to VROLL signals.



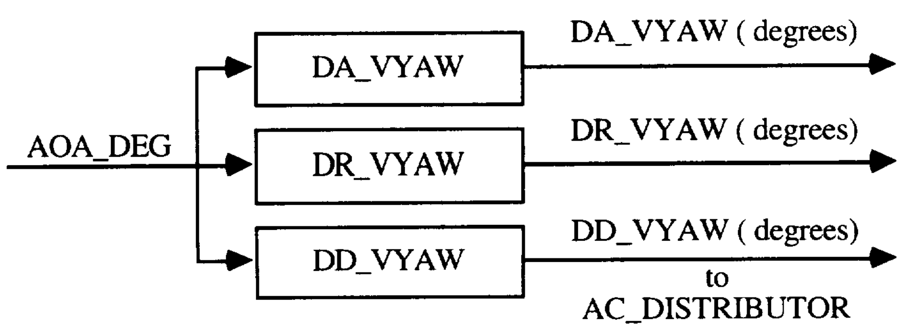
AOA_DEG	DR_VROLL
−10.0	3.0
15.0	3.0
34.0	−4.5
54.0	−24.0
58.0	−24.0
70.0	15.0
90.0	15.0

AOA_DEG	DD_VROLL
−10.0	4.313
10.0	4.313
28.0	8.625
40.0	8.625
60.0	−1.725
90.0	−1.725

DA_VROLL = 15.0 constant

4.2.4.2 Yaw Distributor Gains

Calculate the distributor gains used to command body-axis yaw moments according to VYAW signals.



AOA_DEG	DA_VYAW
−10.0	1.8750
−4.0	1.8750
20.0	0.00
44.0	−10.00
52.0	−11.25
62.0	−11.25
72.0	7.50
90.0	7.50

AOA_DEG	DD_VYAW
−10.0	4.313
0.0	4.313
16.0	3.45
40.0	−5.175
52.0	−17.25
90.0	−17.25

DR_VYAW = −30.0 constant

4.2.5 DX_STRAKE_ENGAGE(USR59FJL) 20 Hz

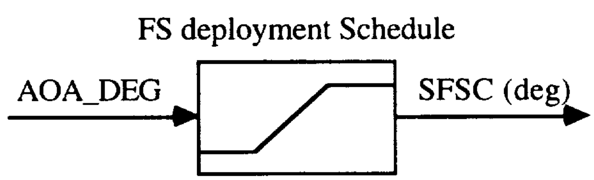
This section presents the strake engage module for the ANSER control law. This module (1) deploys the forebody strakes symmetrically at high angles of attack, (2) engages differential strake operation according to the angle of attack, and (3) calculates the yaw moment available from differential strake deflections. The deployment and engagement functions are controlled by external input signals (on-off). The outputs of this module can be fixed at zero for operations without the forebody strakes by setting these inputs to zero (off).

1. FS_DEPLOY = 0.0	The forebody strakes are commanded to zero deflections. This option must be used if the strakes are not installed or are not able to respond to commands as for NASA-1A
2. FS_DEPLOY = 1.0 FS_ENGAGE = 0.0	The forebody strakes are deployed symmetrically beginning at 30 AOA until they are deflected 30 degrees at 60 AOA.
3. FS_DEPLOY = 1.0 FS_ENGAGE = 1.0	The forebody strakes are deployed symmetrically as above and they are modulated differentially to produce control moments.

FS_DEPLOY and FS_ENGAGE can be transitioned smoothly between zero and one during mode changes.

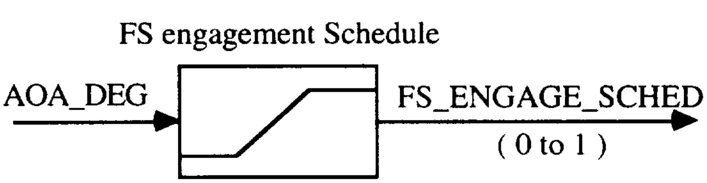
4.2.5.1 Forebody Strake Schedules (ANSER)

The strake deployment schedule is used to symmetrically deploy the forebody strakes beginning at AOA 30 degrees and ending with the strakes deflected at 30 degrees each at AOA 60 degrees.



AOA_DEG	SFSC
-10.0	0.0
30.0	0.0
60.0	30.0
90.0	30.0

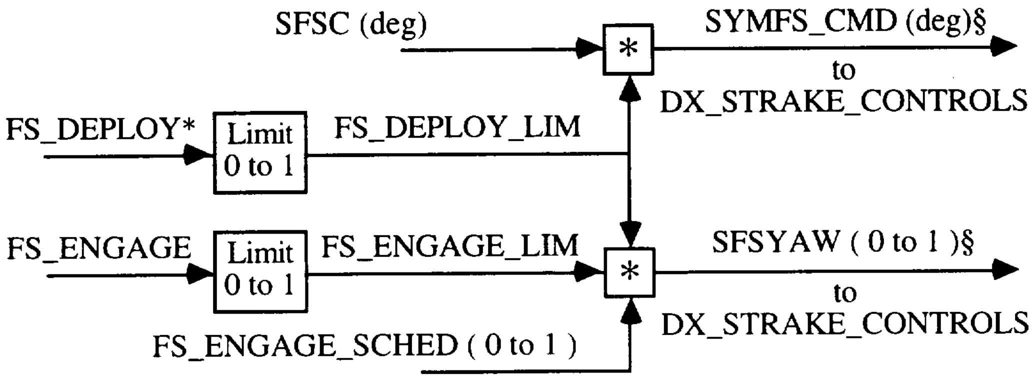
The strake-engagement schedule is used to engage differential strake operation beginning at AOA 15 degrees and ending with the strakes fully engaged at AOA 20 degrees.



AOA_DEG	FS_ENGAGE_SCHED
-10.0	0.0
15.0	0.0
20.0	1.0
90.0	1.0

4.2.5.2 Strake Deploy/Engage Logic (ANSER)

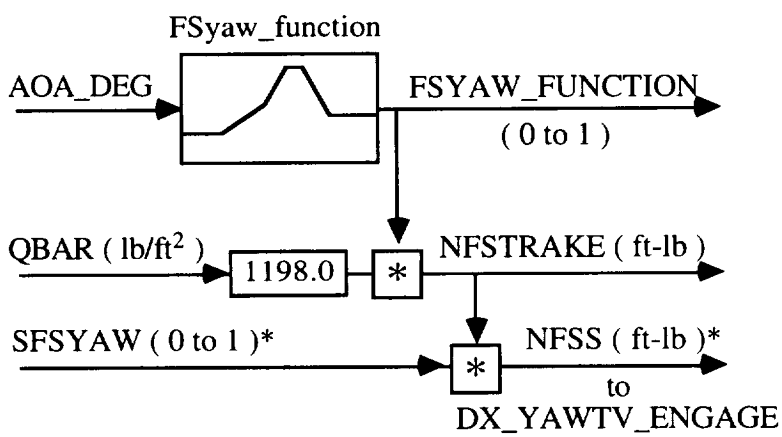
Gate the symmetric strake command to the deployment schedule SYMFS_CMD by the FS_DEPLOY control input. The engagement schedule is gated to the strake engagement variable SFSYAW by the FS_DEPLOY and FS_ON controls. The FS_DEPLOY and FS_ON controls are limited to the range of zero to one.



* Set FS_DEPLOY to zero for NASA-1A
§ Outputs equal zero for NASA-1A

4.2.5.3 Available Strake Yaw Moment (ANSER)

Calculate the yaw moment capability of the forebody strakes NFSTRAKE as a function of angle of attack and dynamic pressure. Calculate the yaw control moment available from the forebody strakes NFSS according to the strake engagement variable SFSYAW.



* Equals zero for NASA-1A

AOA_DEG	FSYAW_FUNCTION
-10.0	0.00
19.0	0.00
40.0	0.45
40.0	1.00
53.0	1.00
70.0	0.30
90.0	0.30

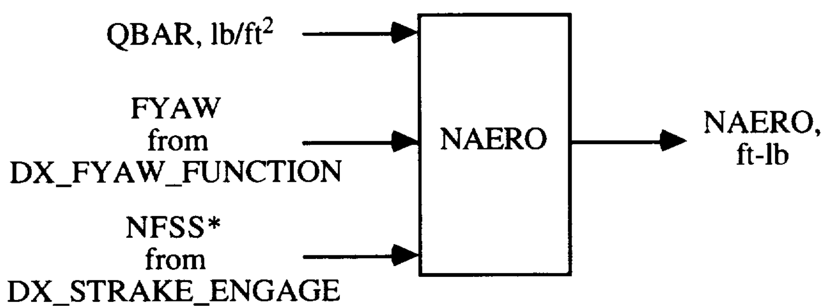
4.2.6 DX_YAWTV_ENGAGE (USR52FJL) 40 Hz

This module manages the yaw-moment producing controls and implements automatic yaw thrust-vectoring logic.

1. Calculates yaw-moment capabilities of primary aerodynamic and thrust-vectoring controls.
2. Calculates limited ratio of aerodynamic and thrust-vectoring yaw moments.
3. Implements yaw thrust-vectoring engagement logic.
4. Implements automatic yaw thrust-vectoring engage schedule.
5. Calculates the yaw moment available from the combined aerodynamic and thrust-vectoring controls.
6. Includes yaw-moment capability of forebody strake controls.

4.2.6.1 Yaw-Moment Capability of Aerodynamic Controls

Calculate the yaw moment produced by the primary controls for one unit of yaw Pseudo Control (VYAW = 1.0).

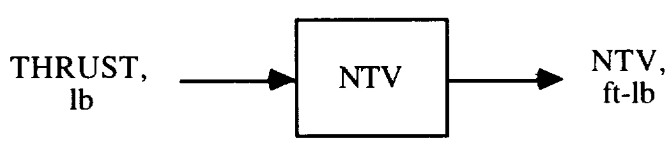


$$NAERO = 599.0 * QBAR * FYAW + NFSS$$

* NFSS equals zero for NASA–1A

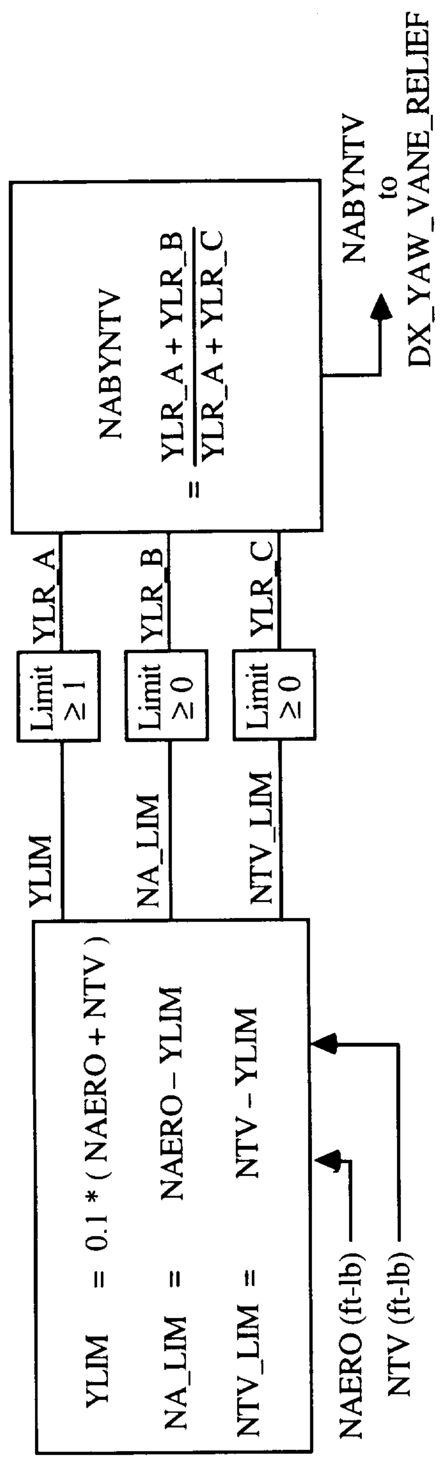
4.2.6.2 Yaw-Moment Capability of Thrust-Vectoring Controls

Calculate the yaw moment produced by the thrust-vectoring controls for 10 degrees of yaw thrust-vectoring.



$$NTV = 3.54 * THRUST$$

4.2.6.3 Limited Ratio of Aerodynamic and Yaw Thrust-Vectoring Moments

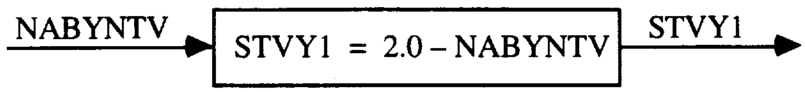


$NAERO < 9 * NTV$ and $NTV > 9 * NAERO$	$NABYNTV = \frac{NAERO}{NTV}$
$NTV > 9 * NAERO$	$NABYNTV = \frac{0.1\,(NAERO + NTV)}{NTV} \geq 0.1$
$NAERO > 9 * NTV$	$NABYNTV = \frac{NAERO}{0.1\,(NAERO + NTV)} \leq 10.0$

NABYNTV approaches 1.0 for $NAERO + NTV < 10.0$

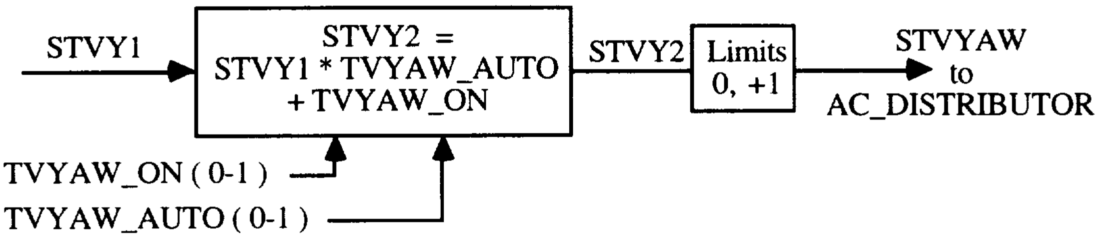
4.2.6.4 Yaw Thrust-Vector Automatic Engagement Schedule

Calculate the automatic yaw thrust-vectoring engagement schedule according to the ratio of aerodynamic and thrust-vectoring yaw moments.



4.2.6.5 Yaw-Thrust Vector Engagement Logic

Engage yaw thrust-vectoring according to mode controls and the automatic schedule.



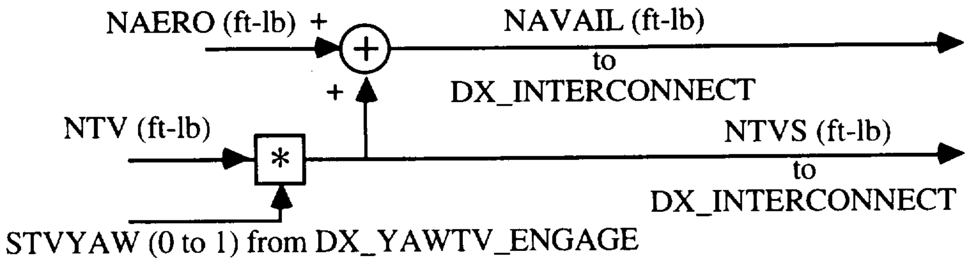
Variable STVY1 is the yaw automatic thrust-vector schedule. Yaw thrust vectoring may be engaged according to the automatic schedule or by external signals according to the following table.

TVYAW_ON	TVYAW_AUTO	STVYAW (0-off, 1-on)
0	0	= 0 (yaw TV off)
>0 and <1	0	= TVYAW_ON (transition)
1	0	= 1 (yaw TV on)
0	1	= STVY1 { 0 - off; 1 - on; transition between }

TVYAW_ON and TVYAW_AUTO must both be zero if the thrust-vectoring system is not able to respond to commands from this software.

4.2.6.6 Available Yaw Moment

Calculate the yaw moment available for control accounting for the state of engagement of the yaw thrust-vectoring controls.



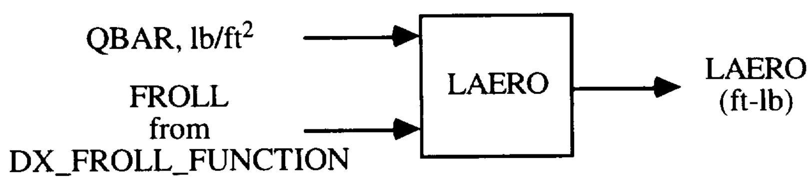
4.2.7 DX_ROLLTV_ENGAGE (USR51FJL) 40 Hz

This module manages the roll-moment producing controls and implements automatic yaw thrust-vectoring logic.

1. Calculates roll-moment capabilities of primary aerodynamic and thrust-vectoring controls.
2. Calculates limited ratio of aerodynamic and thrust-vectoring roll moments.
3. Implements roll thrust-vectoring engagement logic.
4. Implements automatic roll thrust-vectoring engage schedule.
5. Calculates the roll-moment available from the combined aerodynamic and thrust-vectoring controls.

4.2.7.1 Roll-Moment Capability of Aerodynamic Controls

Calculate the roll moment produced by the primary controls for one unit of roll Pseudo Control (VROLL = 1.0).



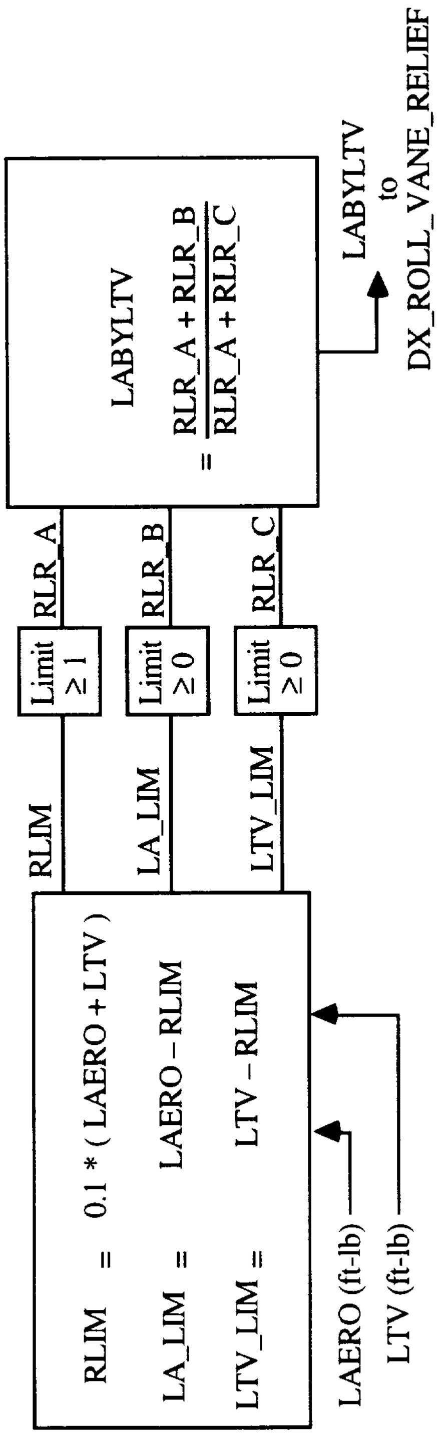
LAERO = 1048.0 * QBAR * FYAW

4.2.7.2 Roll-Moment Capability of Thrust-Vectoring Controls

Calculate the roll moment produced by the thrust-vectoring controls for 15 degrees of roll thrust-vectoring.

LTV = 0.40 * THRUST

4.2.7.3 Limited Ratio of Aerodynamic and Roll Thrust-Vectoring Moments

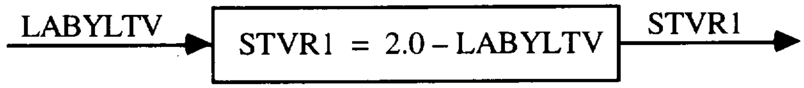


LAERO < 9 * LTV and LTV > 9 * LAERO	$LABYLTV = \frac{LAERO}{LTV}$
LTV > 9 * LAERO	$LABYLTV = \frac{0.1\,(LAERO + LTV)}{LTV} \geq 0.1$
LAERO > 9 * LTV	$LABYLTV = \frac{LAERO}{0.1\,(LAERO + LTV)} \leq 10.0$

LABYLTV approaches 1.0 for LAERO + LTV< 10.0

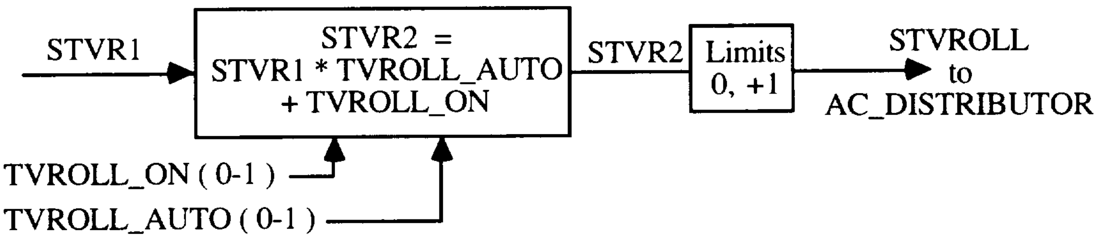
4.2.7.4 Roll Thrust-Vector Automatic Engagement Schedule

Calculate the automatic roll thrust-vectoring engagement schedule according to the ratio of aerodynamic and thrust-vectoring roll moments.



4.2.7.5 Roll Thrust-Vector Engagement Logic

Engage roll thrust-vectoring according to mode controls and the automatic schedule.



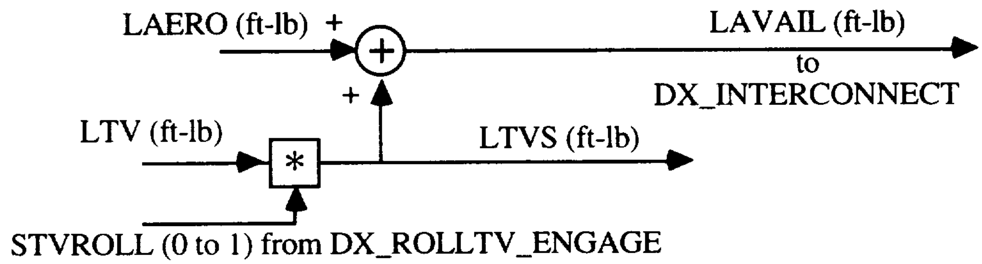
Variable STVR1 is the automatic roll thrust-vector schedule. Roll thrust vectoring may be engaged according to the automatic schedule or by external signals according to the following table.

TVROLL_ON	TVROLL_AUTO	STVROLL (0-off, 1-on)
0	0	= 0 (roll TV off)
>0 and <1	0	= TVROLL_ON (transition)
1	0	= 1 (roll TV on)
0	1	= STVR1 { 0 - off; 1 - on; transition between }

TVROLL_ON and TVROLL_AUTO must both be zero if the thrust-vectoring system is not able to respond to commands from this software.

4.2.7.6 Available Roll Moment

Calculate the roll moment available for control accounting for the state of engagement of the thrust-vectoring controls.

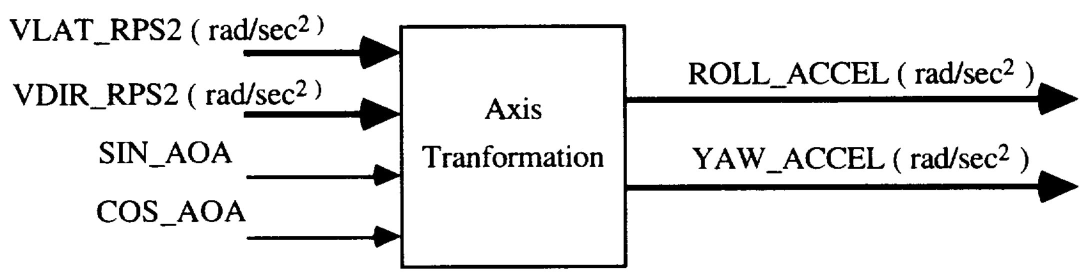


4.2.8 DX_INTERCONNECT (USR35FJL) 80 Hz

This module transforms stability-axis roll and yaw acceleration commands (VLAT_RPS2 and VDIR_RPS2) calculated by the lateral/directional feedback control law into body-axis moments and generates roll and yaw Pseudo Control variables (VROLL and VYAW).

4.2.8.1 Axis Transformation

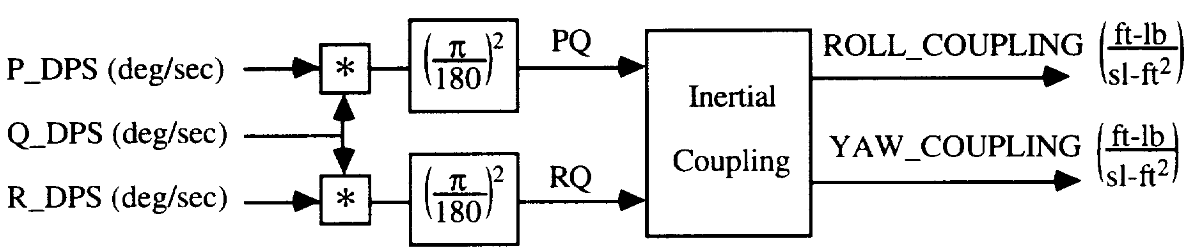
Convert stability-axis commands VLAT_RPS2 and VDIR_RPS2 into body-axis commands ROLL_ACCEL and YAW_ACCEL.



ROLL_ACCEL = VLAT_RPS2 * COS_AOA – VDIR_RPS2 * SIN_AOA
YAW_ACCEL = VLAT_RPS2 * SIN_AOA + VDIR_RPS2 * COS_AOA

4.2.8.2 Inertial Coupling

Calculate the control moments needed to compensate for roll and yaw accelerations for coupled airplane rotations about pitch, roll, and yaw axes.



ROLL_COUPLING = P1 * PQ + P2 *RQ
YAW_COUPLING = P3 * PQ + P4 * RQ

where

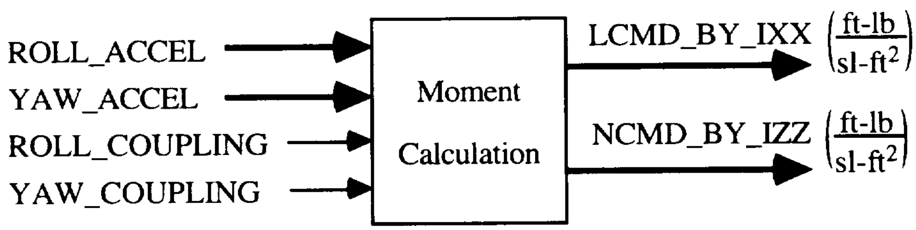
$$P1 = -\frac{I_{XZ}}{I_{XX}} = 0.09419 \qquad P3 = \frac{I_{YY} - I_{XX}}{I_{ZZ}} = 0.80077$$

$$P2 = \frac{I_{ZZ} - I_{YY}}{I_{XX}} = 0.66676 \qquad P4 = \frac{I_{XZ}}{I_{ZZ}} = -0.01126$$

ROLL_COUPLING is a roll moment (ft-lb) divided by the roll-axis moment of inertia I_{XX} (sl-ft^2). YAW_COUPLING is a yaw moment (ft-lb) divided by the yaw-axis moment of inertia I_{ZZ} (sl-ft^2).

4.2.8.3 Moments

Calculate the roll and yaw moments required to produce the desired accelerations about the airplane roll and yaw axes.



$$\text{LCMD\_BY\_IXX} = \text{ROLL\_ACCEL} + \text{P1} * \text{YAW\_ACCEL} + \text{ROLL\_COUPLING}$$

$$\text{NCMD\_BY\_IZZ} = \text{YAW\_ACCEL} + \text{P2} * \text{ROLL\_ACCEL} + \text{YAW\_COUPLING}$$

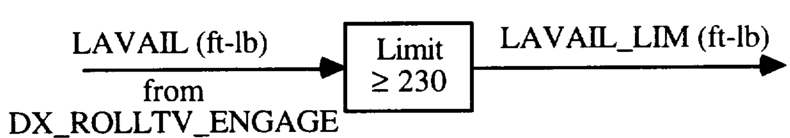
$$P1 = -\frac{I_{XZ}}{I_{XX}} = 0.09419$$

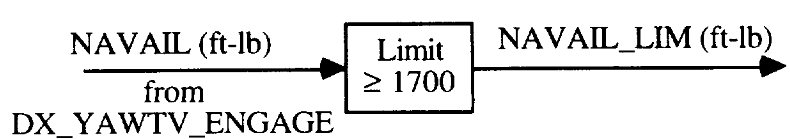
$$P2 = -\frac{I_{XZ}}{I_{ZZ}} = 0.01126$$

LCMD_BY_IXX is a roll moment (ft-lb) divided by the roll-axis moment of inertia I_{XX} (sl-ft^2). NCMD_BY_IZZ is a yaw moment (ft-lb) divided by the yaw-axis moment of inertia I_{ZZ} (sl-ft^2).

4.2.8.4 Available Moment Limits

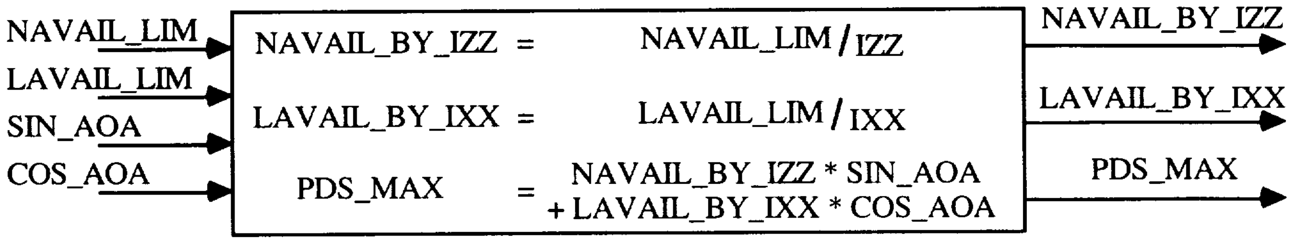
Apply lower limits to the available roll and yaw moments.





4.2.8.5 Available Accelerations

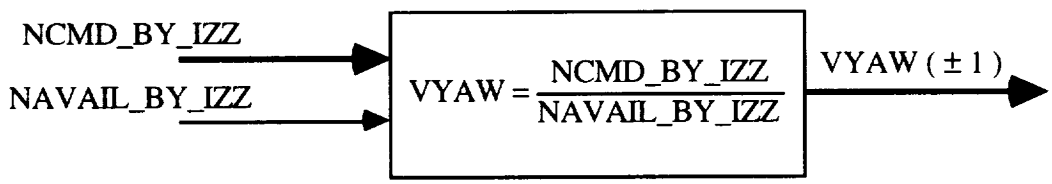
Calculate the yaw acceleration produced by the available yaw moment NAVAIL_BY_IZZ and the roll acceleration produced by the available roll moment LAVAIL_BY_IXX. Calculate the maximum stability-axis roll acceleration PDS_MAX. *The calculation of PDS_MAX is not part of the NASA–1A specification.*



I_{ZZ} = 189 336 sl-ft^2
I_{XX} = 22 632 sl-ft^2

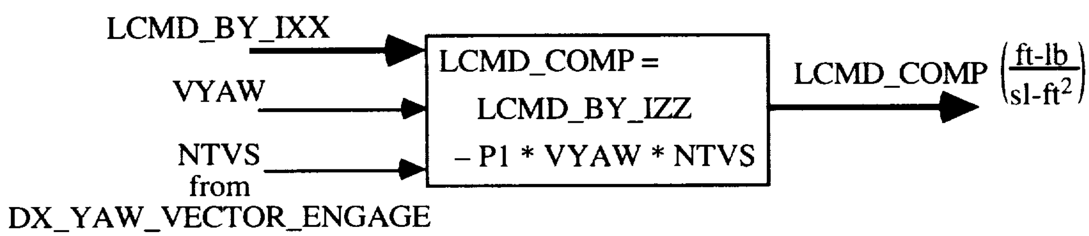
4.2.8.6 VYAW Pseudo Control

Calculate the yaw Pseudo Control variable VYAW (± 1) that equals the fraction of the available yaw moment needed to produce the desired body-axis yaw moment.



4.2.8.7 Nozzle Compensation

Compensate the roll-moment command to account for the vertical distance between the thrust-vectoring nozzles and the airplane center-of-gravity.



$$P1 = \frac{l_Z}{l_X * I_{XX}} = 9.78 \times 10^{-7}$$

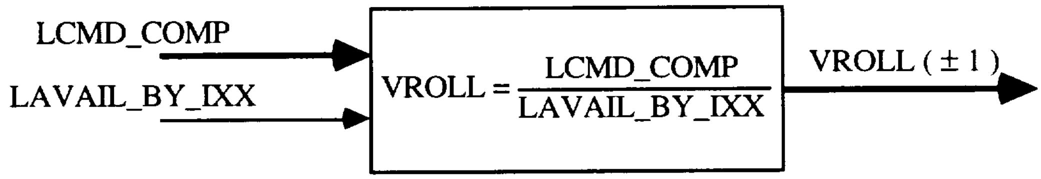
l_X – distance of thrust-vectoring nozzles behind airplane center-of-gravity, 20.33 ft

l_Z – distance of thrust-vectoring nozzles below airplane center-of-gravity, 0.45 ft

I_{XX} = 22 632 sl-ft^2

4.2.8.8 VROLL Pseudo Control

Calculate the roll Pseudo Control VROLL (± 1) that equals the fraction of the available roll moment needed to produce the desired body-axis roll moment.

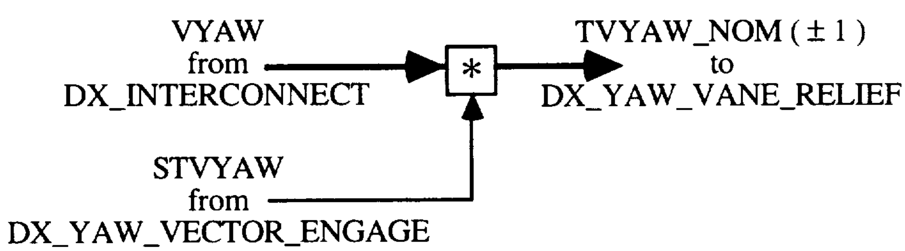


4.2.9 AC_DISTRIBUTOR (USR38FJL) 80 Hz

This module distributes the roll and yaw Pseudo Control variables (VROLL and VYAW) among the primary aerodynamic controls (ailerons, rudders, and differential stabilator) and the roll and yaw thrust-vectoring controls. This module employs DX_YAW_VANE_RELIEF(USR54FJL) and DX_ROLL_VANE_RELIEF(USR53FJL) to alleviate long-term commands to the thrust-vectoring system.

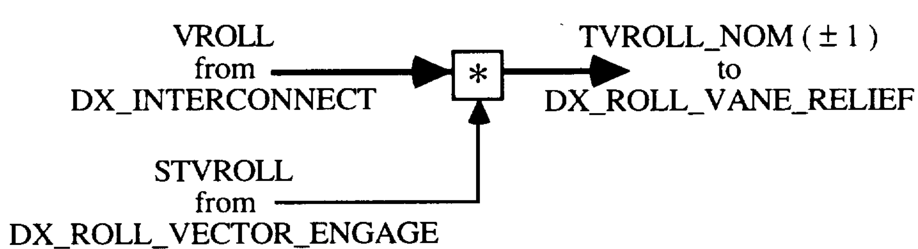
4.2.9.1 Yaw Thrust-Vector Pseudo Control

Calculate the yaw thrust-vector Pseudo Control TVYAW_NOM equal to the product of the yaw Pseudo Control variable VYAW and the yaw thrust-vectoring engagement signal STVYAW.



4.2.9.2 Roll Thrust-Vector Pseudo Control

Calculate the roll thrust-vector Pseudo Control TVROLL_NOM equal to the product of the roll Pseudo Control variable VROLL and the yaw thrust-vectoring engagement signal STVROLL.



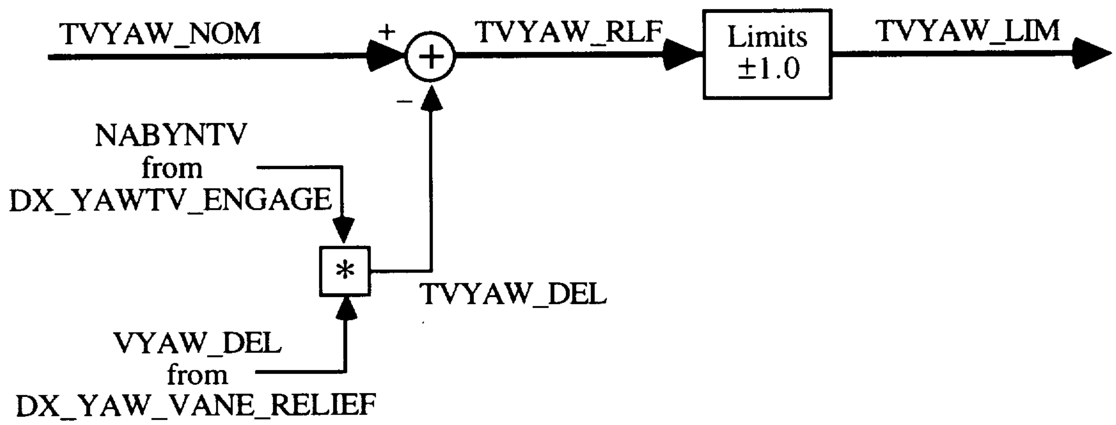
4.2.9.3 Vane Relief

Execute vane-relief modules depending on multirate clock state.

Call module DX_YAW_VANE_RELIEF(USR54FJL) if ENBL54 is true
Call module DX_ROLL_VANE_RELIEF(USR53FJL) if ENBL53 is true

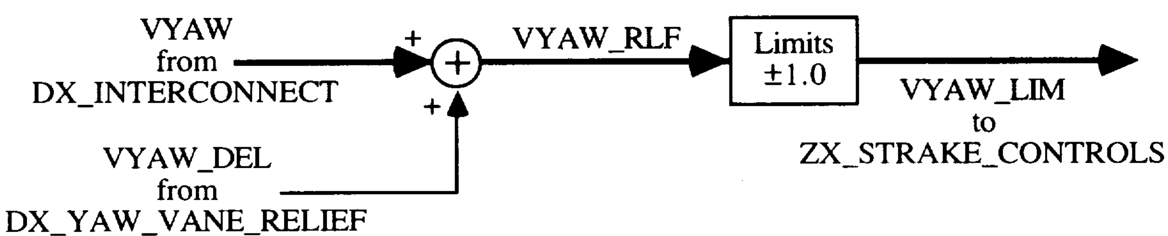
4.2.9.4 Yaw Thrust-Vectoring Pseudo Control Relief

Reduce the yaw thrust-vectoring Pseudo Control by output VYAW_DEL of the yaw vane-relief function.



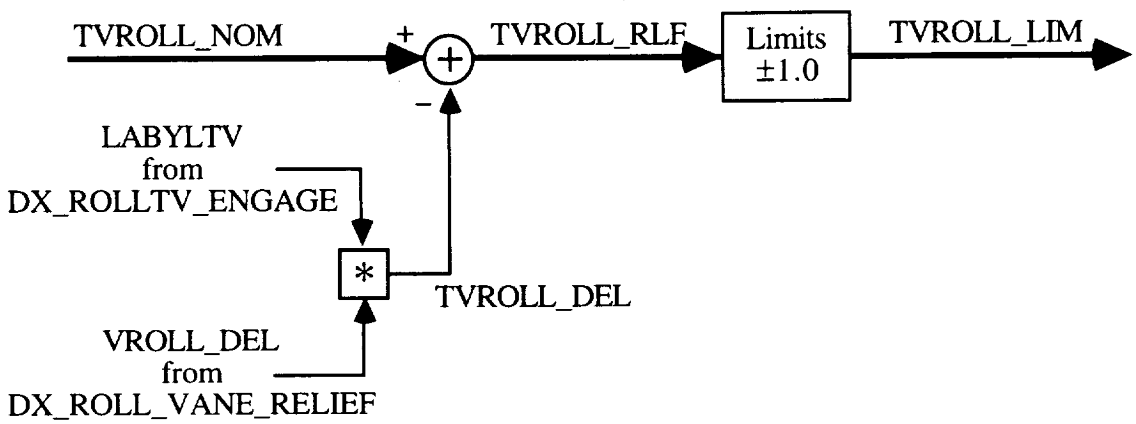
4.2.9.5 Yaw Pseudo Control Relief

Increase the aerodynamic yaw Pseudo Control by output VYAW_DEL of the yaw vane-relief function to compensate for relief of the yaw thrust-vectoring control.



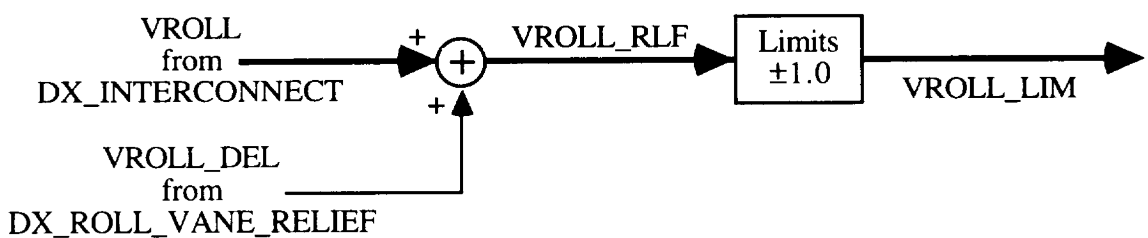
4.2.9.6 Roll Thrust-Vectoring Pseudo Control Relief

Reduce the roll thrust-vectoring Pseudo Control by output VROLL_DEL of the roll vane-relief function.



4.2.9.7 Roll Pseudo Control Relief

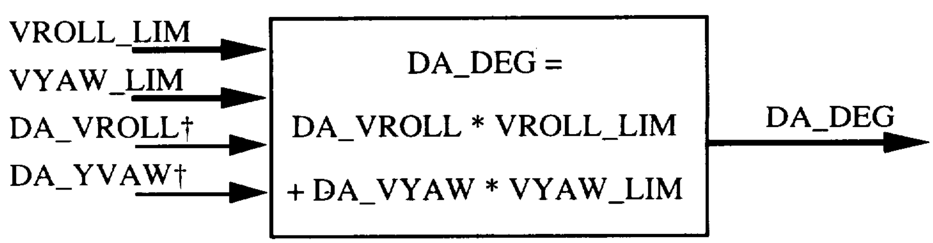
Increase the aerodynamic roll Pseudo Control by output VROLL_DEL of the roll vane-relief function to compensate for relief of the roll thrust-vectoring control.



4.2.9.8 Distribution of Pseudo Controls

Distribute the aerodynamic Pseudo Controls to the aerodynamic control surfaces and the thrust-vectoring Pseudo Controls to the thrust-vectoring commands.

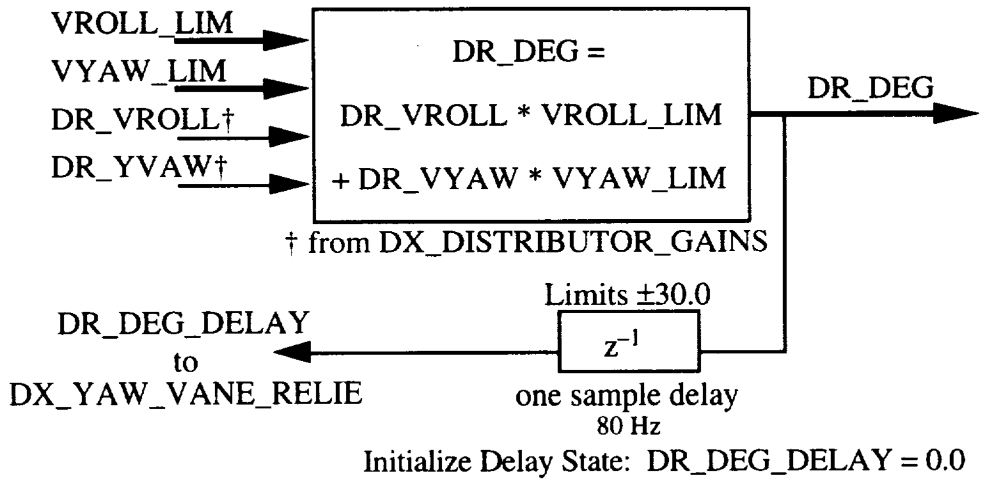
Ailerons



†from DX_DISTRIBUTOR_GAINS

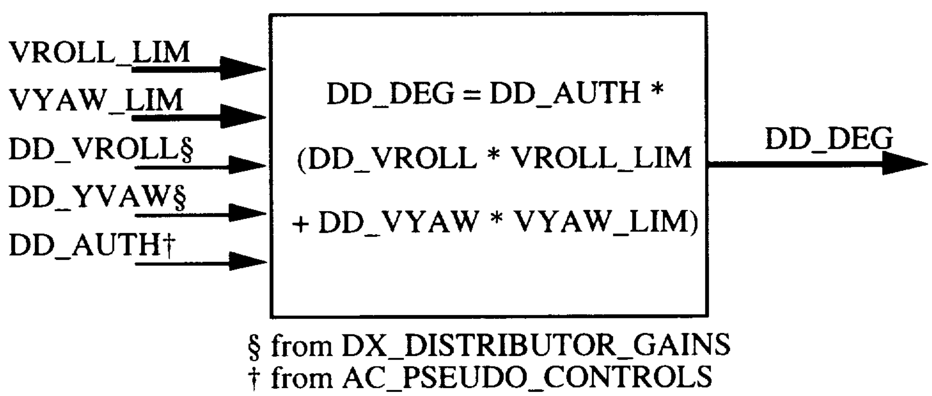
One degree of DA_DEG commands one degree TED motion of the left aileron and one degree TEU motion of the right aileron to produce a right-wing-down roll moment.

Rudders



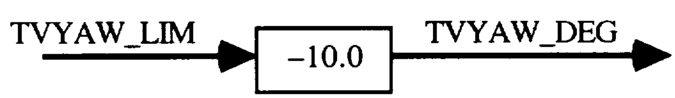
One degree of DR_DEG commands one degree TEL motion of both rudders to produce a nose-left yaw moment.

Differential Stabilator



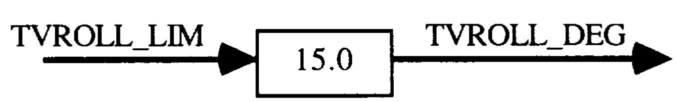
One degree of DD_DEG commands one degree TED motion of the left stabilator and one degree TEU motion of the right stabilator to produce a right-wing-down roll moment.

Yaw Thrust Vectoring



One degree of TVYAW_DEG commands one true degree of vectoring to the left of both vane sets to produce a nose-left moment.

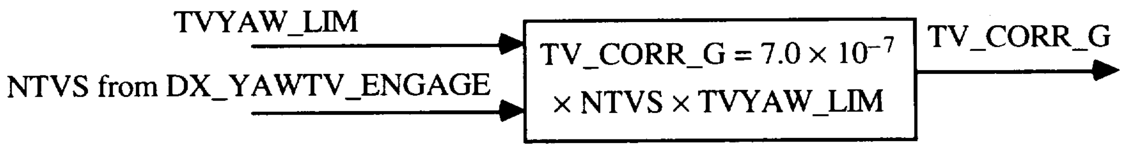
Roll Thrust Vectoring



One degree of TVROLL_DEG commands one true degree of vectoring of the left vane set downward and one true degree of vectoring of the right vane set upward to produce a right-wing-down moment.

4.2.9.9 Accelerometer Correction

Calculate the interference of yaw thrust-vectoring commands on the lateral accelerometer output. *This function is not part of the NASA–1A specification.*



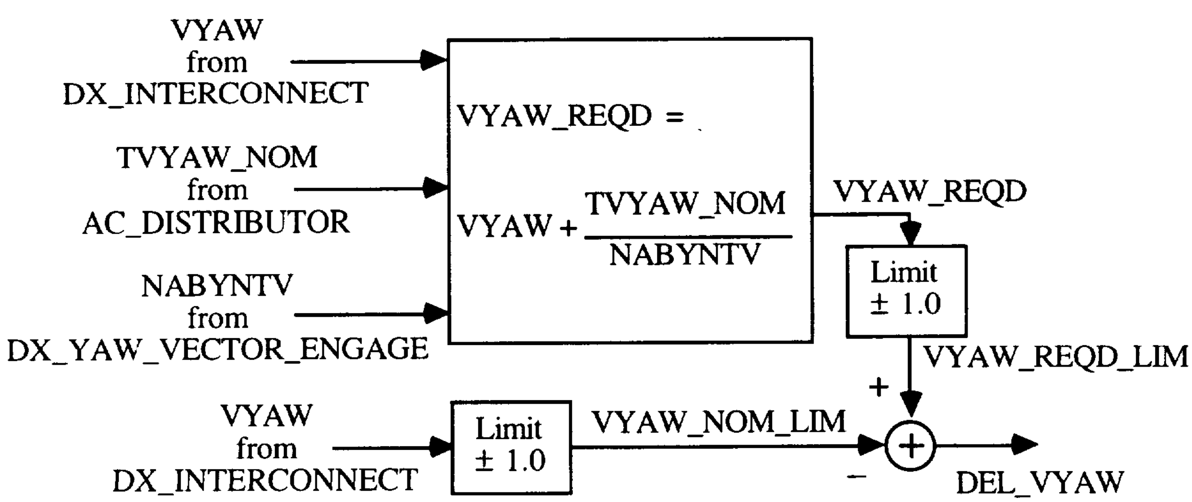
4.2.10 DX_YAW VANE RELIEF(USR54FJL) 40 Hz

The yaw vane-relief function is included in the Pseudo Controls system to reduce long-term deflections of the thrust-vectoring system by substituting equivalent deflections of the aerodynamic controls (commanded through VYAW) whenever possible. As a result of simulation tests, a delayed value of the commanded rudder position is used to limit the yaw vane relief function if it should interfere with coordination of the rudder with the other controls when rudder is used in the generation of coordinated roll moments (commanded through VROLL).

Timing of the relief action is provided by a nonlinear low-pass filter. The filter functions like a unity-gain filter with a 1.25 second time constant while it is substituting aerodynamic controls for yaw thrust-vectoring control. When yaw commands are decreasing, the aerodynamic and thrust-vectoring controls conflict in that they oppose each other. A conflict detector causes the loop gain of the filter to increase to a fast (0.125 second) time constant to quickly reduce the relief action.

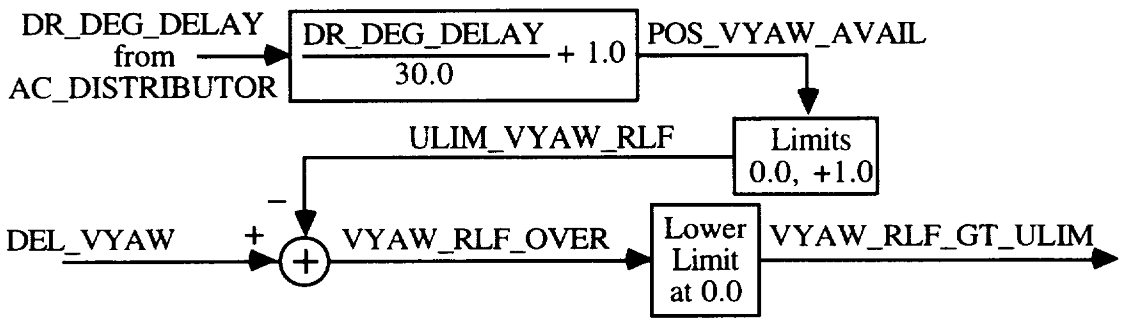
4.2.10.1 VYAW Required

Calculate the amount VYAW needs to be increased to alleviate TVYAW without exceeding VYAW = ±1.0.



4.2.10.2 Positive Limit

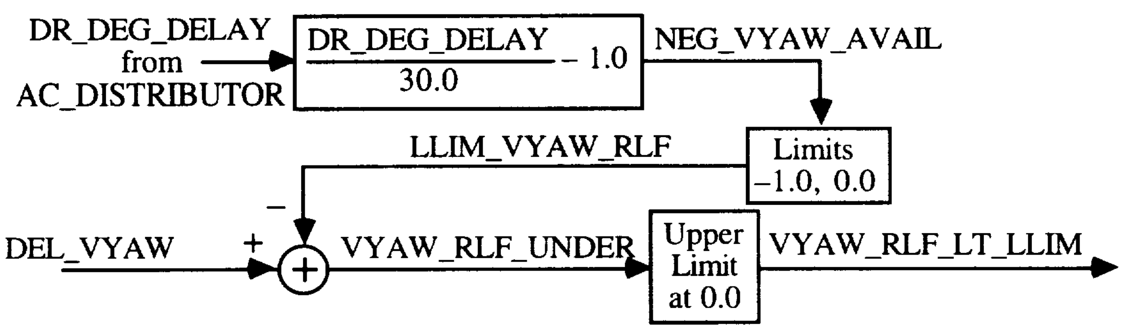
Calculate the amount DEL_VYAW exceeds the rudder capability for positive VYAW.



A change of VYAW of one unit causes a change of the rudder command of –30 degrees. This function calculates the amount of VYAW that is available for positive changes (POS_VYAW_AVAIL) based on the previous rudder position command (DR_DEG_DELAY). This is compares with change of VYAW calculated above (DEL_VYAW) to yield the amount that DEL_VYAW exceeds the amount that would drive the rudder into saturation (VYAW_RLF_GT_ULIM).

4.2.10.3 Negative Limit

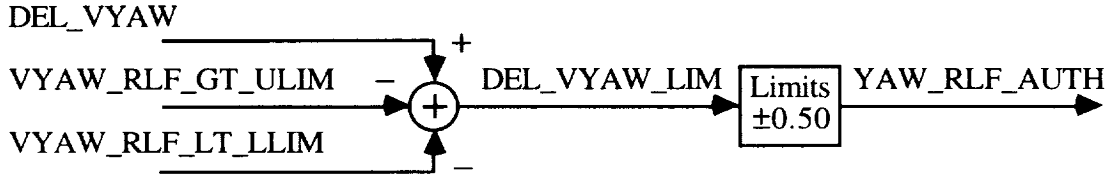
Calculate the amount DEL_VYAW exceeds the rudder capability for negative VYAW.



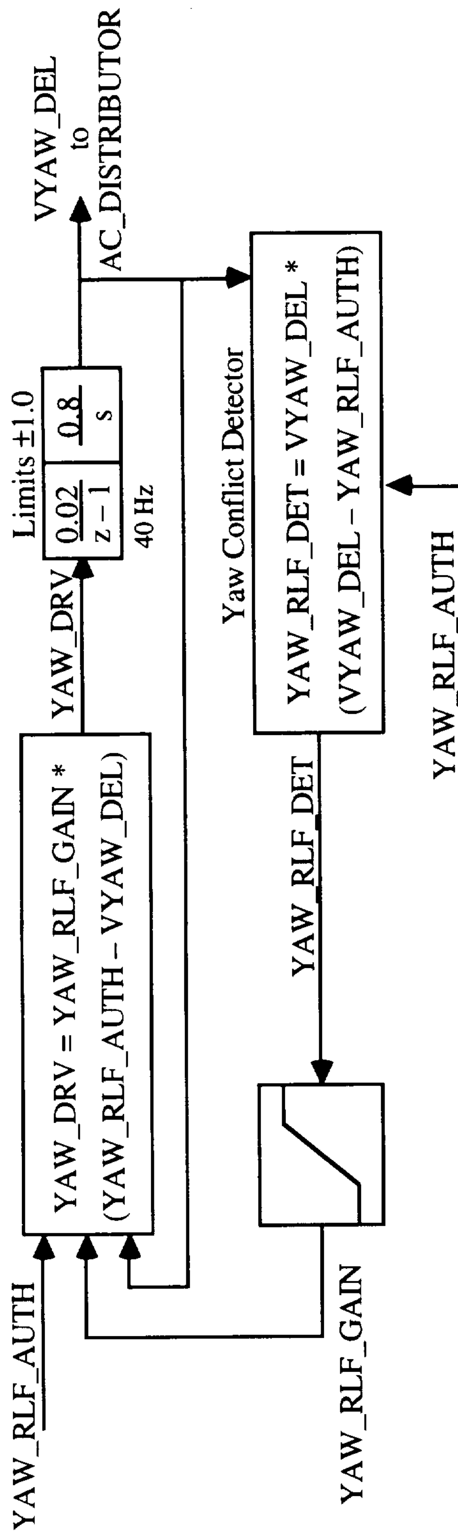
This function is the similar to the positive limit except that it is based on negative changes of VYAW.

4.2.10.4 Yaw-Relief Authority

Calculate the amount VYAW can be changed in relieving TVYAW without exceeding rudder deflection limits. The authority of the yaw vane relief function is further limited to being able to change VYAW by 0.50 (50 percent authority).



4.2.10.5 Yaw-Relief Dynamics – Nonlinear Low-Pass Filter



Initialize Filter State
VYAW_DEL = 0.0

YAW_RLF_DET	YAW_RLF_GAIN
–0.001	1.0
0.000	1.0
0.001	10.0
0.002	10.0

Piece-wise linear interpolation or equivalent

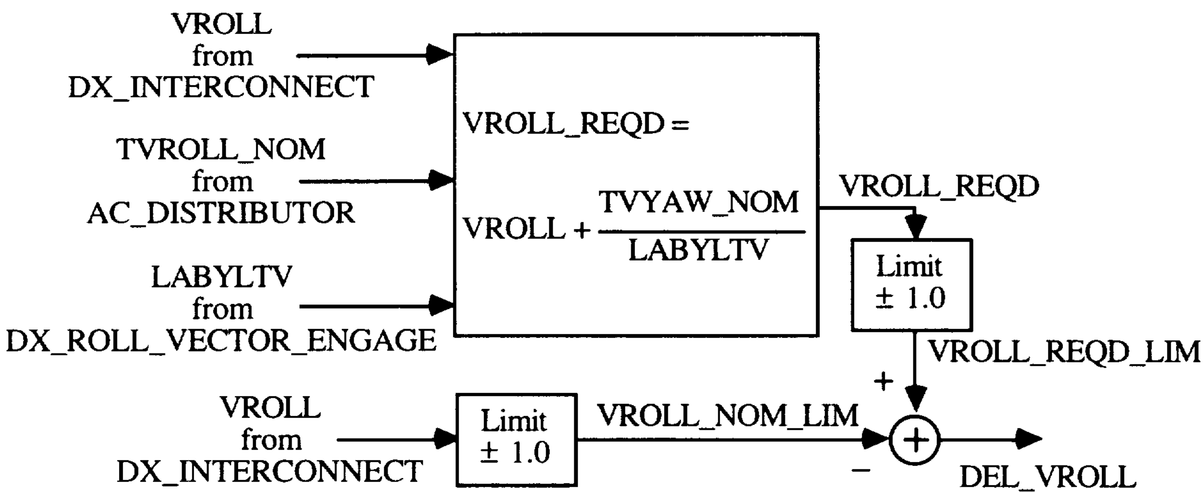
4.2.11 DX_ROLL VANE RELIEF (USR53FJL) 40 Hz

The roll vane-relief function is included in the Pseudo Controls system to reduce long-term deflections of the thrust-vectoring system by substituting equivalent deflections of the aerodynamic controls (commanded through VROLL) whenever possible.

Timing of the relief action is provided by a nonlinear low-pass filter. The filter functions like a unity-gain filter with a 1.25 second time constant while it is substituting aerodynamic controls for roll thrust-vectoring control. When roll commands are decreasing, the aerodynamic and thrust-vectoring controls conflict in that they oppose each other. A conflict detector causes the loop gain of the filter to increase to a fast (0.125 second) time constant to quickly reduce the relief action.

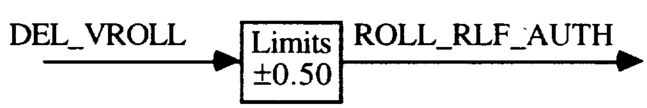
4.2.11.1 VROLL Required

Calculate the amount VROLL needs to be increased to alleviate TVROLL without exceeding VROLL = ±1.0.

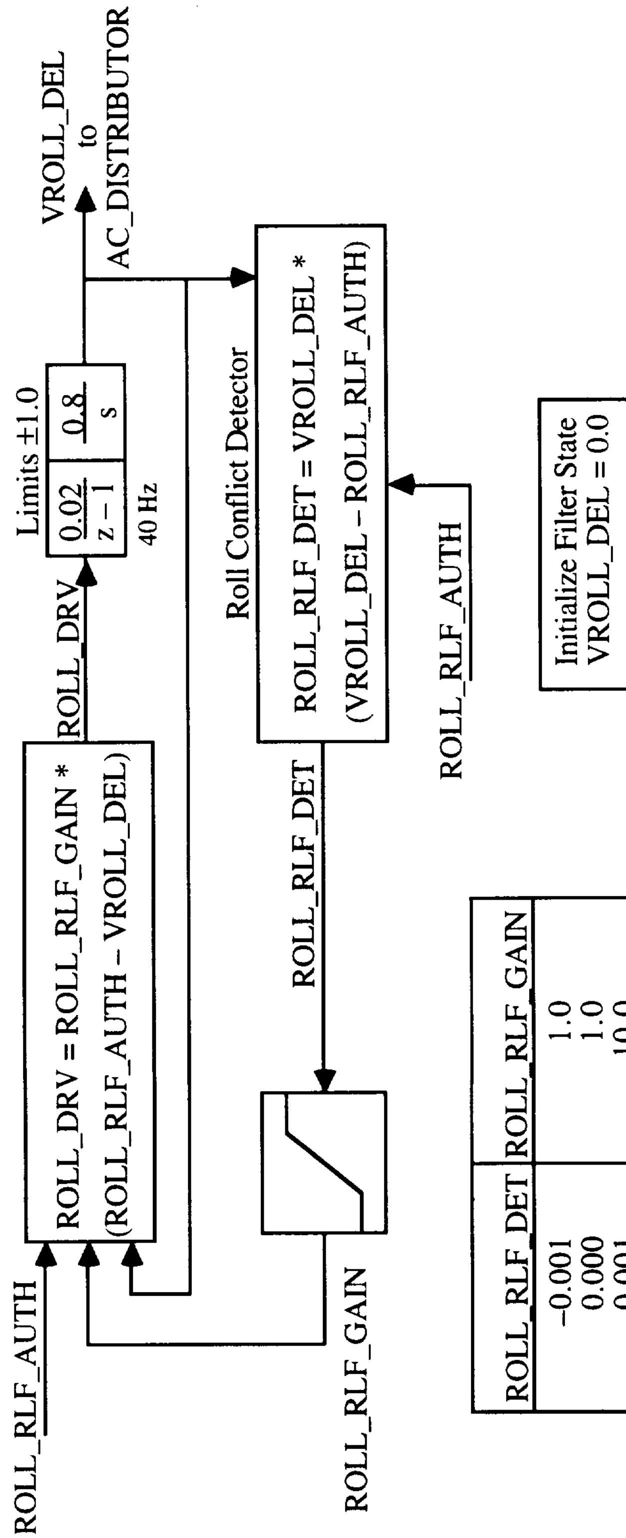


4.2.11.2 VROLL Authority

The authority of the roll vane relief function is limited to changing VROLL by 0.50 (50% authority).



4.2.11.3 Roll-Relief Dynamics – Nonlinear Low-Pass Filter



ROLL_RLF_DET	ROLL_RLF_GAIN
-0.001	1.0
0.000	1.0
0.001	10.0
0.002	10.0

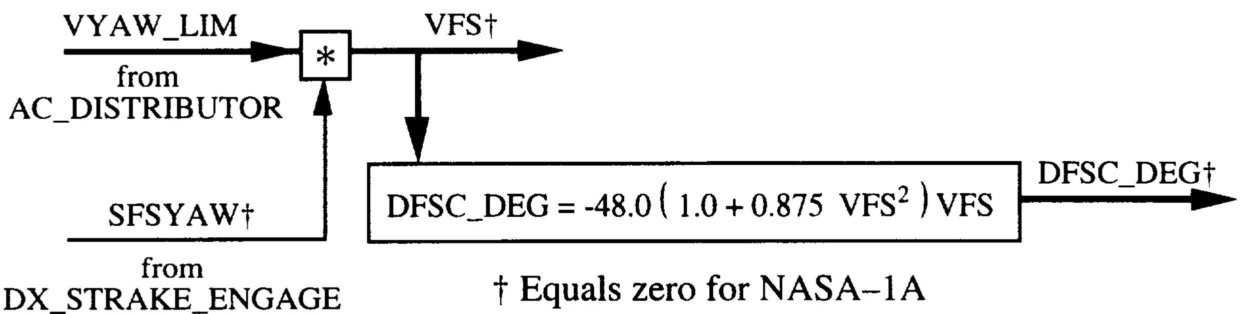
Piece-wise linear interpolation or equivalent

4.2.12 DX_STRAKE CONTROLS (USR58FJL) 80 Hz

This section presents the strake controls module for the ANSER control law. Yaw moment commands from the distributor module are combined with the symmetric deployment commands from the strake-engage module to form individual left and right forebody strake commands. An estimate of the interference of the forces generated by the strakes on the lateral accelerometer signal is calculated using the yaw moment commands.

4.2.12.1 Differential Strake Command (ANSER)

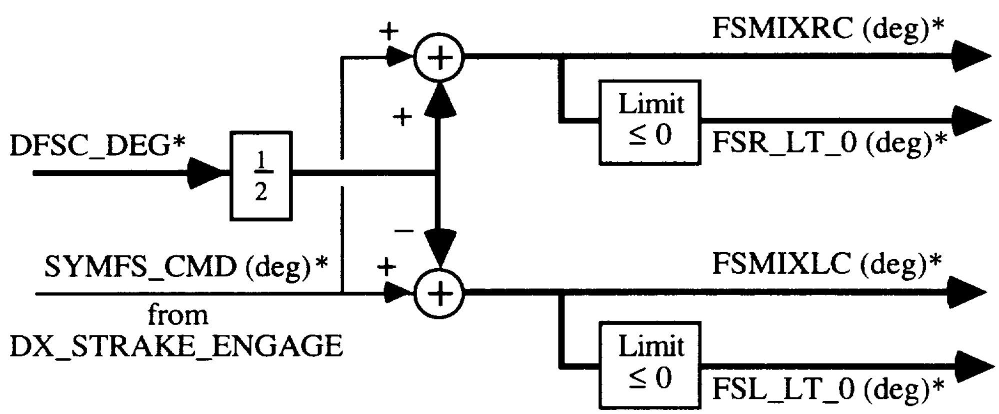
The normalized differential strake command VFS is the product of the limited yaw Pseudo Control VYAW_LIM and the strake engage variable SFSYAW. This command transformed into the differential strake angle command DFSC_DEG by a nonlinear calibration function.



† Equals zero for NASA–1A

4.2.12.2 Strake Command Mixing (ANSER)

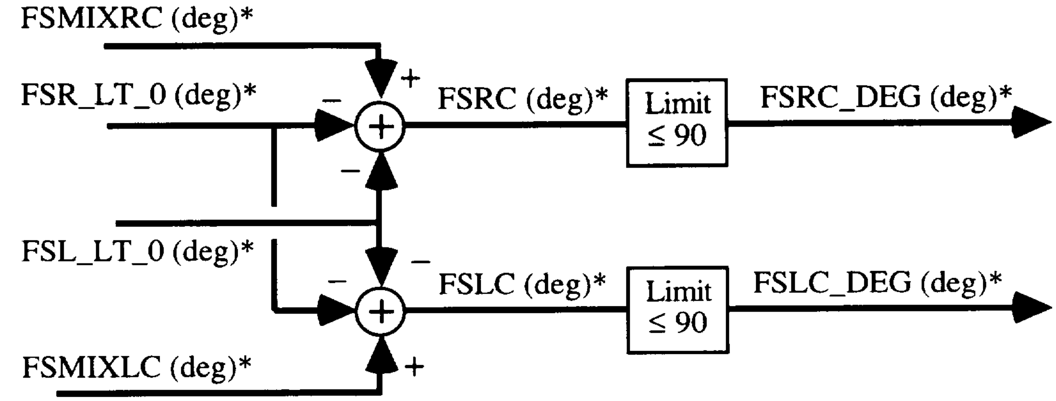
The differential and symmetric strake commands are mixed to generate preliminary angle commands for the individual left and right strakes FSMIXLC and FSMIXRC, respectively. Lower limits at zero are applied to these commands to form FSL_GT_0 and FSR_GT_0.



* Equals zero for NASA–1A

4.2.12.3 Individual Strake Commands (ANSER)

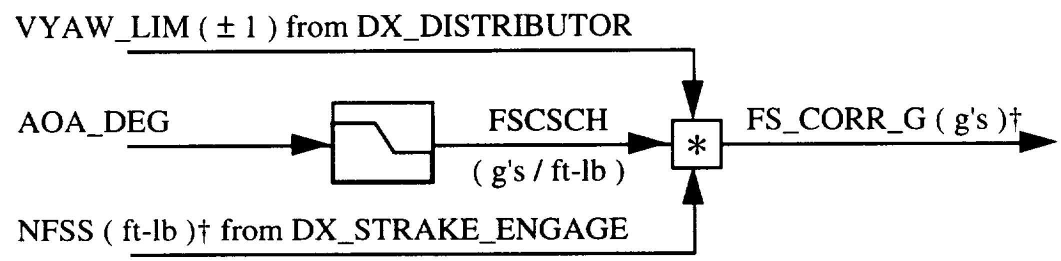
Individual commands for the left and right forebody strakes FSRC and FSLC are calculated from the mixed commands. These are limited to 90 degrees maximum (FSRC_DEG and FSLC_DEG).



* Equals zero for NASA–1A

4.2.12.4 Accelerometer Correction (ANSER)

Calculate the interference of differential forebody strake deflections on the lateral accelerometer output.



* Equals zero for NASA–1A

AOA_DEG	FSCSCH
20.0	4.2×10^{-6}
36.0	4.2×10^{-6}
50.0	3.0×10^{-6}
75.0	3.0×10^{-6}

4.2.13 Common Storage

Variables used to communicate data among the modules are placed in a common storage block in the LaRC implementation. These variables are listed in the following table. The table presents: 1) the location of the data in the common block; 2) the FORTRAN name of the data variable; 3) the variable identification and units; 4) the module numbers where the variable values are calculated; and 5) the module(s) where the data is used. This common block does not include variables that are defined and used entirely within a given module.

Common Variables

No.	Name	Description	Definition †	Usage †
1	AOA_DEG	Angle of Attack, deg	Ext	33, 34, 35, 58, 59
2	MACH	Mach Number	Ext	33, 34
3	ALT_FT	Altitude, ft	Ext	33, 34
4	DE_DEG	Symmetric Stab Command, deg	Ext	39
5	FYAW	Yaw Aero Coefficient	33	52
6	FROLL	Roll Aero Coefficient	34	51
7	DD_AUTH	Diff Stabilator Authority, 0 to 1	39	33, 34, 38
8	DA_VROLL	Distributor Gain, deg	36	38
9	DR_VROLL	Distributor Gain, deg	36	38
10	DD_VROLL	Distributor Gain, deg	36	38
11	*FSLC_DEG	Left Forebody Strake, 0 deg	58	Ext
12	DA_VYAW	Distributor Gain, deg	36	38
13	DR_VYAW	Distributor Gain, deg	36	38
14	DD_VYAW	Distributor Gain, deg	36	38
15	*FS_DEPLOY	Strake Deploy Mode, 0 to 1	Ext	59
16	*FS_ON	Strake On Mode, 0 to 1	Ext	59
17	*SYMFS_CMD	Symmetric Strake Command, deg	59	58
18	*SFSYAW	Strake Engage, 0 to 1	59	58, Ext
19	*FSRC_DEG	Right Forebody Strake, deg	58	Ext
20	QBAR	Dynamic Pressure, lb/ft^2	Ext	59, 52, 51
21	THRUST	Total Estimated Thrust, lb	Ext	52, 51, 39
22	TVYAW_AUTO	Yaw TV Automatic Mode, 0 to 1	Ext	52
23	TVYAW_ON	Yaw TV On Mode, 0 to 1	Ext	52
24	TVROLL_AUTO	Roll TV Automatic Mode, 0 to 1	Ext	51
25	TVROLL_ON	Roll TV On Mode, 0 to 1	Ext	51
26	NAVAIL	Available Yaw Moment, ft-lb	52	35
27	LAVAIL	Available Roll Moment, ft-lb	51	35
28	NTVS	TV Yaw Moment, ft-lb	52	35, 38
29	NABYNTV	Aero ÷ TV Yaw Moment, no unit	52	54, Ext
30	LABYLTV	Aero ÷ TV Roll Moment, no unit	51	53, Ext
31	STVYAW	Yaw Thrust-Vector Engage, 0 to 1	52	38, Ext
32	STVROLL	Roll Thrust-Vector Engage, 0 to 1	51	38, Ext
33	VLAT_RPS2	Lateral Acceleration Cmd, rad/sec^2	Ext	35
34	VDIR_RPS2	Directional Accel Command, rad/sec^2	Ext	35
35	SIN_AOA	Sine of Angle of Attack	Ext	35
36	COS_AOA	Cosine of Angle of Attack	Ext	35
37	P_DPS	Roll Rate, deg/sec^2	Ext	35
38	Q_DPS	Pitch Rate, deg/sec^2	Ext	35
39	R_DPS	Yaw Rate, deg/sec^2	Ext	35
40	VYAW	Yaw Pseudo Control, ±1	35	38, 54 Ext
41	VROLL	Roll Pseudo Control, ±1	35	38, 53, Ext
42	TVROLL_MP	Roll TV Command for Mix/Pred, deg	39	Ext

Common Variables, continued

No.	Name	Description	Definition †	Usage †
43	DA_DEG	Aileron Command, deg	38	Ext
44	DR_DEG	Rudder Command, deg	38	Ext
45	DD_DEG	Differential Stabilator Command, deg	38	Ext
46	TVYAW_DEG	Yaw Thrust-Vector Command, deg	38	39
47	TVROLL_DEG	Roll Thrust-Vector Command, deg	38	39
48	TVYAW_NOM	Nominal Yaw TV Pseudo Control	38	54
49	TVROLL_NOM	Nominal Roll TV Pseudo Control	38	53
50	DR_DEG_DLY	Delayed Rudder Command, deg	38	54
51	VROLL_DEL	Roll Aero Relief Change	53	38
52	VYAW_DEL	Yaw Aero Relief Change	54	38
53	TVYAW_DEL	Yaw TV Relief Change	54	38
54	TVROLL_DEL	Roll TV Relief Change	53	38
55	TVYAW_MP	Yaw TV Cmd for Mix/Pred, deg	39	Ext
56	VYAW_LIM	Limited Aero Pseudo Control	38	58
57	*NFSS	Available Strake Yaw Moment, ft-lb	59	52,58
58	§PDS_MAX	Available Stab Roll Accel, rad/sec^2	35	Ext
59	*§FS_CORR_G	Strake–Accelerometer Correction, g's	58	39
60	§TV_CORR_G	Yaw TV–Accelerometer Correction, g	38	39
61	§AY_CORR_G	Lateral Accelerometer Correction, g's	39	Ext
62	§SPARE	Unused spare variable	Ext	–

* Variable has value zero for NASA–1A control law.
§ Variable added for ANSER control law.
† 'Ext' refers to external inputs and outputs.

Numbers refer to module 'USR' names as follows:
33 – DX_FYAW_FUNCTION(USR33FJL)
34 – DX_FROLL_FUNCTION(USR34FJL)
35 – DX_INTERCONNECT(USR35FJL)
36 – DX_DISTRIBUTOR_GAINS(USR36FJL)

38 – AC_DISTRIBUTOR(USR38FJL)
39 – AC_PSEUDO_CONTROLS(USR39FJL)
51 – DX_ROLLTV_ENGAGE(USR51FJL)
52 – DX_YAWTV_ENGAGE(USR52FJL)

53 – DX_ROLL_VANE_RELIEF(USR53FJL)
54 – DX_YAW_VANE_RELIEF(USR54FJL)
58 – DX_STRAKE_CONTROLS(USR58FJL)
59 – DX_STRAKE_ENGAGE(USR59FJL)

4.3 Horizontal Block Diagram

This section contains consolidated (horizontal) block diagrams for the ANSER Pseudo Control system in the form of MATRIX$_X$® SystemBuild™ diagrams. An Input/Output list for Pseudo Controls is included in section 4.3.1. A consolidated diagram of the Pseudo Controls modules is shown in figures 4.4 (a) through 4.4 (c). A consolidated diagram of the ANSER controls module is shown in figure 4.5.

4.3.1 Input - Output Lists

Externals:

DX_FYAW_FUNCTION	USR33FJL	
DX_FROLL_FUNCTION	USR34FJL	
DX_DISTRIBUTOR_GAINS	USR36FJL	
DX_STRAKE_ENGAGE	USR59FJL	
DX_YAWTV_ENGAGE	USR52FJL	
DX_ROLLTV_ENGAGE	USR51FJL	
DX_INTERCONNECT	USR35FJL	
AC_DISTRIBUTOR	USR38FJL	1 state variable
DX_YAW_VANE_RELIEF	USR54FJL	1 state variable
DX_ROLL_VANE_RELIEF	USR53FJL	1 state variable
DX_STRAKE_CONTROLS	USR58FJL	

Inputs:

1	vlat_rps2	Instantaneous roll acceleration command	rad/sec^2
2	vdir_rps2	Instantaneous yaw acceleration command	rad/sec^2
3	AOA_deg	Angle of attack (for scheduling)	degrees
4	p_dps	Body-axis roll rate (for inertial decoupling)	deg/sec
5	q_dps	Body-axis pitch rate (for inertial decoupling)	deg/sec
6	r_dps	Body-axis yaw rate (for inertial decoupling)	deg/sec
7	qbar	Dynamic Pressure (for determination of aerodynamic control moments)	lb/ft^2
8	Thrust	Total thrust both engines (for determination of thrust-vectoring moments)	lbs
9	spare	unused input	
10	Mach	Mach number (for scheduling)	
11	alt_ft	Altitude (for scheduling)	feet
12	Sin_AOA	Sine of AOA (for axis transformation)	
13	Cos_AOA	Cosine of AOA (for axis transformation)	
14	de_deg	Symmetric Stabilator (elevator) command	degrees (+10.5 TED, -24.0 TEU)
15	TVyaw_auto	Enable automatic operation of yaw thrust-vectoring engagement algorithm.	

Inputs: (Continued)

----

16 TVyaw_on Manual engagement of yaw thrust vectoring

The above two inputs control yaw thrust vectoring:

a) TVyaw_on = 0.0 and TVyaw_auto =0.0 for no yaw TV

b) TVyaw_on = 0.0 and TVyaw_auto = 1.0 for automatic yaw TV. TVyaw_auto may be 'ramped' between 0.0 and 1.0 while TVyaw_on = 0.0 during mode changes.

c) TVyaw_on = 1.0 and TVyaw_auto = 0.0 for yaw TV "on" full time. TVyaw_auto = 0.0 during mode changes.

d) Using values for TVyaw_on and TVyaw_auto other than discussed above should be avoided.

17 TVroll_auto Enable automatic operation of roll thrust-vectoring engagement algorithm.

18 TVroll_on Manual engagement of roll thrust vectoring

The above two inputs control roll thrust vectoring. They operate in the same manner as TVyaw_on and TVyaw_auto discussed above.

19 FS_Deploy Commands forebody strakes to follow symmetric deployment schedule (0 to 1: 0 = park, 1 = deploy)

20 FS_On 0 to 1 (0 = disengage, 1 = engage)

Outputs:

1	da_deg	Aileron command (+25 degrees for left aileron 25 degrees down and right aileron 25 degrees up)	degrees
2	dr_deg	Rudder command (+30 degrees for both rudders 30 degrees left)	degrees
3	dd_deg	Differential stabilator command (+10 degrees for left stabilator 10 degrees TED and right stabilator 10 degrees TEU)	degrees
4	TVyaw_MP	Collective lateral thrust-vectoring command	degrees
5	TVroll_MP	Differential vertical thrust-vectoring command	degrees

----

Outputs: (Continued)

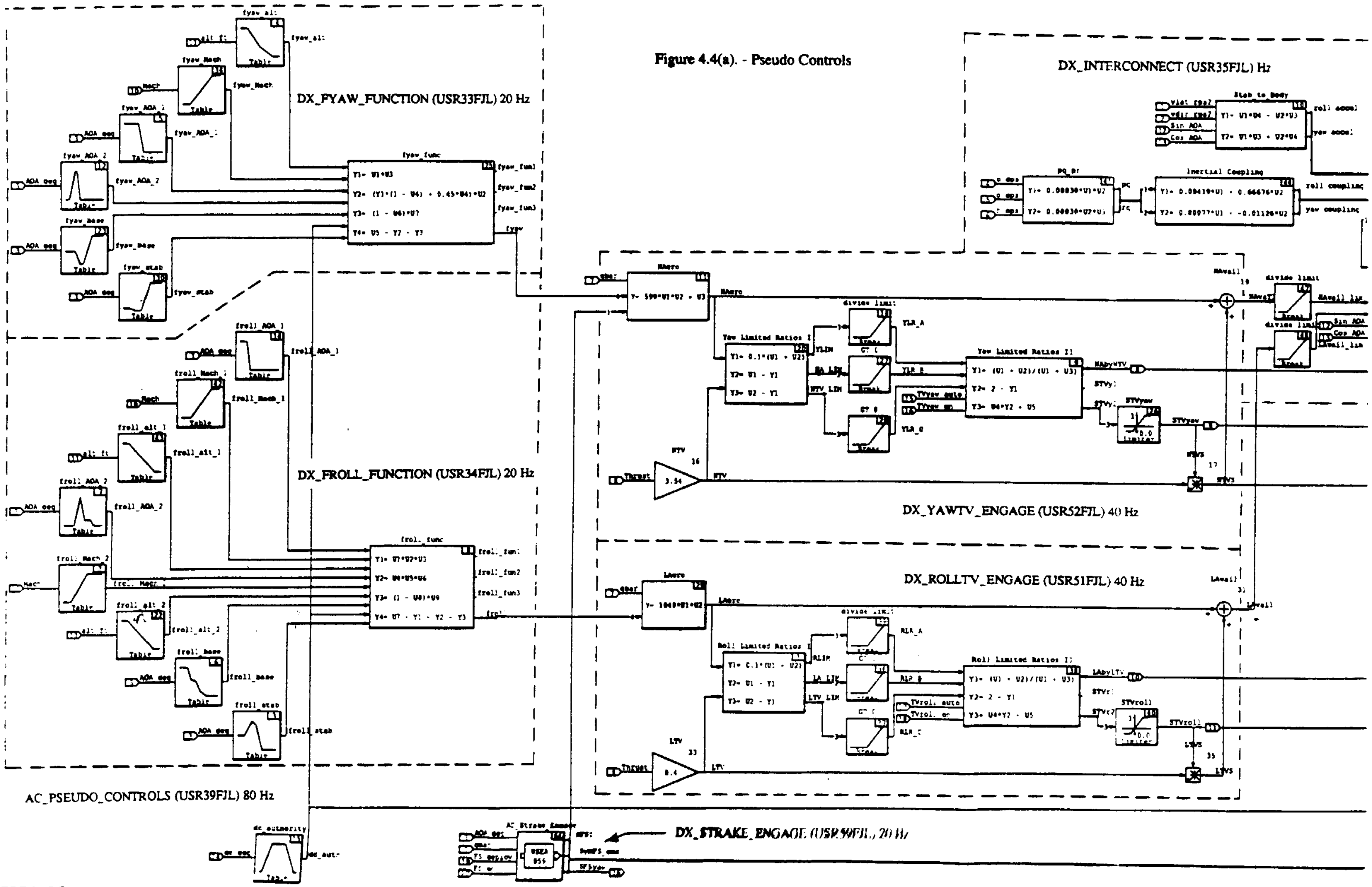
6	vroll	Roll Pseudo Control variable (body-axis roll moment), +/- 1	
7	vyaw	Yaw Pseudo Control variable (body-axis yaw moment), +/- 1	
8	NAbyNTV	Ratio of available aerodynamic and thrust-vectoring yaw control moments (limited for division)	
9	STVyaw	Yaw thrust vectoring engagement variable; 0=off, 1=on	
10	LAbyLTV	Ratio of available aerodynamic and thrust-vectoring roll control moments (limited for division)	
11	STVroll	Roll thrust vectoring engagement variable; 0=off, 1=on	
12	FSRC_deg	Right forebody strake command	degrees
13	FSLC_deg	Left forebody strake command	degrees
14	ay_corr_g	Calculated interference in lateral accelerometer output This quantity may be subtracted from the lateral accelerometer output to correct for direct pick-up of forces from the forebody strake and yaw thrust-vectoring controls.	g's
15	pds_max	Calculated value of the available stability-axis roll acceleration	rad/sec^2
16	SFSyaw	Forebody strake engagement variable; 0=off, 1=on	

4.4 References

4.1 Lallman, Frederick J.: *Relative Control Effectiveness Technique With Application to Airplane Control Coordination.* NASA TP 2416, Apr. 1985.

4.2 Lallman, Frederick J.: *Preliminary Design Study of a Lateral-Directional Control System Using Thrust Vectoring.* NASA TM 86425, Nov. 1985.

Figure 4.4(a). - Pseudo Controls



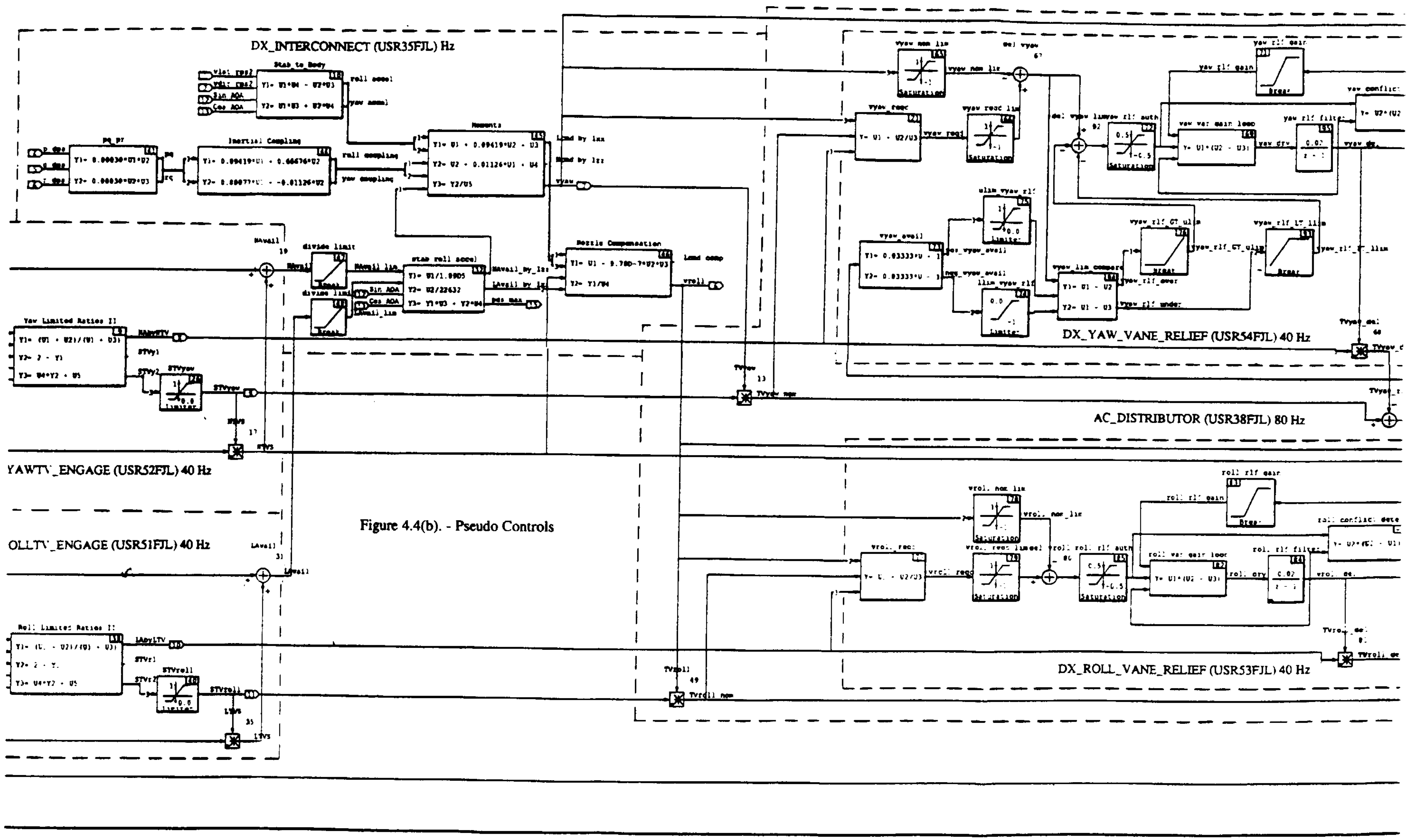


Figure 4.4(b). - Pseudo Controls

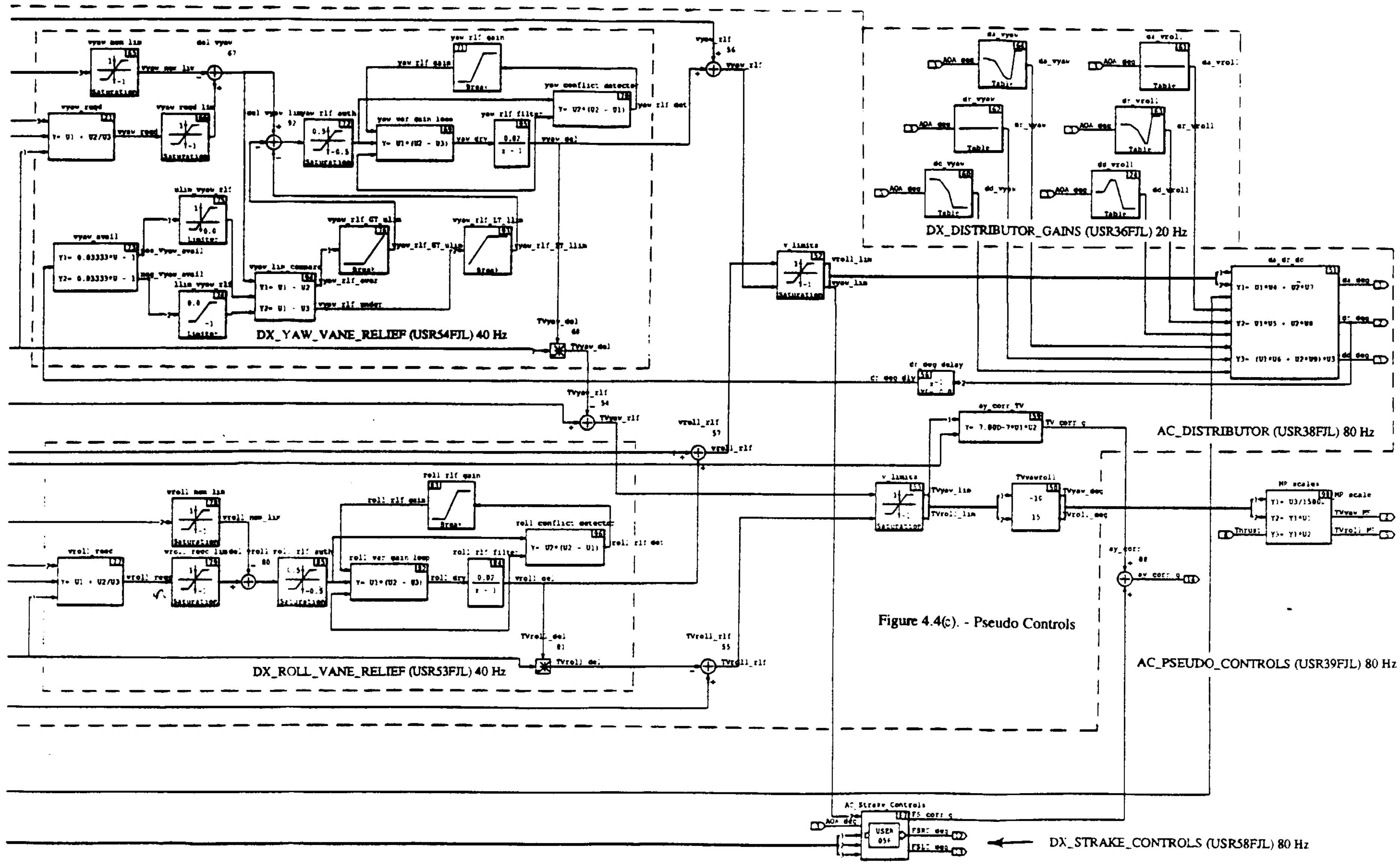


Figure 4.4(c). - Pseudo Controls

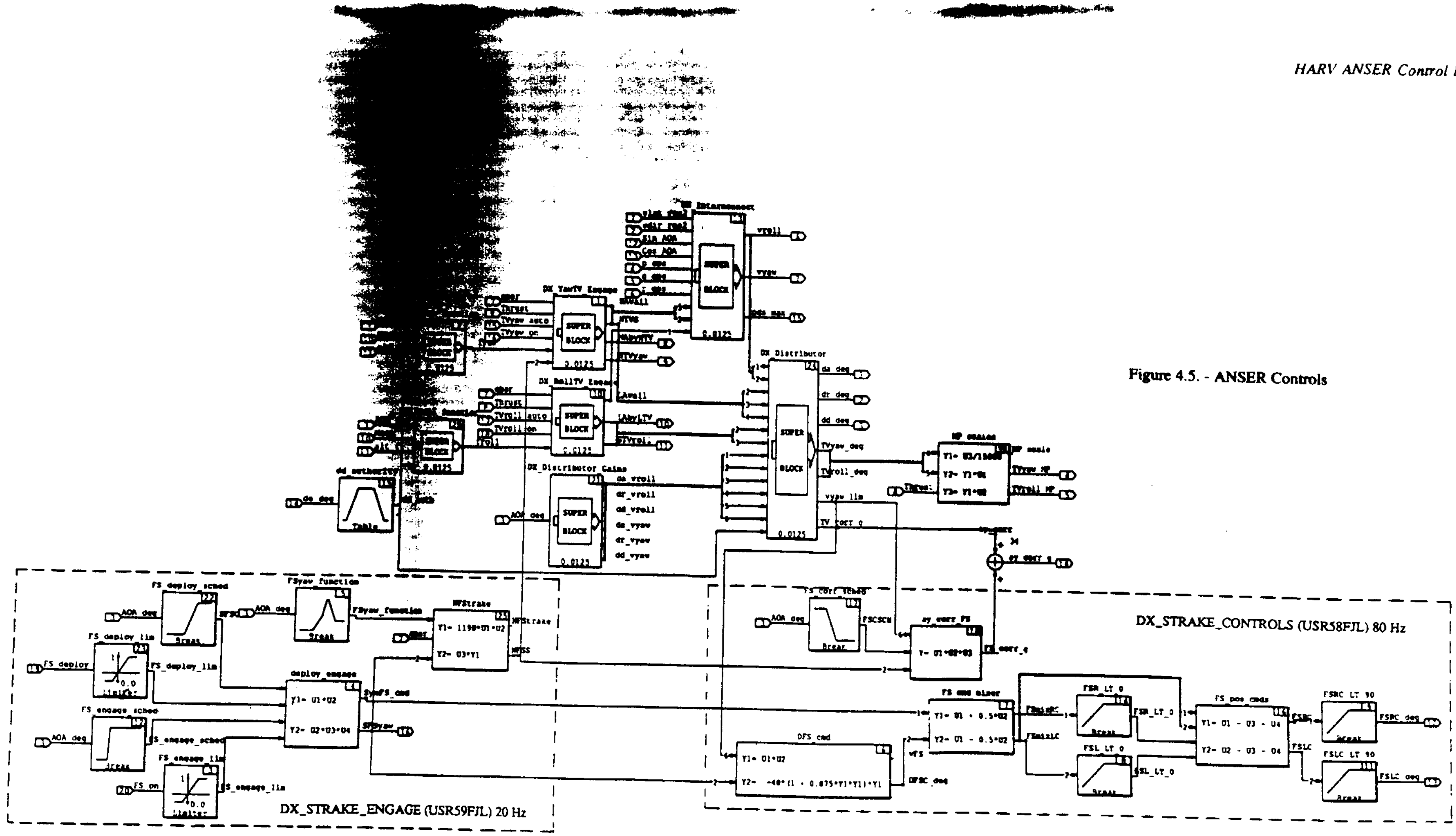


Figure 4.5. - ANSER Controls

Chapter 5
Interface

5.1 General

The purpose of this chapter is to define the interface between the HARV ANSER Control Laws and the "outside world". Inputs include pilot stick and pedal commands, OBES commands, measurements, calculated parameters, and discretes to turn "ON"/"OFF" various control law functions. Table 5.1 lists the inputs for the Longitudinal and Lateral/Directional ANSER Control Laws only. The Mixer/Predictor I/O has not been included in the HARV ANSER Control Law Specification. The requested outputs from the F-18/HARV instrumentation are defined in Table 5.2. These instrumentation parameters include deflection commands to the aerodynamic surfaces, thrust-vectoring commands to the Mixer/Predictor, and internal variables brought out for diagnostic purposes only. Units are included in the input and instrumentation tables. The variable names for the input and instrumentation tables agree with the corresponding variable names in the FORTRAN code. The calculated inputs along with certain required accuracies are contained in section 5.3.

5.2 Input and Instrumentation Lists

TABLE 5.1.- INPUTS.

NO	AUTO CODE SYMBOL	DEFINITION	UNITS
1	PSTICK	Pitch stick	in
2	LATST_IN	Lateral Stick (-3 to +3)	in
3	RUDPED_LBS	Rudder Pedal (-100 to +100)	lbs
4	PTRIM	Pitch trim	in
5	YTRIM	Yaw trim (-1 to +1)	n.d.
6	RTRIM	Roll trim (-1 to +1)	n.d.
7	PS_DPS P_DPS	Sensed body-axis roll rate	deg/sec
8	Q QS_DPS Q_DPS	Sensed body-axis pitch rate	deg/sec
9	RS_DPS R_DPS	Sensed body-axis yaw rate	deg/sec
10	NZ NZ_G	Normal acceleration - positive along z-axis	g
11	SINPHI	Sine of INS roll angle	n.d.
12	COSPHI	Cosine of INS roll angle	n.d.
13	SINTHE SINTHETA	Sine of INS pitch angle	n.d.
14	COSTHE COSTHETA	Cosine of INS pitch angle	n.d.
15	NY_G	Sensed lateral acceleration	g

TABLE 5.1.- INPUTS (Concluded).

NO	AUTO CODE SYMBOL	DEFINITION	UNITS
16	VT VTRUE_FPS	True airspeed	ft/sec
17	MACH	Mach number	n.d.
18	AOAP	Angle-of-attack PROBE	deg
19	AOAINS	Angle-of-attack INS	deg
20	BDOT_INERT_ DPS	Sideslip rate inertial	deg/sec
21	H_FT ALT_FT	Altitude (above sea level)	ft
22	PS	Static pressure	lb/ft^2
23	QBAR	Dynamic pressure	lb/ft^2
24	QCFILTER1	2.5 rad/sec filtered impact pressure	lb/ft^2
25	QCFILTER2 QCFILTER2_PSF	10 rad/sec filtered impact pressure	lb/ft^2
26	RI	Pressure ratio - (QCFILTER2/PS)	n.d.
27	FGTOTL_LBS	Left engine thrust	lbs
28	FGTOTR_LBS	Right engine thrust	lbs
29	DELSTM	Stabilator, and pitch jet commanded position for trim	deg
30	TRMMING	Trim flag (real) - 0.0 = Operate (Engaged) 1.0 = Trim (Armed)	n.d.
31	XTVYAW	Yaw-vectoring control flag (0. or 1.)	n.d.
32	XSTRAKE	Forebody strake control flag (0,1, 2)	n.d.
33	OBES_LATST	OBES lateral stick (-1 to +1)	n.d.
34	OBES_RudPed	OBES rudder pedal (-1 to +1)	n.d.
35	OBES_LONST	OBES longitudinal stick	in
36	OBE_COLLECTIVE_ STABILATOR_CMD	OBES symmetric stabilator command	deg
37	OBE_COLLECTIVE_ TEF_CMD	OBES symmetric trailing-edge flap command	deg
38	OBE_PITCH_VANE_ CMD	OBES pitch vane command	deg
39	OBE_DIFFER_ STAB_CMD	OBES differential stabilator command	deg
40	OBE_RUDDER_CMD	OBES rudder command	deg
41	OBE_AILERON_CMD	OBES aileron command	deg
42	OBE_RIGHT_ STRAKE_CMD	OBES right strake command	deg
43	OBE_LEFT_ STRAKE_CMD	OBES left strake command	deg

TABLE 5.2.- INSTRUMENTATION LIST @ 80 Hz.

NO	PARAMETER	DEFINITION	UNITS
AV01	TVSC	Pitch thrust-vectoring command	deg
AV02	TVYAW_MP	Yaw thrust-vector command	deg
AV03	VROLL	Roll Pseudo Control	n.d.
AV04	VYAW	Yaw Pseudo Control	n.d.
AV05	LAT_CMD_RPS2	Lateral command	rad/sec2
AV06	DIR_CMD_RPS2	Directional command	rad/sec2
AV07	VANEC(1)	Left top vane command	in.
AV08	VANEC(2)	Left inboard vane command	in.
AV09	VANEC(3)	Left outboard vane command	in.
AV10	LATST_CMD	Lateral stick command	n.d.
AV11	NY_ADJ_G	Adjusted lateral acceleration	g
AV12	RSTABCOR_DPS	Compensated Rstab	deg/sec
AV13	SFSYAW	Differential Strake Engage	n.d.
AV14	FSLC_LIM_DEG	Left Forebody Strake Command	deg
AV15	FSRC_LIM_DEG	Right Forebody Strake Command	deg
AV16	OBE_VARIABLES. FNCTION2	OBES function generator 2	n.d.
AV17	BDOT_INERT_DPS	Sideslip rate inertial	deg/sec
AV18	N/A	RFCS flag word	n.d.
AV19	PSGTERM	Stick boost gain output	deg/in.
AV20	FGI	Fader gain input for AOA (used to initialize fader gain state)	n.d.
AV21	OBES_VARIABLES.F NCTION	OBES variables function	rad/sec
AV22	AOAINS	Angle-of-attack INS	deg
AV23	Q QS_DPS Q_DPS	Sensed body-axis pitch rate	deg/sec
AV24	RS_DPS R_DPS	Sensed body-axis yaw rate	deg/sec
AV25	AOATR	Estimated angle-of-attack trim	deg
AV26	QCOMP	Compensated pitch-rate	deg/sec
AV27	AOA	Selected angle of attack	deg
AV28	DY	Error in regulated variable	n.d.
AV29	UME11	Feedforward control variable	deg/sec
AV30	MACH	Mach number	n.d.
AV31	UK1	Control variable for stabilator cmd.	deg
AV32	QC QC_PSF	Impact pressure	lb/ft^2
AX01	SBPAC1	Collective stabilator command	deg

TABLE 5.2.- INSTRUMENTATION LIST @ 80 Hz (Concluded).

NO	PARAMETER	DEFINITION	UNITS
AX02	LEFSC1	Collective LEF command	deg
AX03	TEFSC1	Collective TEF command	deg
AX04	DD_LIM_DEG	Differential stabilator command	deg
AX05	QCFILTER1	2.5 rad/sec filtered impact pressure	lb/ft^2
AX06	QCFILTER2	10 rad/sec filtered impact pressure	lb/ft^2
AX07	DA_LIM_DEG	Differential aileron command	deg
AX08	DR_LIM_DEG	Rudder command	deg
AX09	PSGTOT	Total stick command	in
AX10	VANEC(4)	Right top vane command	in.
AX11	VANEC(5)	Right inboard vane command	in.
AX12	VANEC(6)	Right outboard vane command	in.
AX13	N/A	Vane actuator shutoff	n.d.
AX14	BDOTINT_RPS	Sideslip rate	rad/sec
AX15	PS_DPS P_DPS	Sensed body-axis roll rate	deg/sec
AX16	RUDPED_CMD	Normalized pedal command	n.d.
AX17	NZ NZ_G	Normal acceleration - positive along z-axis	g
AX18	NY_G	Sensed lateral acceleration	g
AX19	NABYNTV	Yaw moment ratio	n.d.
AX20	AOAP	Selected angle of attack	deg
AX21	PSTICK	Pitch stick	in.
AX22	LATST_IN	Lateral Stick (-3 to +3)	in.
AX23	RUDPED_LBS	Rudder Pedal (-100 to +100)	lbs
AX24	LABYLTV	Roll moment ratio	n.d.
AX25	PSTAB_RPS	Stability-axis roll rate	rad/sec
AX26	N/A	RFCS flag word	n.d.
AX27	VBRK1	Rate command for stabilator	deg/sec
AX28	AYCORR_G	Lateral accelerometer corection	g
AX29	PDSMAX	Lateral stick command gain	n.d.
AX30	YCMD	Command to the feedback control	n.d.
AX31	STVYAW	Yaw thrust vectoring engage	n.d.
AX32	N/A	RFCS_DISC_WORD_WRAP_ AROUND	n.d.

TABLE 5.3.- INSTRUMENTATION LIST @ 20 Hz

NO	PARAMETER	DEFINITION	UNITS
ICA1314	GTILY1	Feedback gain (proportional) for angle of attack	1/sec
1CA1315	GTILY2	Feedback gain (proportional) for pitch rate	n.d.
ICA1316	GTILY3	Feedback gain (proportional) for load factor	deg/s/g
ICA1317	GTILU1	Feedback gain for filter	1/sec
ICA1318	GTILZ1	Feedback gain for integrator	n.d.
ICA1319	PS	Static pressure	lb/ft^2

5.3 Calculated Inputs

IMPACT PRESSURE MEASUREMENT FILTERS

INPUTS

QC Impact pressure (lb/ft^2)

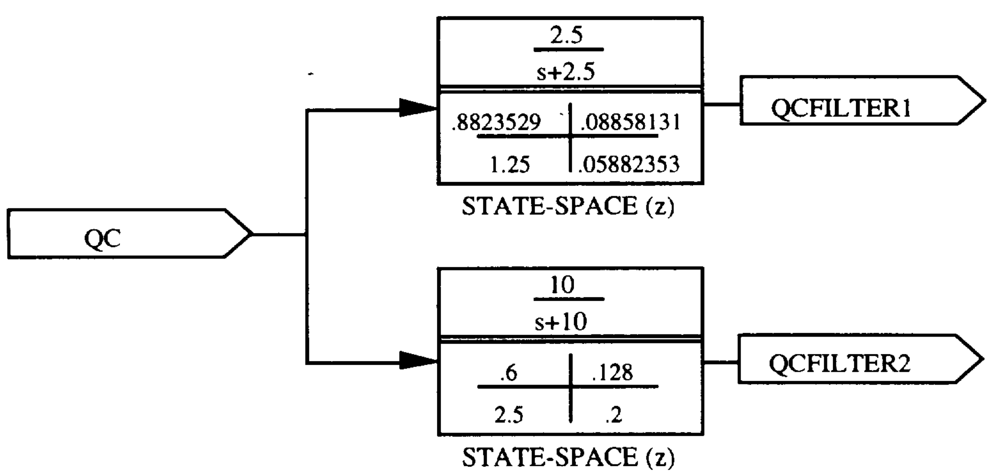
OUTPUTS

QCFILTER1 2.5 rad/sec filtered impact pressure (lb/ft^2)
QCFILTER2 10 rad/sec filtered impact pressure (lb/ft^2)

STATES

QCFILTER1 Forcing Function : QC
X(1) = .752941 * QC

QCFILTER2 Forcing Function : QC
X(2) = .32 * QC



Sampling period .05 second

RI — Pressure ratio (n.d.) - calculated as follows

$$RI = \frac{QCFILTER2}{PS}$$

MACH — Mach number (n.d.) - calculated as follows:

```
If ( RI <= 0.278 ) then
     - 32.967 * RI 2
     + 168.96 * RI3
     + 513.56 * RI5
Else
     MACH = 0.32293 + 1.1798 * RI
     - 0.65244 * RI2
     + 0.23755 * RI3
     - 0.043113 * RI4
     + 0.003024 * RI5
Endif

If ( MACH > 2.0 ) then
     MACH = 2.0
Endif
```

VT — Total airspeed (ft/sec) - calculated as follows:

VTRUE_FPS — VT = MACH * (897.3145 + 0.17518 * PS - 0.3404E-4 * PS * PS)

QBAR — Dynamic pressure (lb/ft^2) - calculated as follows

$$QBAR = \frac{QCFILTER2}{(1.0 + .25 * MACH^2 + .025 * MACH^2 * MACH^2)}$$

```
If ( QBAR < 40.0 ) then
 QBAR = 40.0
Endif
```

SINTHE, SINTHETA — Sin(θ) - computed to the accuracy of a truncated power series with terms out to at least $\theta^7/7!$ for $-90° \le \theta \le 90°$

COSTHE, COSTHETA — Cosine(θ) - computed to the accuracy of a truncated power series with terms out to at least $\theta^6/6!$ for $-90° \le \theta \le 90°$

SINPHI — Sin(ϕ) - computed to the accuracy of a truncated power series with terms out to at least $\phi^9/9!$ for $-180° \le \phi \le 180°$

COSPHI — Cosine(ϕ) - computed to the accuracy of a truncated power series with terms out to at least $\phi^8/8!$ for $-180° \le \phi \le 180°$

PTRIM — Pitch stick trim input (inch) - calculated as in NASA-0 RFCS

YTRIM — Yaw trim input (deg) - calculated as in NASA-0 RFCS

RTRIM — Roll stick trim input (inch) - calculated as in NASA-0 RFCS

AOAINS — Angle of attack calculated according to CCR 531

5.4 Remarks

The ANSER Control Laws defined by this specification (Version 151) were implemented in Ada code in the HARV RFCS and completed verification and validation testing at the Dryden Flight Research Center. These Control Laws were extensively flighted tested at Dryden beginning in July 1995.

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Specifications for a flight control law are delineated in sufficient detail to support coding the control law in flight software. This control law was designed for implementation and flight test on the High-Alpha Research Vehicle (HARV), which is an F/A-18 aircraft modified to include an experimental multi-axis thrust-vectoring system and actuated nose strakes for enhanced rolling (ANSER). The control law, known as the HARV ANSER Control Law, was designed to utilize a blend of conventional aerodynamic control effectors, thrust vectoring, and actuated nose strakes to provide increased agility and good handling qualities throughout the HARV flight envelope, including angles of attack up to 70 degrees.

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