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An Example of Requirements for Advanced Subsonic Civil Transport (ASCT) Flight Control System Using Structured Techniques

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PREFACE

The requirements documented in this technical note were generated in support of NASA contract NAS1-18586, Design and Validation of Digital Flight Control Systems Suitable for Fly-By-Wire Applications, Task Assignment 2. These requirements are for an Advanced Subsonic Civil Transport (ASCT) flight control system and were generated using structured techniques. The requirement definition started with performing a mission analysis of a typical transport aircraft to identify the high-level control system requirements and control functions necessary to control the mission flight. The functional requirements were then decomposed using structured method techniques. Finally, detailed performance requirements obtained from the Federal Aviation Requirements (FAR), FAR Special Conditions, and Military Specifications (MIL-SPEC) were allocated to the funcitonal requirements. The result is an example set of control system requirements that can provide a research focus for studying structured design methodologies and in particular design-for-validation philosophies. This set is a collection of requirements from different sources (FAR and MIL-SPECs) and as such does not represent the design requirements for any actual airplane.

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TABLE OF CONTENTS

1.0 Introduction

This technical note documents a set of structured flight control system requirements and the methodology used to generate these. Functional requirements were generated for an advanced flight control system for an Advanced Subsonic Commercial Transport (ASCT) of the mid-1990s. These requirements have been generated and organized using a structured approach in a manner to support structured design methodologies. High level flight control functional requirements for the ASCT were defined based on a mission analysis. These requirements were then decomposed in a structured manner using the Extended System Modeling Language (ESML) to obtain the flight control detailed functional requirements. Detailed performance, safety and availability requirements were then added to the functional model. Finally, the requirements were entered and stored in a database using the Excelerator/RTS software package which supports structured modeling and in particular the ESML for structured requirements generation. The result is an example set of control system requirements to provide a research focus for studying structured design methodologies and candidate system architectures for future aircraft.

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2.0 Requirements Generation

The functional requirements were developed using a structured approach to system design (Appendix A) which makes use of the Extended System Modeling Language (ESML) described in Appendix B. The use of ESML requires starting with a high level function to be performed rather than immediately addressing a particular system or subsystem. Using this approach allows one to take a top down approach and consider the complete function to be performed independent of the implementation (system design). This allows for considering all functions to be performed and for allocating those functions to systems in a logical manner such that the implementation is based on sound engineering judgment and is not overly biased by previous designs.

Once the overall high level function is defined, it is decomposed into several levels of functional requirements. Detailed performance, availability and safety requirements are added to the functional requirements. Subsequently, several candidate architectural models (Appendix C) are developed. The low level functional requirements are then allocated to the architecture which best meets the detailed performance requirements.

This effort involved the generation of requirements for a flight control system (FCS). The FCS is used together with the airframe, propulsion system, sensor system, crew and operating environment to fly a mission. Thus, the highest level functional requirement is to Fly Mission. Starting at such a high level allows for setting performance requirements on the complete system rather than solely on the subsystem of interest (FCS). Thus, for example one can include handling qualities requirements which the airframe, sensor system, flight control system and operating environment must meet as a whole. The functional requirements and the associated performance requirements are then decomposed to levels where all low level functions can be allocated to entities on the architectural model. If the performance requirements are properly decomposed and if each lower level function meets its requirements, then the high level requirements will be satisfied. And correspondingly, if each architectural entity satisfies the performance requirements of the functions assigned to it, then the complete architecture will satisfy the high level requirement.

Decomposition of the Fly Mission function results in many functions which certainly will not be allocated to the flight control system. An example is the Navigate function on the Fly Mission transform graph, which would be performed by the crew or a flight management computer. For this exercise, only those functions which may be performed in whole or in part by the FCS were further decomposed and assigned detailed performance requirements. Functions which clearly will not be performed by the FCS appear on a transform graph but are not defined in detail. The following details the functional decomposition, detailed requirements specification and allocation of functions to the flight control system.

The functional requirements were developed by starting with a functional requirement to Fly Mission. This function involves the generation of a target flight path by some kind of Navigation function based on the mission and the generation of the actual flight path by the Control Mission Flight function based on the desired flight path. The decomposition of a high level function (Fly Mission) into lower level functions (Navigate and Control Mission Flight) illustrates the process of functional decomposition and is shown pictorially with a transform graph (see Fly Mission transform graph on page 12). (Note that the blocks used to represent functional requirements on a transform graph are referred to as the transform graph processes.) The Navigation and Control Mission Flight functions and data flows on the Fly Mission transform graph are defined and entered into the project data base. A mission analysis was performed to define the control system requirements necessary to control the mission flight. These are then grouped into control functions which form the functional requirements for the Control Mission Flight transform graph (see pages 16 and 87). Detailed performance and availability requirements were then generated for the Control Mission Flight function. The detailed performance requirements include handling qualities requirements, flight envelope requirements and dynamic maneuver response requirements. Many of the detailed requirements were obtained from Federal Aviation Regulations (FARs) (Ref. 1), FAR Special Conditions (Ref. 2) and Military Specifications MIL-F-8785C (Ref. 3) and MIL-F-9490D (Ref. 4) and these have been crossreferenced to the appropriate document. Availability requirements are expressed as a probability of loss of the function per flight hour.

Functional requirements (transform graphs) and detailed performance requirements were then generated for each of the functions on the Control Mission Flight which pertained to the flight control system (i.e. Control Aerodynamic Braking, Control Lift Configuration, Control Pitch, Control Roll and Control Yaw). This process of breaking down a function into lower level functional requirements and generating detailed performance requirements was continued to a level of detail at which it was unambiguous as to whether or not the function should be assigned to the FCS. Context diagrams were then generated for the Control Pitch, Control Roll and Control Yaw functions to show which functions will be performed by the FCS and to identify any necessary interface functions to the non FCS functions. Those functions not to be performed by the FCS are allocated to other entities on a preliminary version of the architecture model. The remaining functions are to be performed by the FCS. Context diagrams (i.e. Flight Cntrl Sys Pitch Context) capture this information by showing all the FCS functions grouped into one function (i.e. Flight Control System Pitch Functions), surrounded by the external architectural entities (i.e. the Pilot, Copilot, and Auto-Flight System) which have been assigned the non FCS functions under the Control Pitch function. The transform graph for the Flight Control System Pitch Functions will then contain all the FCS pitch axis functions previously identified, but will also include any additional functions required as a result of the assignment of non FCS functions to architectural entities. For the pitch axis example, the following additional functional requirements were generated: Provide Pilot Pitch Interface, Provide Copilot Pitch Interface, and Resolve Pitch Control Contention. These three functional requirements were all generated as a result of assigning the function, Generate Flight Path Command Manual, to both the pilot and copilot. The use of the context diagram allows for quickly identifying additional functional requirements generated as a result of the architectural assignment and thus provides a degree of feedback to the architecture design process and allows for early evaluation of candidate architectures.

An architectural model was generated starting with The System which is composed of the Flight Environment and the Aircraft. The Aircraft is then decomposed into major subsystems including the Flight Control System, Airframe Systems, Propulsion System, Sensor System, Auto-Flight System and the Crew. Finally the Flight Control System is broken into subsystems including crew controllers, flight control computers, and actuation systems. The flight control system functions were then allocated to the architectural model as appropriate. The architectural entities then assume the detailed performance and availability requirements of the functions assigned to them. Subsequently design trade studies are conducted to determine a design which best satisfies the detailed requirements. The result of the trade studies are design requirements for the architectural entities. In this study some preliminary design requirements have been included to demonstrate the nature of the design requirements.

3.0 Excelerator/RTS Overview

Excelerator/RTS (Reference 5) is a set of automated tools for real time system modeling, analysis and design. These tools allow for depicting systems with time-critical control and processing such as avionics systems. They support the techniques presented by key theoreticians and used by many real time systems practitioners. In particular the system supports the Extended System Modeling Language (ESML) described in Appendix A and Appendix B.

Automated tools make analysis and design more efficient and reliable. Design can be quickly and easily modified to incorporate test results and user feedback. Project work can be shared among many engineers, while controlling updates and data integrity. A variety of analysis and reporting tools allow for evaluation of completeness and correctness. Together these tools allow for iterative systems design.

The Excelerator/RTS tools are grouped into the following capabilities:

- A graphics facility which allows for visual representation of systems that handle timing control and monitoring functions. The transform graph feature of this facility was used to document the functional requirements decomposition. This illustrated both functions to be performed and the data flows associated with these functions.

- A data dictionary wherein the information describing the system is stored. Descriptions of the functional requirements, associated data flows and associated detailed performance requirements were stored in the data base for subsequent report generation and analysis.

- Analysis reports to help evaluate the consistency and methodological accuracy of the system model. An example is graph balancing which checks for data and control flow consistency between parent and child transform graphs.

- Prototyping facilities to design screens and reports customized for the particular project. Screens were designed for each of the entities on transform graphs to allow for defining such entities and assigning performance requirements to each. The reports generated for the transform graphs were all generated using this feature.

- A documentation facility that allows for producing system documents. The final requirements document was generated by linking all the necessary graphics, reports and analysis for the complete functional requirements model using this feature.

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4.0 Advanced Flight Control System Requirements

This section contains the example set of structured requirements for an advanced flight control system for an Advanced Subsonic Civil Transport (ASCT) of the mid–1990s. The requirements are not representative of any actual airplane design but rather shall provide a research focus for studying structured design methodologies. These requirements were generated as described in section 2.0 and are organized as follows.

The transform graphs representing the functional requirements decomposition are shown in Figure 1. The top level, Fly Mission, is decomposed into two functions Navigate and Control Mission Flight (see page 12). The Navigate function is outside the Flight Control System (FCS) context and thus is not functionally decomposed in this document. The Control Mission Flight is within the FCS context and is functionally decomposed as shown on page 87 (Control Mission Flight transform graph). Those functions within the FCS context are further decomposed and are shown on Figure 1. Note that the Control Thrust, Control Braking on Ground, Control Heading on Ground and the Update Aircraft State functions were not considered to be part of the primary flight control system and thus were not decomposed. Figure 1 shows how the functional requirements have been organized in this chapter. Start at the top level (Control Mission Flight) and move down the tree from left to right going down to the lowest level possible on each branch. Figure 2 shows the reports generated for each transform graph. These consist of the transform graph figure followed be a set of reports describing the elements on the transform graphs. These are shown on page 13 for the Fly Mission transform graph. If performance requirements are levied on a function on a transform graph, a report detailing the associated requirements files and the actual requirements files are included. These are shown on pages 17 thru 86 for the Control Mission Flight function on the Fly Mission transform graph (page 12). Referring to Figure 1, the Control Aerodynamic Braking requirements (transform graph, reports and requirements) follow the Control Mission Flight requirements. The Control Aerodynamic Braking transform graph is shown on page 105 and associated reports and requirements are on pages 106 thru 111.

The architectural model is organized in a hierarchical fashion starting at The System level composed of the Flight Environment and Aircraft which is decomposed into several levels down to the elements of the Flight Control System. Each level in the decomposition consists of an architecture diagram, and architecture requirements report and the associated requirements.

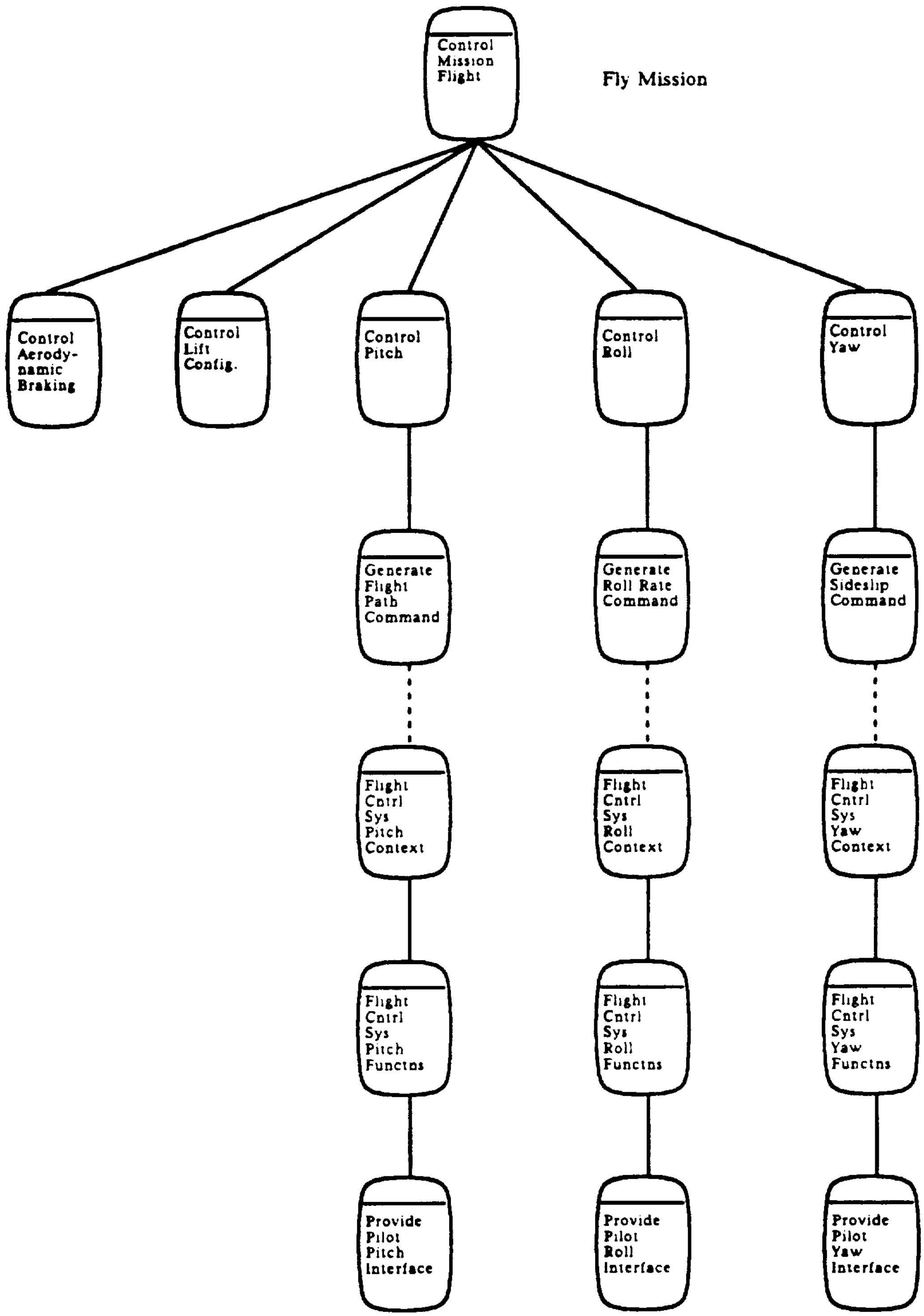


Figure 1
Organization of Control Functions with Detailed Requirements
(Described Data Transforms)

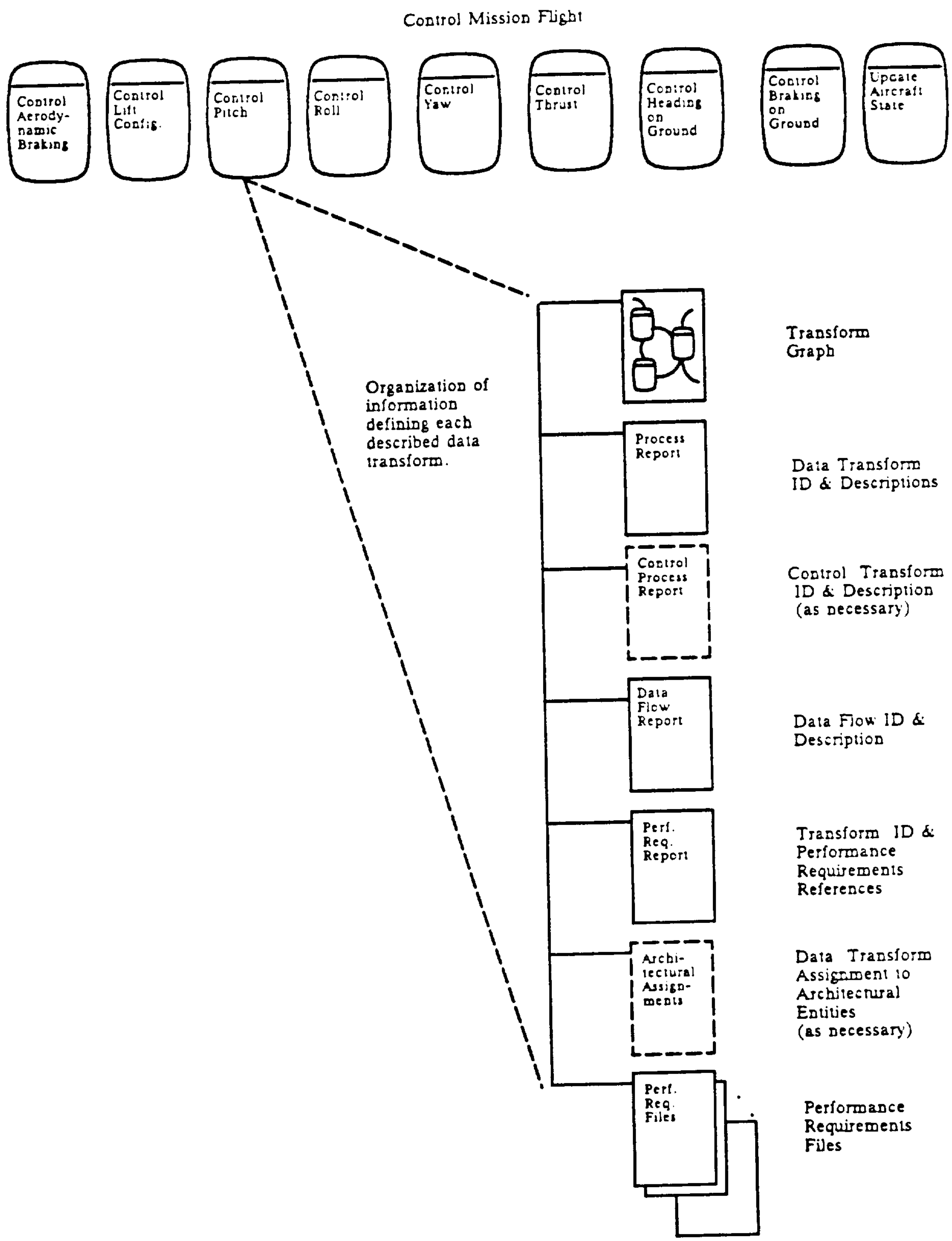
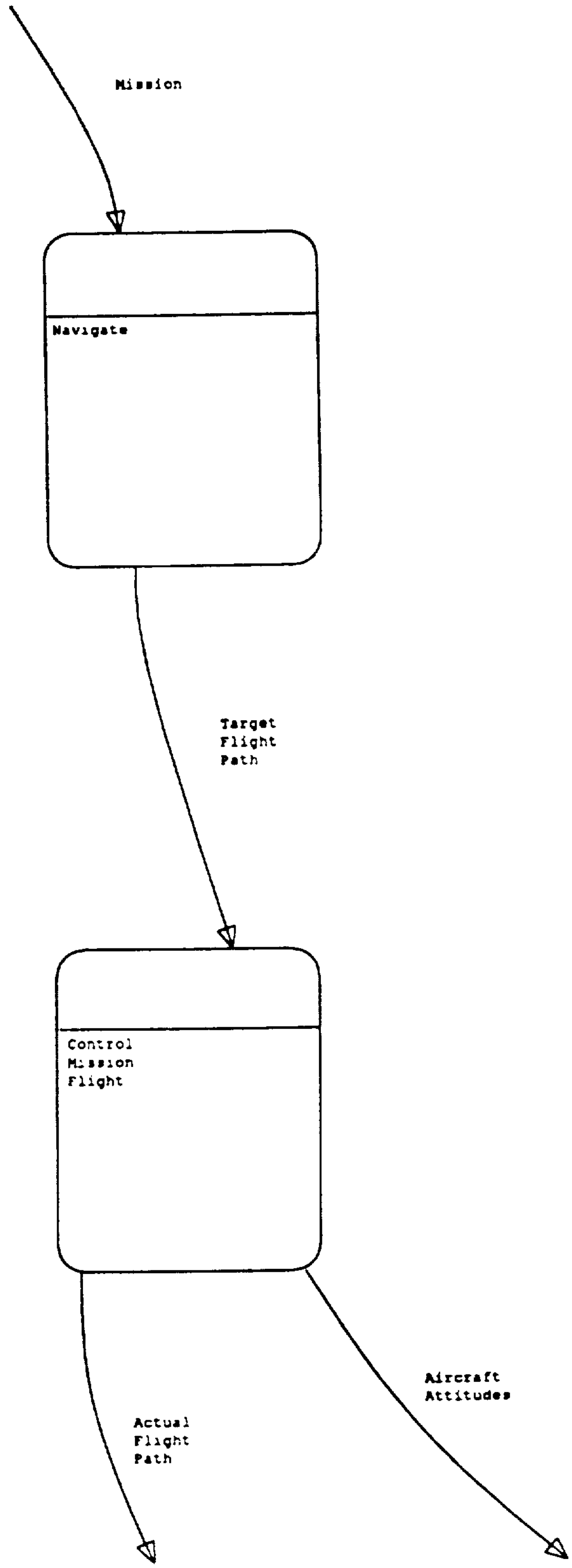


Figure 2
Reports Generated for Each Defined Function on a Transform Graph
(see page 87)



Fly Mission
Created by: RMcLees
Revised by: RMcLees
Date changed: 02-SEP-88
Product Name:

Process Descriptions
Fly Mission

Description	Expl name
This function receives a target flight path (generated by navigation) and generates control signals for the actuation systems which generate the forces and moments to control the aircraft attitudes to generate a flight path which matches the target flight path.	Control Mission Flight
This function generates the target flight path based on the particular mission requirements and, anticipated and sensed environmental conditions.	Navigate

Data Flow Description
Fly Mission

Description	Name
The sensed 4 dimensional flight path & attitudes of the aircraft as well as any other sensed values necessary to satisfy the control requirements.	Actual Flight Path
Aircraft pitch, roll and heading attitudes.	Aircraft Attitudes
Definition of particular flight mission from which the target flight path can be generated.	Mission Definition
The desired 4 dimensional flight path and attitudes generated by some navigation function.	Target Flight Path

Process Requirements Links
Fly Mission

Expl name	I-L Reference
Control Mission Flight	Mission.Analysis Cntrl.Mission.Flight.Req.List
Navigate	

TYPICAL MISSION PROFILE

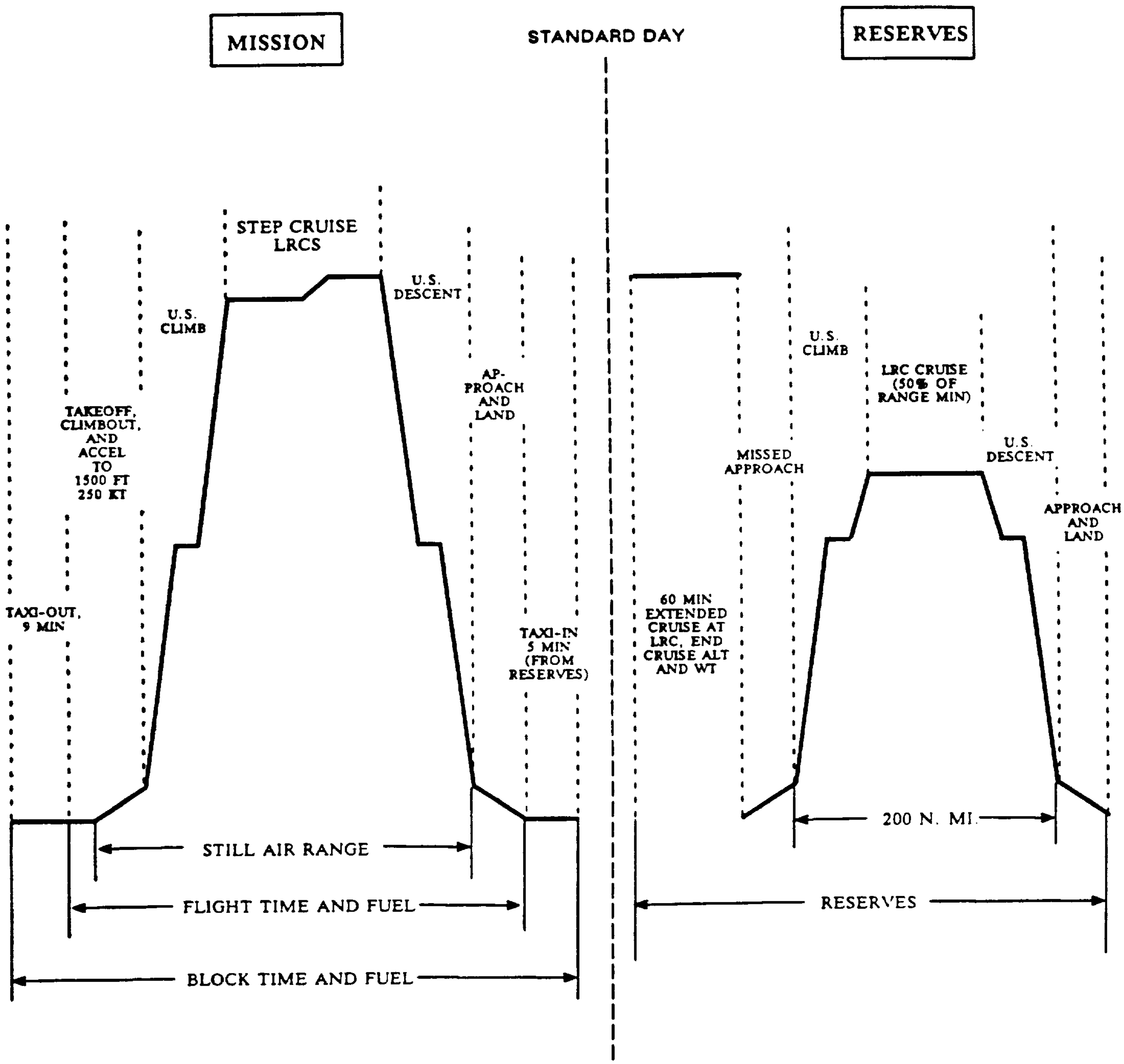


FIGURE Mission.Analysis.1 Mission Segments

TABLE 1. Analysis of Mission Segments

MISSION SEGMENT	CONTROL ACTION	DRIVER	CONTROL SYSTEM REQUIREMENT
TAXI-OUT & TAXI-IN	MOVE FROM PASSENGER TERMINAL TO RUNWAY.	TERRAIN AND OBSTACLE AVOIDANCE.	SPEED CONTROL NOSEWHEEL STEERING.
TAKEOFF	ACCELERATE TO TAKEOFF SPEED & DEPART RUNWAY.	RUNWAY LENGTH THRUST LIMITS CROSSWIND CONDITIONS.	SET HIGH LIFT SET TAKEOFF TRIM THRUST SETTING NOSEWHEEL STEERING ENGINE OUT AUGMENTATION ON GROUND BRAKING STALL ANGLE OF ATTACK WARNING MANUAL TRAJECTORY CONTROL
CLIMBOUT & CLIMB	ASCEND TO CRUISE ALTITUDE AND SPEED	TIME CONSTRAINT FUEL CONSUMPTION EASE PILOT WORKLOAD RIDE QUALITY AIRSPACE CONTROL TURBULENCE	THRUST SETTING MANUAL TRAJECTORY CONTROL AUTO TRAJECTORY CONTROL MANUAL & AUTO TRIM ENVELOPE PROTECTION AUTO CONTROL LIMITING LIFT CONTROL
CRUISE	CRUISE	EASE PILOT WORKLOAD FUEL CONSUMPTION MINIMIZE DRAG RIDE QUALITY	SPEED CONTROL MANUAL TRAJECTORY CONTROL AUTO TRAJECTORY CONTROL MANUAL & AUTO TRIM ENVELOPE PROTECTION AUTO CONTROL LIMITING LIFT CONTROL
DESCENT & APPROACH	DESCEND FROM CRUISE TO APPROACH ALTITUDE AND SLOW TO LANDING SPEED	EASE PILOT WORKLOAD RIDE QUALITY CROSSWIND CONDITIONS ALL WEATHER APPROACHES TIGHT PATH FOLLOWING	SPEED CONTROL MANUAL TRAJECTORY CONTROL AUTO TRAJECTORY CONTROL MANUAL & AUTO TRIM ENVELOPE PROTECTION AUTO CONTROL LIMITING LIFT CONTROL
LANDING	FLARE, TOUCHDOWN & DECCELERATE TO TAXI SPEED	RUNWAY LENGTH CROSSWIND CONDITIONS RAPID SPEED CHANGE TIGHT PATH FOLLOWING ALL WEATHER LANDINGS EASE PILOT WORKLOAD	SPEED CONTROL MANUAL TRAJECTORY CONTROL AUTO TRAJECTORY CONTROL ENVELOPE PROTECTION AUTO CONTROL LIMITING LIFT CONTROL STALL ANGLE OF ATTACK WARNING ON GROUND BRAKING
MISSED APPROACH	RAPID THRUST CHANGE QUICK, HARD MANEUVERS	TERRAIN AND OBSTACLE AVOIDANCE. WIND SHEARS RIDE QUALITY	THRUST CONTROL MANUAL TRAJECTORY CONTROL ENVELOPE PROTECTION LIFT CONTROL ENGINE OUT AUGMENTATION STALL ANGLE OF ATTACK WARNING

TABLE 2 Assignment of Control Requirements to Functions

Control System Requirements		Control Functions
MANUAL TRAJECTORY CONTROL	Longitudinal Lateral Directional	Control Pitch Control Roll Control Yaw
AUTOMATIC TRAJECTORY CONTROL	Longitudinal Lateral Directional	Control Pitch Control Roll Control Yaw
MANUAL & AUTO TRIM	Pitch Trim Roll Trim Sideslip Trim	Control Pitch Control Roll Control Yaw
ENVELOPE PROTECTION	Stall Load Factor Overspeed Pitch Attitude Bank Angle Sideslip Angle	Control Pitch Control Pitch Control Pitch Control Pitch Control Roll Control Yaw
SPEED CONTROL	Propulsive Thrust Aerodynamic Braking Ground Force Braking	Control Thrust Control Aerodynamic Braking Control Braking on Ground
LIFT CONTROL	Increase Lift Spoil Lift	Control Lift Configuration Control Aerodynamic Braking
NOSEWHEEL STEERING	Ground Track	Control Heading on Ground
AUTOMATIC CONTROL LIMITING	Longitudinal Lateral Directional	Control Pitch Control Roll Control Yaw
THRUST SETTING	Altitude Speed	Control Thrust
STALL ANGLE OF ATTACK WARNING	Alpha	Control Pitch
ENGINE OUT AUGMENTATION	Lateral Directional	Control Yaw
ON GROUND BRAKING	Speed	Control Braking on Ground

Control Mission Flight Performance Requirement List

(This is the list performance requirements imposed on the Control Mission Flight function. The requirements are defined on the following pages.)

C.M.F.1 General Control Requirements
C.M.F.2 Handling Qualities
C.M.F.3 Operational Flight Envelope
C.M.F.4 Manual and Automatic Trim Functions
C.M.F.5 Envelope Protection
C.M.F.6 Autopilot Limiting and Actuation
C.M.F.7 Maneuver Control Lags
C.M.F.8 Requirements in Icing Conditions
C.M.F.9 Control System Stability Requirement
C.M.F.10 Residual Oscillations
C.M.F.11 Longitudinal Control Power Requirements
C.M.F.12 Longitudinal Trim Authority
C.M.F.13 Enhanced Longitudinal Control Maneuver Response
C.M.F.14 Roll Mode Time Constant
C.M.F.15 Pilot - Induced Oscillations
C.M.F.16 Stall Characteristics
C.M.F.17 Lateral Control Power Requirements
C.M.F.18 Roll Response Linearity
C.M.F.19 Roll Control Cross Coupling
C.M.F.20 Lateral Trim Authority
C.M.F.21 Enhanced Roll Maneuver Control
C.M.F.22 Dynamic Stability
C.M.F.23 Turn Coordination
C.M.F.24 Directional Control Power Requirements
C.M.F.25 Directional Trim Authority
C.M.F.26 Flutter Prevention Requirements

GENERAL CONTROL REQUIREMENTS (C.M.F.1)

Two modes of manual aircraft control shall be provided: core control and enhanced control.

The core control mode provides the minimum level of augmentation (e.g. yaw damper, Mach trim, etc.) required for FAA certification at all failure levels not extremely improbable (probability < 1.0E–9). Core control satisfies normal handling qualities criteria with all probable failures. With improbable failures (probability of failure between 1.0E–5 and 1.0E–9), core control shall satisfy the minimum acceptable handling qualities requirements.

The enhanced control mode provides a reduction in pilot workload and increased control precision. It provides handling qualities equivalent to those for core control and includes envelope protection features and aircraft state hold modes.

Transfer between core and enhanced control shall be automatic or crew selectable. Mode transition transients shall not result in a normal acceleration greater than 0.5 g, a lateral acceleration greater than 0.2 g or result in an unsafe condition during normal airline operation.

Figure C.M.F.1–1 indicates the affect of handling qualities on the ability of the aircraft to carry out its mission. Normal handling qualities criteria guarantee that the aircraft can complete its scheduled flight. When handling qualities are degraded to the minimum acceptable level, continued safe flight and landing is possible but the scheduled mission may be affected. Detailed criteria for normal and minimum acceptable handling qualities are presented later in this document.

An autoflight system will also generate maneuver control commands. The minimum level of augmentation provided by core control shall be available for the autoflight system.

HANDLING QUALITY CRITERIA AND AIRCRAFT OPERATIONAL STATE

NORMAL

No significant flying qualities degradation

Therefore:

No change in operational procedures required.

No change in flight plan

Failure effects not apparent to the passengers

MINIMUM ACCEPTABLE

The aircraft shall be capable of continued safe flight and landing without requiring exceptional pilot skill or strength.

As a result one or more of the following will apply:

Changes in operating procedures required

Changes in flight plan may be required

Flight envelope limitations may be imposed

Significant reduction in the ability of the crew to cope with adverse condition

Significant crew workload

FIGURE C.M.F.1-1

HANDLING QUALITIES (C.M.F.2)

Handling qualities shall be evaluated in piloted simulations. The following pilot ratings (as defined below) shall be satisfied in the normal flight envelope (shown in Figure C.M.F.3-1 – page 49) with light atmospheric turbulence.

Control Level	Pilot Rating
Core Control (Normal)	Satisfactory
Core Control (Minimum Acceptable)	Adequate
Enhanced Control	Satisfactory

C.M.F.2.1 Handling Qualities Tasks and Aircraft System States
(Ref. 3 - MIL-F-8785C 3.8 & Ref. 6 - FAA Handling Qualities Assessment)

a) A series of task-related maneuvers is defined which allows overall flying qualities to be evaluated in piloted simulations. These task related maneuvers are designed to allow for qualitative evaluation of the handling qualities for a given system failure state, flight envelope (figure C.M.F.3-2) and atmospheric disturbance environment. The basic premise is that the acceptable failure probability interval must be based on an inverse relationship between the probability of the failure condition and the severity of its effect on the aircraft. (FAR AC 25.1309-1) The qualitative degrees of suitability of flying qualities are categorized as follows:

Satisfactory	Full performance criteria met with routine pilot effort and attention.
Adequate	Adequate for continued safe flight and landing; full or specified reduced performance met, but with heightened pilot effort and attention.
Controllable	Inadequate for continued safe flight and landing, but controllable for return to safe flight condition, a safe flight envelope and/or reconfiguration so that handling qualities are at least adequate.

This three-level category system can be used by a pilot to grade the overall aircraft performance in a given control system failure state, portion of the flight envelope and atmospheric disturbance environment.

b) Figure C.M.F.2-1 classifies control system failure states into two groups, A and B, as a function of failure probability interval.

c) Figure C.M.F.2-2 defines qualitative flying qualities required for each combination of atmospheric disturbance environment, flight envelope and control system failure state.

These requirements shall be evaluated in piloted simulations of the task-related maneuvers described in Paragraph C.M.F.2.4 with the appropriate control system failure states and the atmospheric disturbance environment.

d) Figure C.M.F.2-3 defines the atmospheric disturbance levels as a function of the probability of exceedance. The atmospheric disturbance models to be used in the simulations are defined in paragraph C.M.F.2.3 and are a function of the probability of exceedance and altitude of the evaluation maneuver. The models of wind shear and random turbulence shall be used to assess:

1) The effects of certain environmental conditions on the flying qualities of the airplane;
2) The ability of the pilot to recover from upsets caused by environmental conditions.
3) Flight path control precision during landing.

C.M.F.2.2 Multiple Failures

For multiple control system failure states that are not extremely improbable including stability augmentation system failures, the airplane shall be capable of the safe completion of a flight segment and landing. (FAR 25.671, FAR 25.672) This requirement shall also apply to operation in the backup control mode.

AIRCRAFT SYSTEM FAILURE STATE

AIRCRAFT CONTROL SYSTEM FAILURE STATE	PROBABILITY OF FAILURE STATE
A	PROBABLE (Probable failure conditions are those anticipated to occur one or more times during the entire operational life of each airplane.)
B	IMPROBABLE (Improbable failure conditions are those not anticipated to occur during the entire operational lift of a single random airplane. However, they may occur occasionally during the entire operational life of all airplanes of one type.)

EXAMPLES: PROBABLE FAILURES (STATE A):

Loss of one hydraulic system
Partial loss of high lift control capability

IMPROBABLE FAILURES (STATE B):

Loss of two hydraulic systems
Loss of two pairs of spoilers or one pair of spoilers and ailerons
Any jam not shown to be extremely improbable
Any single failure which is not considered a probable failure
Loss of control and stability augmentation systems

FIGURE C.M.F.2-1

Atmospheric Disturbance Environment	Aircraft System State			
	A		B	
	Normal Operational Flight Envelope	Permissible Flight Envelope	Normal Operational Flight Envelope	Permissible Flight Envelope
Light	Satisfactory	Acceptable	Acceptable	Controllable
Moderate	Acceptable	Controllable	Controllable	Controllable
Severe	Controllable	Controllable		

Figure C.M.F.2-2
Minimum Qualitative Handling Qualities Requirements

Atmospheric Disturbance	Probability of Exceedance
Light	$10^{-1} < P$
Moderate	$10^{-3} < P \leq 10^{-1}$
Severe	$10^{-5} \leq P \leq 10^{-3}$

Figure C.M.F.2-3
Atmospheric Disturbance Levels Definition

C.M.F.2.3 Atmospheric Environment

Safe controllability shall be ensured in atmospheric turbulence. The following mean wind, turbulence and wind-shear models will be used for flight control system design but will be limited to acceleration levels which do not exceed the structural limits. Mean wind and turbulence levels are defined by a probability of exceedance and altitude. For the low altitude models (below about 3000 feet), the probability of exceedance defines a mean wind profile to be used for cross wind takeoff and landing evaluation. This wind level then defines the turbulence levels. For high altitude operation (above about 3000 feet), mean winds are not important for handling qualities so exceedance probabilities directly define turbulence levels and a mean wind model is not used.

C.M.F.2.3.1 Mean Wind (Low Altitudes)

a) The probability of exceeding a wind level at a given altitude is dependent upon surface roughness conditions. For average airport conditions, the level of total wind occurring from any direction at 20 feet above the surface is determined from Figure C.M.F.2-4 for a specified exceedance probability.

b) The wind level at any other altitude h is determined from the extrapolation formula:

$$\bar{V} = \bar{V}_{20} \frac{\ln\left[\dfrac{h+z}{z}\right]}{\ln\left[\dfrac{20+z}{z}\right]}$$

where z = .15 ft for average airport conditions

The mean wind profiles for average airport surface roughness conditions is shown on Figure C.M.F.2-5 for reference.

C.M.F.2.3.2 Turbulence Levels

a) Low Altitude Turbulence (h < 3,000 feet)

The root mean square level of the turbulence component acting perpendicular to the earth, σ_w, is derived from the mean wind speed at 20 feet above the surface from:

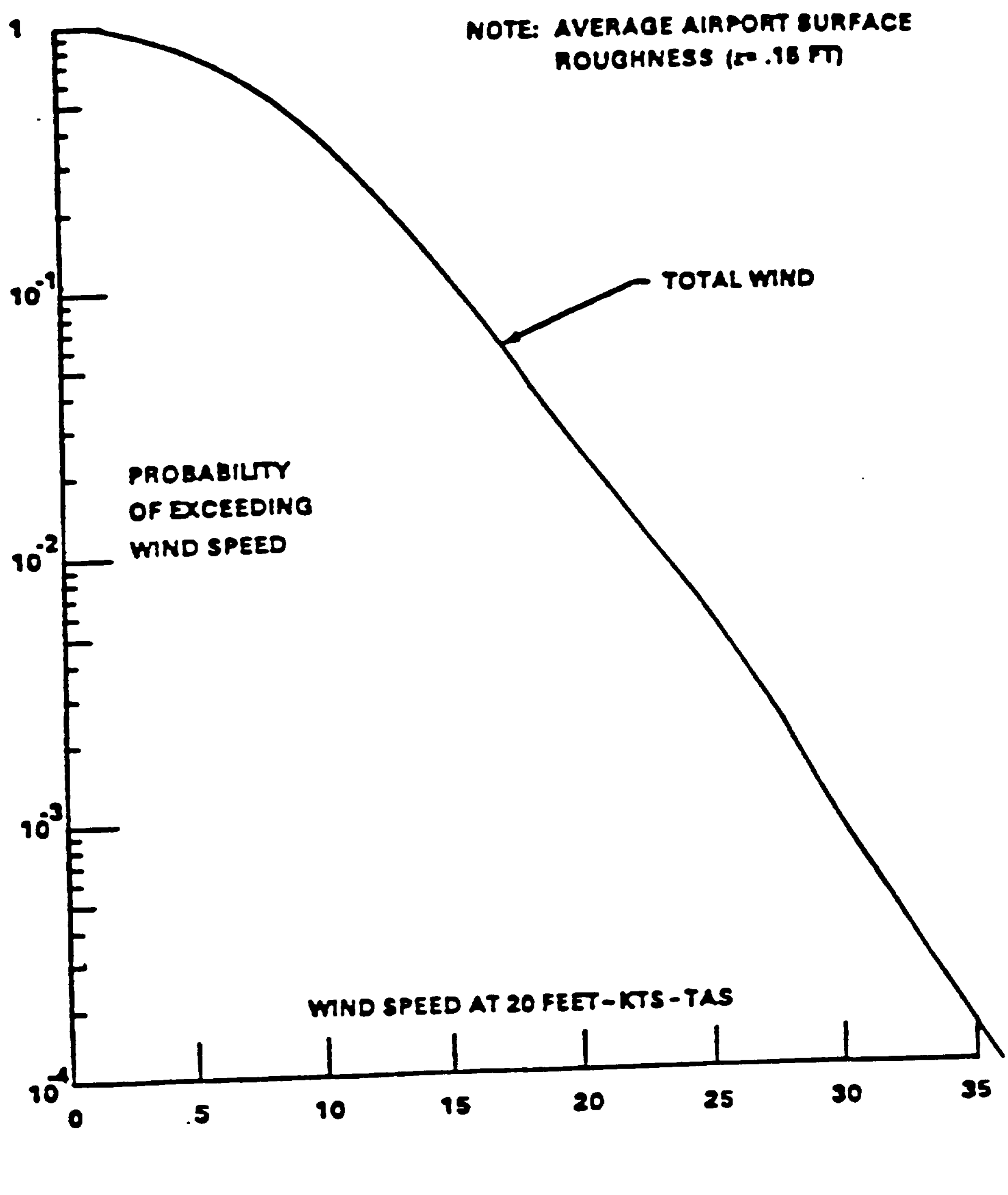


FIGURE C.M.F. 2-4 PROBABILITY OF EXCEEDING WIND SPEED

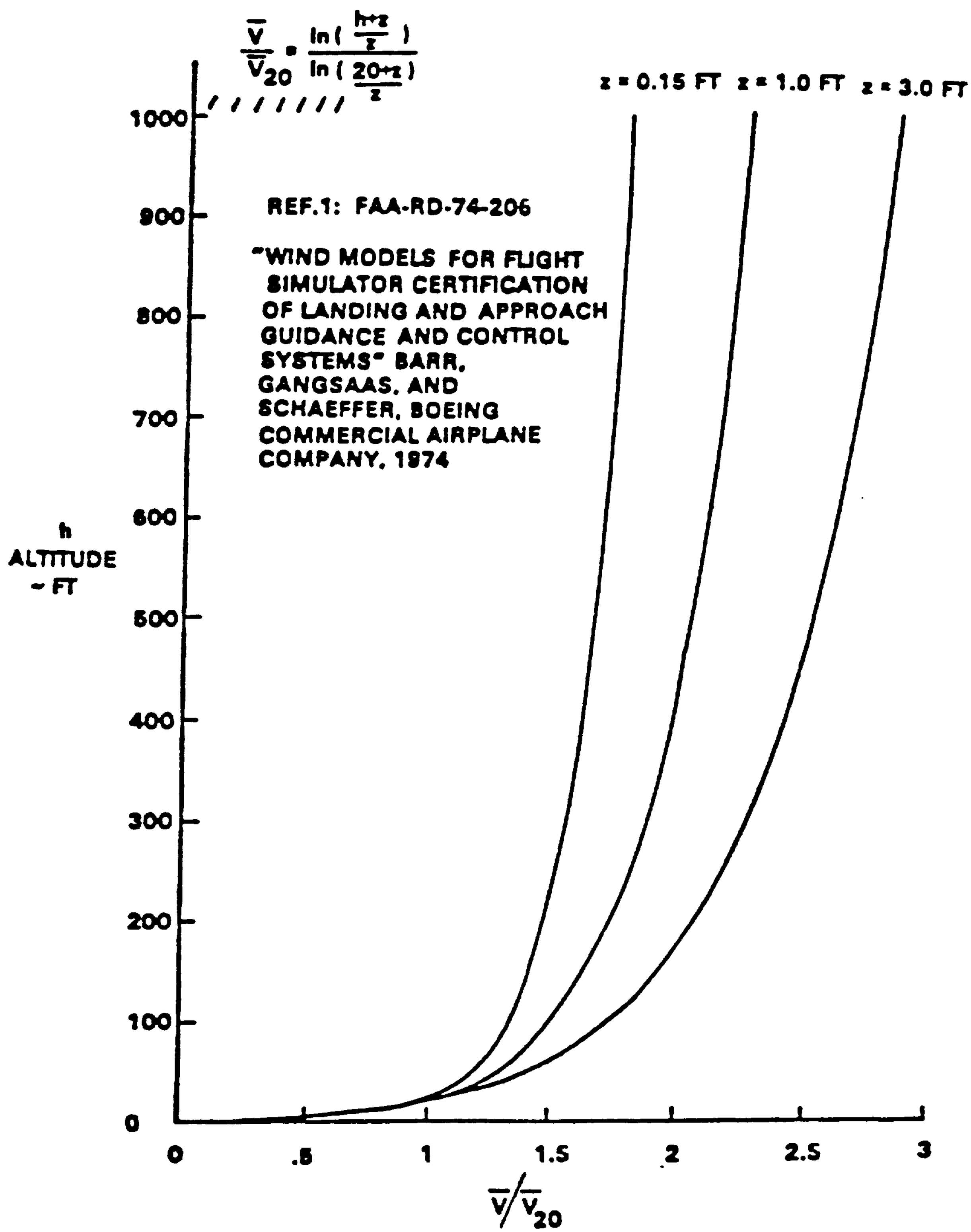


FIGURE C.M.F. 2-5 MEAN WIND PROFILES

$$\sigma_w = .52 \frac{\overline{V}_{20}}{\ln\left(\frac{20+z}{z}\right)} - \frac{h}{800} \geq 0$$

RMS levels of horizontal components of turbulence are found from using Figure C.M.F.2–6

b) High Altitude Turbulence (h > 3,000 feet)

For high altitudes, the levels of turbulence components oriented in any direction are equals:

$$\sigma_u = \sigma_v = \sigma_w.$$

The levels of high altitude turbulence (including storm turbulence) are determined from exceedance probabilities using Figure C.M.F.2–7.

C.M.F.2.3.3 Integral Scale Lengths for Turbulence, Lu, Lv, Lw Integral scales for turbulence at all altitudes are determined from Figure C.M.F.2–8 and altitude.

C.M.F.2.3.4 Spectra Shapes for Turbulence

The distribution of turbulence power with frequency for all altitudes is given by the power spectra:

$$\Phi_u(w) = \frac{\sigma_u^2 L_u}{\pi V_T} \times \frac{1}{\left[1 + \left(1.339 \frac{L_u}{V_T} w\right)^2\right]^{5/6}}$$

$$\Phi_v(w) = \frac{\sigma_v^2 L_v}{2 \pi V_T} \times \frac{1 + \frac{8}{3}\left(1.339 \frac{L_v}{V_T} w\right)^2}{\left[1 + \left(1.339 \frac{L_v}{V_T} w\right)^2\right]^{11/16}}$$

$$\Phi_w(w) = \frac{\sigma_w^2 L_w}{2 \pi V_T} \times \frac{1 + \frac{8}{3}\left(1.339 \frac{L_w}{V_T} w\right)^2}{\left[1 + \left(1.339 \frac{L_w}{V_T} w\right)^2\right]^{11/16}}$$

V_T = TRUE AIRSPEED (FT/SEC)

w = FREQUENCY (RAD/SEC)

σ_i = TURBULENCE COMPONENTS (FT/SEC)

L_i = TURBULENCE SCALE LENGTHS (FT)

The spectra filters, when combined with normalized random noise, yield time varying u, v, w gust components. For low altitude, the σ_w component refers to the component perpendicular to the earth while the u and v components are aligned parallel and perpendicular (respectively) to the airplane's relative velocity vector projected onto the plane of the earth. For high altitudes, the components are aligned to the airplane's relative velocity vector.

REF.1: FAA-RD-74-206 WIND MODELS FOR FLIGHT SIMULATOR CERTIFICATION OF LANDING AND APPROACH GUIDANCE AND CONTROL SYSTEMS", BARR, GANGSAAS, AND SCHAEFFER, BOEING COMMERCIAL AIRPLANE CO., 1974.

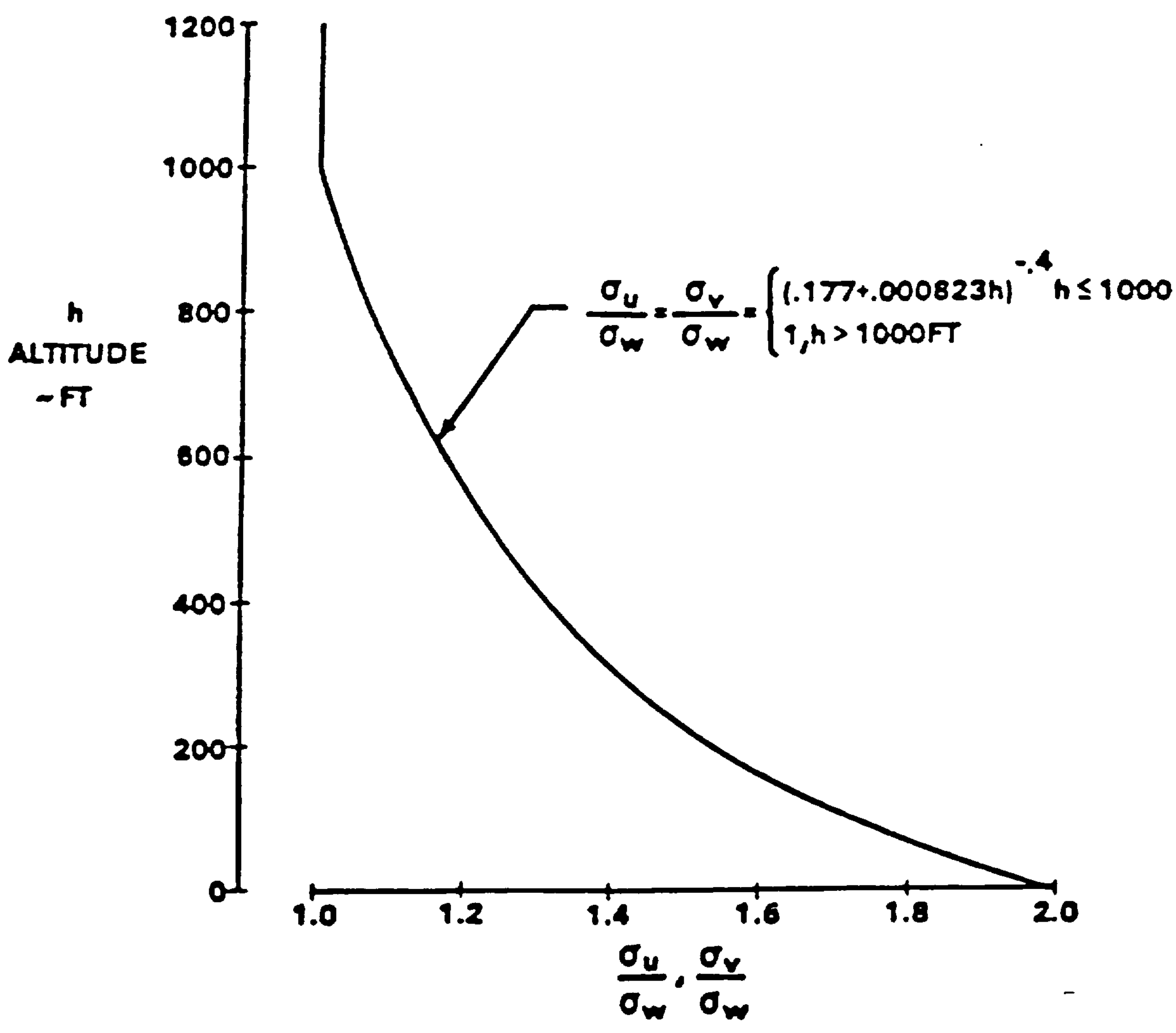


FIGURE C.M.F. 2-6 TURBULENCE LEVELS - HORIZONTAL COMPONENTS

PROBABILITY OF EXCEEDING $\sigma_u = \sigma_v = \sigma_w$
DURING ROUTINE OPERATIONS

INCLUDES STORM TURBULENCE

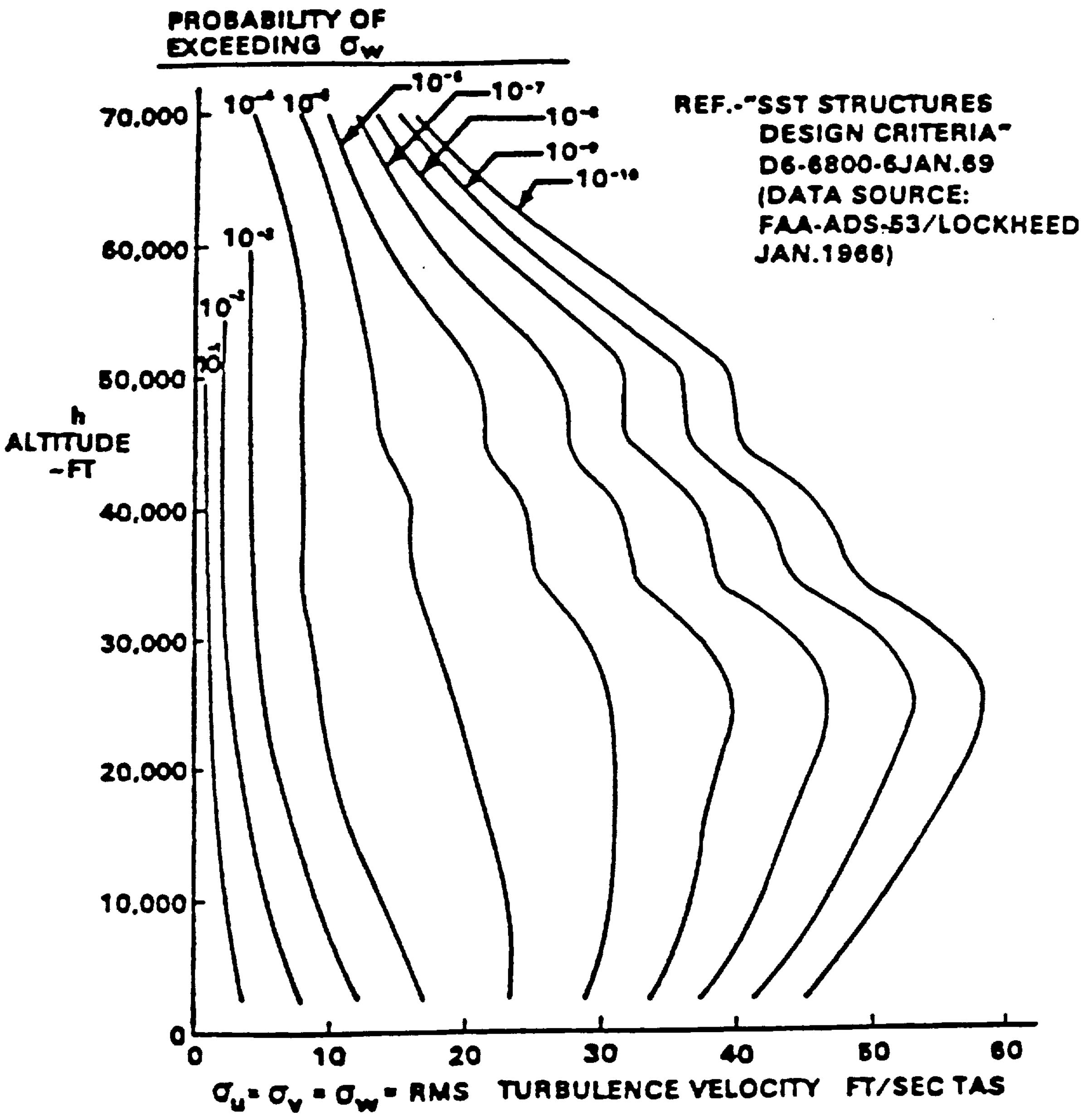


FIGURE C.M.F. 2-7 HIGH ALTITUDE - TURBULENCE LEVELS

REF.1: FAA-RD-74-206, "WIND MODELS FOR SIMULATOR CERTIFICATION OF LANDING AND APPROACH GUIDANCE AND CONTROL SYSTEM" BARR, GANGSAAS, SCHAEFFER, BOEING COMMERCIAL AIRPLANE CO, 1974.

$$L_w = \begin{cases} h, & h \le 1000 \text{ FT} \\ 1000 \text{ FT}, & h > 1000 \text{ FT} \end{cases}$$

$$L_u = L_v = L_w \left(\frac{\sigma_w}{\sigma_u}\right)^3$$

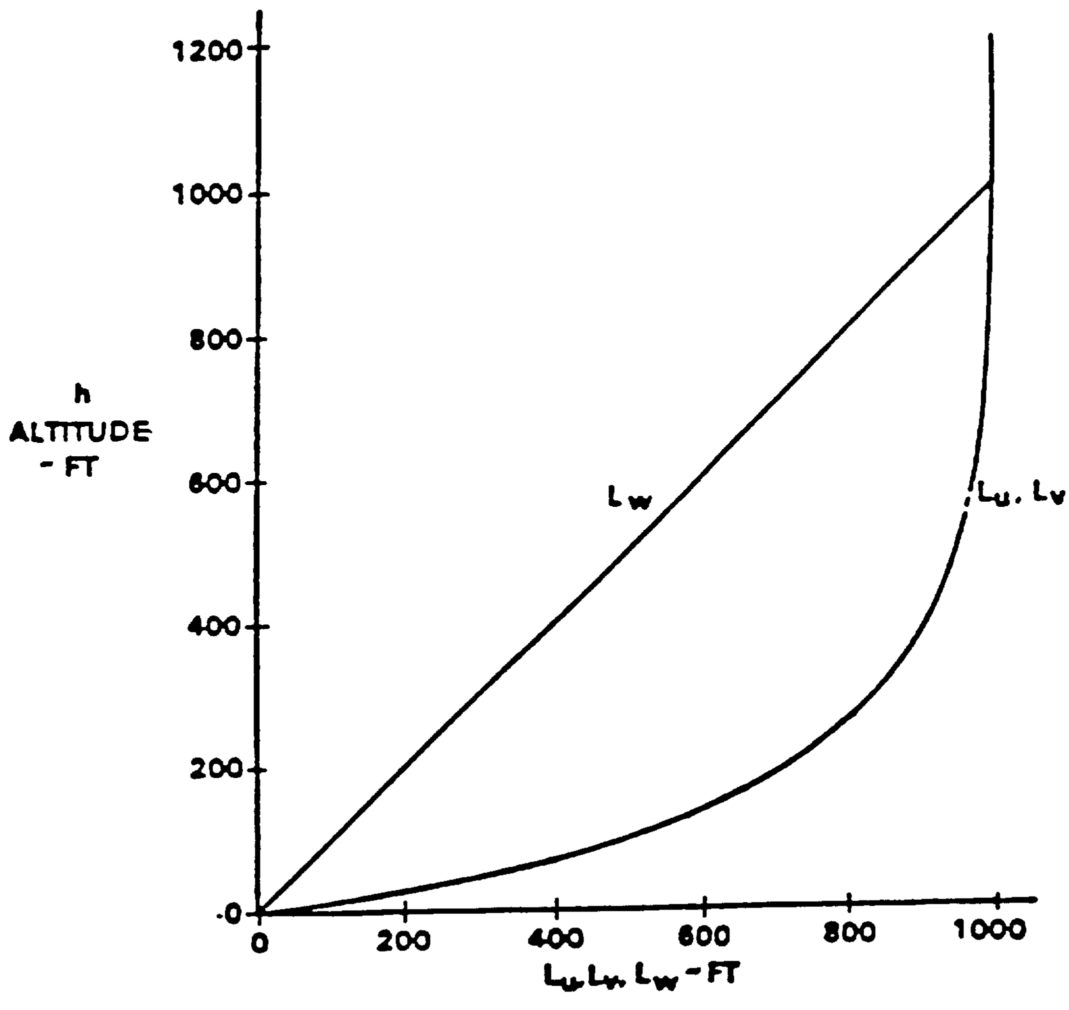


FIGURE C.M.F. 2-8 TURBULENCE SCALE LENGTHS

C.M.F.2.3.5 Transformation to Body Axes Components

The transformations required to obtain body axes components of turbulence for low altitudes follow:

$$\begin{bmatrix} u_T \\ v_T \\ w_T \end{bmatrix} = \begin{bmatrix} \cos\Delta\psi \cos\theta & \sin\Delta\psi \cos\theta & -\sin\theta \\ (\cos\Delta\psi \sin\theta \sin\phi + \sin\Delta\psi \sin\theta \sin\phi) & (\sin\Delta\psi \sin\theta \sin\phi + \cos\Delta\psi \cos\phi) & \cos\theta \sin\phi \\ (\cos\Delta\psi \sin\theta \cos\phi + \sin\Delta\psi \sin\theta) & (\sin\Delta\psi \sin\theta \cos\phi - \cos\Delta\psi \sin\phi) & \cos\phi \cos\phi \end{bmatrix} \begin{bmatrix} u_{T_E} \\ v_{T_E} \\ w_{T_E} \end{bmatrix}$$

Body Axes Gust Components — Low-Altitude Turbulence Transformation Matrix — Earth-Oriented Gust Componen

where

$\Delta\psi$ = angle from projection of airspeed vector on plane of earth to X body axis projection on plane of earth

$$= -\tan^{-1}\left[\frac{v_{AP}}{u_{AP}}\right] = -\beta$$

$$u_{AP} = \left[\cos\alpha \cos\beta \cos\theta + \sin\beta \sin\theta \sin\phi + \sin\alpha \cos\beta \sin\theta \cos\phi\right] V_A$$

$$v_{AP} = \left[\sin\beta \cos\phi - \sin\alpha \cos\beta \sin\phi\right] V_A$$

For the high-altitude model a transformation is required to bring the turbulence components from relative wind orientation to body axes orientation:

$$\begin{bmatrix} u_B \\ v_B \\ w_B \end{bmatrix} = \begin{bmatrix} \cos\alpha \sin\beta & -\cos\alpha \sin\beta & -\sin\alpha \\ \sin\beta & \cos\beta & 0 \\ \sin\alpha \cos\beta & -\sin\alpha \sin\beta & \cos\alpha \end{bmatrix} \begin{bmatrix} u_{RW} \\ v_{RW} \\ w_{RW} \end{bmatrix}$$

Body Axes Gust Components — High-Altitude Turbulence Transformation Matrix — Relative Earth-Oriented Gust Components

where

θ = Euler pitch angle

ϕ = Euler roll angle

α = $\tan^{-1} \dfrac{wa}{ua}$

$$\beta = \sin^{-1}\frac{v_A}{v_T}$$

$$u_A = u - (u_{TURB})$$

$$v_A = v - (v_{TURB})$$

$$w_A = w - (w_{TURB})$$

u, v, w = inertial components of velocity in body axes

u_{TURB}, v_{TURB}, w_{TURB} = components of turbulence and mean winds in body axes

$$V_T = [\, u_A^2 + v_A^2 + w_A^2 \,]^{1/2}$$

C.M.F.2.3.6 Mean Wind and Turbulence Models for Automatic Landing Certification

Limited application models in accordance with FAA Advisory Circular 20-57A and British Civil Air Regulation (BCAR) Paper 575 shall be used for automatic landing performance evaluation.

C.M.F.2.3.7 Wind Shear

The wind shear model for the severe atmospheric condition to be used for airplane controllability evaluation is shown on Figure C.M.F.2-9. For the light and moderate atmospheric conditions the magnitudes of the wind shear model of C.M.F.2-9 should be scaled appropriately.

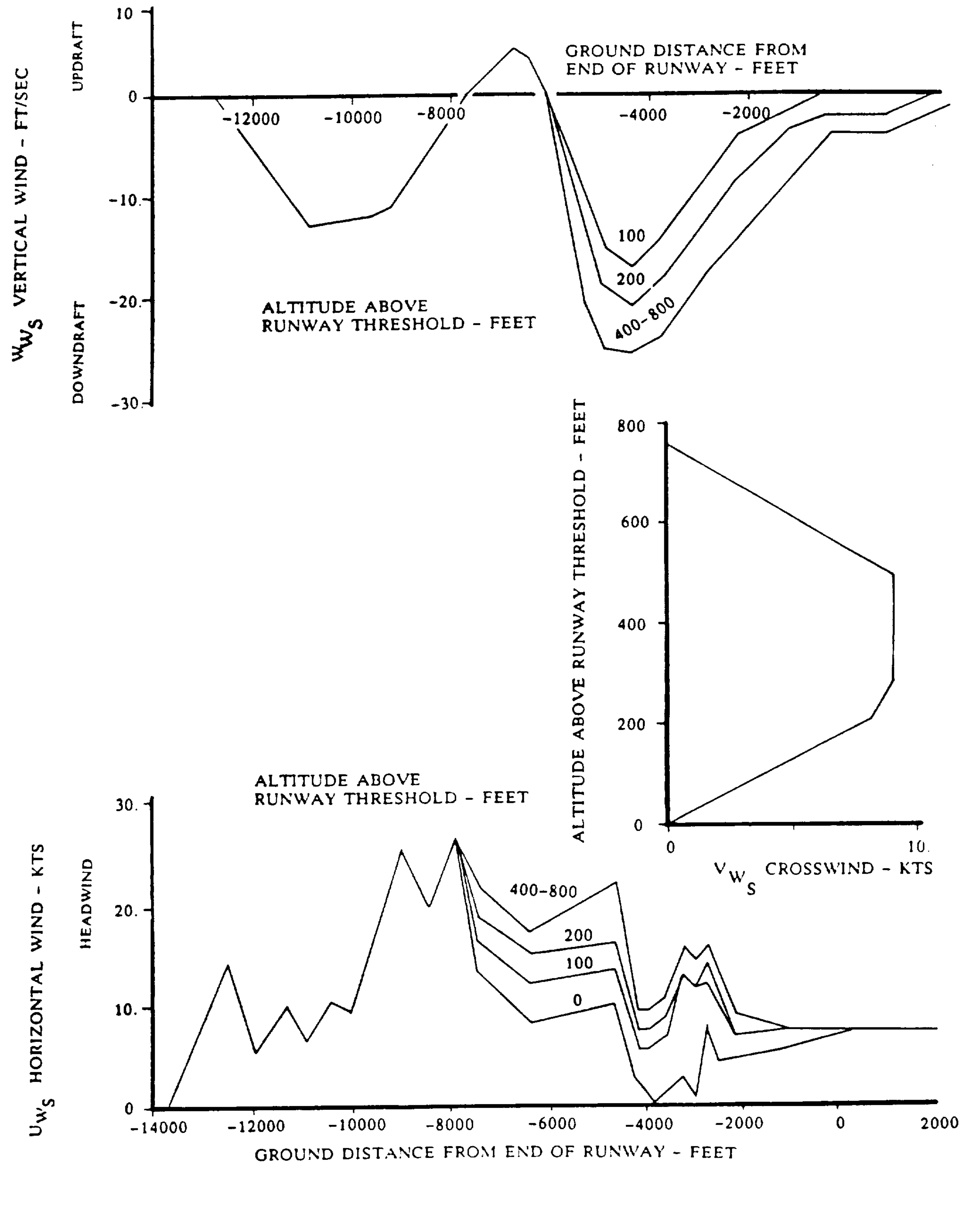


FIGURE C.M.F. 2-9 WIND SHEAR MODEL

C.M.F.2.4 Handling Qualities Evaluation Task-Related Maneuvers

This section presents task-related maneuvers to be evaluated in piloted simulations with the appropriate aircraft system states, operational envelope and atmospheric conditions to verify compliance with the qualitative handling qualities requirements of Figure C.M.F.2-2. General categories and candidate tasks presented in Reference 6 are shown verbatim in Figure C.M.F.2-10. (This is representative of current FAA thinking but has not yet been adopted.) Specific task-related maneuvers are described in the following paragraphs. Within these requirements are some which apply only for conventional control and others which apply only for maneuver demand type control, which have been marked as Conventional and Maneuver Demand respectively. For these particular requirements the designer need only meet those applicable to the particular control law design. The requirements on control forces are a mix of control forces for wheel controllers, center stick and sidestick controllers as the FAR and MIL-Specs requirements have been included verbatim. The designer shall modify these as appropriate for the particular control system design.

A. TRIM & UNATTENDED OPERATION

Characteristics of the airplane to stay at or depart from an initial "trim" or unaccelerated condition.

Dynamic and flight-path response to pulse (3 axes)
Dynamic and flight-path response to atmospheric disturbance
Spiral stability (e.g., release at 40 deg bank)

B. LARGE AMPLITUDE MANEUVERING

Generally, these are open-loop maneuvers in which the pilot attempts a significant change in airplane path, speed or attitude. Maneuvers may be initiated outside the normal flight envelope and transition flight envelopes. Many of these maneuvers are representative of engineering airworthiness and control tests.

1) Pitch/Longitudinal	- Wind-up-turn or symmetric pull-up/push-over - Slow-down-turn at fixed g or on AOA or G-limiter - Stall or AOA-limiter approach - Push/pull off trim speed
2) Roll	- Rapid bank-to-bank roll
3) Yaw	- Sudden heading change - Constant heading sideslip
4) Operational	- Pitch/roll upset recovery - Emergency descent - Climbing/diving turn - Takeoff/land wind shear escape maneuver - Go around/power application from low speed - Arrest of high sink rate, at touchdown/level-off altitude - Collision avoidance roll/pull - Takeoff and landing flare with abuse or high crosswind

C. CLOSED-LOOP PRECISION REGULATION OF FLIGHT PATH

Generally, these are tightly-bounded, pilot closed-loop tasks performed in routine commercial flight. These controlling tasks are almost exclusively associated with the normal flight envelope, or certainly not far outside the normal flight envelope boundary.

ILS and precision touchdown, various atmospheric disturbance and initial offset
Formation flying (as simulator for maneuver tracking)
Compound SPD/ALT/HDG tracking, high gain flight phase, in various atmospheric disturbance and cockpit display status

Figure C.M.F.2-10 General Handling Qualities Task Categories

C.M.F.2.4.1 Stall Characteristics and Recovery (FAR 25.201)

a) Stalls must be shown in straight flight and in 30 degree banked turns with–

  1) Power off; and
  2) The power necessary to maintain level flight at 1.6 V_{S1}

b) In either condition required by paragraph (a), it must be possible to meet the applicable stall characteristics and recovery requirements of FAR 25.203 with–

  1) Flaps and landing gear in any likely combination of positions;
  2) Representative weights within the range for which certification is requested:
  3) The most adverse center of gravity for recovery.

c) The following procedure must be used to show compliance with FAR 25.203;

  1) With the airplane trimmed for straight flight at the speed prescribed in FAR 25.103(b)(1), reduce the speed with the elevator control until it is steady at slightly above stalling speed. Apply elevator control so that the speed reduction does not exceed one knot per second until
     i) The airplane is stalled or
     ii) The control reaches the stop
  2) As soon as the airplane is stalled, recover by normal recovery techniques.

C.M.F.2.4.2 Engine-Out

a) Ground Minimum Control Speed (V_{MCG}) (FAR 25.149(e)):

V_{MCG} is the calibrated airspeed during the takeoff run, at which, when the critical engine is suddenly made inoperative, it is possible to recover control of the airplane with the use of primary aerodynamic controls alone to enable the takeoff to be safely continued using normal piloting skill and rudder control forces not exceeding 150 lbs. Assuming that the path of the airplane accelerating with all engines operating is along the centerline of the runway, its path from the point at which the critical engine is failed to the point at which recovery to a direction parallel to the centerline is completed may not deviate more than 30 feet laterally from the centerline at any point. V_{MCG} must be established with–

  1) The most critical takeoff configuration;
  2) Maximum available takeoff power or thrust on the operating engines;
  3) The most unfavorable center of gravity;
  4) The airplane trimmed for takeoff;
  5) The most unfavorable weight in the range of takeoff weights.

b) Minimum Control Speed (V_{MC}) (FAR 25.149(b)-(d)):

V_{MC} is the calibrated airspeed, at which, when the critical engine is suddenly made inoperative, it is possible to recover control of the airplane with that engine still inoperative, and maintain straight flight either with zero yaw or with an angle of bank of not more than 5 degrees.

V_{MC} may not exceed 1.2 V_S with-

1) Maximum available takeoff power or thrust on the engines;
2) The most unfavorable center of gravity;
3) The airplane trimmed for takeoff;
4) The maximum sea level takeoff weight
5) The airplane in the most critical takeoff configuration existing along the flight path after the airplane becomes airborne, except with the landing gear retracted; and
6) The airplane airborne and the ground effect negligible.

The rudder forces required to maintain control at V_{MC} may not exceed 150 lbs nor may it be necessary to reduce power or thrust of the operative engines. During recovery, the airplane may not assume any dangerous attitude or require exceptional piloting skill, alertness, or strength to prevent a heading change of more than 20 degrees.

c) Asymmetric Thrust - Yaw Controls Free (MIL-F-8785C 4.1 & 3.3.9.4):

Verify the static directional stability is such that at all speeds above 1.4V_S, with asymmetric loss of thrust from the most critical engine while the other engine(s) develops normal rated thrust, the airplane with yaw control pedals free (no rudder control) may be balanced directionally in steady straight flight with less than 30 pounds of center stick roll-control force :

1) All speeds above 1.4V_S
2) All altitudes
3) Aircraft trimmed for wings-level straight flight prior to the failure

C.M.F.2.4.3 Go-Around:

The airplane shall have sufficient pitch control to perform a go-around. (FAR 25.145(c)) The following maneuver will be used to evaluate compliance with this requirement:

It must be possible, without exceptional piloting skill, to prevent loss of altitude when complete retraction of the high lift devices from any position is begun during steady, straight level flight at 1.2 V_{S1} with-

1) Simultaneous application of not more than takeoff power taking into account the critical engine operating condition;

2) The landing gear extended;
3) The critical combination of landing weights and altitudes.

If gated high-lift device control positions are provided, retraction must be shown from any position from the maximum landing position to the first gated position, between gated positions, and from the last gated position to the full retraction position. In addition, the first gated control position from the landing position must correspond with the high-lift devices configuration used to establish the go-around procedure form the landing configuration.

C.M.F.2.4.4 Approach & Landing

Verify that acceptable landing characteristics are available via compliance with the following requirements :

a) Approach (static longitudinal stability (FAR 25.175) - Conventional Control) - The stick force curve must have a stable slope at speeds between 1.1 V_{S1} and 1.8 V_{S1}, with-

1) Wing flaps in the approach position;
2) Landing gear retracted;
3) Maximum landing weight; and
4) The airplane trimmed at 1.4 VS1 with enough power to maintain level flight at this speed.

b) Landing (static longitudinal stability (FAR 25.175) - Conventional Control)- The stick force curve must have a stable slope and the stick force may not exceed 80 pounds (wheel controller), at speeds between 1.1 V_{So} and 1.8 V_{So} with-

1) Wing flaps in the landing position;
2) Landing gear extended;
3) Maximum landing weight;
4) Power or thrust off on the engines; and
5) The airplane trimmed at 1.4 V_{So} with power off.

c) Longitudinal Stability (Maneuver Demand Control) In lieu of compliance with the requirements of paragraphs 25.171, 25.173, 25.175, and 25.181(a) of the FAR, the airplane must be shown to have suitable dynamic and static longitudinal stability in any condition normally encountered in service, including the effects of atmospheric disturbance. (Airbus A-320 FAR Special Conditions)

d) Approach (directional control (FAR 25.147)) - It must be possible, while holding the wings approximately level, to safely make reasonably sudden changes in heading in both directions. This must be shown at 1.4 VS1 for heading changes up to 15 degrees with-

1) The critical engine inoperative in the minimum drag position;
2) The power required for level flight at 1.4VS1, but not more than maximum

continuous power;
3) The most unfavorable center of gravity;
4) Landing gear retracted;
5) Flaps in the approach position; and
5) Maximum landing weight.

e) Longitudinal Control (FAR 25.145)

With the landing gear extended, no change in trim control, or exertion of more than 50 pounds control force (wheel controller) may be required for the following maneuvers:

1) With power off, flaps retracted, and the airplane trimmed at $1.4V_{S1}$, extend the flaps as rapidly as possible while maintaining the airspeed at approximately 40 percent above the stalling speed existing at each instant throughout the maneuver.

2) Repeat subparagraph (1) except initially extend the flaps and then retract them as rapidly as possible.

3) Repeat subparagraph (2) except with takeoff power.

4) With power off, flaps retracted, and the airplane trimmed at $1.4\ V_{S1}$, apply takeoff power rapidly while maintaining the same airspeed.

5) Repeat subparagraph (4) except with flaps extended.

6) With power off, flaps extended, and the airplane trimmed at $1.4\ V_{S1}$, obtain and maintain airspeeds between $1.1\ V_{S1}$ and either $1.7\ V_{S1}$, or V_{FE}, whichever is lower.

f) Approach in crosswind (MIL-F-8785C 3.3.7.1)

It must be possible to develop at least 10 degrees of sideslip with yaw control pedal forces not exceeding 100 lbs. and roll control not exceeding 75% of total control power available to the pilot, with-

1) Power approach configuration;
2) Trimmed at V_{REF};
3) Most critical configuration of c.g., flaps, and weight,
4) With a 30 knot crosswind.

g) Landing in crosswind (MIL-F-8785C 3.3.9)

The airplane shall be safely controllable following sudden asymmetric loss of thrust in a landing with a 30 knot crosswind from the unfavorable direction, with-

1) Trimmed at V_{REF}
2) Most critical configuration of c.g., flaps, weight

C.M.F.2.4.5 Takeoff

Verify adequate controllability during takeoff for the following task-related maneuvers:

a) Lateral control (FAR 25.147)

It must be possible to make 20 degree banked turns, with and against the inoperative engine, from steady state flight at a speed equal to 1.4 VS1 with–

1) The critical engine inoperative;
2) The remaining engine(s) at maximum continuous power;
3) The most unfavorable center of gravity;
4) Landing gear (i) retracted and (ii) extended;
5) Flaps in the most favorable climb position; and
6) Maximum takeoff weight.

b) Climb (FAR 25.175 - Conventional Control)

The stick force curve must have a stable slope at speeds between 85 and 115 percent of the speed at which the airplane–

1) Is trimmed with–
   i) Wing flaps retracted;
   ii) Landing gear retracted;
   iii) Maximum takeoff weight; and
   iv) Maximum power or thrust for use during climb; and
2) Is trimmed at the speed for best rate-of-climb except that the speed need not be less than 1.4 VS1.

c) Longitudinal Stability (Maneuver Demand Control)

In lieu of compliance with the requirements of paragraphs 25.171, 25.173, 25.175, and 25.181(a) of the FAR, the airplane must be shown to have suitable dynamic and static longitudinal stability in any condition normally encountered in service, including the effects of atmospheric disturbance. (Airbus A-320 FAR Special Conditions)

d) Crosswind takeoff (MIL-F-8785C 3.3.7)

It shall be possible to takeoff with normal pilot skill and technique in a 90-degree 30 knot crosswind with no more than 20 lbs (center stick) roll control force and 100 lbs yaw control force, with

1) 30 knot crosswind
2) All engines operating
3) Maximum takeoff power
4) Most critical configuration - c.g., flaps, weight
5) Normal rotation

e) Thrust loss during takeoff roll (MIL-F-8785C 3.3.9.1)

It shall be possible for the pilot to maintain control of an airplane on the takeoff surface following sudden loss of thrust from the most critical engine. Thereafter, it shall be possible to achieve and maintain a straight path on the takeoff surface without a deviation of more than 30 feet from the path originally intended.

1) For continued takeoff, verify with speeds from the refusal speed to the maximum take off speed, with
   - i) Takeoff thrust on the operative engine(s)
   - ii) Using only control not dependent upon friction against the takeoff surface or upon release of the pitch, roll, yaw or throttle controls.
   - iii) Most critical configuration - c.g., flaps, weight.

2) For the aborted takeoff, verify with all speeds below the maximum takeoff speed, with
   - i) Use of nosewheel steering and differential braking allowed,
   - ii) Most critical configuration - c.g., flaps, weight.

C.M.F.2.4.6 Dive/Upset:

Verify that sufficient control is available to meet the following speed increase and recovery characteristics: (FAR 25.253)

1) Operating conditions and characteristics likely to cause inadvertent speed increases (including upsets in pitch and roll) must be simulated with the airplane trimmed at any likely cruise speed up to VMO/MMO. These conditions include:
   - i) gust upsets;
   - ii) inadvertent control movements;
   - iii) passenger movement;
   - iv) leveling off from climb; and
   - iv) descent from Mach to airspeed limit altitudes.

2) Allowing for pilot reaction time after speed warning occurs, it must be shown that the airplane can be recovered to a normal altitude and its speed reduced to VMO/MMO, without-
   - i) Exceptional piloting strength or skill;
   - ii) Exceeding VD/MD, VDF/MDF or the structural limitations;
   - iii) Buffeting that would impair the pilot's ability to read the instruments or control the airplane for recovery.

C.M.F.2.4.7 Cruise

a) Static longitudinal stability must be shown in the cruise condition as follows (static longitudinal stability FAR 25.175(b) - Conventional Control):

1) With the landing gear retracted at high speed, the stick force curve must have a stable slope at all speeds within a range which is the greater of 15 percent of the trim speed plus the resulting free return speed range, or 50 knots plus the resulting free return speed range, above and below the trim speed with–

i) The wing flaps retracted;
ii) The center of gravity in the most adverse position;
iii) The most critical weight between the maximum takeoff and maximum landing weights;
iv) Maximum cruising power;
v) The airplane trimmed for level flight.

2) With the landing gear retracted at low speed, the stick force curve must have a stable slope at all speeds within a range which is the greater of 15 percent of the trim speed plus the resulting free return speed range, or 50 knots plus the resulting free return speed range, above and below the trim speed with

i) The wing flaps retracted;
ii) The center of gravity in the most adverse position;
iii) The most critical weight between the maximum takeoff and maximum landing weights;
iv) Power required for level flight at a speed equal to $(V_{MO}+1.4V_{S1})/2$;
v) The airplane trimmed for level flight.

3) With the landing gear extended, the stick force curve must have a stable slope at all speeds within a range which is the greater of 15 percent of the trim speed plus the resulting free return speed range, or 50 knots plus the resulting free return speed range, above and below the trim speed with

i) The wing flaps retracted;
ii) The center of gravity in the most adverse position;
iii) The most critical weight between the maximum takeoff and maximum landing weights;
iv) Maximum cruising power;
v) The aircraft trimmed for level flight.

b) Longitudinal Stability (Maneuver Demand Control)

In lieu of compliance with the requirements of paragraphs 25.171, 25.173, 25.175, and 25.181(a) of the FAR, the airplane must be shown to have suitable dynamic and static longitudinal stability in any condition normally encountered in service, including the effects of atmospheric disturbance. (Airbus A-320 FAR Special Conditions)

Operational Flight Envelope(C.M.F.3)

C.M.F.3.1 General

At all altitudes, the operational flight envelope is defined in terms of a suitable normal acceleration and speed boundary for each configuration of the aircraft. Within these envelopes, the aircraft shall comply with the control and handling qualities criteria except where specifically exempted. Minimum and maximum design and operating speeds are presented in Figure C.M.F.3-1, and defined below. (FAR 25.1503)

C.M.F.3.2 Normal Acceleration

The maximum normal acceleration considered is determined from stall considerations, structural limits, or maximum control authority which ever is most restrictive. Maximum positive and negative normal accelerations, n_z, are presented in Figure C.M.F.3-2. (FAR 25.333(b) and FAR 25.1531)

C.M.F.3.3 Minimum Speeds

The minimum speeds associated with the operational flight envelopes shall be determined for each configuration on the basis of minimum demonstrated speed considerations as explained in the following paragraphs. (Note that the FAA is currently specifying new regulations to define the stall speed.)

a) Stalling Speed - V_S

Stalling speed is the lowest airspeed that will be demonstrated inflight with idle power using a deceleration of 1 knot per second. This is the FAA stall speed. (V_{SO} - Stall speed in the landing configuration, V_{S1} - stalling speed appropriate to the configuration). (FAR 25.201(c), FAR 25.49)

b) Minimum Warning Speed -$V_{MIN\ WARN}$

Minimum warning speed is the airspeed at which positive warning is given to the pilot, either through natural aerodynamic means or through an artificial warning or control subsystem. (FAR 25.207)

c) Minimum Operating Speed -$V_{MIN\ OP}$

Minimum operating speed is the minimum airspeed at which the aircraft is intentionally operated. This includes consideration of all operating concerns such as performance, handling qualities, systems operations, etc.

d) Minimum Control Speed

1) Minimum Control Speed, Ground - V_{MCG}

This is defined as the minimum speed during takeoff at which, if a critical engine becomes inoperative, control can be maintained through primary aerodynamic controls. The lateral deviation following an engine failure at V_{MCG} shall not exceed 30 feet from the runway centerline. The effect of nosewheel steering shall not be included. (FAR 25.149 and FAR 25.1513)

2) Minimum Control Speed, Air - V_{MCA}

This is defined as the minimum airplane speed in the takeoff configuration at which, if a critical engine becomes inoperative, control is regained, and straight steady flight maintained with either zero yaw or no more than 5 degrees of bank, with the operating engine(s) at maximum takeoff thrust. (FAR 25.149(b))

3) Minimum Control Speed During Landing Approach - V_{MCL}

This is defined as the minimum airplane speed in the approach configuration at which, if a critical engine becomes inoperative, control is regained, and straight steady flight maintained with either zero yaw or no more than 5 degrees of bank, with the operating engine(s) at maximum takeoff thrust. (FAR 25.149(f))

e) Takeoff Speeds

1) Engine Inoperative Speed - V_{EF}

This speed shall be at least equal to the minimum speed during takeoff at which primary aerodynamic controls alone are adequate to safely continue the takeoff when the critical engine suddenly fails. $V_{EF} \geq V_{MCG}$ (FAR 25.109(a))

2) Minimum Climb Speed - V_{2MIN}

This speed shall provide at least the minimum required gradient of climb (FAR 25.121(b)) between 35 and 400 feet with the critical engine inoperative and shall be at least $1.10 V_{MCA}$ or $1.20\ V_{S1}$. (FAR 25.107(b))

3) Rotation Speed - V_R

This speed shall be at least $1.05 V_{MCA}$ and allow attainment of $V_{2\ MIN}$. (FAR 25.107(e))

f) Landing Approach Speed - V_{REF}

1) A calibrated airspeed that is not less than $1.3\ V_{SO}$. This speed shall be maintained down to the 50 foot height for landing. (FAR 25.125(a)(2))

2) This speed shall be greater than or equal to V_{MCL} + 5 Kt. (BCAR D2-8-3.5 (Ref. 8))

C.M.F.3.4 Maximum Speeds

The maximum speeds associated with the operational flight envelopes shall be determined for each configuration, on the basis of the following:

a) Flap Extended Speed -V_{FE}

The flap extended speed, V_{FE}, for each flap position shall be sufficiently greater than the operating speed recommended for the corresponding stage of flight (including balked landings) to allow for probable variations in control of airspeed and for transition from one flap position to another. V_{FE} must be equal to or less than the design flap speed, V_F. (FAR 25.1511, FAR 25.335(e) and FAR 25.345)

b) Landing Gear Operating Speed - V_{LO}

The landing gear operating speed shall not exceed the speed at which it is safe to extend or retract the landing gear, either for structural load or flight characteristics reasons. (FAR 25.1515 and FAR 25.729)

c) Landing Gear Extended Speed - V_{LE}

The landing gear extended speed shall not exceed the speed at which it is safe to fly with the landing gear secured in the fully extended position. (FAR 25.1515, FAR 25.729)

d) Maximum Operating Speeds/Mach Numbers - V_{MO}/M_{MO}

The maximum operating speeds and Mach numbers (V_{MO}/M_{MO}) shall be determined for the cruise configuration in such a manner as to include all normal operational flight conditions, including climb, cruise and descent, consistent with the appropriate thrust requirements. (FAR 25.1505, FAR 215.335(b) and FAR 25.253)

e) Design Dive Speed, - V_D/M_D

The design dive speed, V_D/M_D, is based on the following criteria: From an initial condition of stabilized flight at V_{MO}/M_{MO} the airplane is upset, flown for twenty seconds along a flight path of 7.5 degrees below the initial path, and then pulled up at a normal load factor of 1.5 (0.5 g acceleration increment). Cruise power will be maintained until the pullup is initiated, at which time power reduction and pilot controlled drag devices shall be applied. The maximum speed reached in this maneuver shall be less than V_D/M_D. The speed margin between M_{MO} and M_D shall not be less than Mach = 0.05 for FAA, or less than Mach = 0.07 for CAA. (FAR 25.335(b), FAR 25.253)

f) Flight Characteristics Demonstration Speeds - V_{FC}/M_{FC}

V_{FC}/M_{FC} is the maximum speed at which normal control and stability requirements shall be met. V_{FC} is the speed mid-way between V_{MO} and V_D. M_{FC} is .01 Mach higher than M_{MO} when a Mach overspeed device is used. Otherwise it is mid-way between M_{MO} and M_D. (FAR 25.253(b))

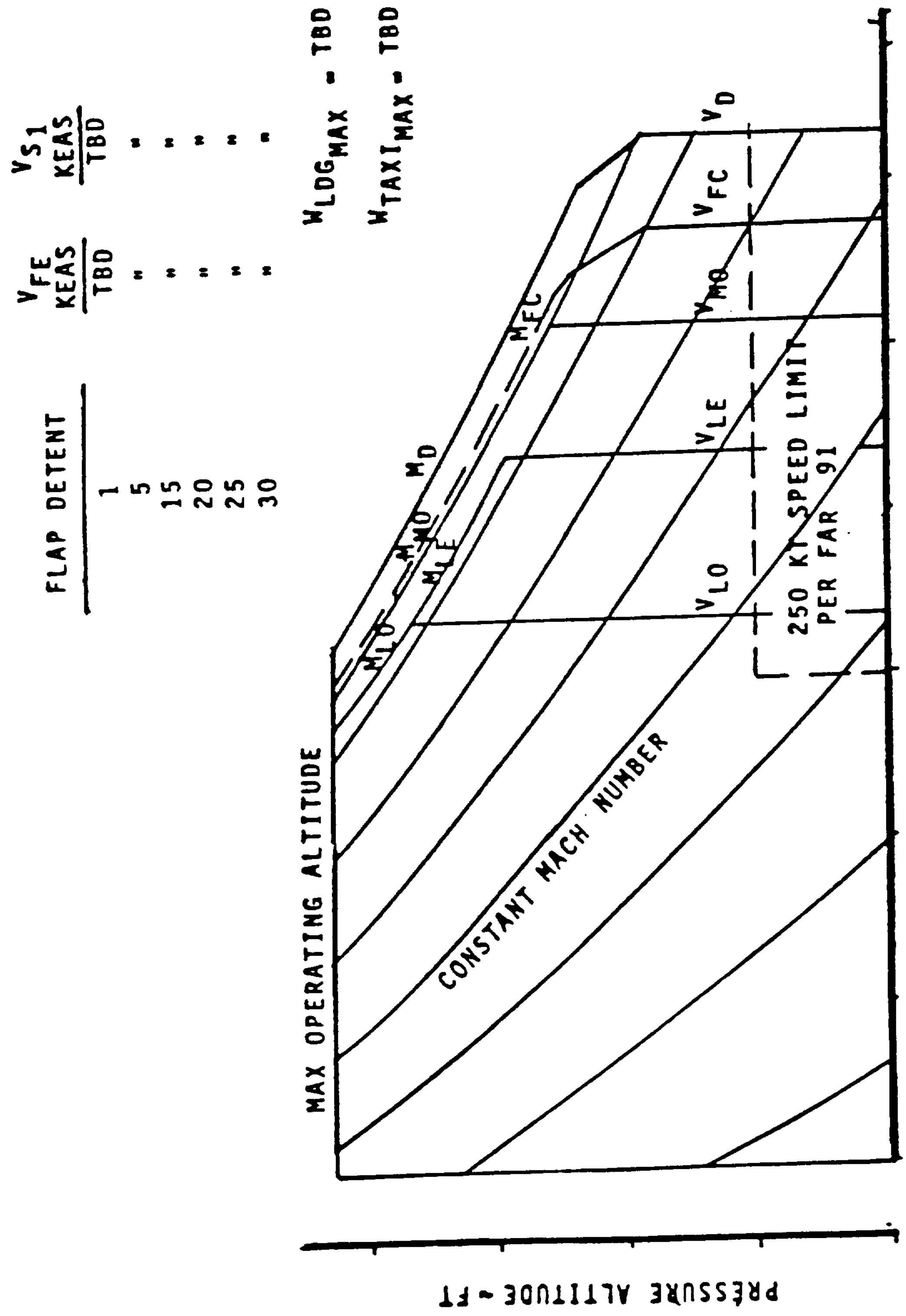


FIGURE C.M.F. 3-1 OPERATIONAL ENVELOPE

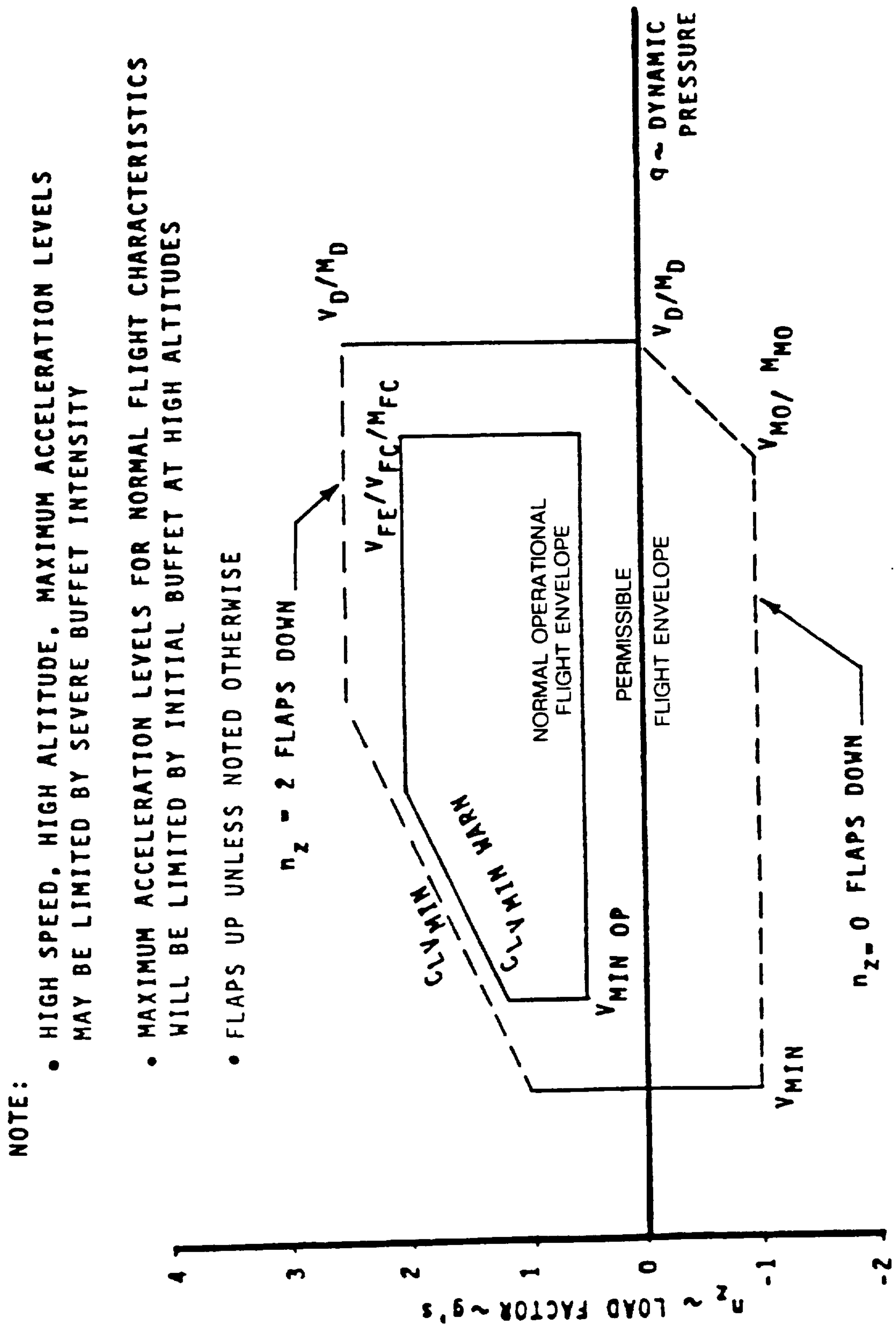


FIGURE C.M.F. 3-2 HANDLING QUALITIES DESIGN BOUNDARIES

Manual and Automatic Trim Functions (C.M.F.4)

Longitudinal Trim

Manual pitch trim and autotrim shall be provided over the normal flight envelope trim range. The crew shall have an alternate trim capability independent of the normal and automatic trim capability. Alternate crew trim shall have control capability over the entire mechanical trim range and shall override normal crew and automatic trim control at all times. (MIL-F-9490D 3.1.3.5) The probability of loss of manual trim shall be < 10E-7.

Automatic trim control shall be operable during autopilot and enhanced maneuver control following lift-off. The automatic trim mode shall reduce steady-state elevator deflections to the neutral position by offloading to the stabilizer. The probability of loss of automatic trim shall be < 10E-06.

Longitudinal Trim Indication

There shall be positive indication of the trim position in the flight deck. A takeoff configuration warning shall be provided when the throttles are advanced for takeoff and the stabilizer is in a position that would not allow a safe takeoff. Annunciation of failure to trim on command and uncommanded trim operation shall be provided except when either the pilot or co-pilot is using the trim controls. (FAR 25.677(b), FAR 25.703)

Lateral Trim

Manual and automatic lateral trim shall be provided. Crew trim control shall be provided for use in the core control (normal and minimum acceptable). Automatic trim control shall be provided during enhanced and autopilot control. Probability of loss of function shall be < 10E-6.

Lateral Trim Indication

Trim position indication shall be displayed to the flight crew. (FAR 25.677(b)

Directional Trim

Manual and automatic directional trim shall be provided. Crew trim control shall be provided for use in the core control (normal and minimum acceptable). Automatic trim control shall be provided during enhanced and autopilot control. Probability of loss of function shall be < 10E-6.

Directional Trim Indication

Trim position indication shall be displayed to the flight crew. (FAR 25.677(b)

Trim Indication Reliability

No single failure or combination of failures shall cause erroneous trim position indication unless the failure(s) is improbable. (FAR 25.677(b), FAR 25.703, FAR 25.671)

Envelope Protection (C.M.F.5)

Envelope protection functions shall be provided to prevent the aircraft from exceeding the normal operating envelope boundaries. Protection shall be provided for stall, load factor, pitch attitude, overspeed, sideslip, and roll angle boundaries. The following envelope protection functions shall be provided with a probability of loss of function $< 10E-06$.

Function

Stall
Load Factor
Overspeed
Pitch Attitude
Bank Angle
Sideslip Angle

Autopilot Limiting and Actuation (C.M.F.6)

Core control shall provide autopilot authority limiting and actuation. Autopilot limiting and monitoring shall limit the maneuver response of the airplane to autoflight malfunctions and protect the airplane against autoflight oscillatory failures. The autoflight limiting function shall protect against single and multiple axes failures. The probability of loss of autopilot limiting shall be < 10E–6.

Maneuver Control Lags (C.M.F.7)

a) The airplane response to pilot controller inputs shall have an equivalent time delay (τ_E) within the following limits: (MIL-F-8785C 3.5.3)

$$\tau_E \leq 0.1 \text{ sec.}$$

b) The equivalent time delay shall be measured from the pitch and roll rate responses to step controller inputs as shown in Figures C.M.F.7-1 and C.M.F.7-2 respectively.
The time delay contributions of all system elements from the pilot controller to the control surface shall be included. The airplane responses shall meet the requirements for both small inputs typical of fine tracking tasks and large maneuvers.

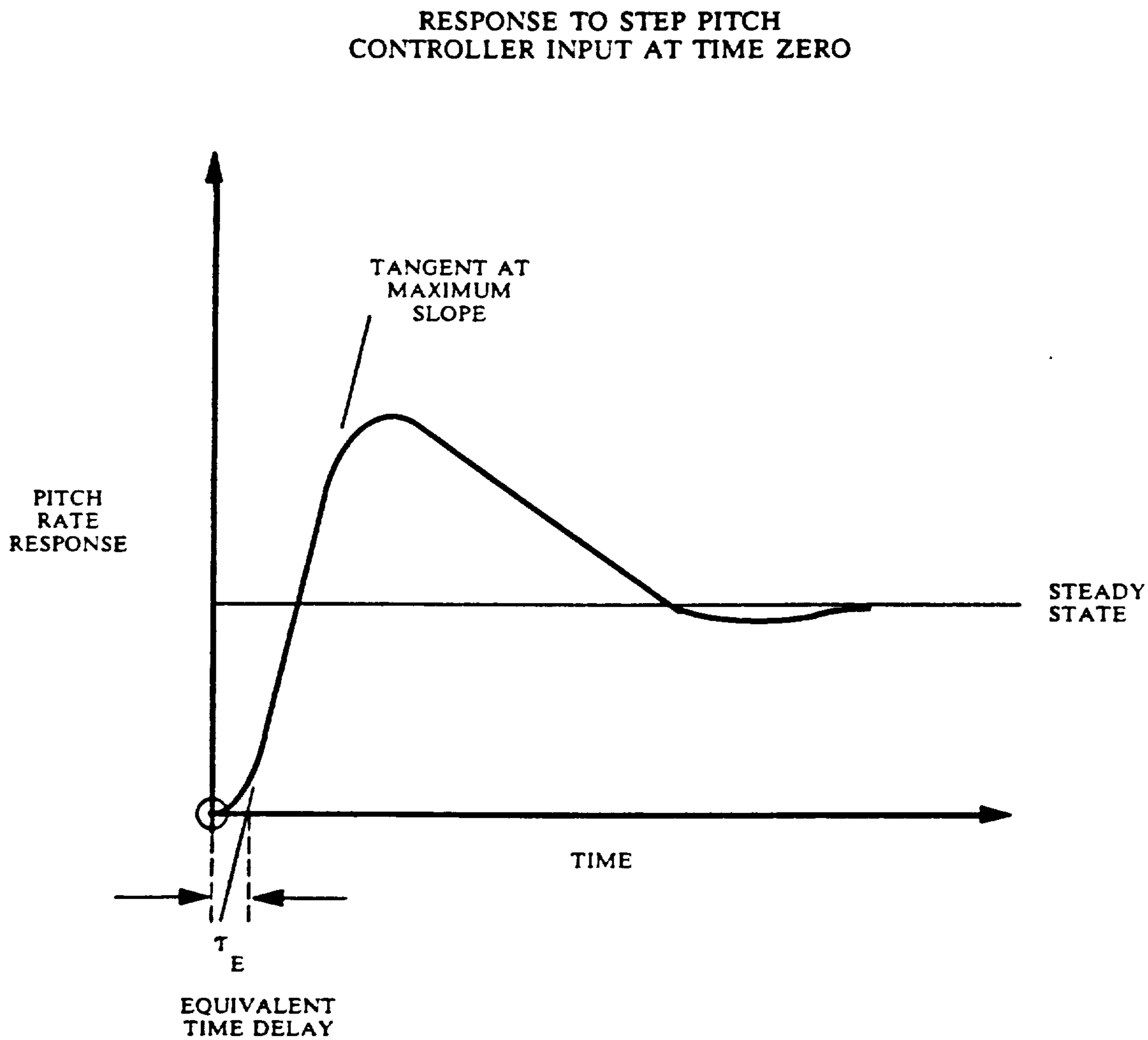


FIGURE C.M.F.7-1 EQUIVALENT TIME DELAY FOR PITCH

RESPONSE TO STEP ROLL
CONTROLLER INPUT AT TIME ZERO

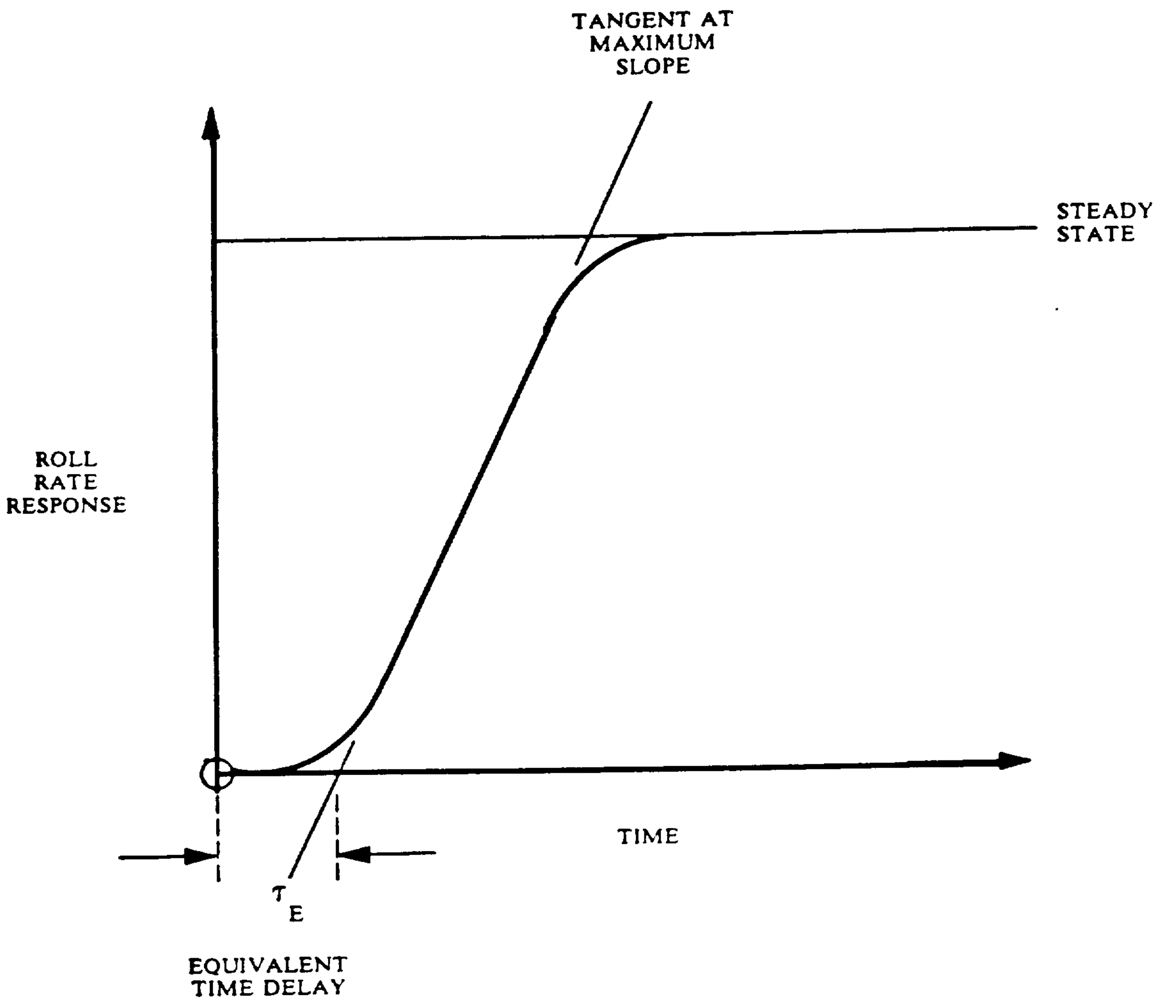


FIGURE C.M.F.7-2 EQUIVALENT TIME DELAY FOR ROLL

Requirement in Icing Conditions (C.M.F.8)

C.M.F.8.1 Ice Protection System Operation General

Ice protection systems whether manual or automatic shall provide acceptable maneuver margins and handling qualities. (FAR 25.1419)

C.M.F.8.2 Handling Qualities/Controllability

The airplane stall characteristics and longitudinal control power shall meet the requirements of the following sections for operation in icing conditions with the ice protection system functioning: (FAR 25.1419)

Paragraph #	Title
C.M.F.11	Stall Recovery
C.M.F.11	Landing Go-Around
C.M.F.12	Trim Range Limits
C.M.F.16	Stall Characteristics (Lateral Stability)

C.M.F.8.3 Maneuver Margin and Stall Warning

a) A maneuver margin equivalent to 40 deg of bank to natural or artificial stall warning must be available for any flap setting and speed normally used for holding, descent, and approach. A 30 deg bank margin must be available for the flap setting and speed normally used for go-around. (FAA Issue Paper F-3)

b) Natural or artificial stall warning shall meet the requirements of paragraph P.S.A.W.1.1 (page 126).

c) The evaluation will be made with the ice protection system in operation and ice accreted at any flap setting and speed normally used for holding, descent, and approach. (FAR 25.1419)

C.M.F.8.4 Stall Warning with Failed Ice Protection System Elements

Crew warning shall be provided when the failed ice protection system element could result in an unsafe condition if the pilot were not aware of the failure. (FAR 25.672(a))

Control System Stability Requirement (C.M.F.9)

a) There shall be no tendency for system or pilot induced oscillations resulting from the efforts of the pilot to control the airplane. This shall include saturation effects due to control system rate or position limits. The control system shall produce no objectionable airplane response or control characteristics including the effect of:

Feedback gain magnitudes
System rate limits
System position limits
System time delays
Structural mode coupling
Power supply variations
Abnormal flight conditions such as stall, speeds to 1.2 VD/MD, or large maneuver angles.

b) Stability Margin Criteria

1) The FCS shall satisfy the stability criteria in Table C.M.F.9-1. The criteria apply to either single or multiloop systems. In a multiloop system the phase and gain of the feedback paths, except for the path under investigation, shall be held at nominal values. The criteria shall be satisfied at all possible airplane weights and center of gravity locations and for any flight condition within the design flight envelope. The term gain (or phase) margin as used in Table C.M.F.9-1 means the variation in loop gain (or phase) from nominal that is allowable without causing the loop and mode in question to become unstable. (MIL-F-9490D 3.1.3.6.1)

2) With any single failure, regardless of probability, or any combination of failures not extremely improbable, flight control shall be free of instabilities which preclude safe flight at any speed up to VD. (FAR 25.629(d)(1), FAR 25.1309)

TABLE C.M.F.9-1 GAIN AND PHASE REQUIREMENTS (DB, DEGREES)

Airspeed / Mode Frequency - Hz	Below $V_{MIN\ OP}$	$V_{MIN\ OP}$ To V_{MO}	At V_D	At 1.15 V_D
$f_M < 0.06$	GM = 6 DB (NO PHASE REQUIREMENT BELOW $V_{MIN\ OP}$)	GM = + 4.5 PM = + 30	GM = + 3.0 PM = + 20	GM = 0 PM = 0 (Stable at Nominal Phase and Gain)
$0.06 \leq f_M \leq$ FIRST AERO-ELASTIC MODE		GM = + 6.0 PM = + 45	GM = + 4.5 PM = + 30	
$f_M >$ FIRST AERO-ELASTIC MODE		GM = + 8.0 PM = + 60	GM = + 6.0 PM = + 45	

f_M = Mode Frequency
GM = Gain Margin
PM = Phase Margin

Residual Oscillations (C.M.F.10)

a) Any limit cycle that occurs in normal or enhanced control shall not exceed flight crew or passenger perception threshold levels. These thresholds are defined as 0.04 g peak-to-peak in the vertical direction and 0.02 g peak-to-peak in the lateral direction. (MIL-F-9490D 3.1.3.8)

b) Any residual oscillation or sustained limit cycle that occurs during degraded operation (minimum acceptable control) shall not interfere with the pilot's ability to control and safely land the airplane. Accordingly, normal acceleration at the crew station due to residual oscillations shall not exceed $\pm$ 0.05 g. (MIL-F-8785C 3.2.2.1.3) Residual oscillations in roll and yaw attitude at the pilot's station shall not exceed 0.6 degrees peak to peak. (MIL-F-9490D 3.1.3.8)

Longitudinal Control Power Requirements (C.M.F.11)

C.M.F.11.1 Takeoff Control Requirements

C.M.F.11.1.1 Normal Takeoff (All Engines)

Normal rotation at V_R shall provide liftoff attitude at the liftoff speed with the following requirements: (FAR 25.107(e))

a) Not more than 75% of the available elevator control shall be required.(MIL-F-8785C 3.2.3.3.2)

b) There shall be a perceptible pitch response to controller input at rotation.

C.M.F.11.1.2 Mistrim Takeoff (All Engines)

The airplane shall be capable of safe takeoff with the longitudinal trim set at any position within the normal takeoff trim range.

C.M.F.11.1.3 Takeoff With Adverse Failures

For failure conditions not extremely improbable there shall be sufficient control to takeoff safely. (FAR 25.671)

C.M.F.11.2 Maneuver Control Requirements

C.M.F.11.2.2 Longitudinal Control In Maneuvering Flight

a) It must be possible at any speed between the trim speed prescribed in FAR 25.103(b) and V_S to pitch the nose downward so that the acceleration to this selected trim speed is prompt with- (FAR 25.145(a))

1) The airplane trimmed at the trim speed (FAR 25.103(b))
2) The landing gear extended
3) The wing flaps (i) retracted and (ii) extended, and
4) Power (i) off and (ii) at maximum continuous power.

b) With the landing gear extended, no change in trim control, or exertion of more than 50 pounds of wheel controller force may be required for the following maneuvers: (FAR 25.145(b))

1) With power off, flaps retracted, and the airplane trimmed at 1.4 V_{S1}, extend the flaps as rapidly as possible while maintaining the airspeed at approximately 40 percent above the stalling speed existing at each instant throughout the maneuver.

2) Repeat subparagraph (1) except initially extend the flaps and then retract them as rapidly as possible.

3) Repeat subparagraph (2) except with takeoff power.

4) With power off, flaps retracted, and the airplane trimmed at 1.4 V_{S1}, apply takeoff power rapidly while maintaining the same airspeed.

5) Repeat subparagraph (4) except with flaps extended.

6) With power off, flaps extended, and the airplane trimmed at 1.4 V_{S1}, obtain and maintain airspeeds between 1.1 V_{S1} and either 1.7 V_{S1}, or V_{FE}, whichever is lower.

c) Within the Operational Flight Envelope, it shall be possible to develop, by use of the pitch control alone, the maximum and minimum service load factors as defined in MIL-F-8785C 3.1.8.4. This maneuvering capability is required at the 1g trim speed and, with trim and throttle settings not changed by the crew, over a range about the trim speed the lesser of ± 15 percent or ± 50 knots equivalent airspeed (except where limited by the boundaries of the Operational Flight Envelope) (MIL-F-8785C 3.2.3.2)

C.M.F.11.2.3 Maneuvering After High-Speed Upsets

There shall be no reversal in the effectiveness of the pitch control surfaces at speeds up to 1.15 V_D. (MIL-F-9490D 3.1.3.6.1)

C.M.F.11.3 Landing Control Requirements

The pitch control shall be sufficiently effective in the landing flight phase in close proximity to the ground, that in calm air:

a) The geometry-limited touchdown attitude can be maintained in level flight or

b) The lower of $V_{S(L)}$ or the guaranteed landing speed can be obtained.

This requirement shall be met with the airplane trimmed for the approach flight phase at the recommended approach speed. (MIL-F-8785C 3.2.3.4)

C.M.F.11.4 Stall

a) There shall be sufficient nose down pitch capability to ensure prompt acceleration to the trim speed from the stall speed, power on and off. (FAR 25.145)

b) There shall be sufficient elevator control power with idle power, trim at 1.3 V_S, and at the forward center-of-gravity limit, to demonstrate F.A.R. stall speeds in all airplane configurations. (FAR 25.201)

C.M.F.11.5 Stall Recovery

a) It shall be possible to recover from a stall by simple use of the pitch, roll and yaw controls with cockpit control forces not to exceed those of F.C.S.8. and to regain level flight without excessive loss of altitude or buildup of speed. Throttles shall remain fixed until speed has begun to increase and an angle of attack below the stall has been regained unless compliance would result in exceeding engine operating limitations. In straight-flight stalls with the airplane trimmed at an airspeed not greater than 1.4VS, pitch control shall be sufficient to recover from any attainable angle of attack. (MIL-F-8785C 3.4.2.1.3)

b) It must be possible to produce and to correct roll and yaw by unreversed use of the aileron and rudder controls, up to the time the airplane is stalled. No abnormal nose-up pitching may occur. The longitudinal control force must be positive up to and throughout the stall. In addition, it must be possible to promptly prevent stalling and to recover from a stall by normal use of the controls. (FAR 25.203(a))

c) For level wing stalls, the roll occurring between the stall and the completion of the recovery may not exceed approximately 20 degrees. (FAR 25.203(b))

d) For turning flight stalls, the action of the airplane after the stall may not be so violent or extreme as to make it difficult, with normal piloting skills, to effect a prompt recovery and to regain control of the airplane. (FAR 25.203(c))

e) It must be possible to safely recover from a stall with the critical engine inoperative-

1) Without applying power to the inoperative engine;
2) With flaps and landing gear retracted;
3) With the remaining engines at up to 75 percent of maximum continuous power, or up to the power at which the wings can be held level with the use of maximum control travel, whichever is less. (FAR 25.205(a));
4) The operating engines may be throttled back during the stall recovery.

C.M.F.11.6 Landing Go Around

a) The airplane shall have sufficient pitch control to perform a go-around. (FAR 25.145(c)) The following maneuver will be used to evaluate compliance with this requirement:

It must be possible, without exceptional piloting skill, to prevent loss of altitude when complete retraction of the high lift devices from any position is begun during steady, straight level flight at 1.2 V_{S1} with-

1) Simultaneous application of not more than takeoff power taking into account the critical engine operating condition;
2) The landing gear extended;
3) The critical combination of landing weights and altitudes.

If gated high-lift device control positions are provided, retraction must be shown from any position from the maximum landing position to the first gated position, between gated positions, and from the last gated position to the full retraction position. In addition, the first gated control position from the landing position must correspond with the high-lift devices configuration used to establish the go-around procedure from the landing configuration.

Longitudinal Trim Authority (C.M.F.12)

The following trim system requirements are applicable to airplanes where primary longitudinal trim is provided by a movable horizontal stabilizer or by a trimmable elevator on a fixed stabilizer.

C.M.F.12.1 Trim Range Limits

a) The normal trim limits shall be set to allow the airplane to maintain longitudinal trim during: (FAR 25.655(b))

1) A climb with maximum continuous power at a speed not more than 1.4 V_{S1}, with the landing gear retracted, and the flaps (i) retracted and (ii) in the takeoff position;
2) A glide with power off at a speed not more than 1.4 V_{S1}, with the landing gear extended, the wing flaps (i) retracted and (ii) extended, the most unfavorable center of gravity position approved for landing with the maximum landing weight, and with the most unfavorable center of gravity position approved for landing regardless of weight;
3) Level flight at any speed form 1.4V_{S1} to V_{MO}/M_{MO}, with the landing gear and flaps retracted, and form 1.4V_{S1} to V_{LE} with landing gear extended.

b) The airplane must maintain longitudinal trim at 1.4 V_{S1} during climbing flight with: (FAR 25.161(d))

1) The critical engine inoperative.
2) The remaining engines at maximum continuous power.
3) The landing gear and flaps retracted.

C.M.F.12.2 Trim Rate

The trim rate shall be rapid enough to enable the pilot to maintain low control forces under changing conditions normally encountered in service, yet not so rapid as to cause oversensitivity or trim precision difficulties under any conditions. (MIL-F-8785C 3.6.1.2)

C.M.F.12.3 All Engine Inoperative Trim Capability

Trim capability with all engines inoperative shall be provided unless sufficient longitudinal control power is available. (FAR 25.671(d))

Enhanced Longitudinal Control Maneuver Response (C.M.F.13)

a) Pitch Rate Response

Pitch rate response to a pitch control step input shall comply with the requirements of figure C.M.F.13-1. (Ref. 7 - AFWAL-TR-81-3109 3.2.2.1)

Transient Peak Ratio

The transient peak ratio $\Delta q_2 / \Delta q_1$ shall meet the following requirement:

$$\Delta q_2 / \Delta q_1 \leq .30$$

where Δq_1 = magnitude of first overshoot

Δq_2 = magnitude of first undershoot.

Rise Time Parameter

The rise time parameter, $\Delta t = t_2 - t_1$ shall have a value between the following limits:

Nonterminal Flight Phase	Terminal Flight Phase
Min Max	Min Max
$\frac{9}{V_T} \leq \Delta t \leq \frac{500}{V_T}$	$\frac{9}{V_T} \leq \Delta t \leq \frac{200}{V_T}$

where V_T = ft/sec true airspeed

t_1 = equivalent time delay

t_2 = time to reach first crossing of steady state pitch rate.

FIGURE C.M.F.13-1 PITCH RATE RESPONSE REQUIREMENTS

b) Frequency and Damping

1) Short period frequencies shall be within the boundaries shown in Figures C.M.F.13-2 and C.M.F.13-3. (MIL-F-8785C 3.2.2.1.1.)

2) Short period damping ratios shall be within: $0.35 \leq \zeta_{sp} \leq 1.0$ (MIL-F-8785C 3.2.2.1.2)

3) Stability augmentation shall suppress any aerodynamic long period oscillation by holding a selected airplane state constant when the pilot's controller is neutral.

c) Longitudinal Stability With Respect to Speed (Conventional Control)

The stick force versus speed average gradient shall be greater than or equal to 1 pound per 6 knots. (FAR 25.173(c))

d) Longitudinal Stability (Maneuver Demand Control)

In lieu of compliance with the requirements of paragraphs 25.171, 25.173, 25.175, and 25.181(a) of the FAR, the airplane must be shown to have suitable dynamic and static longitudinal stability in any condition normally encountered in service, including the effects of atmospheric disturbance. (Airbus A-320 FAR Special Conditions)

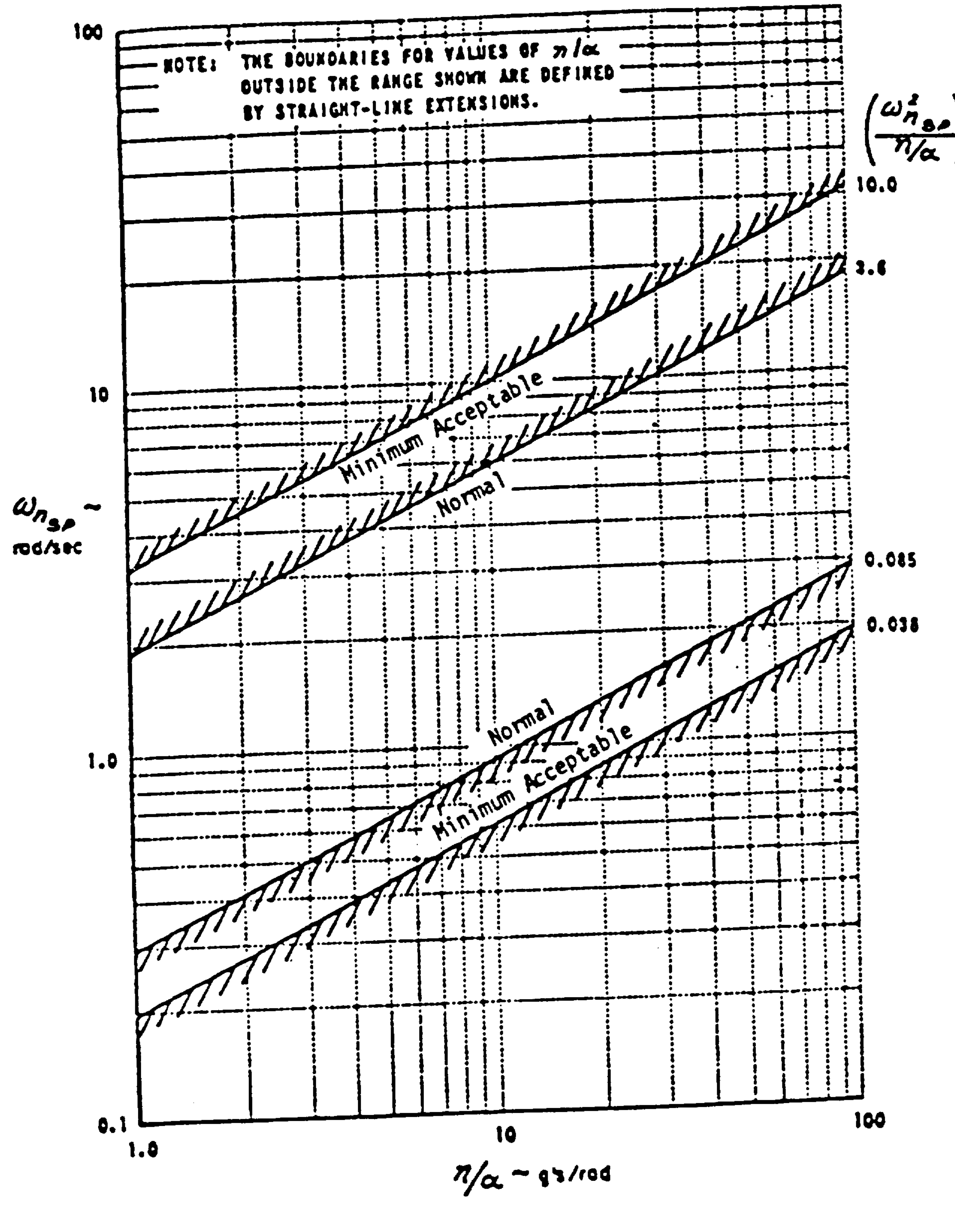


FIGURE C.M.F. 13-2 SHORT-PERIOD FREQUENCY REQUIREMENTS-
CLIMB, CRUISE, DESCENT FLIGHT PHASES

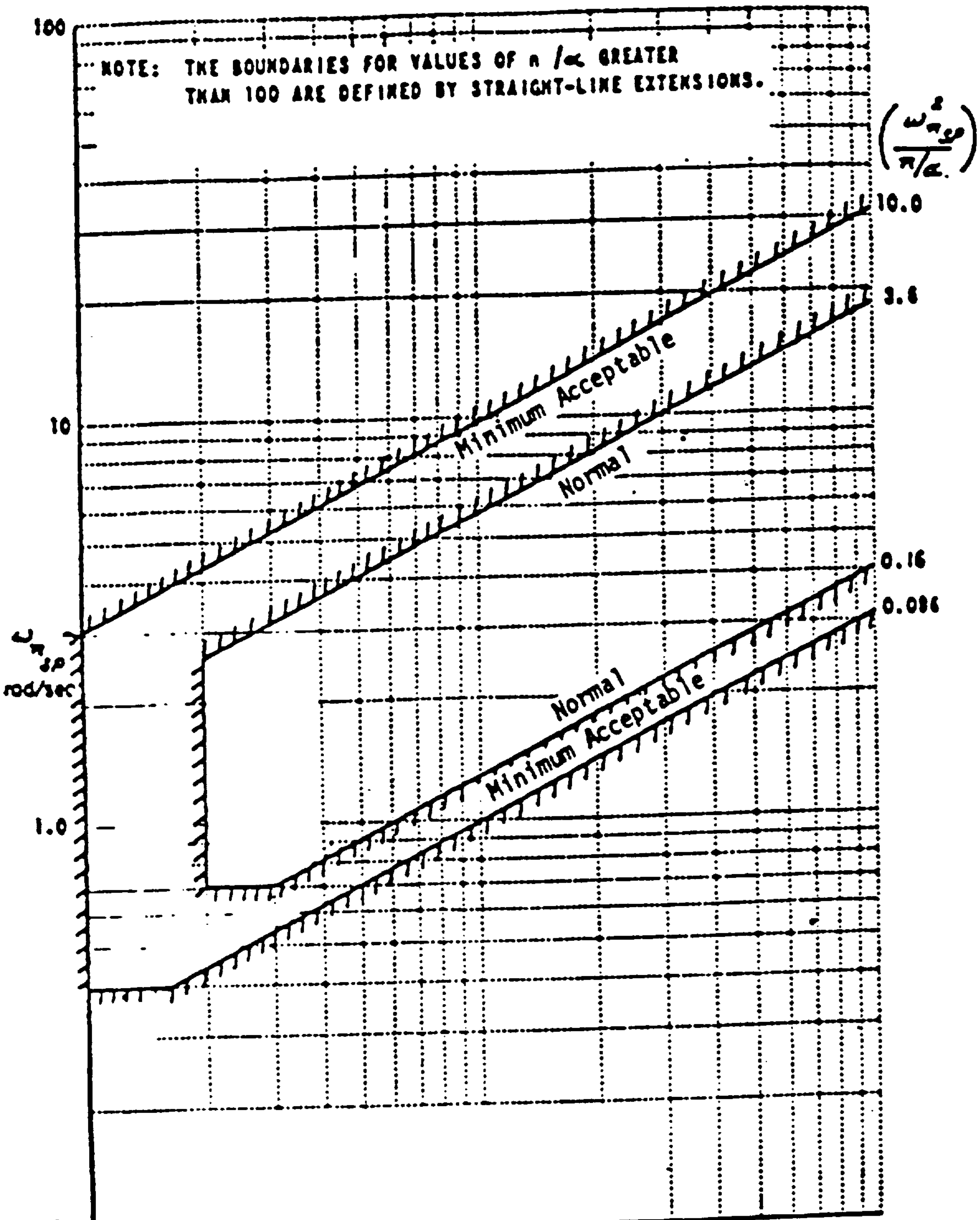


FIGURE C.M.F. 13-3 SHORT-PERIOD FREQUENCY REQUIREMENTS-TAKEOFF, APPROACH AND LANDING FLIGHT PHASES

Roll Mode Time Constant (C.M.F.14)

The roll-mode time constant shall be no greater than the following: (MIL-F-8785C 3.3.1.2 - Class II-L & III aircraft)

NORMAL	MINIMUM ACCEPTABLE
1.4 Sec	10.0 Sec

Pilot - Induced Oscillations (C.M.F.15)

There shall be no tendency for sustained or uncontrollable lateral-directional oscillation resulting from effort of the pilot to control the airplane. (MIL-F-8785C 3.3.3)

Stall Characteristics (C.M.F.16)

The lateral control shall be sufficient to control the bank angle to less than a 20 deg upset during a stall recovery. (FAR 25.203(b))

Lateral Control Power Requirements(C.M.F.17)

C.M.F.17.1 Static Balance

a) The static directional stability shall be such that at all speeds above 1.4 V_{MIN}, with asymmetric loss of thrust from the most critical engine while the other engine(s) develop normal rated thrust, the airplane with yaw control pedals free may be balanced directionally in steady straight flight. (MIL-F-8785C 3.3.9.4)

b) There must be enough excess lateral control in sideslips (up to sideslip angles that might be required in normal operation), to allow a limited amount of maneuvering and to correct for gusts. (FAR 25.147(e))

c) It must be possible to make 20 deg banked turns, with and against the inoperative engine, from steady flight at a speed equal to 1.4 V_{S1} with - (FAR 25.147(c))

1) The critical engine inoperative and its propeller (if applicable) in the minimum drag position;
2) The remaining engines at maximum continuous power;
3) The most unfavorable center of gravity;
4) Landing gear (i) retracted and (ii) extended;
5) Flaps in the most favorable climb position;
6) Maximum takeoff weight

d) It shall be possible to take off and land with normal pilot skill and technique in a 30 knots 90-degree crosswind from either side. (MIL-F-8785C 3.3.7) Minimum acceptable: Directional stability shall be adequate to permit safe use of rudder to takeoff and land on dry runways in a crosswind of 20 knots or 0.2 V_{SO}, whichever is greater, except that it need not exceed 25 knots. (FAR 25.237)

e) Yaw and roll control power shall be adequate to develop at least 10 degrees of sideslip (yaw-control-induced steady, zero-yaw-rate sideslip with airplane trimmed for wings-level straight flight) in the power approach configuration. Roll control shall not exceed 75% of control power available to the pilot. (MIL-F-8785C 3.3.7.1)

f) Following sudden asymmetric loss of thrust from any factor, the airplane shall be safely controllable in the crosswinds of paragraph d) above, from the unfavorable direction. (MIL-F-8785C 3.3.9)

g) During takeoff it shall be possible to achieve straight flight following sudden asymmetric loss of thrust from the most critical engine at speeds from V_{MIN} to V_{MAX} and thereafter to maintain straight flight throughout the climbout (without a change in selected configuration). Roll control shall not exceed 75 percent of available control power, with takeoff thrust maintained on the operative engine(s) and trim at normal setting for takeoff with symmetric thrust. (MIL-F-8785C 3.3.9.2)

C.M.F.17.2 Roll Response

Lateral control for maneuvering shall be defined by the time required to achieve a specific bank angle in a given time in response to a maximum roll command. The required bank angle responses are:

a) Terminal Flight Phase - (Flaps down, 1.3 V_{S1} to V_{FE}.)(MIL-F-8785C 3.3.4.2)

1) Change bank angle 30 degrees within not more than 2.5 seconds, with probable system failures.

2) Minimum Acceptable: Under the most adverse failure conditions change bank angle 30 degrees within not more than 6 seconds.

b) Nonterminal Flight Phase - (Flaps up, 1.3 V_{S1} to V_{MO}/M_{MO}.)(MIL-F-8785C 3.3.4.2)

1) Change bank angle 30 degrees within not more than 2.3 seconds, with probable system failures.

2) Minimum Acceptable: Under the most adverse failure conditions change bank angle 30 degrees within not more than 5 seconds.

c) High speed (V_{MO}/M_{MO} to V_D/M_D)

With all hydraulic or electrical systems operating, lateral control shall be sufficient to roll from a steady 30 degrees banked turn through 60 degrees so as to reverse the direction of the turn in not more than 11 seconds with no pilot rudder controller input, and in no more than 14 seconds with full rudder controller used in the conventional sense (where rudder application has an adverse effect on rate of roll). (BCAR D2-8, 6.5.4)

Roll Response Linearity (C.M.F.18)

There shall be no objectionable nonlinearities in the variation of rolling response with roll control deflection or force. Sensitivity or sluggishness in response to small control deflections or force shall be avoided. (MIL-F-8785C 3.3.4.4)

Roll Control Cross Coupling (C.M.F.19)

Lateral control deflection shall not cause objectionable pitch and/or yaw transients. (MIL-F-8785C 3.4.3)

Lateral Trim Authority (C.M.F.20)

a) The lateral trim system shall be capable of reducing roll moments to zero in straight flight and the bank angle may not exceed five degrees at 1.4 V_{S1} during climbing flight with: (FAR 25.161(d))

1) The critical engine inoperative.
2) The remaining engines at maximum continuous power.
3) The landing gear and flaps retracted.

b) The airplane must maintain lateral trim with the most adverse lateral displacement of the center of gravity (maximum wing tank fuel asymmetry) within the relevant operating limitations, during normally expected conditions of operation (including operation at any speed from 1.4 V_{S1} to V_{MO}/M_{MO}). (FAR 25.161(b))

c) Trim inputs shall not prevent the pilot from obtaining full surface displacement achievable at that condition.

Enhanced Roll Maneuver Control (C.M.F.21)

The normal augmentation function shall suppress the aerodynamic spiral mode by holding a selected airplane state (e.g. roll attitude) constant when the lateral controllers are centered.

In addition a heading or track angle hold shall be provided as an enhanced manual control mode.

Dynamic Stability (C.M.F.22)

a) Normal Operation: Dutch roll frequency and damping shall meet the following requirements. (MIL-F-8785C 3.3.1.1 - Most restrictive requirement for class II and III type aircraft.)

FLIGHT CONDITION	Min ζ_D	Min $\zeta_D \omega_D$	Min ω_D
TAKEOFF, LANDING	0.19	0.35	0.4
CLIMB, CRUISE, DESCENT	0.19	0.35	0.4

(For passenger comfort a more stable platform is desirable and thus a $\zeta_D = 0.4$ is an objective.)

b) Minimum Acceptable: Dutch roll damping shall be greater than zero. (FAR 25.181(b))

Turn Coordination (C.M.F.23)

a) Normal Operation: Automatic turn coordination shall be provided, such that:

1) With rudder pedals fixed the lateral acceleration at the cg shall not exceed ±0.1 g for maximum roll rates of C.M.F.17. This limit shall be met for aircraft in essentially constant altitude flight while rolling smoothly from one side to the other. (MIL-F-9490D 3.1.2.4.2)

2) With rudder pedals fixed, the sideslip angle shall not be greater than 2 degrees and lateral acceleration shall not exceed 0.03g, while at steady bank angles up to the maneuver bank angle limit. (MIL-F-9490D 3.1.2.4.1)

3) The airplane shall be capable of making heading changes without requiring the use of rudder pedals to coordinate the turn entry and exit maneuvers. It is required that heading rate follow bank angle with an average lag (τ_{ψ}) of less than TBD seconds (Figure C.M.F.23-1).

b) Minimum Acceptable: It shall be possible to coordinate the turn entry with normal pilot use of the rudders.

NOTE: LATERAL CONTROL IS APPLIED AS NECESSARY TO PROVIDE THE BANK ANGLE RESPONSE.
THE AVERAGE YAW RATE RESPONSE TIME LAG IS MEASURED WITH RESPECT TO THE IDEAL YAW RATE RESPONSE TO BANK ANGLE: $\dot{\psi} = (g/V) \tan \phi$

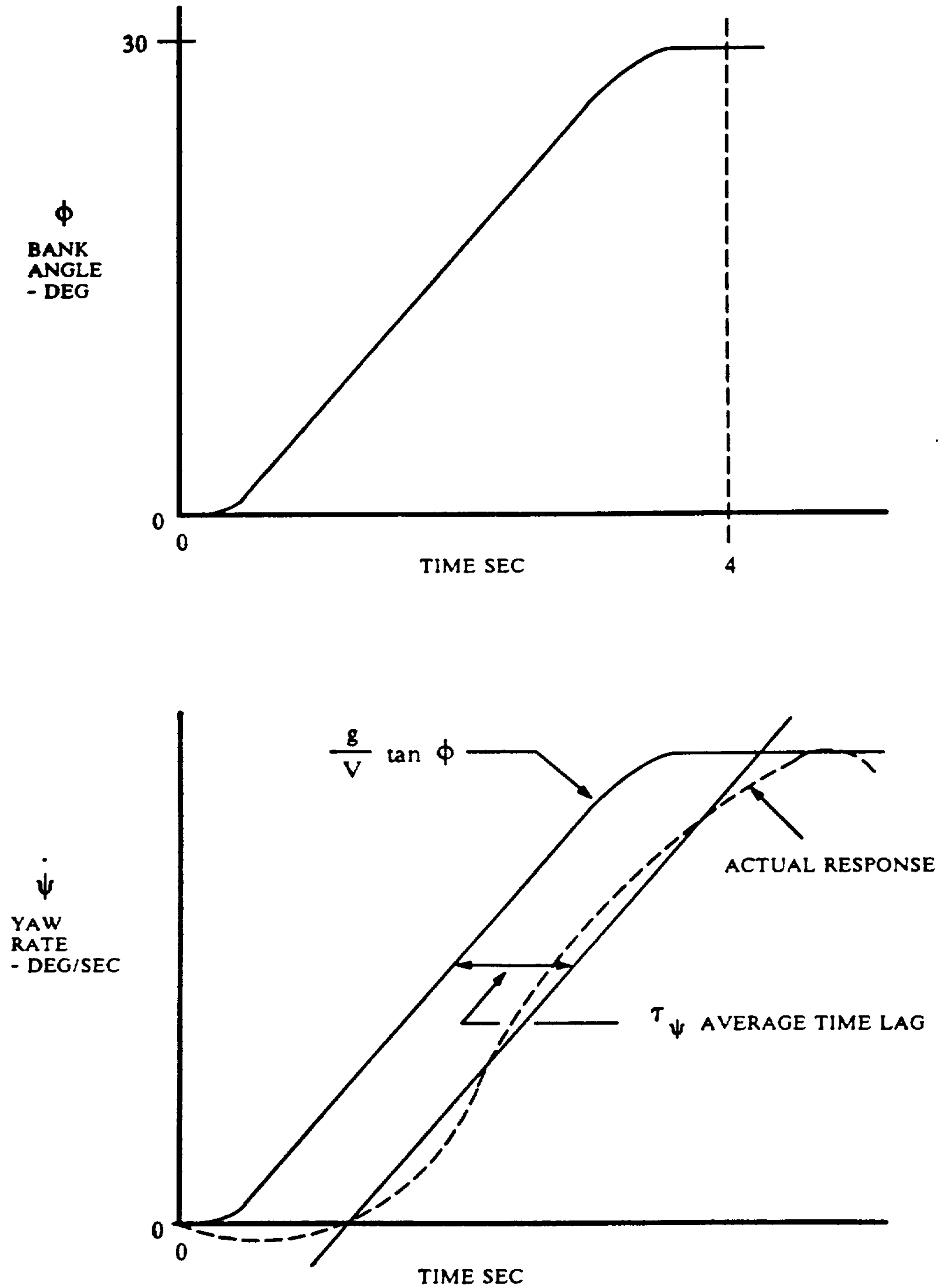


FIGURE C.M.F.23-1
TURN COORDINATION TIME LAG

Directional Control Power Requirements (C.M.F.24)

The airplane should have sufficient directional control such that engine inoperative minimum control speeds (V_{MCA} and V_{MCG}) will not limit performance over the normal range of operating weights.

C.M.F.24.1 Engine Inoperative Control Requirements

a) $V_{MCA} \leq V_2/1.1$ and $V_R/1.05$ at critical weight. (FAR 25.107(b) and FAR 25.125(a))

b) $V_{MCL} \leq 1.3\ V_{SO}$ -5 knots at critical weight. (BCAR D2-8, 3.2.2(c))

c) $V_{MCG} \leq V_{EF}$. (FAR 25.107(a)(1))

C.M.F.24.2 Crosswind Control Requirements

a) The airplane shall have the capability to takeoff and land in a 30 knot crosswind. (MIL-F-8785C 3.3.7)

b) Minimum acceptable: Directional stability shall be adequate to permit safe use of rudder to takeoff and land on dry runways in a crosswind of 20 knots or 0.2 V_{SO}, whichever is greater, except that it need not exceed 25 knots. (FAR 25.237)

Directional Trim Authority (C.M.F.25)

The directional trim authority shall be sufficient to trim with the most critical engine failed for the following conditions:

a) Enroute Climb (FAR 25.161)

b) Approach flaps with power for level flight at 1.4 V_S at maximum landing weight. (FAR 25.161)

c) V_2 with takeoff thrust and at minimum service takeoff gross weight (typically 1.25 OEW). (FAR 25.161)

d) The rudder trim rate shall be rapid enough to enable the pilot to maintain low control forces under changing conditions normally encountered in service (i.e. engine failure with flaps down), yet not so rapid as to cause oversensitivity or trim precision difficulties under any conditions. (MIL-F-8785C 3.6.1.2)

Trim inputs shall not prevent the pilot from obtaining full surface displacement achievable at that condition.

Flutter Prevention Requirements (C.M.F.26)

The airplane shall comply with the flutter requirements in FAR 25.629. A flutter suppression function may be provided by the flight control system to satisfy the flutter requirements. There shall be no flutter, buzz or divergence of the airplane or its components at all speeds up to 1.2 V_D for all ranges of altitudes, maneuvers (including maneuvers within the V_D/M_D envelope where losses in rigidity may occur) and loading conditions. Clearance to 1.2 M_D must also be shown, except the Mach effects need not be included for Mach numbers greater than 1.0 as long as a proper margin of damping exists at all speeds up to M_D and there is no large and rapid reduction in damping as M_D is approached. The damping coefficient, ζ, for any critical flutter mode shall be at least 0.03 for all altitudes and speeds up to V_D for unfailed conditions. Compliance with these requirements may be shown by analyses, tests, or some combination thereof. Ground vibration testing will be used to collect modal data for the airplane and some of the components. Flight testing will be used to demonstrate flutter compliance of the airplane at speeds up to V_D/M_D. (FAR 25.629(a)&(b))

Fail-Safe Requirements

a) It shall be shown by analysis or tests that the airplane is free from such flutter or divergence that would preclude safe-flight at any speed up to V_D after each of the failures, malfunctions or adverse conditions listed below. (FAR 25.629(d))

1) Failure of any single element of the structure supporting any engine, independently mounted propeller shaft, or large externally mounted aerodynamic body.

2) Any single failure of the engine structure that would reduce the yaw or pitch rigidity of the engine fan or propeller rotational axis.

3) Absence of propeller aerodynamic forces resulting from the feathering of any single propeller. In addition any single feathered propeller must be paired with the failures specified in (1) and (2) above.

4) Any single engine fan or propeller rotating at the highest likely overspeed.

5) Any structural failure resulting in reduced stiffness of a single nacelle strut, including complete engine loss.

6) Failure of each single principal structural element for which fail-safe strength is demonstrated. This may be substantiated by showing that losses in rigidity or changes in frequency, mode shape, or damping are within the parameter variations shown to be satisfactory in the flutter and divergence investigations. (FAR 25.571(c))

7) Any single failure or malfunction or combination thereof, in the flight control system considered under FAR 25.671, 25.672 and 25.1309, and any single failure in any flutter damper system. Investigation of forced structural vibration other than

flutter, resulting from failures, malfunctions, or adverse conditions in the automatic flight control system may be limited to airspeeds up to V_C/M_C.

8) Any other combination of failures affecting flutter or divergence not shown to be extremely improbable.

b) In complying with the above conditions, the following must be considered for the flight control system:

1) The airplane must be shown to be free from flutter after any of the following failures in the flight control system and surfaces: (FAR 25.671(c)(d), FAR 25.672(c))

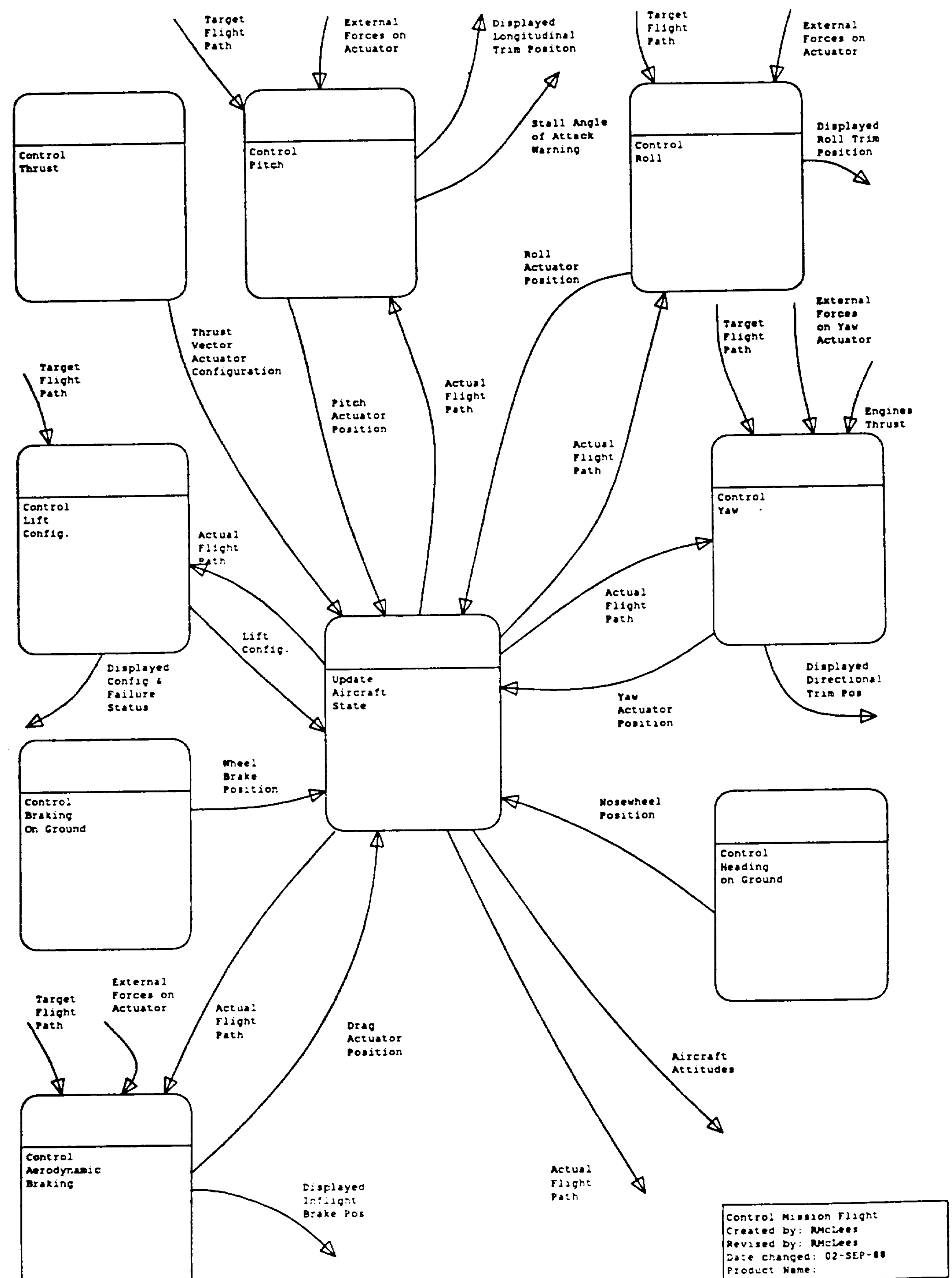
- Any single failure such as disconnection or failure of mechanical elements, or structural failure of hydraulic components such as actuators, control spool housing, and valves.
- Any combination of failures not shown to be extremely improbable such as dual hydraulic system failure, or any single failure in combination with any probable hydraulic failure.

2) It must be shown that after any single failure of the stability augmentation system or any other automatic or power operated system that flutter does not occur within the airplane operating envelope. (FAR 25.672(c))

3) The airplane must not flutter if any or all engines fail. Compliance with this requirement may be shown by analysis where that method has been shown to be reliable. (FAR 25.671(c)(d))

4) The airplane systems and associated components, considered separately and in relation to other systems, must be designed so that the occurrence of any failure condition which would prevent the continued safe flight and landing of the airplane is extremely improbable. Compliance with this requirement must be shown by analysis and where necessary, by appropriate tests. The analysis must consider possible modes of failure, including malfunctions and damage from external sources. Also the probability of multiple failures or undetected failures must be considered. (FAR 25.1309(b)(d))

5) If a failure, malfunction or adverse condition is simulated during a flight test, the maximum speed investigated need not exceed V_{FC} if it is shown, by correlation of the flight test data with other test data or analyses, that flutter will not occur at any speed up to V_D. (FAR 25.629(d))


Control Thrust
Target Flight Path
Control Pitch
External Forces on Actuator
Displayed Longitudinal Trim Positon
Stall Angle of Attack Warning
Target Flight Path
External Forces on Actuator
Control Roll
Displayed Roll Trim Position
Roll Actuator Position
Thrust Vector Actuator Configuration
Pitch Actuator Position
Actual Flight Path
Target Flight Path
External Forces on Yaw Actuator
Engines Thrust
Target Flight Path
Control Lift Config.
Actual Flight Path
Actual Flight Path
Control Yaw
Actual Flight Path
Lift Config.
Update Aircraft State
Displayed Config & Failure Status
Displayed Directional Trim Pos
Yaw Actuator Position
Control Braking On Ground
Wheel Brake Position
Nosewheel Position
Control Heading on Ground
Target Flight Path
External Forces on Actuator
Actual Flight Path
Drag Actuator Position
Aircraft Attitudes
Control Aerodynamic Braking
Displayed Inflight Brake Pos
Actual Flight Path
Control Mission Flight
Created by: RMcLees
Revised by: RMcLees
Date changed: 02-SEP-88
Product Name:

Process Descriptions
Control Mission Flight

Description	Expl name	Page
This function controls drag and lift dumping to provide an aerodynamic braking capability.	Control Aerodynamic Braking	105
This function configures the wing for different lift properties such that required lift and control is achieved at low speed (takeoff & landing) and low drag can be achieved at high speeds.	Control Lift Configuration	112
This function performs all functions required to control the longitudinal axis by controlling the pitch angle.	Control Pitch	120
This function performs all functions required to control the lateral axis by controlling the roll angle.	Control Roll	145
This function controls the aircraft directional axis.	Control Yaw	189
This function includes the airframe and the flight environment and outputs the aircraft flight state as a result of the flight state and the configuration of the flight control system.	Update Aircraft State	

Data Flow Description
Control Mission Flight

Description	Name
The sensed 4 dimensional flight path & attitudes of the aircraft as well as any other sensed values necessary to satisfy the control requirements.	Actual Flight Path
Aircraft pitch, roll and heading attitudes.	Aircraft Attitudes
Directional trim actuator position displayed to the crew.	Displayed Directional Trim Pos
Indication to the crew of the speedbrake position and status.	Displayed Inflight Brake Pos
Longitudinal trim position displayed to the crew.	Displayed Longitudinal Trim Pos
Roll trim position displayed to the crew.	Displayed Roll Trim Position
Crew displayed high lift device positions and failure status annunciation.	Displayed Config & Failure Statu
Position of the system used to generate drag used for in air and on ground aerodynamic braking.	Drag Actuators Position
Thrust measurements of engines to determine capture engine out event.	Engines Thrust
All forces (in particular environmental forces) other than the actuation forces acting on the aerodynamic braking and roll actuation system.	External Forces on Actuator
All forces (in particular environmental forces) other than the actuation forces acting on the aerodynamic braking system.	External Forces on Pitch Actuato
All forces (in particular environmental forces) other that the actuation forces acting on the yaw actuation system.	External Forces on Yaw Actuator
Configuration of lift system to achieve necessary lift to support desired flight path angle at all mission phases (speeds and altitudes). The record consists of the leading edge and trailing edge flap positions.	Lift Configuration
Angular position of the nosewheel used for on ground low speed heading control.	Nosewheel Position
Position of the actuator(s) which provide aircraft pitch maneuver and trim control.	Pitch Actuator Position
Position of the surface which makes the aircraft roll.	Roll Actuator Position
Audible and visual indication to the crew that the aircraft is approaching the stall angle of attack.	Stall Angle of Attack Warning
The desired 4 dimensional flight path and attitudes generated by some navigation function.	Target Flight Path
Configuration of the system which controls the magnitude and direction of the thrust vector.	Thrust Vector Actuator Config

Data Flow Description

Control Mission Flight

Description	Name
The position of the wheel brake actuator.	Wheel Brake Position
Position of the system which caused the aircraft to yaw (rudders).	Yaw Actuator Position

Process Requirements Links
Control Mission Flight

Expl name	Reference	Page
Control Aerodynamic Braking	C.A.B.1	90
	C.A.B.2	91
Control Lift Configuration	C.L.C.1	92
	C.L.C.2	93
Control Pitch	C.P.1	94
	C.P.2	95
Control Roll	C.R.1	96
	C.R.2	97
Control Yaw	C.Y.1	98
	C.Y.2	99
Update Aircraft State	U.A.S.1	100
	U.A.S.2	101
	U.A.S.3	102
	U.A.S.4	103
	U.A.S.5	104

Control Aerodynamic Braking (C.A.B.1)

Manual and automatic control of aerodynamic braking shall be available. Manual control shall be able to override the automatic control function. The aerodynamic speed brake control function shall be available for on-ground and in-flight operation.

1.0 Ground Speed Brake Control

Ground speedbrake control shall provide ground deceleration capability consistent with operational field landing length requirements.

2.0 Inflight Speed Brake Control

a) The inflight speed brake actuators shall be sized to give adequate inflight deflection at VMO/MMO for emergency descent.

b) Normal descent speed brake requirements shall not cause objectionable horizontal tail buffet or engine flow distortion. (FAR 25.251(b))

c) Control forces to trim the pitching moment change shall be less than or equal to those required by FAR 25.143(b).

Aerodynamic Braking Functional Availability Requirements (C.A.B.2)

a) Each individual speed brake device shall provide fail-passive control for failure modes more probable than 10-7/flt hour.

b) Loss of all speedbrake control shall be less than 10-7/flt hour.

Control Lift Configuration (C.L.C.1)

The wing high lift design (both leading edge and trailing edge devices) shall be adjustable to provide a variable lift capability to ensure the achievement of low speed performance requirements coupled with certifiable handling characteristics. Manual and automatic system operation shall be provided. High lift device position indication and failure status shall be available.

Lift Configuration Control Functional Availability Requirements (C.L.C.2)

The high lift system shall provide the following functional availability:

Function	Probability of Loss of Function	
L. E. and T. E. Control	<	10-7
L. E. Control	<	10-6
T. E. Control	<	10-6
Autoslat	<	10-5
Flap Load Relief	<	10-5
LE and TE Failure Annunciation	<	10-5
LE Control and LE Failure Annunciation	<	10-9
TE Control and TE Failure Annunciation	<	10-9

Trim Control System Dynamics (C.P.1)

The stabilizer shall operate at a constant rate in response to a trim command.

Trim system start-up and run-on equivalent time delays shall be less than 0.10 seconds.

Longitudinal Control Functional Availability Requirements (C.P.2)

The longitudinal control system shall provide the following functional availability:

Function	Probability of Loss of Function	
Pilot Control		
Enhanced mode	<	10-6
Normal Core	<	10-7
Min Acceptable Core	<	10-9
Stab Trim	<	10-7
Feel and Centering	<	10-9
Envelope Protection		
Load factor	<	10-6
Stall	<	10-6
Overspeed	<	10-6
Pitch Attitude	<	10-6
Autopilot Limiting	<	10-6
Pitch Augmentation	<	10-6

Lateral Control Functional Availability Requirements (C.R.1)

The lateral control system shall provide the following functional availability:

Function	Probability of Loss of Function	
Pilot Control		
Enhanced Mode	<	10-6
Normal Core	<	10-7
Min. Acceptable Core	<	10-9
Lateral Trim	<	10-6
Feel and Centering	<	10-9
Envelope Protection		
Bank Angle	<	10-5
Autopilot Limiting	<	10-6

Lateral Trim Control Dynamics (C.R.2)

Trim rate shall be 2.5% (TBV) max lateral control per second. Startup and run-on shall be less than 0.10 seconds.

Directional Control Functional Availability Requirements (C.Y.1)

The directional control system shall provide the following functional availability:

Function		Probability of Loss of Function
Pilot Control		
Enhanced mode	<	10-6
Normal Core	<	10-7
Min Acceptable Core	<	10-9
Directional Trim	<	10-6
Feel and Centering	<	10-9
Engine-Out Control Augmentation	<	10-6
Envelope Protection		
Sideslip Limiting	<	10-6
Autopilot Limiting	<	10-6
Rudder Position Limiting	<	10-9

Directional Trim Control Dynamics (C.Y.2)

Trim rate shall be 2.5% max rudder per second (TBV). Start-up and run-on shall be less than 0.10 seconds (TBV).

Static and Dynamic Stability Requirements (U.A.S.1)

The airplane shall be designed to have static and dynamic longitudinal characteristics as follows:

a) For normal operation the short-period damping ratio shall be $0.35 \leq \zeta_{sp} \leq 1.0$. (MIL-F-8785C 3.2.2.1.2) The phugoid mode shall be damped under normal flight conditions, i.e., divergent characteristics shall not be acceptable for normal operation. (MIL-F-8785C 3.2.1.2)

b) Positive static longitudinal stability shall be exhibited for all speeds and c.g. locations within the normal flight envelope, i.e. the airplane shall return to the approximate trim speed after a speed upset. (FAR 25.171 Conventional Control)

c) Longitudinal Stability (Maneuver Demand Control)

In lieu of compliance with the requirements of paragraphs 25.171, 25.173, 25.175, and 25.181(a) of the FAR, the airplane must be shown to have suitable dynamic and static longitudinal stability in any condition normally encountered in service, including the effects of atmospheric disturbance. (Airbus A-320 FAR Special Conditions)

d) Minimum acceptable:

Static stability is not required; however, the level of instability shall not exceed that which permits an unstable root having a time to double amplitude of less than six (6) seconds. NOTE: If minimum acceptable dutch roll damping is present, static longitudinal stability shall be neutral or positive. (MIL-F-8785C 3.2.1.1)

Flight Path Stability (U.A.S.2)

a) Conventional Control - An unstable γ vs V relationship is acceptable provided the slope $d\gamma/dV$ is no more than .06 degrees/knots. (MIL-F-8785C 3.2.1.3)

b) Maneuver Demand Control - In lieu of compliance with the requirements of paragraphs 25.171, 25.173, 25.175, and 25.181(a) of the FAR, the airplane must be shown to have suitable dynamic and static longitudinal stability in any condition normally encountered in service, including the effects of atmospheric disturbance. (Airbus A-320 FAR Special Conditions)

Static Lateral Stability (U.A.S.3)

a) The airplane shall have stable static lateral stability in rudder induced sideslips at all speeds from 1.2 V_{S1} to V_{MO}/M_{MO}. (FAR 25.177(b) Conventional Control)

b) For speeds from V_{MO}/M_{MO} to V_{FC}/M_{FC}, any tendency to divergence shall be gradual and easily recognizable and controllable by the pilot. (FAR 25.177(b) Conventional Control)

c) Lateral - Directional Stability (Maneuver Demand Control)

(1) In lieu of compliance with paragraph 25.171 of the FAR, the airplane must be shown to have suitable static lateral-directional stability in any condition normally encountered in service, including the effects of atmospheric disturbance. (Airbus A-320 FAR Special Conditions)

(2) In lieu of compliance with paragraphs 25.177(b) and 25.177(c), the following applies: In straight, steady, sideslips (unaccelerated forward slips) the rudder control movements and forces must be substantially proportional to the angle of sideslip, and the factor of proportionality must lie between limits found necessary for safe operation throughout the range of sidelip angles appropriate to the operation of the airplane. At greater angles, up to the angle at which full rudder control is used or a rudder pedal force of 180 pounds is obtained, the rudder pedal forces may not reverse and increased rudder deflection must produce increased angles of sideslip. Unless the airplane has suitable sideslip indication, there must be enough bank and lateral control deflection and force accompanying sideslipping to clearly indicate any departure from steady unyawed flight. (Airbus A-320 FAR Special Conditions)

Spiral Mode (U.A.S.4)

a) If unstable, the spiral mode time to double amplitude shall be no less than 20 seconds at all speeds from 1.2 V_{S1} to V_{FC}/M_{FC}. (BCAR, D2-8,2 - Conventional Control)

b) The airplane characteristics shall not exhibit a coupled roll-spiral mode in response to the pilot roll control commands. (MIL-F-8785C 3.3.1.4 - Conventional Control)

c) Minimum acceptable: the spiral mode time to double amplitude shall be greater than 4 seconds. (MIL-F-8785C 3.3.1.3 - Conventional Control)

Static Directional Stability (U.A.S.5)

Static directional stability shall be adequate to meet the following requirements:

a) Skid recovery from 1.2 V_{S1} to V_{FC}/M_{FC}. (FAR 25.177(a) - Conventional Control)

b) In straight, steady, sideslips the aileron and rudder control movements and forces must be substantially proportional to the angle of sideslip, and the factor of proportionality must lie between limits found necessary for safe operation throughout the range of sideslip angles appropriate to the operation of the airplane. At greater angles, up to the angle at which full rudder control is used or a rudder pedal force of 180 pounds is obtained, the rudder pedal forces may not reverse and increased rudder deflection must produce increased angles of sideslip. Unless the airplane has a yaw indicator, there must be enough bank accompanying sideslipping to clearly indicate any departure from steady unyawed flight. (FAR 25.177(c) - Conventional Control)

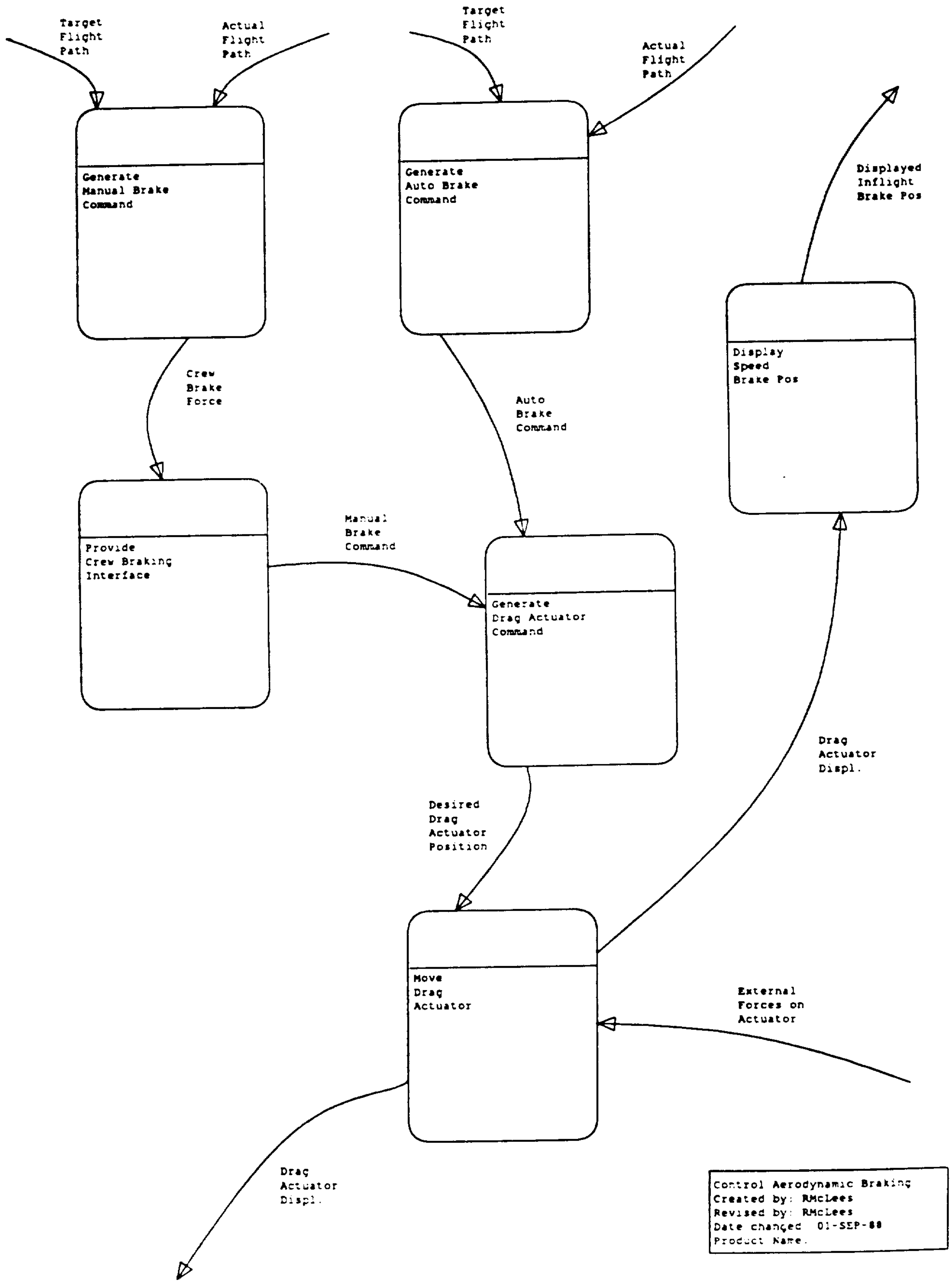
c) Lateral - Directional Stability (Maneuver Demand Control)

(1) In lieu of compliance with paragraph 25.171 of the FAR, the airplane must be shown to have suitable static lateral-directional stability in any condition normally encountered in service, including the effects of atmospheric disturbance. (Airbus A-320 FAR Special Conditions)

(2) In lieu of compliance with paragraphs 25.177(b) and 25.177(c), the following applies: In straight, steady, sideslips (unaccelerated forward slips) the rudder control movements and forces must be substantially proportional to the angle of sideslip, and the factor of proportionality must lie between limits found necessary for safe operation throughout the range of sidelip angles appropriate to the operation of the airplane. At greater angles, up to the angle at which full rudder control is used or a rudder pedal force of 180 pounds is obtained, the rudder pedal forces may not reverse and increased rudder deflection must produce increased angles of sideslip. Unless the airplane has suitable sideslip indication, there must be enough bank and lateral control deflection and force accompanying sideslipping to clearly indicate any departure from steady unyawed flight. (Airbus A-320 FAR Special Conditions)

d) At all speeds above 1.4V_S, lateral control authority shall be adequate to control the airplane without pilot use of rudder controller following a critical engine failure. Roll-control forces shall not exceed 20 pounds (centerstick controller). (MIL-F-8785C 3.3.9.4)

e) Minimum Acceptable: Directional stability shall be adequate to permit safe use of rudder to takeoff and land on dry runways in a crosswind of 20 knots or 0.2 V_{SO}, whichever is greater, except that it need not exceed 25 knots. (FAR 25.237)


Target
Flight
Path
Actual
Flight
Path
Generate
Manual Brake
Command
Target
Flight
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Actual
Flight
Path
Generate
Auto Brake
Command
Displayed
Inflight
Brake Pos
Display
Speed
Brake Pos
Crew
Brake
Force
Auto
Brake
Command
Provide
Crew Braking
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Position
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Actuator
External
Forces on
Actuator
Drag
Actuator
Displ.
Control Aerodynamic Braking
Created by: RMcLees
Revised by: RMcLees
Date changed 01-SEP-88
Product Name.

Process Descriptions
Control Aerodynamic Braking

Description	Expl name
Function which indicates to the flight crew the position of the speedbrake system and annunciates unsafe speedbrake positions and unsafe failures.	Display Speed Brake Pos
Function involving generation of the speedbrake command in an automated fashion.	Generate Auto Brake Command
Function to generate a drag actuator command based on the manual and auto braking commands.	Generate Drag Actuator Command
Function to generate the speedbrake command manually (ie by the crew).	Generate Manual Brake Command
Function to move the position of the system which provides the aerodynamic braking and lift dumping capability (spoiler/speedbrakes).	Move Drag Actuator
Function which converts the force exerted by the crew into an aerodynamic braking command.	Provide Crew Braking Interface

Data Flow Description
Control Aerodynamic Braking

Description	Expl name
Sensed 4 dimensional flight path & attitudes of the aircraft as well as any other sensed values necessary to satisfy the control requirements.	Actual Flight Path
Automatically (non-manual) generated aerodynamic braking command.	Auto Brake Command
Force exerted by crew (pilot or copilot) on the aerodynamic braking controller.	Crew Brake Force
Commanded drag actuator position.	Desired Drag Actuator Position
Indication to the crew of the speedbrake position and status.	Displayed Inflight Brake Pos
Displacement of the drag actuators (ie the speedbrakes).	Drag Actuator Displacement
All forces (in particular environmental forces) other than the actuation forces acting on the aerodynamic braking and roll actuation system.	External Forces on Actuator
Speedbrake command generated as a result of the crew exerting a force on the controller.	Manual Brake Command
Desired 4 dimensional flight path and attitudes generated by some navigation function.	Target Flight Path

Process Requirements Links
Control Aerodynamic Braking

Expl name	I-L Reference	Page
Display Speed Brake Pos	D.S.B.P.1	107
Generate Auto Brake Command	G.A.B.C.1	108
Generate Drag Actuator Command	G.D.A.C.1	109
Generate Manual Brake Command		
Move Drag Actuator	M.D.A.1	110
Provide Crew Braking Interface	P.C.B.I.1	111

Indication (D.S.B.P.1)

a) Means shall be provided to indicate to the flight crew the position of the speed brake system.

b) Annunciation of failures or system operation which could result in an unsafe condition if the crew were not aware of the condition shall be provided. (FAR 25.672)(a)

c) Annunciation to the crew (in the form of an aural warning) shall be provided for speedbrake deployment for the following condition: Take-off power and airplane on ground. (FAR 25.703)(a)

Automatic Speed Brake Control (G.A.B.C.1)

a) Automatic speed brake control shall be available for on-ground operation.

b) Automatic speed brake extension shall occur for the following conditions:

   1) At landing touchdown if the pilot has armed the system.
   2) At take-off if an RTO is conducted.

c) The automatic ground speed brake system shall retract the spoilers and reset the speed brake control when the throttles are advanced to takeoff power.

Aerodynamic Braking Control Requirements (G.D.A.C.1)

a) The system shall maintain its selected position, except for movement produced by an automatic positioning or load limiting device, without further attention by the flight crew.

b) Control surface deflection for devices used both in-flight and on the ground shall be proportional to speed brake lever command.

c) Ground-only speed brake devices shall be inhibited from operating in-flight with speed brakes deployed. Operation shall only be possible when the airplane is in positive contact with the ground. (FAR 25.697(b))

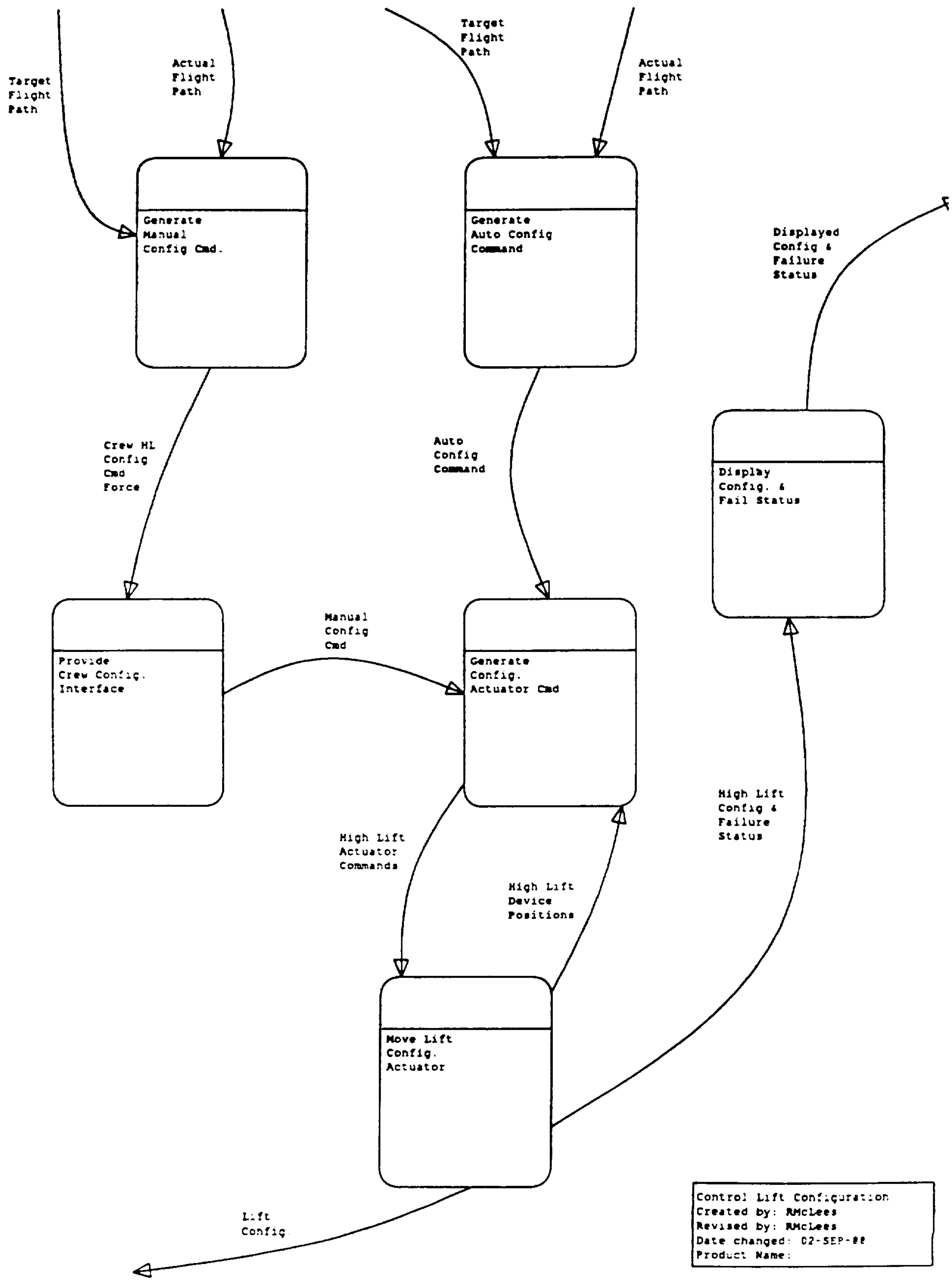
Speed Brake Actuation (M.D.A.1)

It shall be possible to position all speed brakes in the fully extended or fully retracted position on the ground.

All ground speedbrakes shall be capable of maximum deflection at the maximum refused takeoff speed.

Crew to Aerodynamic Braking Interface (P.C.B.I.1)

The controller shall be designed to make inadvertent operation improbable and it shall not creep.


Target Flight Path
Actual Flight Path
Target Flight Path
Actual Flight Path
Generate Manual Config Cmd.
Generate Auto Config Command
Displayed Config & Failure Status
Crew HL Config Cmd Force
Auto Config Command
Display Config. & Fail Status
Manual Config Cmd
Provide Crew Config. Interface
Generate Config. Actuator Cmd
High Lift Config & Failure Status
High Lift Actuator Commands
High Lift Device Positions
Move Lift Config. Actuator
Lift Config.
Control Lift Configuration
Created by: RMcLees
Revised by: RMcLees
Date changed: 02-SEP-88
Product Name:

Process Descriptions
Control Lift Configuration

Description	Expl name
Display to the crew the position of the high lift devices and annunciate any high lift device failure conditions.	Display HL Config & Fail Status
Generate the high lift configuration command in an automated fashion (ie by a computer system).	Generate Auto Config Command
Generate high lift configuration actuator commands based on the manual and auto configuration commands and the sensed high lift device positions.	Generate Config. Actuator Cmd
Generation of the high lift configuration command in a manual fashion (ie by the crew).	Generate Manual Config Cmd.
Actuation of the high lift devices (ie the leading edge & trailing edge flaps).	Move Lift Config. Actuator
Interface which allows the crew to input commands to the high lift system.	Provide Crew Config Interface

Data Flow Description
Control Lift Configuration

Description	Name
The sensed 4 dimensional flight path & attitudes of the aircraft as well as any other sensed values necessary to satisfy the control requirements.	Actual Flight Path
The automatically generated commands for the leading edge and trailing edge high lift devices.	Auto Config Command
This is the force exerted by the crew to generate the manual high lift configuration command.	Crew HL Config Cmd Force
Crew displayed high lift device positions and failure status annunciation.	Displayed Config & Failure Statu
Commands to the various actuators which move the leading edge and trailing edge flaps.	High Lift Actuator Command
Sensed positions of the leading edge and trailing edge high lift positions.	High Lift Device Positions
Position of leading edge and trailing edge high lift devices and failure status of the high lift devices.	High Lift Config & Failure Statu
Configuration of lift system to achieve necessary lift to support desired flight path angle at all mission phases (speeds and altitudes). The record consists of the leading edge and trailing edge wing positions.	Lift Configuration
Manual high lift configuration command.	Manual Config Cmd
The desired 4 dimensional flight path and attitudes generated by the navigation function.	Target Flight Path

Process Requirements Links
Control Lift Configuration

Expl name	I-L Reference	Page
Display HL Config & Fail Status	D.HL.C.F.S.1	114
Generate Auto Config Command	G.A.C.C.1	115
Generate Config. Actuator Cmd	G.C.A.C.1	116
Generate Manual Config Cmd.		
Move Lift Config. Actuator	M.L.C.A.1 M.L.C.A.2	117 118
Provide Crew Config Interface	P.C.C.I.1	119

Position Indication and Warning (D.HL.C.F.S.1)

a) There shall be positive indication of the position of the left and right trailing edge and leading edge flaps. The indicator shall give clear indication of the degree of asymmetry between corresponding left and right flap segments. (FAR 25.699)(a)

b) Monitoring shall be provided to detect and annunciate the following to the flight crew: (FAR 25.699)(a)

1) Uncommanded motion of the leading edge or trailing edge high lift devices.
2) Failure to go to a commanded position.
3) Asymmetry between corresponding left and right LE/TE devices.

c) There must be means to indicate to the pilots the takeoff, en route, approach, and landing lift device positions. (FAR 25.699)(b)

d) If any extension of the lift and drag devices beyond the landing position is possible, the control must be clearly marked to identify the range of extension. (FAR 25.699)(c)

e) A takeoff warning system must be installed and must meet the following requirements: (FAR 25.703)

(1) The system must provide to the pilots an aural warning that is automatically activated during the initial portion of the takeoff roll if the airplane is in a configuration, including the following that would not allow a safe takeoff: The wing flaps or leading edge devices are not within the approved range of takeoff positions.

(2) The warning required by paragraph (1) of this section must continue until-
(i) The configuration is changed to allow a safe takeoff;
(ii) Action is taken by the pilot to terminate the takeoff roll;
(iii) The airplane is rotated for takeoff; or
(iv) The warning is manually deactivated by the pilot.

(3) The means used to activate the system must function properly throughout the ranges of takeoff weights, altitudes, and temperatures for which certification is requested.

Automatic High Lift Control (G.A.C.C.1)

A flap load alleviation function shall be provided that automatically limits the loads that can be applied to the trailing edge flaps. The flap load alleviation function shall satisfy the following requirements.

1) Operate at an adequate margin from normal operating speeds.

2) Preserve the stall warning schedule with flap deflection.

3) Not inhibit normal operation of the flap position indicator. (FAR 25.699(a))

4) The rate of motion of the surfaces in response to the operation of the control and the characteristics of the automatic positioning or load limiting device must give satisfactory flight and performance characteristics under steady or changing conditions of airspeed, engine power, and airplane attitude. (FAR 25.697(c))

Leading Edge and Trailing Edge Control (G.C.A.C.1)

Each lift device control must be designed so that the pilots can place the device in any takeoff, en route, approach, or landing position established under FAR 25.101(d). Lift and drag devices must maintain the selected positions, except for movement produced by an automatic positioning or load limiting device, without further attention by the pilots. (FAR 25.697(a))

Each lift and drag device control must be designed and located to make inadvertent operation improbable. Lift and drag devices intended for ground operation only must have means to prevent the inadvertent operation of their controls in flight if that operation could be hazardous. (FAR 25.697(b))

Trailing Edge Flaps (M.L.C.A.1)

M.L.C.A.1.1 Flap Positioning Flexibility

The flap drive system shall be capable of positioning the flaps at any takeoff, en route, approach, or landing position. (FAR 25.697)

M.L.C.A.1.2 Flap Asymmetry

The motion of trailing edge devices on opposite sides of the plane of symmetry shall be synchronized, unless the airplane has safe flight characteristics with the devices retracted on one side and extended on the other. (FAR 25.701)

M.L.C.A.1.3 Flap Actuation Flight Conditions

Trailing edge flap retraction shall be possible during steady state flight at maximum continuous engine power at all speeds below V_{FE} + 9 knots. (FAR 25.697(d)).

Leading Edge High Lift Devices (M.L.C.A.2)

M.L.C.A.2.1 Leading Edge High Lift Device Extension Requirements

The leading edge device drive system shall be capable of positioning the leading edge devices at any takeoff, en route, approach, or landing position. (FAR 25.697)

M.L.C.A.2.2 Leading Edge Device Actuation Flight Conditions

Leading edge flap retraction shall be possible during steady state flight at maximum continuous engine power at all speeds below V_{FE} + 9 knots. (FAR 25.697(d))

M.L.C.A.2.3 Leading Edge Actuation Flight Conditions

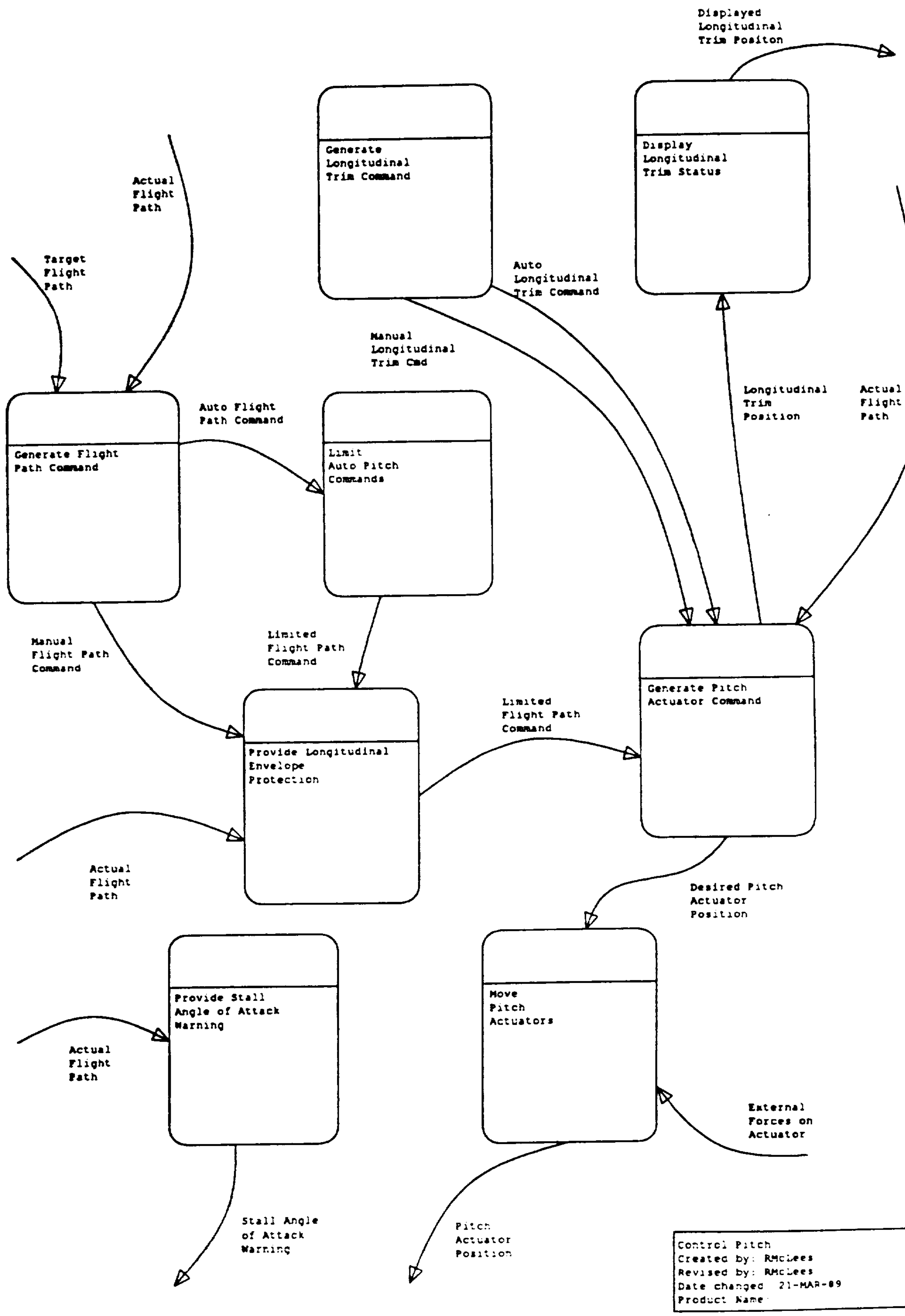
The leading edge devices shall be designed to permit deployment in icing conditions. (FAR 25.1419)

M.L.C.A.2.4 Flap Asymmetry

The motion of leading edge devices on opposite sides of the plane of symmetry shall be synchronized by a mechanical interconnection or equivalent asymmetry monitor unless the airplane has safe flight characteristics with the devices retracted on one side and extended on the other. (FAR 25.701)

Manual High Lift Control (P.C.C.I.1)

Means shall be provided to select specific flap positions (FAR 25.697 (a)). Gates shall be provided on the controller at the go-around flap setting (ACJ 25.697 (a)) and at the position just prior to full retraction of the leading edge devices.


Displayed Longitudinal Trim Positon
Generate Longitudinal Trim Command
Display Longitudinal Trim Status
Actual Flight Path
Target Flight Path
Auto Longitudinal Trim Command
Manual Longitudinal Trim Cmd
Auto Flight Path Command
Longitudinal Trim Position
Actual Flight Path
Generate Flight Path Command
Limit Auto Pitch Commands
Manual Flight Path Command
Limited Flight Path Command
Limited Flight Path Command
Generate Pitch Actuator Command
Provide Longitudinal Envelope Protection
Actual Flight Path
Desired Pitch Actuator Position
Provide Stall Angle of Attack Warning
Move Pitch Actuators
Actual Flight Path
External Forces on Actuator
Stall Angle of Attack Warning
Pitch Actuator Position
Control Pitch
Created by: RMcLees
Revised by: RMcLees
Date changed 21-MAR-89
Product Name

Process Descriptions
Control Pitch

Description	Expl name
This function displays the longitudinal trim status to the crew.	Display Longitudinal Trim Posit.
This function generates trim commands to offload steady state pitch commands from the elevator to the stabilizer.	Generate Longitudinal Trim Cmd
This function compares the actual flight path angle to the desired flight path angle and generates the necessary flight path angle command.	Generate Flight Path Command
This function generates the pitch actuator (elevator & stabilizer) position commands based on the flight path angle and longitudinal trim commands.	Generate Pitch Actuator Command
This function limits the autopilot control authority and protects against failures (in particular hardover and oscillatory failures) in the autopilot.	Limit Auto Pitch Commands
This function receives the desired pitch actuators positions and attempts to move the actuators to those positions.	Move Pitch Actuators
This function monitors the aircraft states and modifies the flight path angle command as necessary to satisfy the longitudinal envelope protection requirements.	Provide Long. Envelope Protect
This function monitors the aircraft flight path state vector and attitudes and generates a warning for the crew when approaching the aircraft stall angle of attack.	Provide Stall AOA Warning

Data Flow Description
Control Pitch

Description	Name
The sensed 4 dimensional flight path & attitudes of the aircraft as well as any other sensed values necessary to satisfy the control requirements.	Actual Flight Path
Flight path command generated in an automated fashion (ie by a computer system).	Auto Flight Path Command
Longitudinal trim command generated automatically during enhanced manual control and autoflight control.	Auto Longitudinal Trim Command
The desired pitch actuator (elevator) position such that the limited flight path angle command is achieved.	Desired Pitch Actuator Position
This flow is the longitudinal trim position displayed to the crew.	Displayed Longitudinal Trim Pos
All forces (in particular environmental forces) other than the actuation forces acting on the pitch actuator.	External Forces on Pitch Actuato
The automatically generated flight path command limited to the autoflight pitch authority.	Limited Auto Flight Path Command
The flight path command limited such that envelope protection is not violated.	Limited Flight Path Command
Position of the longitudinal trim actuator.	Longitudinal Trim Position
Flight path angle command generated manually (ie by the crew).	Manual Flight Path Command
The longitudinal trim command generated by the crew for use during normal and backup control.	Manual Longitudinal Trim Command
Position of the actuator(s) which provide aircraft pitch maneuver and trim control.	Pitch Actuator Position
This flow is the audible and visual indication to the crew that the aircraft is approaching the stall angle of attack.	Stall Angle of Attack Warning
The desired 4 dimensional flight path and attitudes generated by some navigation function.	Target Flight Path

Process Requirements Links
Control Pitch

Expl name	I-L Reference	Page
Display Longitudinal Trim Posit.		
Generate Flight Path Command		
Generate Longitudinal Trim Cmd		
Generate Pitch Actuator Command		
Limit Auto Pitch Commands	L.A.P.C.1	123
Move Pitch Actuators		
Provide Long. Envelope Protect	P.L.E.P.1	124
	P.L.E.P.2	125
Provide Stall AOA Warning	P.S.A.W.1	126

Pitch Autopilot Control and Limiting (L.A.P.C.1)

a) The core longitudinal control shall provide autopilot control authority limiting and actuation for fail-safe operation and Cat IIIb autoland operation.

b) Maximum autopilot maneuver authority shall not result in the following conditions, assuming a pilot delay in initiating recovery from any system malfunction: (FAR 25.1329 & FAA Advisory Circular 25.1329-1A)

1) Speeds beyond V_{FC}/M_{FC}.
2) Structural loads in excess of limit loads due to hardover or oscillatory failures.
3) Airplane stall.
4) Dangerous dynamic conditions or deviations from the flight path.
5) Load factor response in excess of +1.0 g incremental.

The pilot delay from malfunction recognition to initiation of corrective action shall be 3 seconds for normal climb, cruise, and descent, and 1 second for normal maneuvering flight (turning flight) and during low approaches. (FAA Advisory Circular 25.1329-1A)

Enhanced Control Longitudinal Envelope Protection (P.L.E.P.1)

Envelope protection functions shall be provided to assist the pilot or autopilot in preventing the airplane from exceeding normal operating envelope boundaries. The basic FCS shall include protection for stall, load factor, pitch attitude, overspeed, sideslip and roll angle boundaries. The envelope protection limits are TBD.

Automated Envelope Protection (P.L.E.P.2)

Automated envelope protection shall be provided to relieve pilot workload and shall have a probability of loss of function < 10E-06.

Stall Angle of Attack Warning (P.S.A.W.1)

A tactile and/or audible warning of an impending stall shall be provided. Stall Warning shall be provided for all selectable flap/slat configurations and for high lift system failures. The stall warning function is required for dispatch and shall be available after loss of one engine or electrical generator. Stall warning system reference angles of attack and system design shall be such as to minimize nuisance warnings and provide normal maneuver capability.

P.S.A.W.1.1 Normal Operation

"Normal" stall warning, for normal LE/TE configurations, shall:

a) Provide a stall speed warning margin of at least 7 percent to the certified FAR stall speed. (FAR 25.207)

b) Occur prior to "normal 1-g stall speed". The "normal 1-g stall speed" is defined as the minimum 1-g corrected flight speed at which nW/qS becomes a maximum value during an idle thrust, 1 knot/sec entry rate, stall demonstration maneuver.

c) Not occur within the following maneuver envelope:

1) $\phi \leq 40$ deg with flaps up at enroute climb speed, 1 engine out

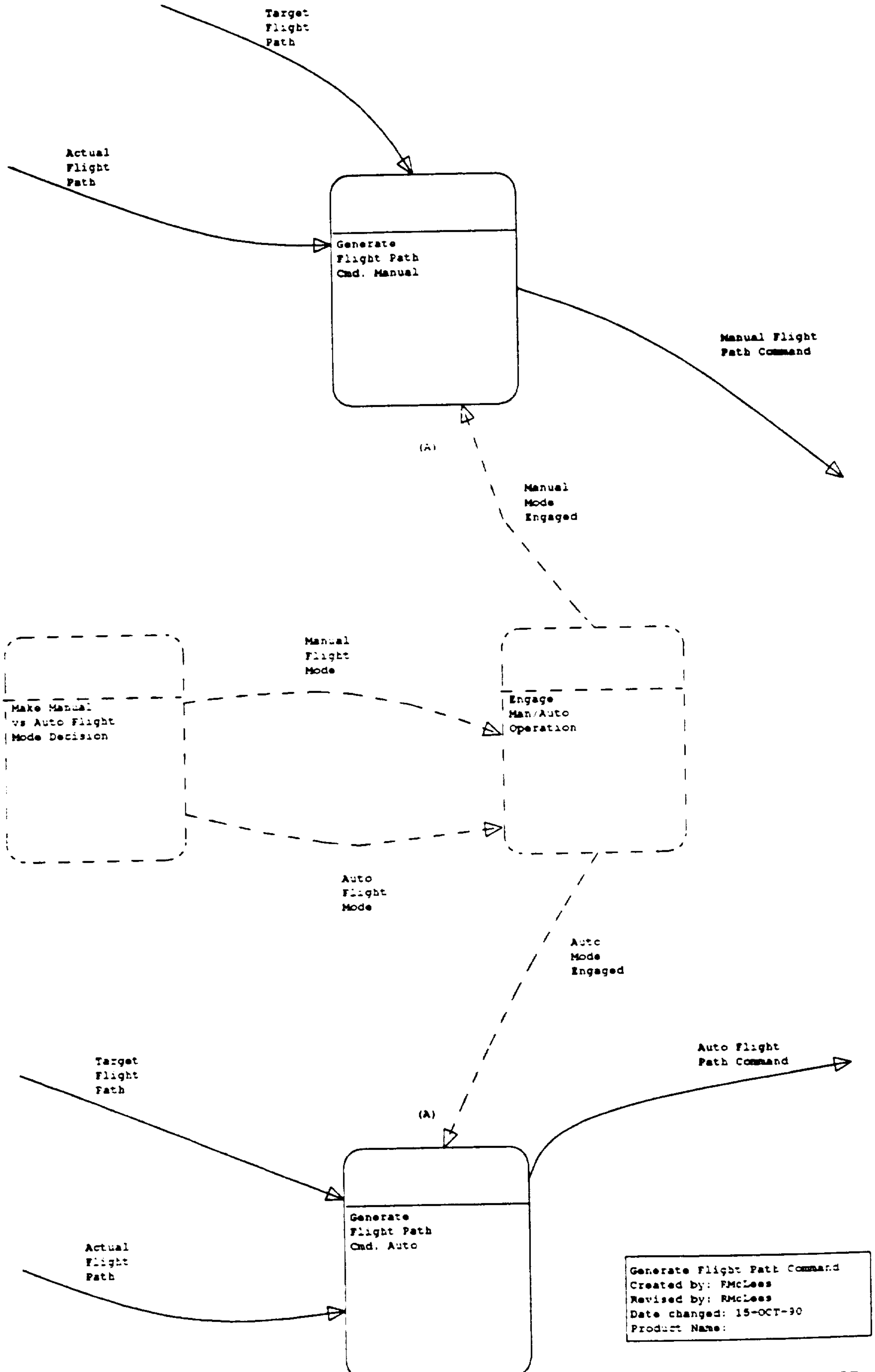
2) $\phi \leq 30$ deg with takeoff flaps at V_2 speed, 1 engine out

3) $\phi \leq 40$ deg with approach and landing flaps at approach speed (1.3 V_S)

where ϕ = bank angle in a level flight balanced turn with no pilot rudder input and power for level flight in the turn. (FAA Issue Paper F-3)

P.S.A.W.1.2 Operation with High Lift System Failures

Stall warning and crew annunciation for failed L.E./T.E. configurations, for which failure of high lift surface element/elements is not shown to be extremely improbable, shall be provided.


Target
Flight
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Mode
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Target
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Auto Flight
Path Command
(A)
Generate
Flight Path
Cmd. Auto
Actual
Flight
Path
Generate Flight Path Command
Created by: RMcLees
Revised by: RMcLees
Date changed: 15-OCT-90
Product Name:

Process Descriptions
Generate Flight Path Command

Description	Expl name
Function to generate a flight path angle command automatically (ie by a computer) as a result of the difference between the actual and target flight paths.	Generate Flight Path Cmd Auto
This function involves the generation of a flight path command manually (ie be the crew) as a result of comparing the target and actual flight paths.	Generate Flight Path Cmd Manual

Control Process Descriptions
Generate Flight Path Command

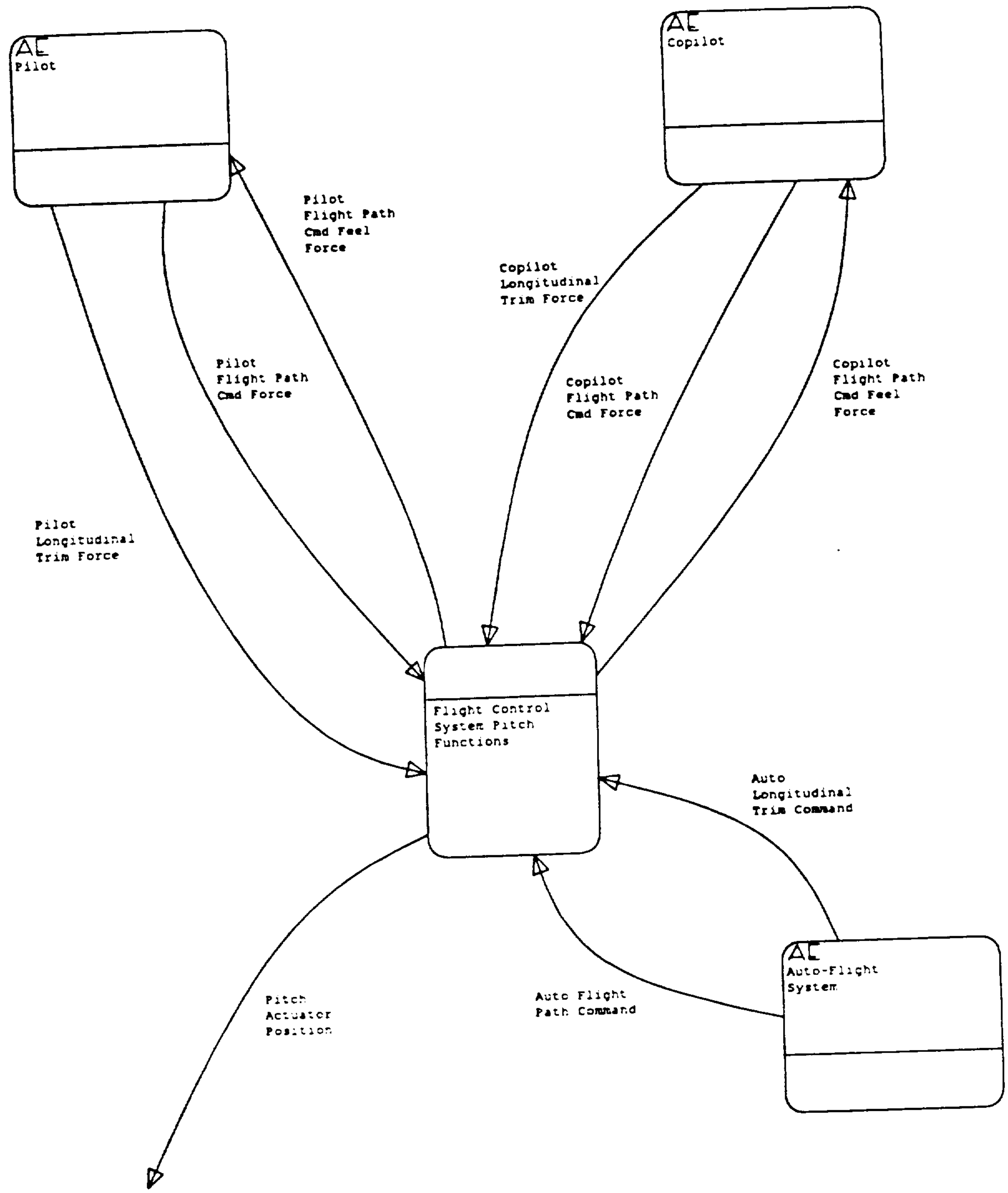
Description	Expl name
This function activates one of the flight path command generation processes depending on the mode engaged.	Engage Man/Auto Operation (FP)
This function decides whether to generate flight path commands manually or automatically.	Make Manual/Auto Flight Decision

Data Flow Description
Generate Flight Path Command

Description	Name
The sensed 4 dimensional flight path & attitudes of the aircraft as well as any other sensed values necessary to satisfy the control requirements.	Actual Flight Path
Flight path command generated in an automated fashion (ie by a computer system).	Auto Flight Path Command
Flight path angle command generated manually (ie by the crew).	Manual Flight Path Command
The desired 4 dimensional flight path and attitudes generated by some navigation function.	Target Flight Path

Process Architectural Assignments
Generate Flight Path Command

Expl name	associated aes
Generate Flight Path Cmd Auto	Auto-Flight System
Generate Flight Path Cmd Manual	Pilot Copilot



Flight Cntrl Sys Pitch Context
Created by: RMcLees
Revised by: RMcLees
Date changed: 01-SEP-88
Product Name:

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Process Descriptions
Flight Cntrl Sys Pitch Context

Description	Expl name
This function contains all the flight control functions assigned to the FCS. As a result of this assignment several new functions are created. Some of these are interface functions and others are as a result of how functions were allocated to AEs. (ie. Envelope Protection was assigned to the FCS with a probability of failure <10E-6. However this function requires <10E-9. Therefore the pilot & copilot must perform envelope protection when not being performed by the FCS. Thus a pilot indication function of the status of envelope protection is generated.) Pilot & copilot can command roll rate, thus there is a functional req. to resolve control contention.	Flight Cntrl Sys Pitch Functns

Data Flow Description
Flight Cntrl Sys Pitch Context

Description	Name
Flight path command generated in an automated fashion (ie by a computer system).	Auto Flight Path Command
Longitudinal trim command generated automatically during enhanced manual control and autoflight control.	Auto Longitudinal Trim Command
This flow is a resistance force exerted by the controller which is a feedback to the copilot indicative of the flight path angle command.	Copilot Flight Path Cmd Feel For
This flow is the physical force generated by the copilot to control the aircraft flight path angle. It is in the form of a force exerted by the pilot's hand.	Copilot Flight Path Cmd Force
This is the physical force exerted by the copilot's hand to generate the desired longitudinal trim command.	Copilot Longitudinal Trim Force
The physical signal created by the pilot to control the aircraft flight path. It is in the form of a force exerted by the pilot.	Pilot Flight Path Cmd Force
This flow is a resistance force exerted by the controller which is a feedback to the pilot indicative of the flight path command.	Pilot Flight Path Feel Force
This flow is the physical force exerted by the pilot's hand to generate the desired longitudinal trim command.	Pilot Longitudinal Trim Force
Position of the actuator(s) which provide aircraft pitch maneuver and trim control.	Pitch Actuator Position

Process Requirements Links
Flight Cntrl Sys Pitch Context

Expl name	I-L Reference	Page
Flight Cntrl Sys Pitch Functns	F.C.S.P.F.1	131
	F.C.S.P.F.2	132

Pilot and co-pilot contention resolution (F.C.S.P.F.1)

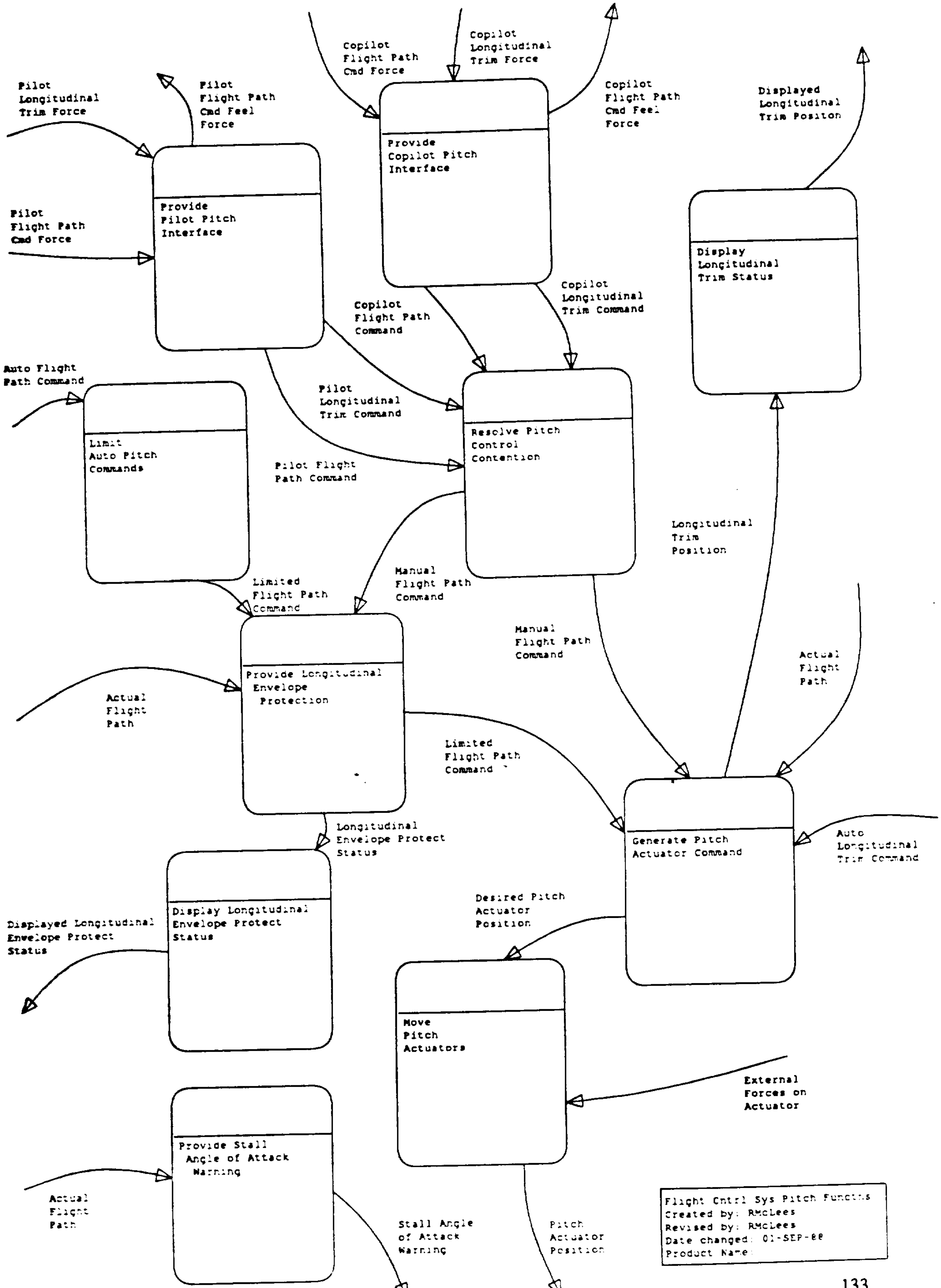
Pilot and co-pilot longitudinal control contention shall be resolved.

(This functional requirement arises because the generate manual flight path command was assigned to both the pilot and copilot AEs)

Envelope Protection Mode Indication and Alert (F.C.S.P.F.2)

Indication shall be provided to inform the pilot when an envelope protection mode has become active. An alert indication shall inform the pilot of loss of an envelope protection function. The loss of an envelope protection function and the failure to inform the pilot of the loss shall be extremely improbable. (FAR 25.672(a))

(This functional requirement was generated because the pilot is responsible for envelope protection when not provided automatically.)



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Process Descriptions
Flight Cntrl Sys Pitch Functns

Description	Expl name
This transform displays the longitudinal trim status to the crew.	Display Longitudinal Trim Posit.
This transform results from the allocation of Provide Longitudinal Envelope Protection to the FCS with a probability of loss of function of <10E-6. Pitch envelope protection has a req for probability of loss of function <10E-9 and thus the crew has responsibility for pitch envelope protection when not performed by the FCS. Thus the crew must be aware of envelope protect status, hence the functional requirement to Display Longitudinal Envelope Protect Status.	Display Pitch Envlp Protct Stats
This process generates the pitch actuator (elevator & stabilizer) position commands based on the flight path angle and longitudinal trim commands.	Generate Pitch Actuator Command
This function limits the autopilot control authority and protects against failures (in particular hardover and oscillatory failures) in the autopilot.	Limit Auto Pitch Commands
This transform receives the desired pitch actuators positions and attempts to move the actuators to those positions.	Move Pitch Actuators
This transform provides the same capability for the copilot as the Provide Pilot Pitch Interface does for the pilot.	Provide Copilot Pitch Interface
This transform converts the signal received from the pilot in the form of a force exerted by the pilot into a flight path angle command signal to be used by the FCS. It also provides the pilot with a feedback feel force indicative of the command.	Provide Pilot Pitch Interface
This transform monitors the aircraft states and modifies the flight path angle command as necessary to satisfy the longitudinal envelope protection requirements.	Provide Long. Envelope Protect
This function monitors the aircraft flight path state vector and attitudes and generates a warning for the crew when approaching the aircraft stall angle of attack.	Provide Stall AOA Warning
This transform was generated by the assignment of the Generate Flight Path Command Manual to both the pilot & copilot.	Resolve Pitch Control Contention

Data Flow Description
Flight Cntrl Sys Pitch Functns

Description	Name
The sensed 4 dimensional flight path & attitudes of the aircraft as well as any other sensed values necessary to satisfy the control requirements.	Actual Flight Path
Flight path command generated in an automated fashion (ie by a computer system).	Auto Flight Path Command
Longitudinal trim command generated automatically during enhanced manual control and autoflight control.	Auto Longitudinal Trim Command
This flow is a resistance force exerted by the controller which is a feedback to the copilot indicative of the flight path angle command.	Copilot Flight Path Cmd Feel For
This flow is the physical force generated by the copilot to control the aircraft flight path angle. It is in the form of a force exerted by the pilot's hand.	Copilot Flight Path Cmd Force
Numeric value of the copilot flight path command obtained from the Copilot Flight Path Cmd Force.	Copilot Flight Path Command
Numeric value of the copilot longitudinal trim command obtained from the Copilot Longitudinal Trim Force.	Copilot Longitudinal Trim Cmd
This is the physical force exerted by the copilot's hand to generate the desired longitudinal trim command.	Copilot Longitudinal Trim Force
The desired pitch actuator (elevator) position such that the limited flight path angle command is achieved.	Desired Pitch Actuator Position
This flow is the longitudinal trim position displayed to the crew.	Displayed Longitudinal Trim Pos
The status of the longitudinal envelope protection function assigned to the FCS.	Dsplyd Long. Envlp Protct Status

Data Flow Description
Flight Cntrl Sys Pitch Functns

Description	Name
All forces (in particular environmental forces) other than the actuation forces acting on the aerodynamic braking system.	External Forces on Pitch Actuato
The automatically generated flight path command limited to the autoflight pitch authority.	Limited Auto Flight Path Command
The flight path command limited such that envelope protection is not violated.	Limited Flight Path Command
Activity and availability of the longitudinal envelope protection function.	Longitudinal Envlop Protect Stat
Position of the longitudinal trim actuator.	Longitudinal Trim Position
Flight path angle command generated manually (ie by the crew).	Manual Flight Path Command
The physical signal created by the pilot to control the aircraft flight path. It is in the form of a force exerted by the pilot.	Pilot Flight Path Cmd Force
Numeric value of the pilot's flight path angle command obtained from the Pilot Flight Path Cmd Force.	Pilot Flight Path Command
This flow is a resistance force exerted by the controller which is a feedback to the pilot indicative of the flight path command.	Pilot Flight Path Feel Force
Numeric value of the pilot's longitudinal trim command obtained from the Pilot Longitudinal Trim Force.	Pilot Longitudinal Trim Command
This flow is the physical force exerted by the pilot's hand to generate the desired longitudinal trim command.	Pilot Longitudinal Trim Force
Position of the actuator(s) which provide aircraft pitch maneuver and trim control.	Pitch Actuator Position
This flow is the audible and visual indication to the crew that the aircraft is approaching the stall angle of attack.	Stall Angle of Attack Warning

Process Requirements Links
Flight Cntrl Sys Pitch Functns

Expl name	I-L Reference
Display Longitudinal Trim Posit.	
Display Pitch Envlp Protct Stats	
Generate Pitch Actuator Command	
Limit Auto Pitch Commands	L.A.P.C.1
Move Pitch Actuators	
Provide Copilot Pitch Interface	
Provide Long. Envelope Protect	P.L.E.P.1 P.L.E.P.2
Provide Pilot Pitch Interface	
Provide Stall AOA Warning	P.S.A.W.1
Resolve Pitch Control Contention	R.P.C.C.1

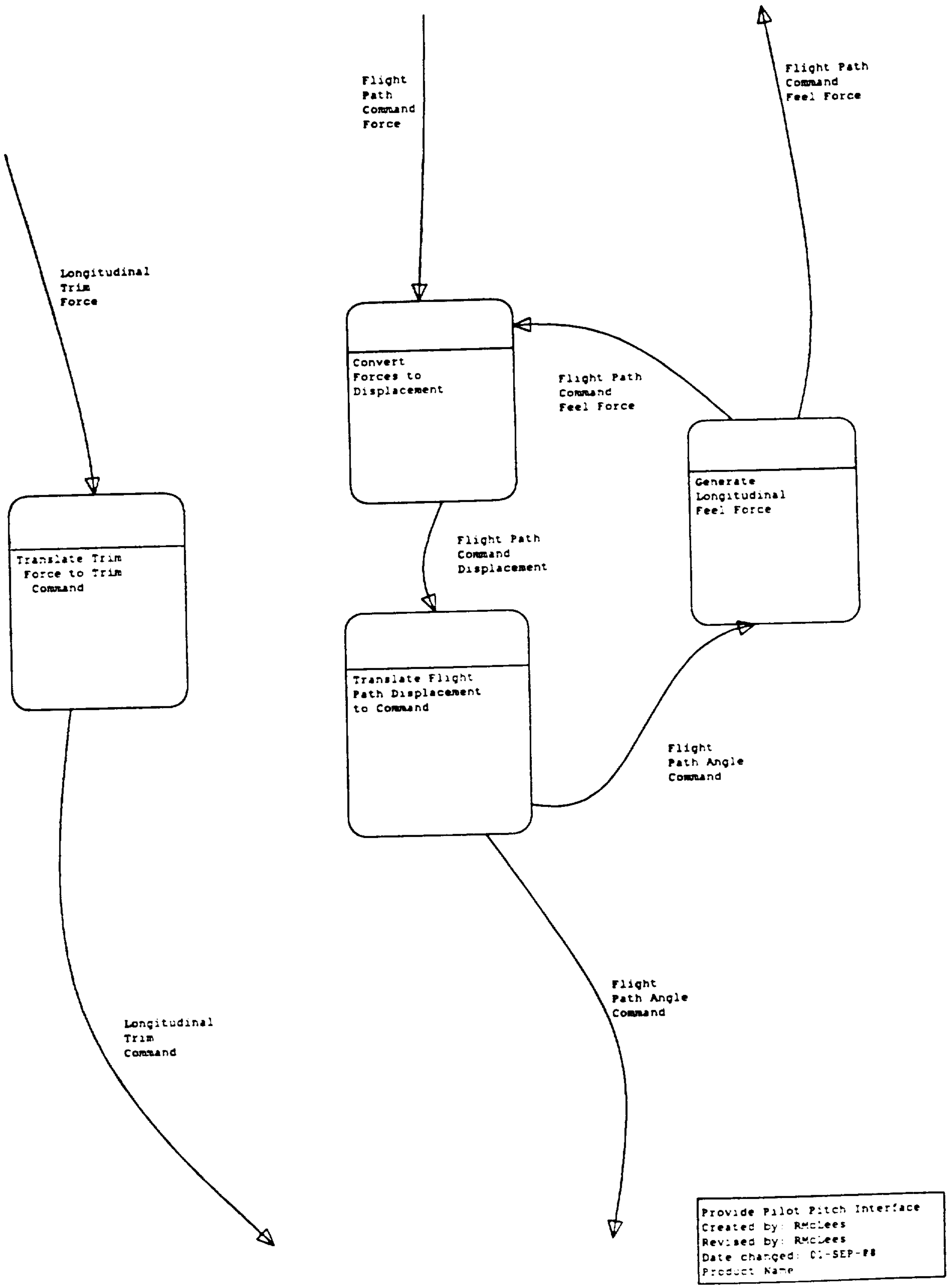
Pilot and co-pilot contention resolution (R.P.C.C.1)

Pilot and co-pilot longitudinal control contention for sidestick controllers shall be resolved as follows.

a) Pilot and copilot commands of same sign chose larger command.

b) Pilot and copilot commands of opposite sign add commands algebraically.

c) In the event of a controller jam the function shall operate as though the jammed controller were in the detent position.


Flight Path Command Force
Flight Path Command Feel Force
Longitudinal Trim Force
Convert Forces to Displacement
Flight Path Command Feel Force
Generate Longitudinal Feel Force
Translate Trim Force to Trim Command
Flight Path Command Displacement
Translate Flight Path Displacement to Command
Flight Path Angle Command
Flight Path Angle Command
Longitudinal Trim Command
Provide Pilot Pitch Interface
Created by: RMcLees
Revised by: RMcLees
Date changed: 01-SEP-88
Product Name

Process Descriptions
Provide Pilot Pitch Interface

Description	Expl name
This transform translates the physical displacement of the pitch controller into a flight path command.	Translate Flight Path Displ-Cmd
This transform generates a force to feedback to the pilot which is indicative of the pitch maneuver and trim commands.	Generate Flight Path Feel Force
This transform converts the physical displacement generated by the physical force exerted by the pilot into a trim command for use by the FCS.	Translate Long Trim Force to Cmd
This transform receives the pilot force and feedback feel force and generates a displacement.	Convert Flight Path Forces-Displ

Data Flow Description
Provide Pilot Pitch Interface

Description	Name
Numeric value of the manual flight path angle command obtained from the flight path angle controller displacement.	Flight Path Angle Command
This flow is the flight path angle command in the form of the controller displacement.	Flight Path Command Displacement
This flow is the resistance force exerted by the controller which is a feedback to the pilot indicative of the flight path command.	Flight Path Command Feel Force
This is the physical signal created by the crew (pilot/copilot) to control the aircraft flight path angle. It is in the form of a physical force exerted by the pilot.	Flight Path Command Force
Numeric value of the pilot's longitudinal trim command obtained from the pilots longitudinal trim command force.	Longitudinal Trim Command
The physical force generated by the pilot to generate the desired longitudinal trim.	Longitudinal Trim Force

Process Requirements Links
Provide Pilot Pitch Interface

Expl name	I-L Reference
Convert Flight Path Forces-Displ	C.F.P.F.1
Generate Flight Path Feel Force	G.F.P.F.F.1 G.F.P.F.F.2 G.F.P.F.F.3
Translate Flight Path Displ-Cmd	
Translate Long Trim Force to Cmd	T.L.T.F.C.1

Longitudinal Controller Deflection Rates (C.F.P.F.1)

No force discontinuities or other objectionable characteristics shall occur for all controller command rates.

Longitudinal Feel Forces (G.F.P.F.F.1)

G.F.P.F.F.1.1 Breakout Forces

Sidestick controller breakout force shall be within 0.5 to 5.0 lbs for normal operation. Minimum acceptable: Sidestick controllers shall have a breakout force range of 0.5 lbs to 10.0 lbs. (MIL-F-8785C 3.5.2.1 Class III)

G.F.P.F.F.1.2 Maneuvering Controller Forces

1) At constant speed in steady turning flight, pullups and pushovers, the variation in pitch controller force with steady-state normal acceleration shall have no objectionable nonlinearities within the following load factor range:

Minimum	Maximum
0.5	$0.5[n_{o}(+) + 1]$

where $n_o(+)$ = maximum service positive load factor.
Outside this range, a departure from linearity resulting in a local gradient which differs from the average gradient for the maneuver by more than 50 percent is considered excessive, except that larger increases in force gradients are permissible at load factors greater than 0.85 n_{LIMIT}. (MIL-F-8785C 3.2.2.2.1)

2) All local force gradients shall be within the following limits:

	Minimum Gradient	Maximum Gradient
Centerstick	3.0 lbs/g	28.0 lbs/g
Wheel Controller	35.0 lbs/g	120.0 lbs/g

In addition the force gradient should be near the upper boundary for combinations of high frequency and low damping. (MIL-F-8785C 3.2.2.2.1)

G.F.P.F.F.1.3 Configuration Change Controller Forces

a) The longitudinal trim changes caused by changes in power, flap setting, landing gear operation, deceleration devices, etc., should not be so large that peak longitudinal control forces in excess of 10 lbs for center stick controller or 50 lbs for wheel controller push or pull are required for compensation under normal flight conditions. This objective shall apply to a time interval of at least 5 seconds following the completion of the pilot action initiating the configuration change. (MIL-F-8785C 3.6.3.1) (FAR 25.145(b))

G.F.P.F.F.1.4 Speed Change Controller Forces

a) The average gradient of the stable slope of the stick force versus speed curve may not be less than 1 pound for each 6 knots for the conditions specified in FAR 25.175. (FAR 25.173(c)) For a sidestick controller the value is 0.5 lb per 6 knots (1/2 the value of conventional controllers).

b) There may be no control reversal about any axis at any speed up to VDF/MDF. Any reversal of elevator control force or tendency of the airplane to pitch, roll, or yaw must be mild and readily controllable, using normal piloting techniques. (FAR 25.253(a)(3))

G.F.P.F.F.1.5 Mistrim Maneuvering Forces

In the out-of-trim condition specified below, it must be possible from an overspeed condition at VDF/MDF to produce at least 1.5 g for recovery by applying not more than 125 pounds for wheel controller or 60 pounds for centerstick (1/2 the value of conventional controllers) using the primary longitudinal control. (FAR 25.255(f))

From an initial condition with the airplane trimmed at cruise speeds up to VMO/MMO, obtain the most out-of-trim nose-up and nose-down conditions resulting from the greater of-(FAR 25.255(a))

1) A three second movement of the longitudinal trim system at its normal rate for the particular flight condition with no aerodynamic load, except as limited by stops in the trim system or;

2) The maximum mistrim that can be sustained by the autopilot while maintaining level flight in the high speed cruising condition.

G.F.P.F.F.1.6 Controller Forces - Stall

The longitudinal control force must be positive up to and throughout the stall. (FAR 25.203)

G.F.P.F.F.1.7 Dynamic Control Forces

a) The buildup of control forces during maneuver entry shall not lag the buildup of normal acceleration at the pilot's location. In addition, the frequency response of normal acceleration at the pilot station to pitch control force input shall be such that the inverse amplitude is greater than the following at frequencies greater than 1.0 rad/sec: (MIL-F-8785C 3.2.2.3.1)

	NORMAL	MINIMUM ACCEPTABLE
ONE-HANDED CONTROLLERS (lbs/g)	$\frac{14}{n_{LIMIT} - 1}$	$\frac{8}{n_{LIMIT} - 1}$

Enhanced Control Maneuver Control Forces (G.F.P.F.F.2)

a) Sidestick Force per g

Sidestick forces shall provide tactile cues that allow the pilot to maneuver the airplane precisely. Sidestick forces shall also provide an indication to the pilot of the proximity of pitch maneuver load factor to structural limits. The pitch sidestick controller shall include a change in force versus deflection gradient at a specified "soft stop." Maneuver limit load shall be commanded with stick forces near the soft stop. The pilot shall be able to command load factors in excess of limit load at his discretion in emergency situations by applying higher forces to the sidestick controller. The maneuver stick force per g shall comply with the requirements below for stick forces less than those of the soft stop. (MIL-F-8785C 3.2.2.2.1)

Flight Condition	F_S/g - lb/g	
	Minimum	Maximum
Landing & Approach	3	28
Climb, Cruise & Descent	3	28

b) Takeoff Rotation Forces

Sidestick control forces during normal takeoff rotation shall not exceed 25 lbs. (This is half the value of conventional controllers of MIL-F-8785C 3.2.3.3.2 for Class III aircraft.)

c) Landing Flare Forces

Sidestick control forces during normal landing flare shall not exceed 25 lbs. (This is half the value of conventional controllers of MIL-F-8785C 3.2.3.4.1 for Class III aircraft.)

Longitudinal Controller Centering (G.F.P.F.F.3)

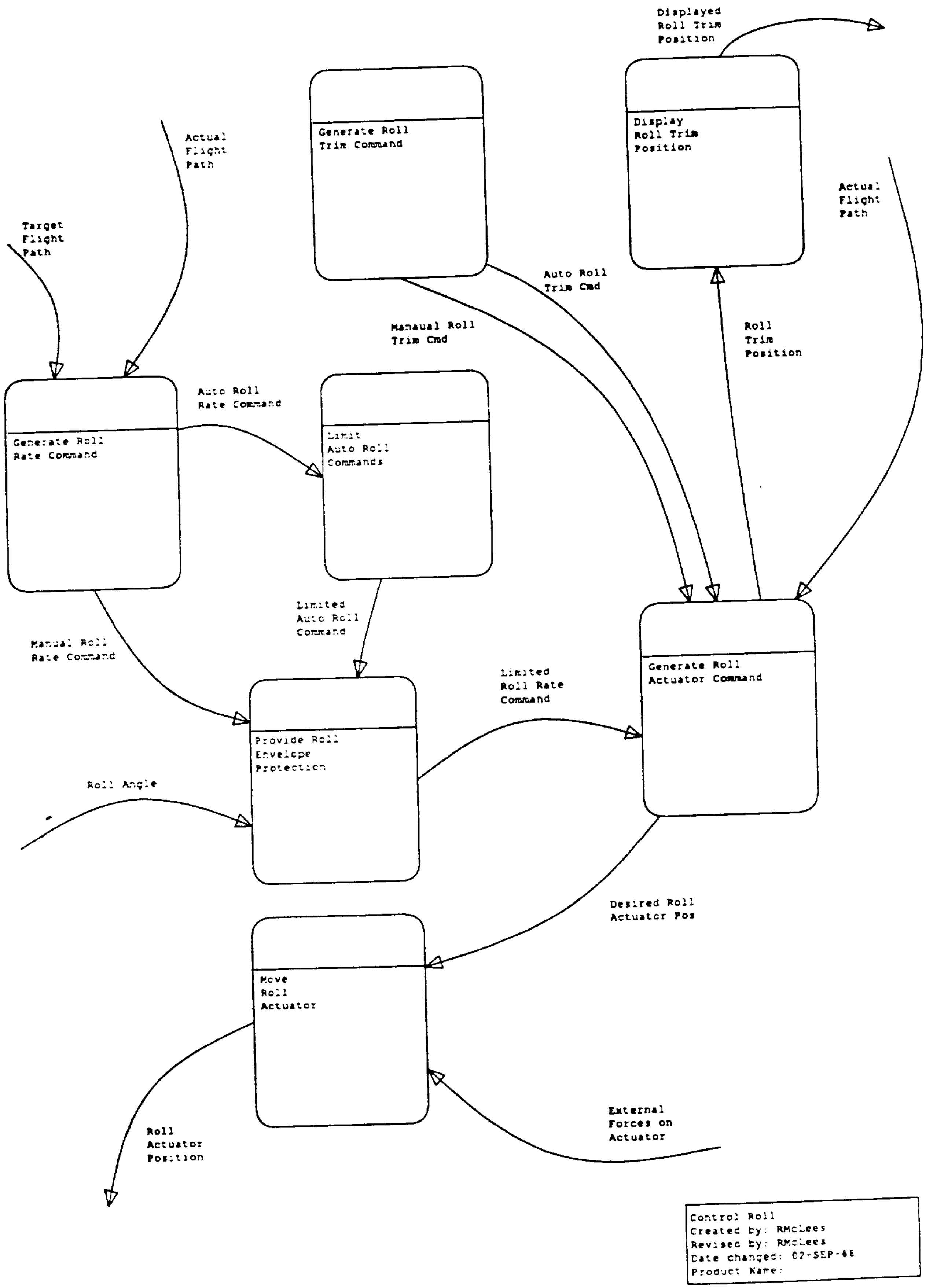
Positive control centering shall be provided in all modes. (MIL-F-8785C 3.5.2.1) A mechanical or electrical detent equivalent to 10 lbs (TBV) of sidestick controller force shall be provided during autopilot control to preclude inadvertent pilot inputs.

Longitudinal Trim Control (T.L.T.F.C.1)

Trim control shall be operable by each of the pilots without removing hands from the longitudinal controllers.

An alternate trim control command path operable by both crew members shall be provided. (MIL-F-8785C 3.6.1)

Means to manually deactivate the trim function shall be provided. (MIL-F-9490D 3.1.3.5)



Displayed Roll Trim Position
Generate Roll Trim Command
Display Roll Trim Position
Actual Flight Path
Target Flight Path
Actual Flight Path
Auto Roll Trim Cmd
Manaual Roll Trim Cmd
Roll Trim Position
Auto Roll Rate Command
Generate Roll Rate Command
Limit Auto Roll Commands
Limited Auto Roll Command
Manual Roll Rate Command
Limited Roll Rate Command
Generate Roll Actuator Command
Provide Roll Envelope Protection
Roll Angle
Desired Roll Actuator Pos
Move Roll Actuator
External Forces on Actuator
Roll Actuator Position
Control Roll
Created by: RMcLees
Revised by: RMcLees
Date changed: 02-SEP-88
Product Name:

Process Descriptions
Control Roll

Description	Expl name
Display roll trim position to the crew.	Display Roll Trim Position
This process generates the roll actuator (aileron / spoiler) position commands based on roll rate & trim commands.	Generate Roll Actuator Command
This function compares the target flight path and actual flight path and generates necessary roll rate command to drive the actual to the target.	Generate Roll Rate Command
This transform generates roll trim commands to offset asymmetries such as engine out, engine loss and lateral winds.	Generate Roll Trim Command
This function limits the autopilot control authority and protects against failures (in particular hardover or oscillatory failures) in the autopilot.	Limit Auto Roll Commands
This transform receives the desired roll actuator position and attempts to move the roll actuator to that position.	Move Roll Actuator
This transform monitors actual roll angle and commanded roll rate and and modifies the roll rate command as necessary to prevent the roll angle from exceeding certain limits.	Provide Roll Envelope Protect

Data Flow Description
Control Roll

Description	Name
The sensed 4 dimensional flight path & attitudes of the aircraft as well as any other sensed values necessary to satisfy the control requirements.	Actual Flight Path
Roll rate command generated in an automated fashion (ie by an autoflight computer).	Auto Roll Rate Command
Roll trim command generated automatically for use during enhanced manual control and autoflight control.	Auto Roll Trim Cmd
The desired roll actuator position such that the limited roll rate command is achieved.	Desired Roll Actuator Pos.
This flow is the roll trim position displayed to the crew.	Displayed Roll Trim Position
All forces (in particular environmental forces) other than the actuation forces acting on the aerodynamic braking and roll actuation system.	External Forces on Actuator
The auto roll rate command limited to the autoflight roll authority.	Limited Auto Roll Command
The roll rate command limited such that the envelope protection criteria are not violated.	Limited Roll Rate Command
Roll rate command generated manually (ie by the crew).	Manual Roll Rate Command
The roll trim command as generated by the crew for normal control. The trim provides a steady state roll angle to offset asymmetries.	Manual Roll Trim Command
Position of the system which makes the aircraft roll.	Roll Actuator Position
Airplane roll angle.	Roll Angle
Position of the roll trim actuator.	Roll Trim Position
The desired 4 dimensional flight path and attitudes generated by some navigation function.	Target Flight Path

Process Requirements Links
Control Roll

Expl name	I-L Reference
Display Roll Trim Position	
Generate Roll Actuator Command	
Generate Roll Rate Command	
Generate Roll Trim Command	
Limit Auto Roll Commands	L.A.R.C.1
Move Roll Actuator	
Provide Roll Envelope Protect	P.R.E.P.1 P.R.E.P.2

Roll Autopilot Control and Limiting (L.A.R.C.1)

a) Core lateral control shall provide autopilot control authority limiting and actuation to ensure safety for probable autopilot failure conditions.

b) Maximum maneuver authority shall not result in the following, assuming a 4 second pilot delay in initiating recovery from any system malfunction: (FAR 25.1309)

1) Bank angle greater than 60 degrees.
2) Structural loads in excess of limit load due to hardover or oscillatory failures.

Automated Envelope Protection (P.R.E.P.1)

Automated envelope protection shall be provided to relieve pilot workload and shall have a probability of loss of function < 10E-06.

Enhanced Control Roll Envelope Protection (P.R.E.P.2)

The enhanced control mode shall provide roll envelope protection that shall satisfy the following requirements:

a) Roll Angle Limits

1) The roll envelope protection function shall operate to the following limits:

Roll Angle Limit Type	Lateral Controller Position	Roll Angle Limit Value (Deg)
Soft	All	+- 35 (TBV)
Hard	Out-of-Detent	+- 60 (TBV)

2) When the pilot's lateral controller is returned to neutral following a maneuver beyond the soft limit, the airplane roll angle shall automatically decrease to 35 deg with the roll mode time constant specified in Paragraph C.M.F.21(b).

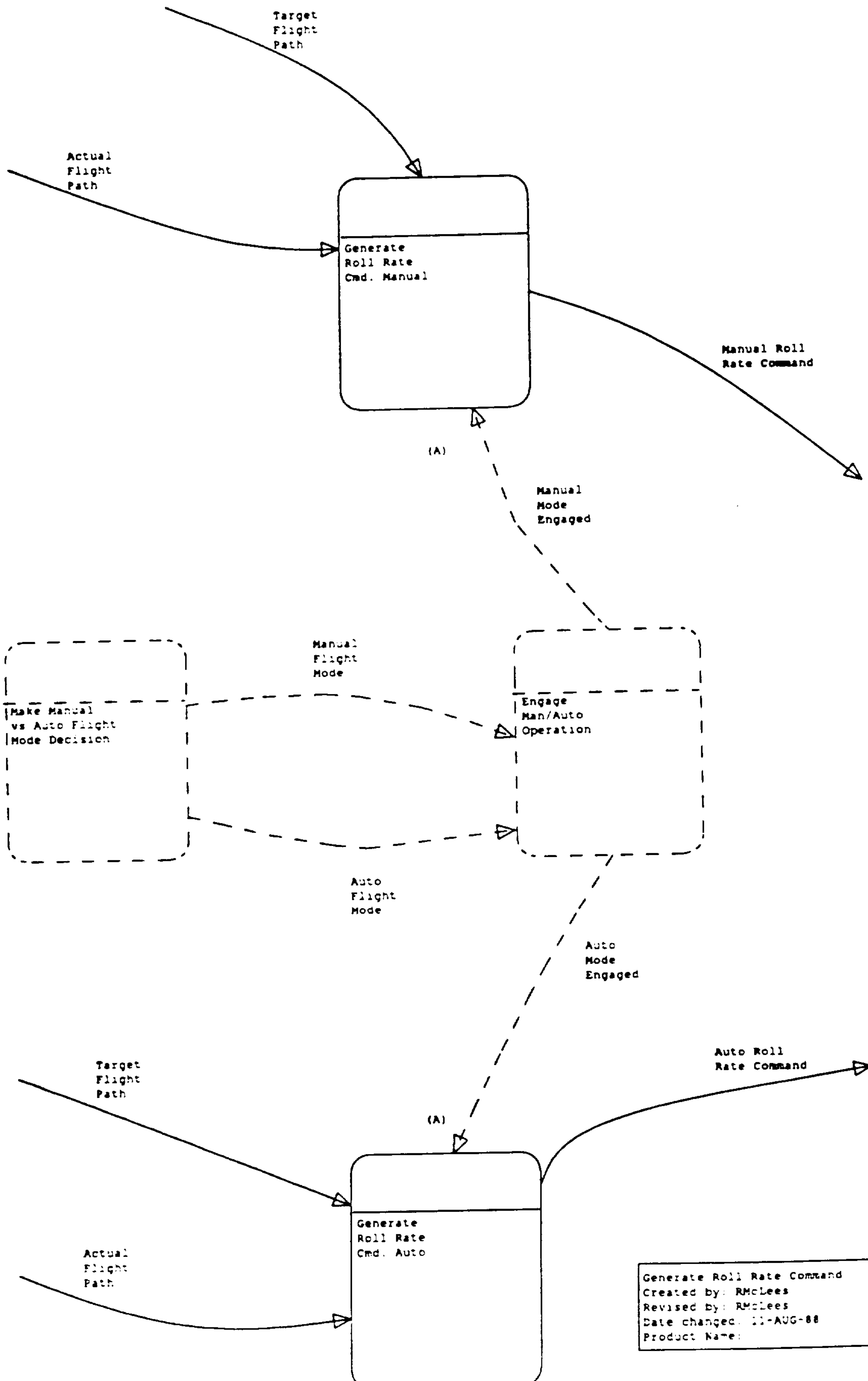
3) If the airplane should be upset to a roll angle greater than 60 degrees, the roll envelope function shall use a pilot lateral controller input as an indication of the preferred direction of roll even if that direction results in a roll angle change greater than the smallest that can be achieved. The roll back from the upset shall be to 35 degrees.

b) Response Characteristics

1) The roll envelope protection function shall not prevent the pilot from attaining the maximum useful airplane performance.

2) The roll envelope protection function shall comply with the roll mode time constant in Paragraph C.M.F.21(b).

3) Control anticipation shall minimize the effect on maneuvers near the protection boundary. Dynamic overshoots of the boundaries shall be minimized consistent with the criticality of the limit.



Generate Roll Rate Command
Created by: RMcLees
Revised by: RMcLees
Date changed: 11-AUG-88
Product Name:

Process Descriptions
Generate Roll Rate Command

Description	Expl name
This process involves the generation of a roll rate command automatically (ie by a computer) as a result of the difference between the actual and target flight path.	Generate Roll Rate Cmd. Auto
This process involves the generation of a roll rate command manually (ie by the crew) as a result of comparing the target and actual flight paths.	Generate Roll Rate Cmd. Manual

Control Process Descriptions
Generate Roll Rate Command

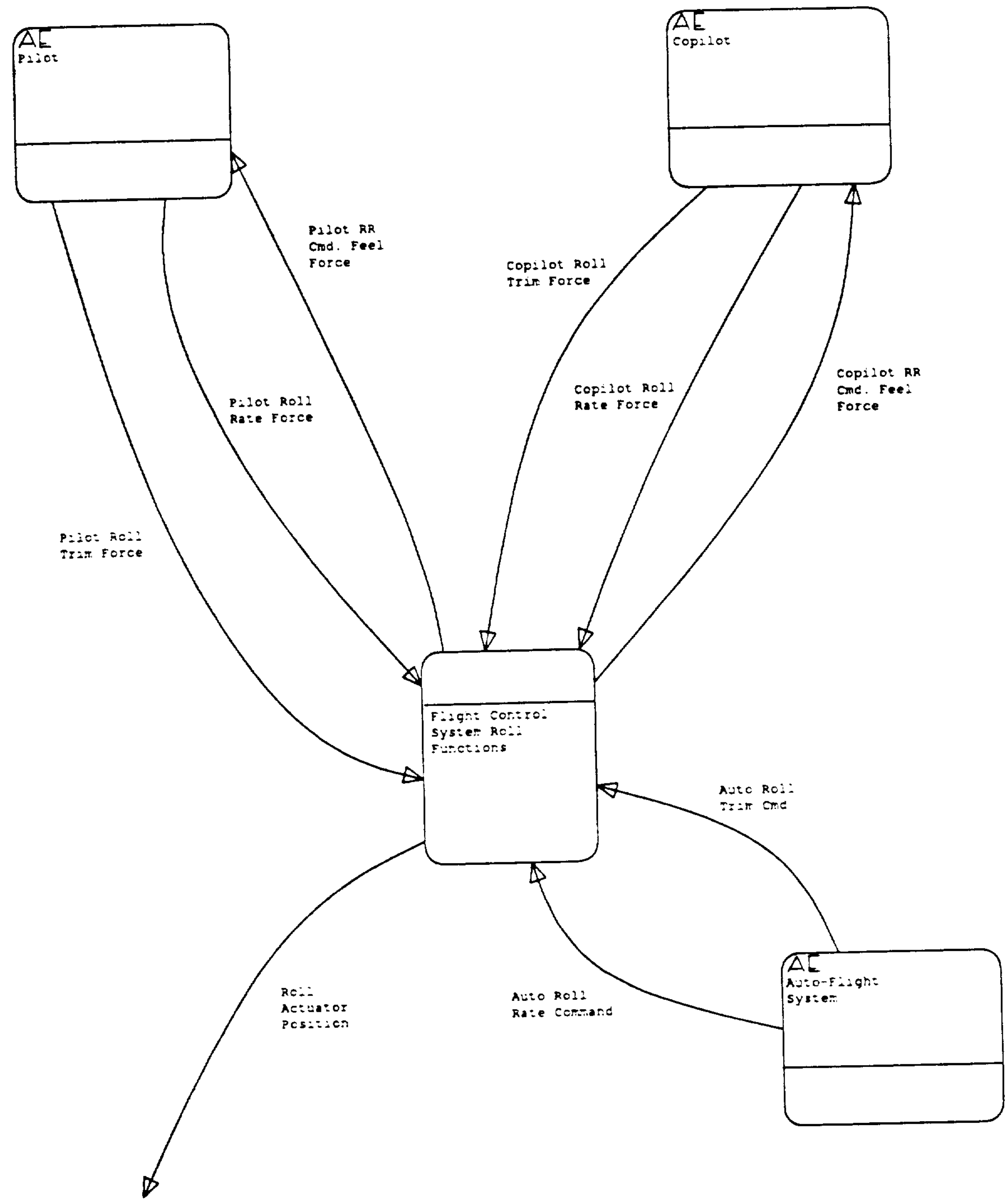
Description	Expl name
This process activates one of the roll rate generation processes depending on the mode engaged.	Engage Man/Auto Operation
This transform decides whether to generate flight path commands manually or automatically.	Make Manual/Auto Flight Decision

Data Flow Description
Generate Roll Rate Command

Description	Name
The sensed 4 dimensional flight path & attitudes of the aircraft as well as any other sensed values necessary to satisfy the control requirements.	Actual Flight Path
Roll rate command generated in an automated fashion (ie by an autoflight computer).	Auto Roll Rate Command
Roll rate command generated manually (ie by the crew).	Manual Roll Rate Command
The desired 4 dimensional flight path and attitudes generated by some navigation function.	Target Flight Path

Process Architectural Assignments
Generate Roll Rate Command

Expl name	associated aes
Generate Roll Rate Cmd. Auto	Auto-Flight System
Generate Roll Rate Cmd. Manual	Pilot Copilot



Flight Cntrl Sys Roll Context
Created by: RMcLees
Revised by: RMcLees
Date changed: 01-SEP-88
Product Name:

Process Descriptions
Flight Cntrl Sys Roll Context

Description	Expl name
This process contains all the flight control functions assigned to the FCS. As a result of this assignment several new processes are created. Some of these are interface functions and others are as a result of how functions were allocated to AEs. (ie. Envelope protection was assigned to the FCS with a probability of failure <10E-6. However this function requires <10E-09. Therefore the pilot & copilot must perform envelope protection when not being performed by the FCS. Thus a pilot indication function of the status of envelope protection is generated.) Pilot & copilot can command roll rate, thus there is a functional req. to resolve control contention.	Flight Cntrl Sys Roll Functns

Data Flow Description
Flight Cntrl Sys Roll Context

Description	Name
Roll rate command generated in an automated fashion (ie by an autoflight computer).	Auto Roll Rate Command
Roll trim command generated automatically for use during enhanced manual control and autoflight control.	Auto Roll Trim Cmd
This flow is a resistance force exerted by the controller which is a feedback to the copilot indicative of the roll rate command.	Copilot RR Cmd. Feel Force
This is the physical signal created by the copilot to control the aircraft. It is in the form of a force exerted by the pilots hand.	Copilot Roll Rate Force
This is the physical force exerted by the copilot's hand to generate the desired roll trim command.	Copilot Roll Trim Force
This flow is a resistance force exerted by the controller which is a feedback to the pilot indicative of the roll rate command.	Pilot RR Cmd. Feel Force
This is the physical signal created by the pilot to control the aircraft. It is in the form of a force exerted by the pilots hand.	Pilot Roll Rate Force
This is the physical force exerted by the pilot's hand to generate the desired roll trim command.	Pilot Roll Trim Force
Position of the system which makes the aircraft roll.	Roll Actuator Position

Process Requirements Links
Flight Cntrl Sys Roll Context

Expl name	I-L Reference
Flight Cntrl Sys Roll Functns	F.C.S.R.F.1 F.C.S.R.F.2

Envelope Protection Mode Indication and Alert (F.C.S.R.F.1)

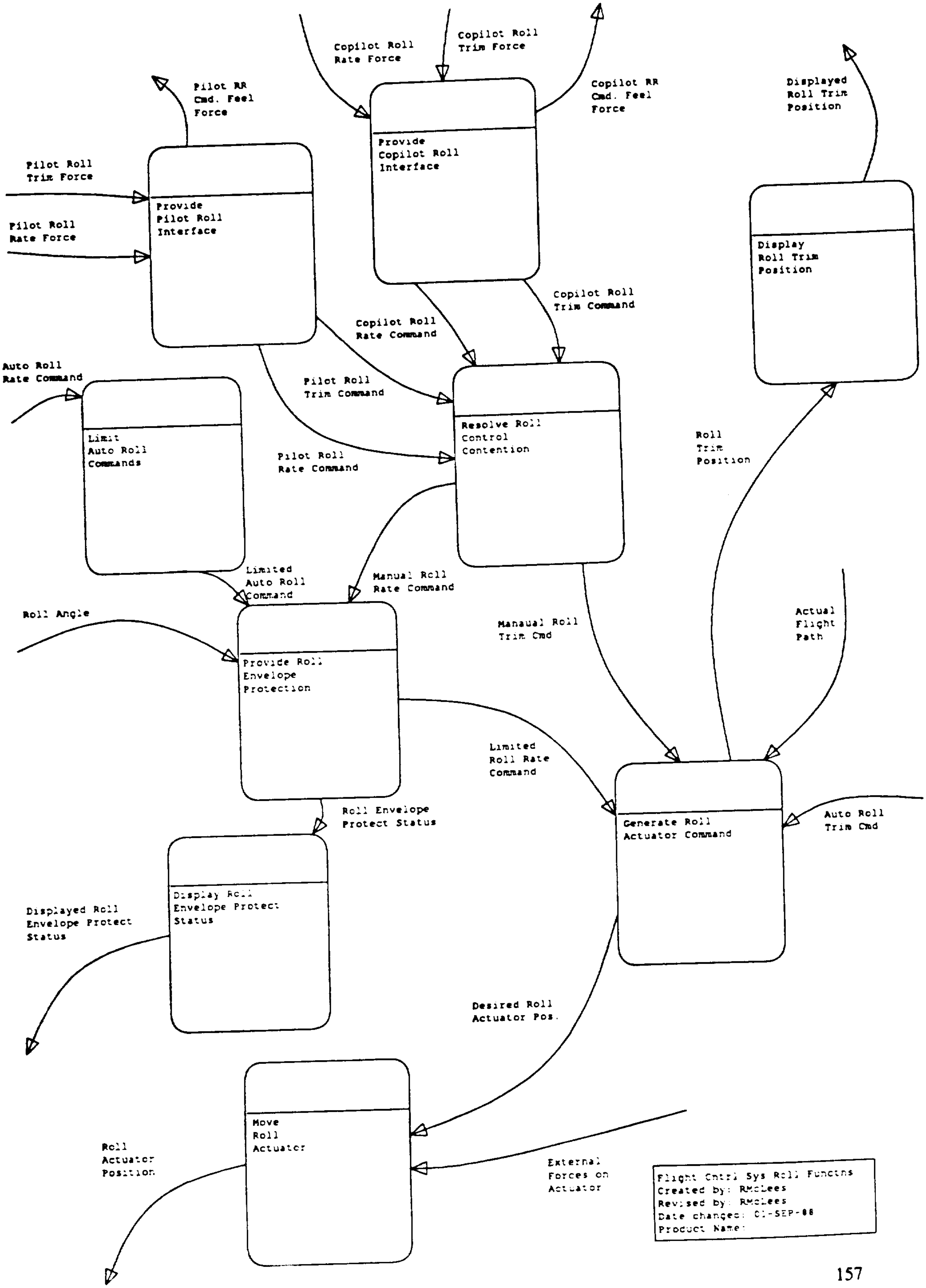
Indication shall be provided to inform the pilot when an envelope protection mode has become active. An alert indication shall inform the pilot of loss of an envelope protection function. The loss of an envelope protection function and the failure to inform the pilot of the loss shall be extremely improbable. (FAR 25.672(a))

(This functional requirement was generated because the pilot is resposible for envelope protection when not provided automatically.)

Pilot and co-pilot roll control contention resolution (F.C.S.R.F.2)

Pilot and co-pilot roll control contention shall be resolved.

(This functional requirement arises because the generate manual roll rate command was assigned to both the pilot and copilot AEs)


Copilot Roll
Rate Force
Copilot Roll
Trim Force
Copilot RR
Cmd. Feel
Force
Provide
Copilot Roll
Interface
Pilot RR
Cmd. Feel
Force
Pilot Roll
Trim Force
Pilot Roll
Rate Force
Provide
Pilot Roll
Interface
Displayed
Roll Trim
Position
Display
Roll Trim
Position
Copilot Roll
Trim Command
Copilot Roll
Rate Command
Auto Roll
Rate Command
Pilot Roll
Trim Command
Resolve Roll
Control
Contention
Limit
Auto Roll
Commands
Pilot Roll
Rate Command
Roll
Trim
Position
Limited
Auto Roll
Command
Manual Roll
Rate Command
Roll Angle
Manaual Roll
Trim Cmd
Actual
Flight
Path
Provide Roll
Envelope
Protection
Limited
Roll Rate
Command
Generate Roll
Actuator Command
Auto Roll
Trim Cmd
Roll Envelope
Protect Status
Displayed Roll
Envelope Protect
Status
Display Roll
Envelope Protect
Status
Desired Roll
Actuator Pos.
Move
Roll
Actuator
Roll
Actuator
Position
External
Forces on
Actuator
Flight Cntrl Sys Roll Functns
Created by: RMcLees
Revised by: RMcLees
Date changed: 01-SEP-88
Product Name:

Process Descriptions
Flight Cntrl Sys Roll Functns

Description	Expl name
Display roll trim position to the crew.	Display Roll Trim Position
This transform results from the allocation of Provide Roll Envelope Protection to the FCS with a probability of loss of function of <10E-6. Provide Roll Envelope Protection has a probability of loss of function of < 10E-9 and thus the crew has responsibility for roll envelope protection when not performed by the FCS. Thus the crew must be aware of envelope protect status, hence the functional requirement to Display Roll Envelope Protect Status.	Display Roll Envlp Protct Stats
This process generates the roll actuator (aileron / spoiler) position commands based on roll rate & trim commands.	Generate Roll Actuator Command
This function limits the autopilot control authority and protects against failures (in particular hardover or oscillatory failures) in the autopilot.	Limit Auto Roll Commands
This transform receives the desired roll actuator position and attempts to move the roll actuator to that position.	Move Roll Actuator
This transform provides the same function for the copilot as the Provide Pilot Roll Interface does for the pilot.	Provide Copilot Roll Interface
This functions converts the signal received from the pilot in the form of a force exerted by the pilots hand into a roll rate signal to be used by the FCS. It also provides the pilot with a feedback feel force proportional to the commanded roll rate.	Provide Pilot Roll Interface
This transform monitors actual roll angle and commanded roll rate and and modifies the roll rate command as necessary to prevent the roll angle from exceeding certain limits.	Provide Roll Envelope Protect
This process was generated by the assignment of the Generate Roll Rate Cmd. Manual to both the pilot & copilot.	Resolve Roll Control Contention

Data Flow Description
Flight Cntrl Sys Roll Functns

Description	Name
The sensed 4 dimensional flight path & attitudes of the aircraft as well as any other sensed values necessary to satisfy the control requirements.	Actual Flight Path
Roll rate command generated in an automated fashion (ie by an autoflight computer).	Auto Roll Rate Command
Roll trim command generated automatically for use during enhanced manual control and autoflight control.	Auto Roll Trim Cmd
This flow is a resistance force exerted by the controller which is a feedback to the copilot indicative of the roll rate command.	Copilot RR Cmd. Feel Force
Numeric value of the copilot roll rate command obtained form the copilot roll rate force.	Copilot Roll Rate Command
This is the physical signal created by the copilot to control the aircraft. It is in the form of a force exerted by the pilots hand.	Copilot Roll Rate Force
Numeric value of the copilot roll trim command as obtained from the copilot roll trim force.	Copilot Roll Trim Command
This is the physical force exerted by the copilot's hand to generate the desired roll trim command.	Copilot Roll Trim Force
This flow is the roll trim position displayed to the crew.	Displayed Roll Trim Position
Status of the availability and activity of the roll envelope protection function displayed to the crew.	Dsplyd Roll Envlp Protct Status
Roll rate command generated manually (ie by the crew).	Manual Roll Rate Command
The roll trim command as generated by the crew for normal control. The trim provides a steady state roll angle to offset asymmetries.	Manual Roll Trim Command
This flow is a resistance force exerted by the controller which is a feedback to the pilot indicative of the roll rate command.	Pilot RR Cmd. Feel Force

Data Flow Description
Flight Cntrl Sys Roll Functns

Description	Name
Numeric value of the pilots roll rate command obtained from the pilots roll rate force.	Pilot Roll Rate Command
This is the physical signal created by the pilot to control the aircraft. It is in the form of a force exerted by the pilots hand.	Pilot Roll Rate Force
Numeric value of the pilots roll trim command obtained from the pilots roll trim force.	Pilot Roll Trim Command
This is the physical force exerted by the pilot's hand to generate the desired roll trim command.	Pilot Roll Trim Force
Position of the system which makes the aircraft roll.	Roll Actuator Position
Airplane roll angle.	Roll Angle
Activity and availability of the roll envelope protection function.	Roll Envelope Protect Status
Position of the roll trim actuator.	Roll Trim Position

Process Requirements Links
Flight Cntrl Sys Roll Functns

Expl name	I-L Reference
Display Roll Envlp Protct Stats	
Display Roll Trim Position	
Generate Roll Actuator Command	
Limit Auto Roll Commands	L.A.R.C.1
Move Roll Actuator	
Provide Copilot Roll Interface	
Provide Pilot Roll Interface	
Provide Roll Envelope Protect	F.R.E.P.1 P.R.E.P.2
Resolve Roll Control Contention	R.R.C.C.1

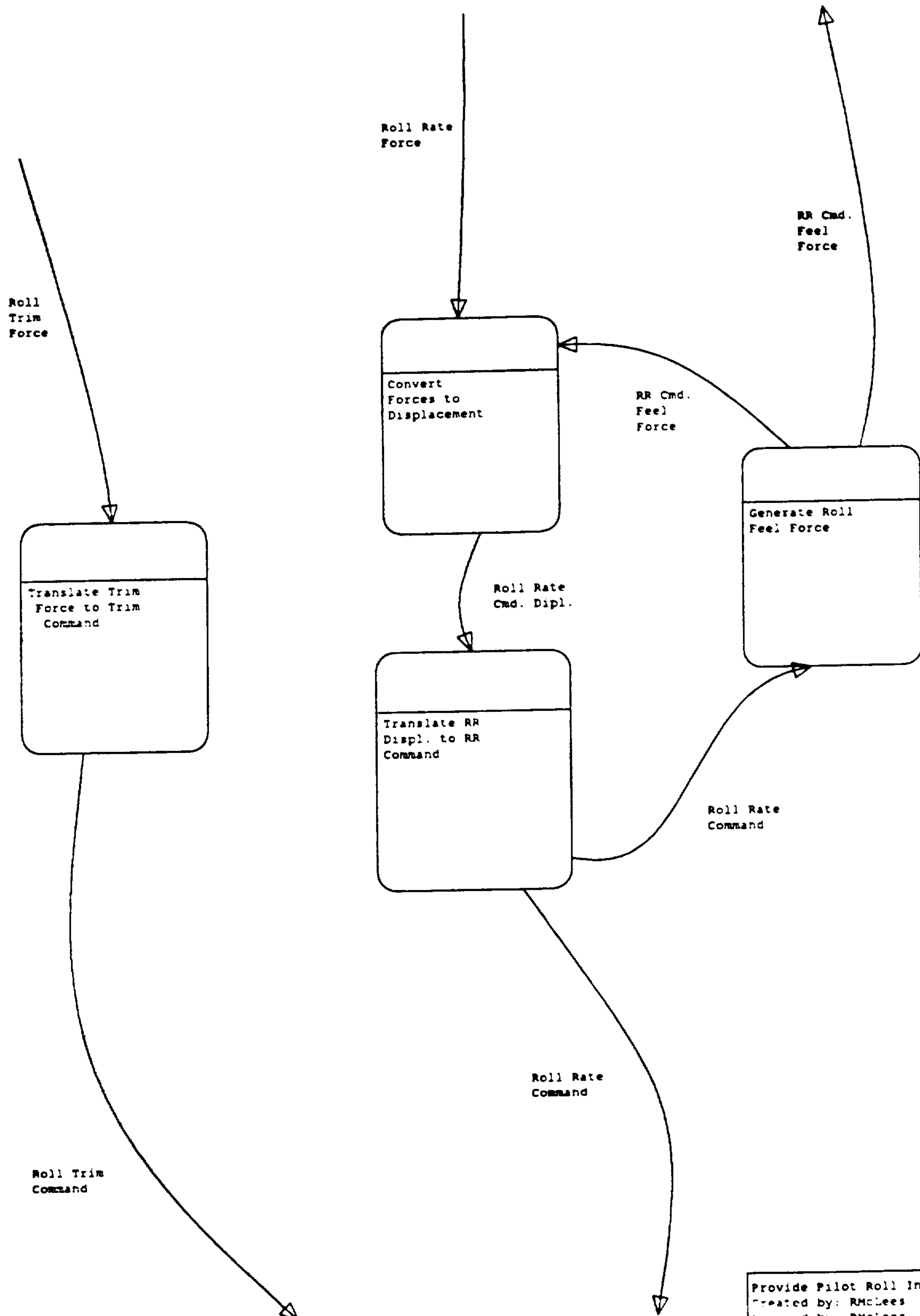
Pilot and co-pilot contention resolution (R.R.C.C.1)

Pilot and co-pilot lateral control contention for sidestick controllers shall be resolved as follows.

a) Pilot and copilot commands of same sign chose larger command.

b) Pilot and copilot commands of opposite sign add commands algebraically.

c) In the event of a controller jam the function shall operate as though the jammed controller were in the detent position.



Provide Pilot Roll Interface
Created by: RMcLees
Revised by: RMcLees
Date changed: 01-SEP-88
Product Name:

Process Descriptions
Provide Pilot Roll Interface

Description	Expl name
This process receives the pilot force and feedback feel force and generates a displacement.	Convert Roll Forces - Displ.
This transform generates a force to feedback to the pilot which is an indication of the commanded roll rate.	Generate Roll Feel Force
This transform translates the sidestick controller displacement to a roll rate command.	Translate RR Displ to RR Command
This process converts the physical displacement generated by the physical force exerted by the pilot into a trim command for use by the FCS.	Translate Trim Force to Command

Data Flow Description
Provide Pilot Roll Interface

Description	Name
This flow is a resistance force exerted by the controller which is a feedback to the pilot indicative of the roll rate command.	RR Cmd.Feel Force
This flow is the roll rate controller displacement in inches.	Roll Rate Cmd. Dipl.
This flow is the roll rate command in deg/sec.	Roll Rate Command
This is the physical signal created by the pilot to control the aircraft. It is in the form of a force exerted by the pilots hand.	Roll Rate Force
The command such that the airplane holds a small steady state roll angle to offset asymmetries.	Roll Trim Command

Process Requirements Links
Provide Pilot Roll Interface

Expl name	I-L Reference
Convert Roll Forces - Displ.	C.R.F.D.1
Generate Roll Feel Force	G.R.F.F.1 G.R.F.F.2 G.R.F.F.3
Translate RR Displ to RR Command	
Translate Trim Force to Command	T.T.F.C.1

Lateral Controller Deflection Rates (C.R.F.D.1)

No force discontinuities or other objectionable characteristics shall occur for all controller command rates. (MIL-F-8785C 3.5.3)

Lateral Feel Forces (G.R.F.F.1)

G.R.F.F.1.1 General

Roll control feel forces shall be designed for one-handed operation.

G.R.F.F.1.2 Normal Operation

The roll control forces for sidestick controls shall be within 12 lbs to 20 lbs for inboard movement and 8 lbs to 20 lbs for outboard movement with preference for the lower end. Centerstick controller breakout forces shall be within .5 lbs to 4.0 lbs. (MIL-F-8785C 3.5.2.1 Class III aircraft) The maximum lateral control force (centerstick controller) shall be less than 20 lbs. (MIL-F-8785C 3.3.4.3)

Lateral Control Linearity (G.R.F.F.2)

There shall be no objectionable nonlinearities in the variation of rolling response with roll control deflection or force. Sensitivity or sluggishness in response to small control deflections or force shall be avoided. (MIL-F-8785C 3.3.4.4)

Overall roll rate per sidestick force shall comply with the requirements of G.R.F.F.1. Controller sensitivity shall increase for larger stick forces as shown in Figure G.R.F.F.2-1 in order to command roll rates needed to comply with the time-to-bank criteria of Paragraph C.M.F.17.2. while preventing sensitivity problems for small stick forces.

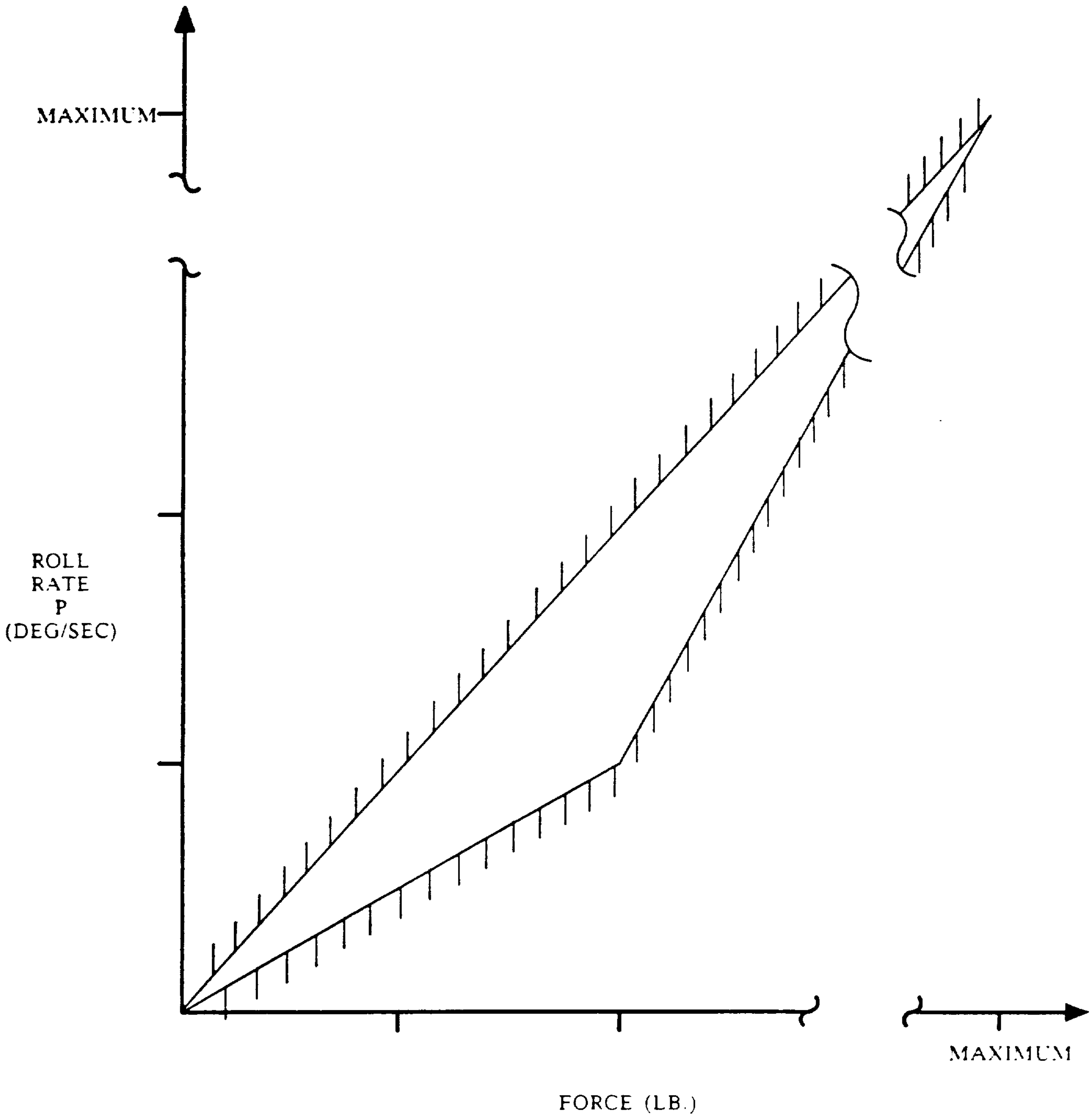


FIGURE G.R.F.F.2-1
LATERAL CONTROL LINEARITY

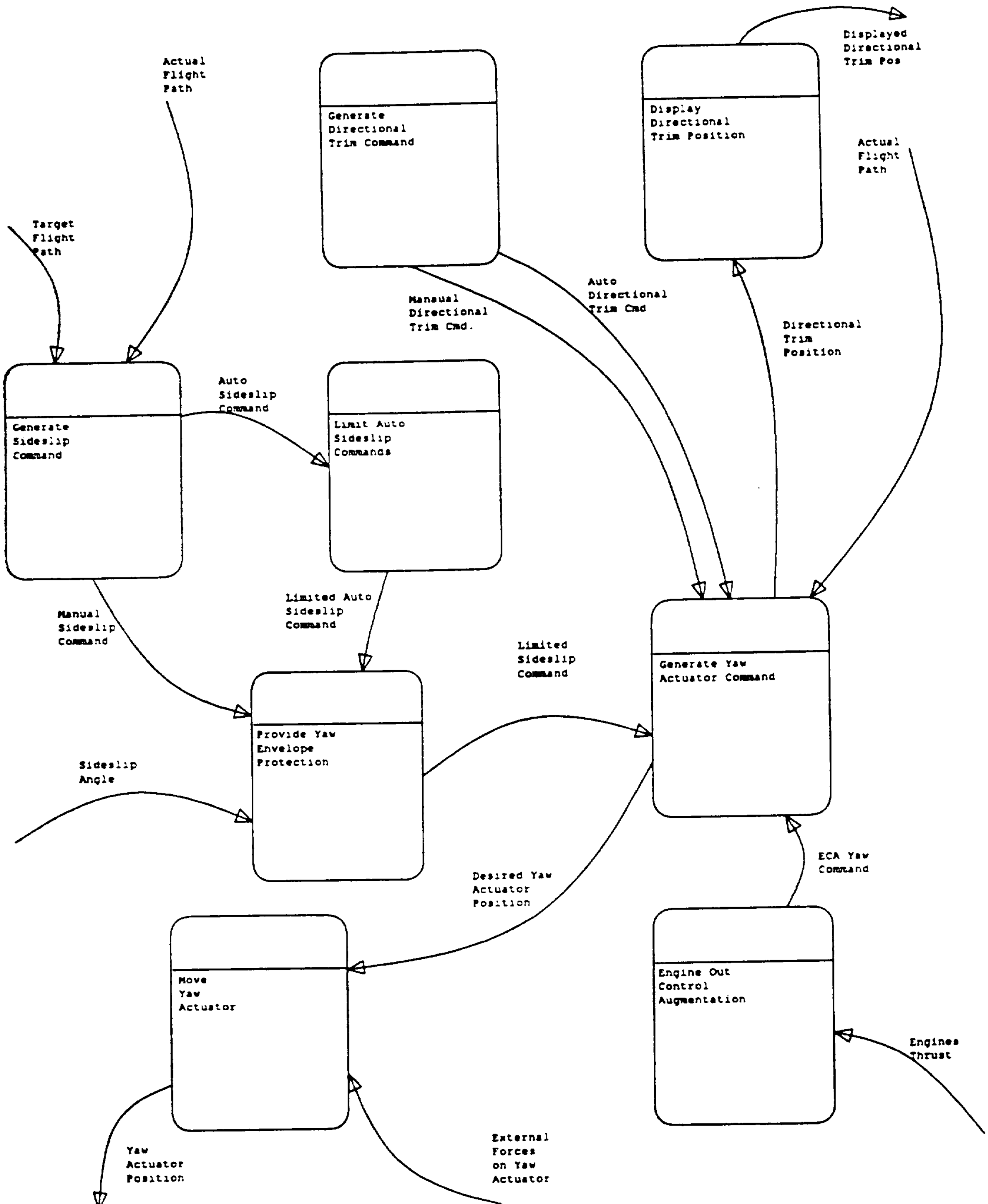
Controller Centering (G.R.R.F.3)

Positive control centering shall be provided in all modes. (MIL-F-8785C 3.5.2.1) A mechanical or electrical detent equivalent to 10 lbs (TBV) of sidestick control force shall be provided during autopilot control to preclude inadvertent pilot inputs.

Lateral Trim Control (T.T.F.C.1)

a) Lateral trim shall be configured such that conventional pilot trimming techniques may be used.

b) Trim inputs shall be in series with the pilot controller.



Control Yaw
Created by: RMcLees
Revised by: RMcLees
Date changed: 01-SEP-88
Product Name:

Process Descriptions
Control Yaw

Description	Expl name
This transform displays the position of the directional trim actuator to the crew.	Display Directional Trim Posit.
This process monitors the engine thrust and generates a yaw command to assist the pilot in compensating for an engine out situation. In particular it helps relieve pilot workload in takeoff and go around which are high pilot workload situations.	Engine Out Control Augmentation
This transform generates directional trim commands to offset asymmetries such as engine out and lateral winds.	Generate Yaw Trim Command
This process involves the generation of sideslip commands to allow for decrab for landings, performing coordinated turns and offsetting certain asymmetries.	Generate Sideslip Command
This process generates the sideslip actuator (rudder) position command based on the limited sideslip command, directional trim command and the engine out control augmentation command.	Generate Yaw Actuator Command
This function limits the autopilot control authority and protects against failures (in particular hardover or oscillatory failures) in the autopilot.	Limit Auto Sideslip Commands
This transform receives the desired yaw actuator position and attempts to move the yaw actuator to that position.	Move Yaw Actuator
This function monitors the commanded sideslip and the actual sideslip and modifies the sideslip command to prevent the sideslip angle from exceeding unsafe limits.	Provide Yaw Envelope Protect

Data Flow Description
Control Yaw

Description	Name
The sensed 4 dimensional flight path & attitudes of the aircraft as well as any other sensed values necessary to satisfy the control requirements.	Actual Flight Path
Directional trim command generated automatically for use during enhanced manual control and autoflight control.	Auto Directional Trim Command
Sideslip command generated in an automated fashion (ie by an autoflight computer).	Auto Sideslip Command
The desired yaw actuator position such that the limited sideslip and directional trim commands are achieved.	Desired Yaw Actuator Position
Position of the directional trim actuator.	Directional Trim Position
This flow is the directional trim actuator position displayed to the crew.	Displayed Directional Trim Pos
Automatically generated yaw command to assist the pilot in controlling the aircraft in an engine out situation.	ECA Yaw Command
Thrust measurements of engines to determine capture engine out event.	Engines Thrust
All forces (in particular environmental forces) other that the actuation forces acting on the yaw actuation system.	External Forces on Yaw Actuator
The auto sideslip command protected against oscillatory failures and limited to autoflight authority.	Limited Auto Sideslip Command
The sideslip command limited such that the sideslip envelope protection criteria are not violated.	Limited Sideslip Command
The directional trim command as generated by the crew for use during normal control to offset asymmetries.	Manual Directional Trim Command
Sideslip command generated manually (ie by the crew).	Manual Sideslip Command
Airplane sideslip angle.	Sideslip Angle
The desired 4 dimensional flight path and attitudes generated by some navigation function.	Target Flight Path
Position of the system which caused the aircraft to yaw (rudders).	Yaw Actuator Position

Process Requirements Links
Control Yaw

Expl name	I-L Reference
Display Directional Trim Posit.	
Engine Out Control Augmentation	E.O.C.A.1
Generate Sideslip Command	
Generate Yaw Actuator Command	
Generate Yaw Trim Command	
Limit Auto Sideslip Commands	L.A.S.C.1
Move Yaw Actuator	
Provide Yaw Envelope Protect	P.Y.E.P.1 P.Y.E.P.2

Engine-Out Control Augmentation (ECA) (E.O.C.A.1)

The ECA function shall comply with the following requirements:

a) ECA shall be available in the enhanced mode except during ground operations where airspeed is below 60 knots and/or reverse thrust is used.

b) The initial airplane yaw response after an engine-out, with ECA operational, shall be toward the failed engine.

Directional Autopilot Control and Limiting (L.A.S.C.1)

The directional control system shall provide autopilot control actuation and authority limiting to ensure safety during any conceived failure condition. (FAR 25.1309(b))

Sideslip Protection (P.Y.E.P.1)

Sideslip protection shall function during all core and enhanced modes to prevent the airplane from exceeding sideslip angle excursions beyond maneuver requirements.

a) Sideslip Angle Limits

For commanded or uncommanded sideslip the maximum sideslip angle shall be controlled to limits scheduled on airspeed as shown in Figure P.Y.E.P.1-1. The actual sideslip values are TBD based on maneuvering (decrab and turn coordination) requirements, lateral control considerations and structural considerations. These sideslip limits shall apply to all airplane configurations. Steady state slideslip angles within the lower boundary shall be available for sideslip maneuvers. Sideslip angle overshoots shall not exceed the upper boundary.

b) Response characteristics

1) The sideslip protection function shall not inhibit compliance with the enhanced yaw maneuver response requirements.

2) The envelope protection function shall not prevent the pilot from attaining the maximum useful airplane performance.

3) Control anticipation shall be included in the design to minimize the effect on maneuvers near the protection boundary. Dynamic overshoots of the boundaries shall be minimized consistent with the criticality of the limit.

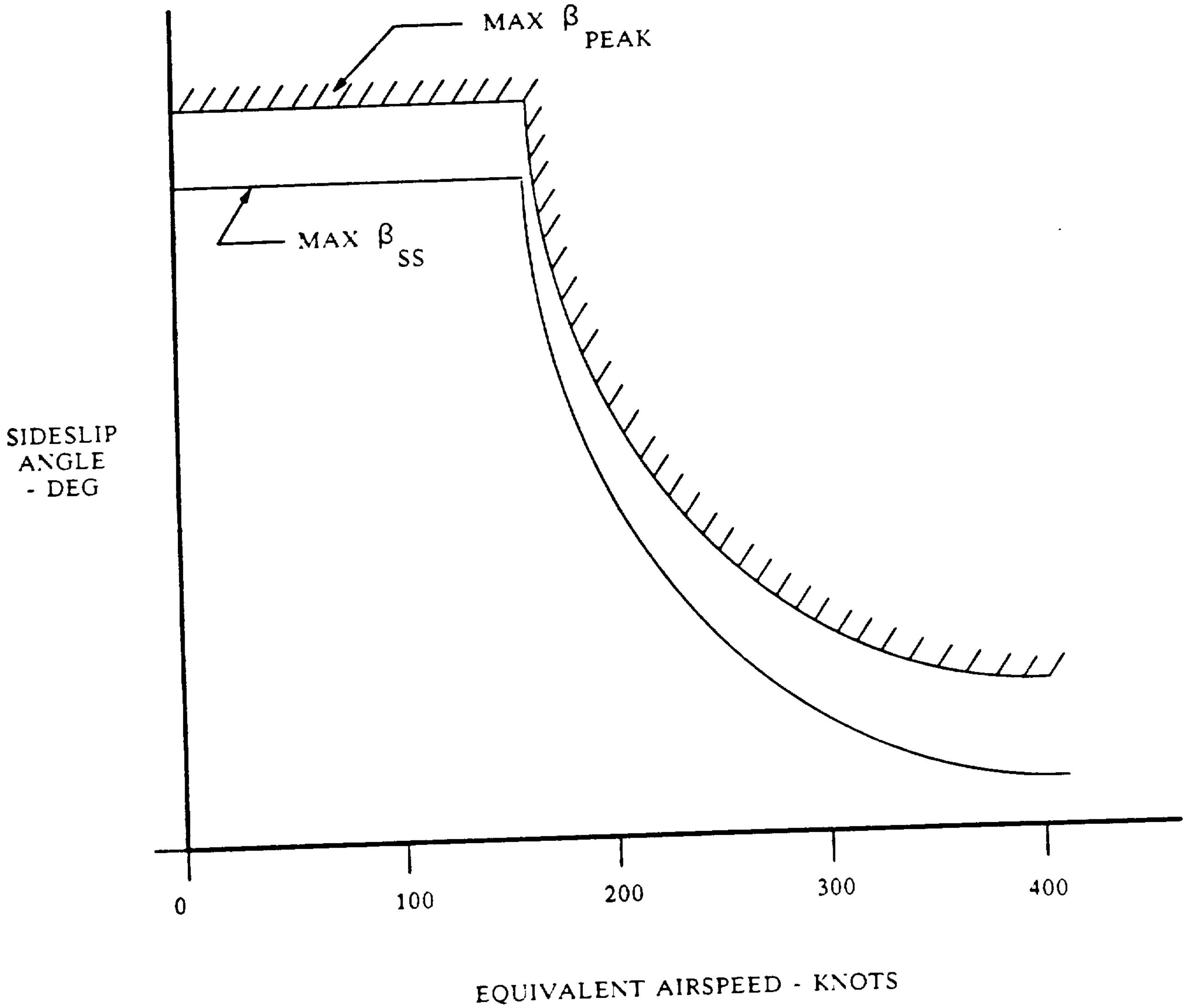
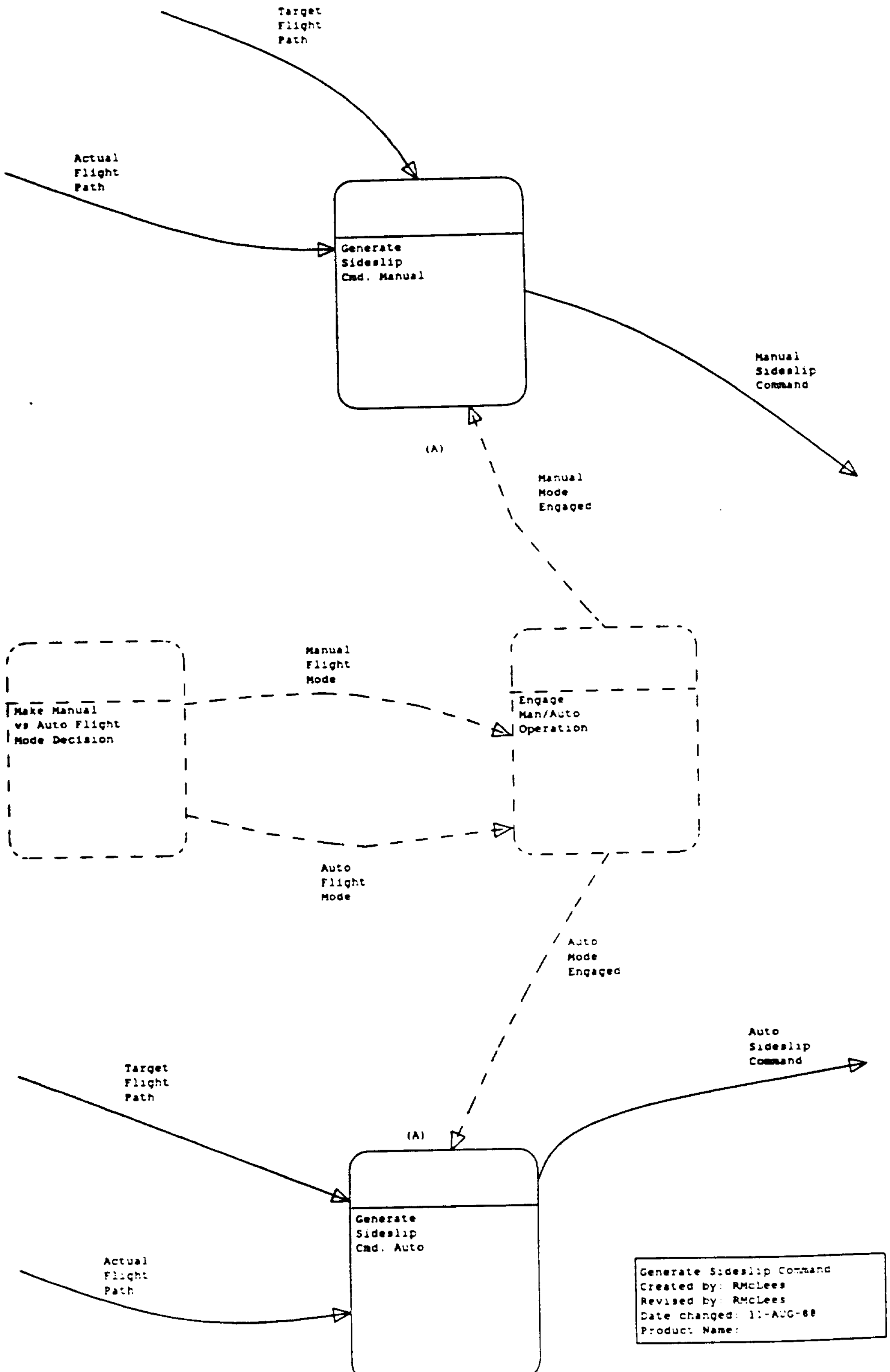


FIGURE P.Y.E.P.1-1 SIDESLIP LIMITS

Automated Directional Envelope Protection (P.Y.E.P.2)

Automated directional envelope protection shall be provided to relieve pilot workload and shall have a probability of loss of function < 10E-06.



Target
Flight
Path
Actual
Flight
Path
Generate
Sideslip
Cmd. Manual
Manual
Sideslip
Command
(A)
Manual
Mode
Engaged
Manual
Flight
Mode
Make Manual
vs Auto Flight
Mode Decision
Engage
Man/Auto
Operation
Auto
Flight
Mode
Auto
Mode
Engaged
Auto
Sideslip
Command
Target
Flight
Path
(A)
Generate
Sideslip
Cmd. Auto
Actual
Flight
Path
Generate Sideslip Command
Created by: RMcLees
Revised by: RMcLees
Date changed: 11-AUG-88
Product Name:

Process Descriptions
Generate Sideslip Command

Description	Expl name
This process involves the generation of a sideslip command automatically (ie by a computer).	Generate Sideslip Cmd. Auto
This process involves the generation of a sideslip command manually (ie by the crew) as a result of comparing the actual and desired flight path (including attitudes).	Generate Sideslip Cmd. Manual

Control Process Descriptions
Generate Sideslip Command

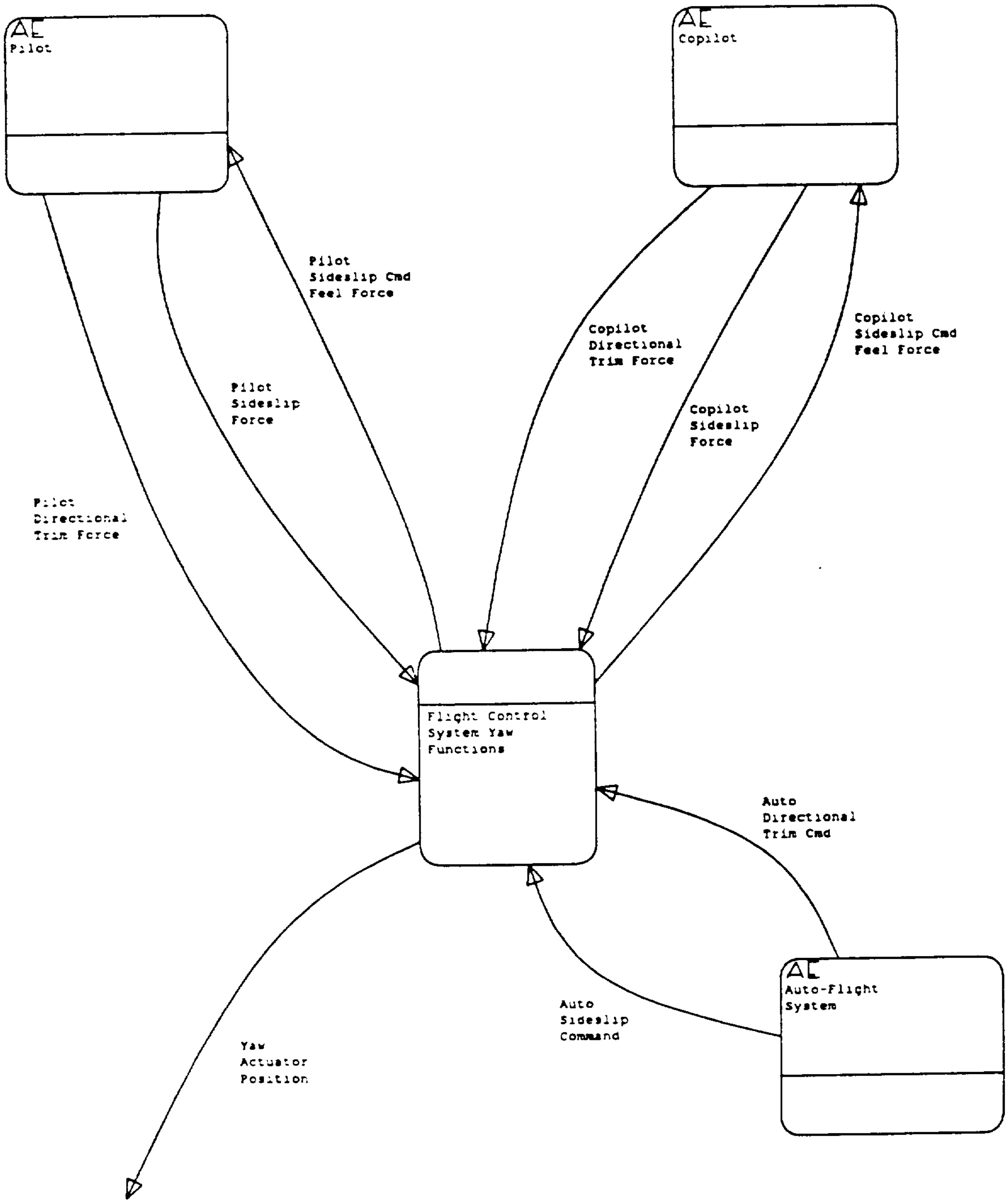
Description	Expl name
This process activates one of the sideslip generation processes depending on the mode engaged.	Engage Man/Auto Operation Yaw
This transform decides whether to generate sideslip and directional trim commands manually or automatically.	Make Manual/Auto Flight Decision

Data Flow Description
Generate Sideslip Command

Description	Name
The sensed 4 dimensional flight path & attitudes of the aircraft as well as any other sensed values necessary to satisfy the control requirements.	Actual Flight Path
Sideslip command generated in an automated fashion (ie by an autoflight computer).	Auto Sideslip Command
Sideslip command generated manually (ie by the crew).	Manual Sideslip Command
The desired 4 dimensional flight path and attitudes generated by some navigation function.	Target Flight Path

Process Architectural Assignments
Generate Sideslip Command

Expl name	associated aes
Generate Sideslip Cmd. Auto	Auto-Flight System
Generate Sideslip Cmd. Manual	Pilot Copilot



Flight Cntrl Sys Yaw Context
Created by: RMcLees
Revised by: RMcLees
Date changed: 01-SEP-88
Product Name:

Process Descriptions
Flight Cntrl Sys Yaw Context

Description	Expl name
This process contains all the directional axis flight control functions assigned to the FCS. As a result of this assignment several new processes are created. Some are interface functions and other arise due to architectural assignments. Envelope protection was assigned to the FCS with prob. of failure < 10E-6, however the function requires <10E-9. Therefore the crew must perform the function when not available from the FCS. Thus a crew indication function of envelope protect status was generated. Also, both pilot and copilot command sideslip and thus control contention must be resolved.	Flight Cntrl Sys Yaw Functns

Data Flow Description
Flight Cntrl Sys Yaw Context

Description	Name
Directional trim command generated automatically for use during enhanced manual control and autoflight control.	Auto Directional Trim Command
Sideslip command generated in an automated fashion (ie by an autoflight computer).	Auto Sideslip Command
The physical force exerted by the copilot to generated the desired directional trim command.	Copilot Directional Trim Force
This flow is a resistance force exerted by the controller which is a feedback to the copilot indicative of the sideslip command.	Copilot Sideslip Cmd Feel Force
The physical force exerted by the copilot to control the aircraft sideslip angle.	Copilot Sideslip Force
This is the physical force exerted by the pilot's hand to generate the desired directional trim command.	Pilot Directional Trim Force
This flow is a resistance force exerted by the controller which is a feedback to the pilot indicative of the sideslip command.	Pilot Sideslip Cmd Feel Force
This is the physical force exerted by the pilot to command the aircraft sideslip.	Pilot Sideslip Force
Position of the system which caused the aircraft to yaw (rudders).	Yaw Actuator Position

Process Requirements Links
Flight Cntrl Sys Yaw Context

Expl name	I-L Reference
Flight Cntrl Sys Yaw Functns	F.C.S.Y.F.1 F.C.S.Y.F.2

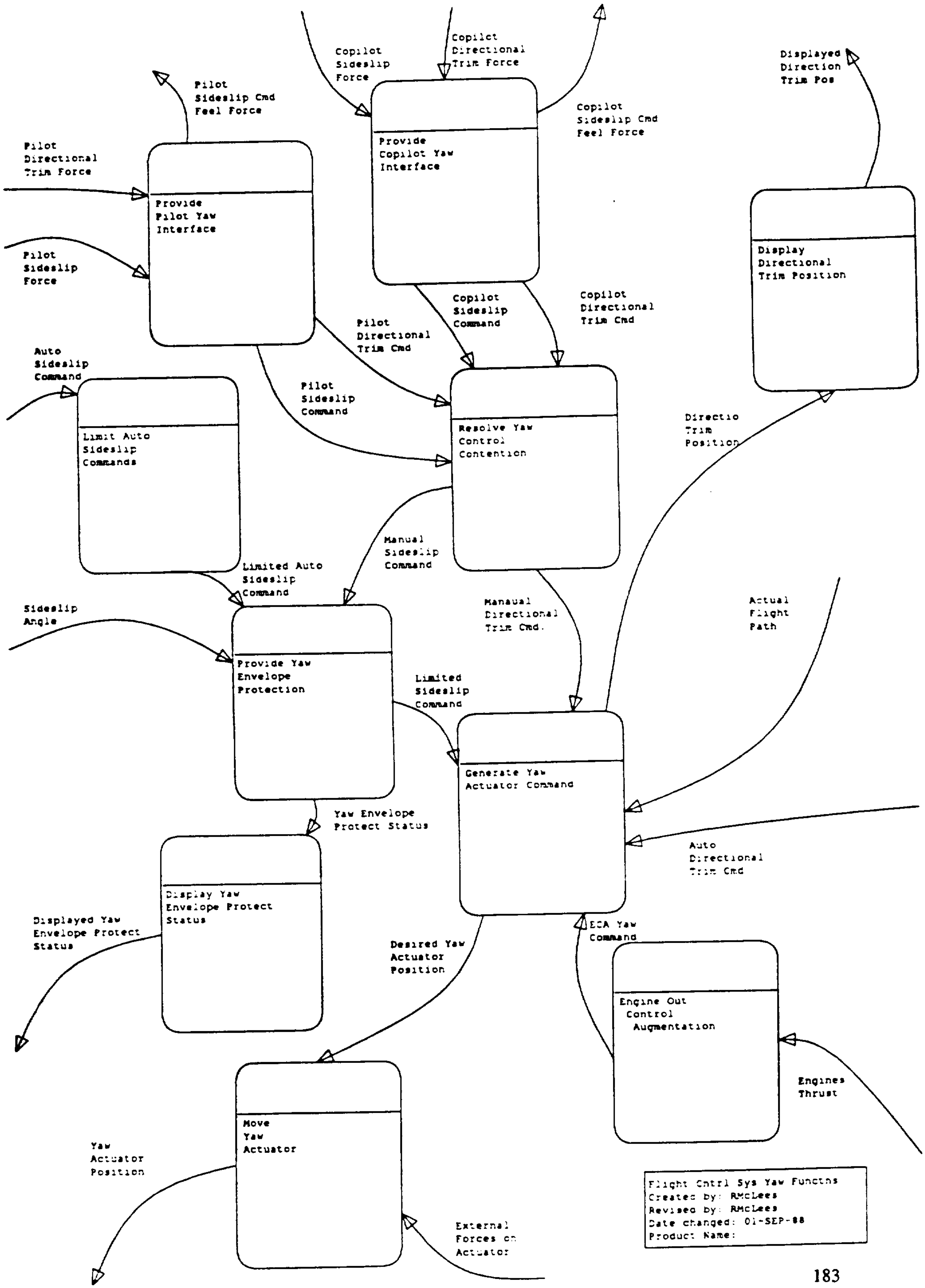
Directional Envelope Protection Mode Indication and Alert (F.C.S.Y.F.1)

Indication shall be provided to inform the pilot when an envelope protection mode has become active. An alert indication shall inform the pilot of loss of an envelope protection function. The loss of an envelope protection function and the failure to inform the pilot of the loss shall be extremely improbable. (FAR 25.672)(a)

(This functional requirement was generated because the pilot is resposible for envelope protection when not provided automatically.)

Pilot and Co-pilot Yaw Control Contention (F.C.S.Y.F.2)

Pilot and co-pilot yaw control contention shall be resolved.



Copilot Sideslip Force
Copilot Directional Trim Force
Displayed Direction Trim Pos
Pilot Sideslip Cmd Feel Force
Copilot Sideslip Cmd Feel Force
Provide Copilot Yaw Interface
Pilot Directional Trim Force
Provide Pilot Yaw Interface
Pilot Sideslip Force
Display Directional Trim Position
Copilot Sideslip Command
Copilot Directional Trim Cmd
Pilot Directional Trim Cmd
Auto Sideslip Command
Pilot Sideslip Command
Resolve Yaw Control Contention
Directio Trim Position
Limit Auto Sideslip Commands
Manual Sideslip Command
Limited Auto Sideslip Command
Manaual Directional Trim Cmd.
Actual Flight Path
Sideslip Angle
Provide Yaw Envelope Protection
Limited Sideslip Command
Generate Yaw Actuator Command
Yaw Envelope Protect Status
Auto Directional Trim Cmd
Display Yaw Envelope Protect Status
Displayed Yaw Envelope Protect Status
ECA Yaw Command
Desired Yaw Actuator Position
Engine Out Control Augmentation
Engines Thrust
Move Yaw Actuator
Yaw Actuator Position
External Forces on Actuator
Flight Cntrl Sys Yaw Functns
Created by: RMcLees
Revised by: RMcLees
Date changed: 01-SEP-88
Product Name:

Process Descriptions
Flight Cntrl Sys Yaw Functns

Description	Expl name
This transform displays the position of the directional trim actuator to the crew.	Display Directional Trim Posit.
This transform results from the allocation of Provide Yaw Envelope Protection to the FCS with a probability of loss of function < 10E-6. Yaw Envelope Protection has a probability of loss of function < 10E-9 and thus the crew has responsibility for yaw envelope protection when not performed by the FCS, hence the crew must be aware of the envelope protection status which leads to this functional requirement.	Display Yaw Envlp Protct Status
This process monitors the engine thrust and generates a yaw command to assist the pilot in compensating for an engine out situation. In particular it helps relieve pilot workload in takeoff and go around which are high pilot workload situations.	Engine Out Control Augmentation
This process generates the sideslip actuator (rudder) position command based on the limited sideslip command, directional trim command and the engine out control augmentation command.	Generate Yaw Actuator Command
This function limits the autopilot control authority and protects against failures (in particular hardover or oscillatory failures) in the autopilot.	Limit Auto Sideslip Commands
This transform receives the desired yaw actuator position and attempts to move the yaw actuator to that position.	Move Yaw Actuator
This function provides the same function for the copilot as the Provide Pilot Yaw Interface does for the pilot.	Provide Copilot Yaw Interface
This function converts the signal received from the pilot in the form of a force exerted by the pilots hand into a sideslip signal to be used by the FCS. It also provides the pilot with a feedback feel force proportional to the commanded sideslip angle.	Provide Pilot Yaw Interface
This function monitors the commanded sideslip and the actual sideslip and modifies the sideslip command to prevent the sideslip angle from exceeding unsafe limits.	Provide Yaw Envelope Protect
This process was generated as a result of the assignment of the Generate Sideslip Cmd Manual to both the pilot and copilot.	Resolve Yaw Control Contention

Data Flow Description
Flight Cntrl Sys Yaw Functns

Description	Name
The sensed 4 dimensional flight path & attitudes of the aircraft as well as any other sensed values necessary to satisfy the control requirements.	Actual Flight Path
Directional trim command generated automatically for use during enhanced manual control and autoflight control.	Auto Directional Trim Command
Sideslip command generated in an automated fashion (ie by an autoflight computer).	Auto Sideslip Command
Numeric value of the copilot directional trim command as obtained from the copilot roll trim force.	Copilot Directional Trim Cmd
The physical force exerted by the copilot to generate the desired directional trim command.	Copilot Directional Trim Force
This flow is a resistance force exerted by the controller which is a feedback to the copilot indicative of the sideslip command.	Copilot Sideslip Cmd Feel Force
Numeric value of the copilot sideslip command obtained from the Copilot Sideslip Force.	Copilot Sideslip Command
The physical force exerted by the copilot to control the aircraft sideslip angle.	Copilot Sideslip Force
The desired yaw actuator position such that the limited sideslip and directional trim commands are achieved.	Desired Yaw Actuator Position
Position of the directional trim actuator.	Directional Trim Position

Data Flow Description
Flight Cntrl Sys Yaw Functns

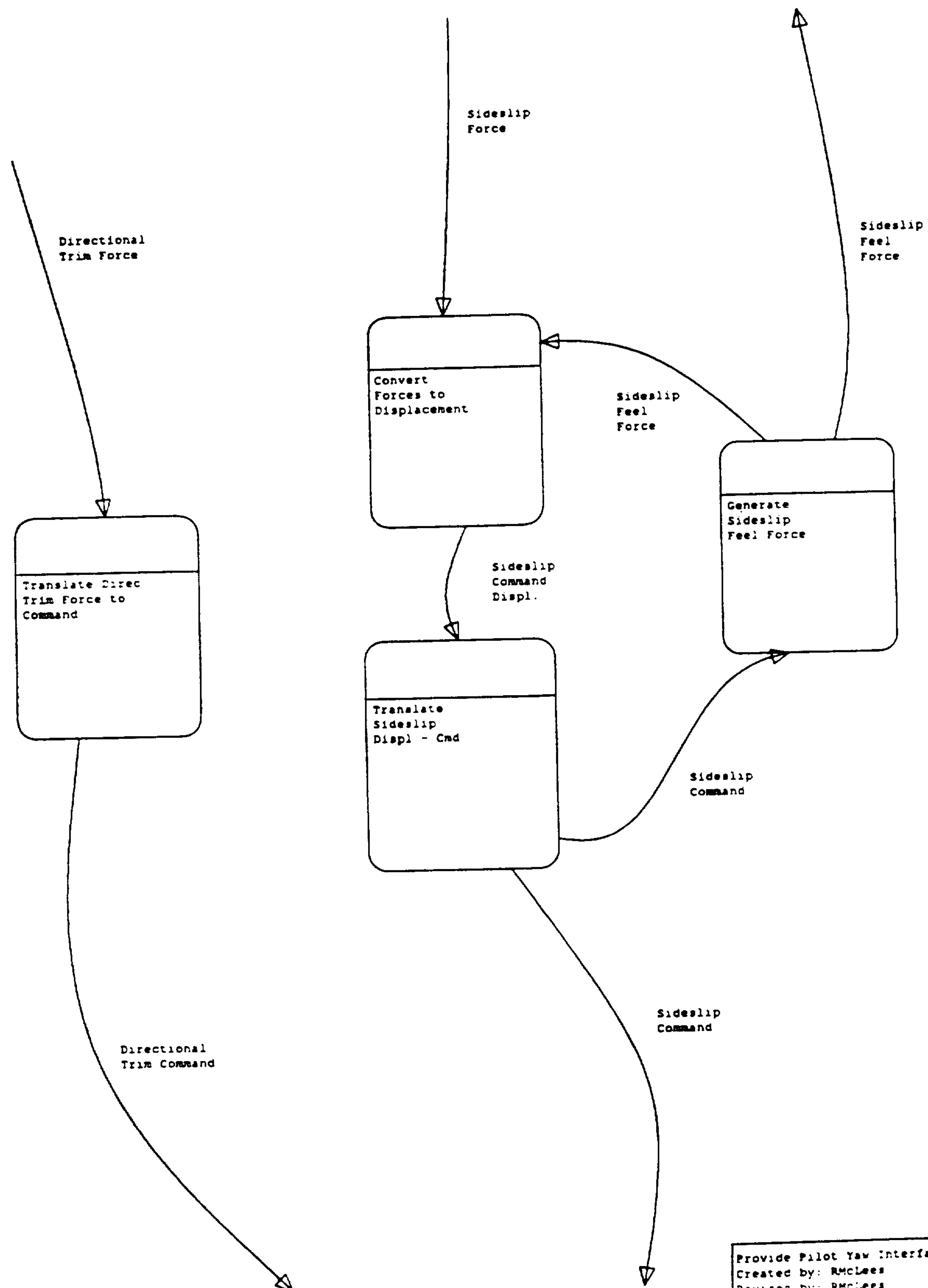
Description	Name
This flow is the directional trim actuator position displayed to the crew.	Displayed Directional Trim Pos
Status of the availability and activity of the yaw envelope protection function displayed to the crew.	Dsplyd Yaw Envlp Protct Status
Automatically generated yaw command to assist the pilot in controlling the aircraft in an engine out situation.	ECA Yaw Command
Thrust measurements of engines to determine capture engine out event.	Engines Thrust
The auto sideslip command protected against oscillatory failures and limited to autoflight authority.	Limited Auto Sideslip Command
The sideslip command limited such that the sideslip envelope protection criteria are not violated.	Limited Sideslip Command
The directional trim command as generated by the crew for use during normal control to offset asymmetries.	Manual Directional Trim Command
Sideslip command generated manually (ie by the crew).	Manual Sideslip Command
Numeric value of the physical force exerted by the pilot's hand to generate the desired directional trim command.	Pilot Directional Trim Cmd
This is the physical force exerted by the pilot's hand to generate the desired directional trim command.	Pilot Directional Trim Force
This flow is a resistance force exerted by the controller which is a feedback to the pilot indicative of the sideslip command.	Pilot Sideslip Cmd Feel Force
Numeric value of the pilot's sideslip command obtained from the Pilot Sideslip Force.	Pilot Sideslip Command
This is the physical force exerted by the pilot to command the aircraft sideslip.	Pilot Sideslip Force
Airplane sideslip angle.	Sideslip Angle
Position of the system which caused the aircraft to yaw (rudders).	Yaw Actuator Position
Activity and availability of the Provide Yaw Envelope Protection function.	Yaw Envelope Protect Status

Process Requirements Links
Flight Cntrl Sys Yaw Functns

Expl name	I-L Reference
Display Directional Trim Posit.	
Display Yaw Envlp Protct Status	
Engine Out Control Augmentation	E.O.C.A.1
Generate Yaw Actuator Command	
Limit Auto Sideslip Commands	L.A.S.C.1
Move Yaw Actuator	
Provide Copilot Yaw Interface	
Provide Pilot Yaw Interface	
Provide Yaw Envelope Protect	P.Y.E.P.1 P.Y.E.P.2
Resolve Yaw Control Contention	R.Y.C.C.1

Pilot and Co-pilot Yaw Control Contention Resolution (R.Y.C.C.1)

The pilot's and co-pilot's pedals shall be bussed together.



Provide Pilot Yaw Interface
Created by: RMcLees
Revised by: RMcLees
Date changed: 01-SEP-88
Product Name:

Process Descriptions
Provide Pilot Yaw Interface

Description	Expl name
This process receives the pilot force and feedback feel force and generates a displacement.	Convert Yaw Forces - Displ.
This transform generates a force to feedback to the pilot which is an indication of the commanded sideslip angle.	Generate Sideslip Feel Force
This transform translates the displacement (rudder pedal) to a sideslip command.	Translate Sideslip Displ to Cmd
This process converts the physical displacement generated by the physical force exerted by the pilot into a trim command for use by the FCS.	Translate Direc Trim Force/Cmd

Data Flow Description
Provide Pilot Yaw Interface

Description	Name
The directional trim command in degrees.	Directional Trim Command
The physical force exerted by the pilot to generate the desired directional trim.	Directional Trim Force
The manually generated sideslip command in degrees.	Sideslip Command
The sideslip controller (rudder pedal) displacement in inches.	Sideslip Command Displacement
This flow is a resistance force exerted by the controller which is a feedback to the pilot indicative of the sideslip command.	Sideslip Feel Force
The physical signal in the form of a force created by the pilot to control the aircraft sideslip angle.	Sideslip Force

Process Requirements Links
Provide Pilot Yaw Interface

Expl name	I-L Reference
Convert Yaw Forces - Displ.	C.Y.F.D.1 C.Y.F.D.2
Generate Sideslip Feel Force	G.S.F.F.1 G.S.F.F.2
Translate Direc Trim Force/Cmd	T.D.T.F.C.1
Translate Sideslip Displ to Cmd	

Pilot Directional Control (C.Y.F.D.1)

Maximum available rudder travel at all flight conditions shall normally be obtained by a rudder pedal deflection of TBD inches.

Directional Controller Deflection Rates (C.Y.F.D.2)

No force discontinuities or other objectionable characteristics shall occur for all controller command rates. (MIL-F-8785C 3.5.3)

Directional Feel Forces (G.S.F.F.1)

a) The total pedal breakout force shall be between 1 lb and 14 lbs including friction. (MIL-F-8785C 3.5.2.1)

b) The maximum pedal force shall not exceed approximately 150 lbs for temporary application and 20 lbs for prolonged application. (FAR 25.143)

Directional Controller Centering (G.S.F.F.2)

Positive control centering shall be provided in all modes. (MIL-F-8785C 3.5.2.1)

Directional Trim Control (T.D.T.F.C.1)

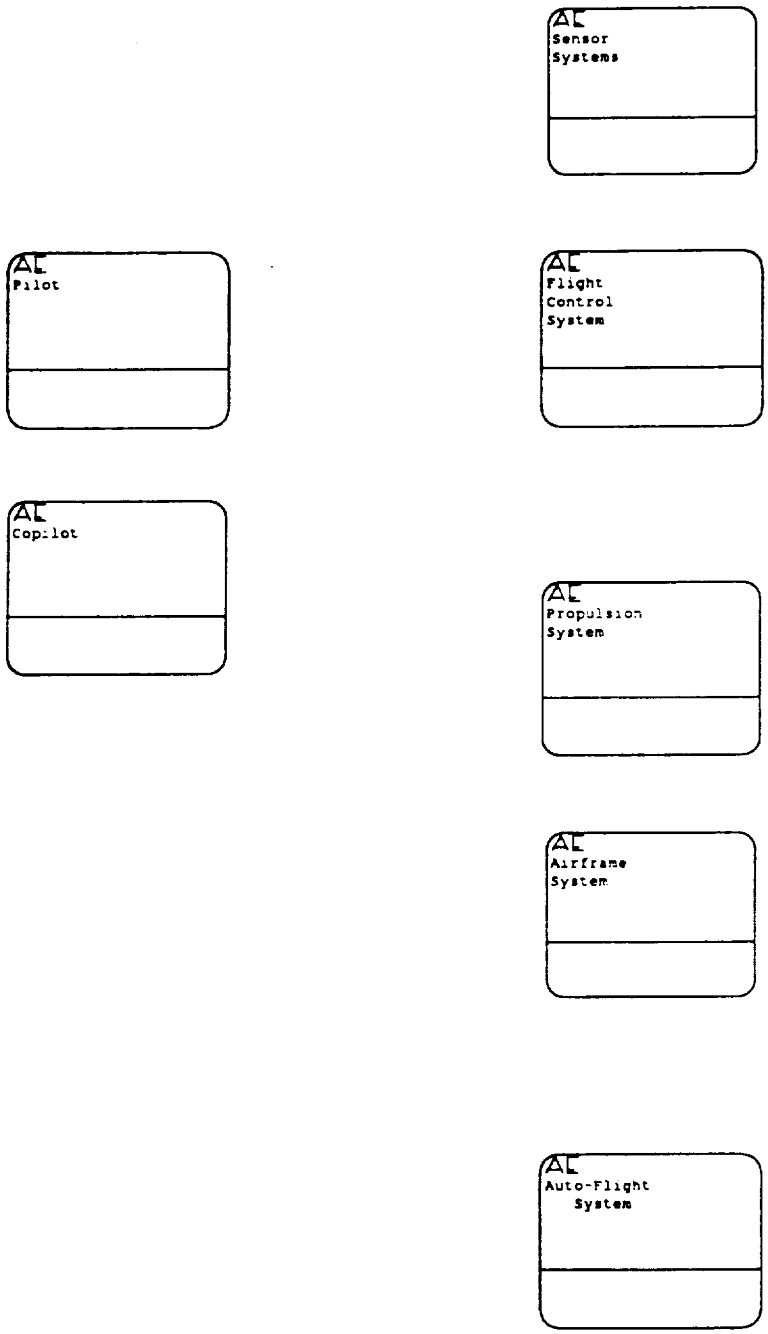
a) The directional trim system implementation shall be consistent with conventional pilot trimming techniques for all-engine and engine-out situations.

b) Trim inputs shall be in series with the pilot pedals.

The System
Created by: RMcLees
Revised by: RMcLees
Date changed: 02-SEP-88
Product Name:

Architecture Element Requirements
The System

Expl name	I-L Reference
Aircraft	
Flight Environment	



Aircraft
Created by: RMcLees
Revised by: RMcLees
Date changed: 21-DEC-88
Product Name:

Architecture Element Requirements
Aircraft

Expl name	I-L Reference
Airframe System	
Auto-Flight System	
Copilot	
Flight Control System	Flight.Control.Sys.Req.List
Pilot	
Propulsion System	
Sensor Systems	

Flight.Control.Sys.Req.List

F.C.S.1 Control System Signal Transmission
F.C.S.2 System Requirements Under Failure Conditions
F.C.S.3 Control System Separation
F.C.S.4 Control System Sensors
F.C.S.5 Control System Actuation
F.C.S.6 System Test Requirement
F.C.S.7 Control Transients
F.C.S.8 Control Force Harmony and Coordination
F.C.S.9 Control Surface Position Indication
F.C.S.10 Flight Control System Caution and Warning
F.C.S.11 Control System Invulnerability
F.C.S.12 Operational Exposure Requirement
F.C.S.13 Longitudinal Control Reliability Requirements with Failure Conditions
F.C.S.14 Lateral Control Reliability Requirements with Failure Conditions
F.C.S.15 Directional Control Reliability Requirements with Failure Conditions
F.C.S.16 Directional Control System
F.C.S.17 High Lift Control Reliability Requirements with Failure Conditions
F.C.S.18 Aerodynamic Braking Reliability Requirements with Failure Conditions

Control System Signal Transmission (F.C.S.1)

The FCS signals between the sensors, computers and the surface actuators shall be transmitted by high speed electrical or optical data buses. Redundant and dissimilar paths shall be provided to meet the FCS safety requirements. Redundant transmission channels shall, to the extent practical, use separate paths to minimize the possibility of simultaneous damage. (MIL-F-9490D 3.1.3.1 & 3.2.3.3)

System Requirements Under Failure Conditions (F.C.S.2)

The flight control system shall as a minimum meet the requirements of Part 25 of the Federal Aviation Regulations. The requirements pertaining to system operation following failures is reproduced verbatim as follows:

FAR 25.671(b)

Each element of each flight control system must be designed, or distinctively and permanently marked, to minimize the probability of incorrect assembly that could result in the malfunctioning of the system.

FAR 25.671(c)

The airplane must be shown by analysis, test, or both to be capable of continued safe flight and landing after any of the following failures or jamming in the flight control system and surfaces (including trim, lift, drag, and feel systems) within the normal flight envelope, without requiring exceptional piloting skill or strength. Probable malfunctions must have only minor effects on control system operation and must be capable of being readily counteracted by the pilot.

1) Any single failure, excluding jamming (for example, disconnection or failure of mechanical elements, or structural failure of hydraulic components, such as actuators, control spool housing, and valves).

2) Any combination of failures not shown to be extremely improbable, excluding jamming (for example, dual electrical or hydraulic system failures, or any single failure in combination with any probable hydraulic or electrical failure).

3) Any jam in a control position normally encountered during takeoff, climb, cruise, normal turns, descent, and landing unless the jam is shown to be extremely improbable, or can be alleviated. A runaway of a flight control to an adverse position and jam must be accounted for if such runaway and subsequent jamming is not extremely improbable.

FAR 25.671(d)

The airplane must be designed so that it is controllable if all engines fail. Compliance with this requirement may be shown by analysis where that method has been shown to be reliable.

FAR 25.672(b)

The design of the stability augmentation system or of any other automatic or power-operated system must permit initial counteraction of failures of the type specified in 25.671(c) without requiring exceptional pilot skill or strength, by either the deactivation of the system or a failed portion thereof, or by overriding the failure by movement of the flight controls in the normal sense.

FAR 25.672(c)

It must be shown that after any single failure of the stability augmentation system or any other automatic or power-operated system:

1) The airplane is safely controllable when the failure or malfunction occurs at any speed or altitude within the approved operating limitations that is critical for the type of failure being considered;

2) The controllability and maneuverability requirements of this Part are met within a practical operational flight envelope (for example, speed, altitude, normal acceleration, and airplane configurations) which is described in the Airplane Flight Manual; and

3) The trim, stability, and stall characteristics are not impaired below a level needed to permit continued safe flight and landing.

FAR 25.729(f)

Equipment that is essential to safe operation of the airplane and that is located in wheel wells must be protected from the damaging effects of:

1) A bursting tire, unless it is shown that a tire cannot burst from overheat; and
2) A loose tire tread, unless it is shown that a loose tire tread cannot cause damage.

FAR 25.1309(a)

The equipment, systems, and installations whose functioning is required by this subchapter, must be designed to ensure that they perform their intended functions under any foreseeable operating condition.

FAR 25.1309(b)

The airplane systems and associated components, considered separately and in relation to other systems, must be designed so that:

1) The occurrence of any failure condition which would prevent the continued safe flight and landing of the airplane is extremely improbable, and
2) The occurrence of any other failure condition which would reduce the capability of the airplane or the ability of the crew to cope with the adverse operating conditions is improbable.

Control System Separation (F.C.S.3)

The control system design shall use physical separation, functional separation and electrical isolation between redundant flight control elements and between the flight control system and other systems to the maximum extent practical to safeguard the integrity of redundant flight control channels.(MIL-F-9490D 3.2.3.1.2) Sources of common mode failures to be considered include:

Failure of local structure
Engine or APU burst
Environmental conditions such as temperature or fluid contamination
Flight crew or maintenance crew errors
Electromagnetic interference
Lightning strike

a) Element Separation

It shall be a requirement to separate control elements and signal transmission paths of redundant channels to the extent practical to minimize the possibility of simultaneous damage to more than one control channel.

b) Functional Partitioning

If different control functions are combined in an LRU, functional partitioning shall be used to the extent practical to minimize the possibility of failure of one function affecting the performance of the other functions.

c) Failure Propagation

Separation and isolation shall be provided to prevent failure of a subsystem or component from degrading the performance of an interfacing subsystem or component that has a higher level of criticality for safety. Nonessential system failures shall not affect essential or critical systems. Essential system failures shall not affect critical systems. It shall be a requirement to minimize failure propagation between systems or elements with similar criticality.

Control System Sensors (F.C.S.4)

The flight control system shall be designed to minimize the number of sensors required.

Control System Actuation (F.C.S.5)

The flight control surfaces shall be actuated by electrical or hydraulic power. Control surface authority, rates, and dynamic characteristics shall satisfy the handling qualities, envelope protection and structural design requirements.

a) Buzz and Flutter Requirements

The actuation system shall provide adequate stiffness to satisfy the buzz and flutter requirements. (MIL-F-9490D 3.1.11.2 & 3.2.6.7.3)

b) Multiple Actuator Requirements

In essential and flight phase essential flight control actuator installations employing multiple connected servoactuators, the actuators shall be synchronized as necessary to assure specified performance and durability as specified in MIL-F-8785C 3.1.11.3 in the structure between actuators without undue structural weight penalties. (MIL-F-9490D 3.2.6.4.4)

System Test Requirement (F.C.S.6)

a) Preflight Test

An automated preflight test shall be provided. It shall have the capability to test the flight control system and its interfaces and annunciate dispatch status to the crew. No control surface motion shall occur during the test. (MIL-F-9490D 3.1.3.9.1.1)

1) Preflight test coverage shall be 98% or greater for those elements essential for flight safety.
2) Preflight test coverage shall be 100% for those elements critical for flight safety.
3) Preflight test shall be inhibited at speeds above low speed taxi.
4) Preflight test from start to completion shall not require longer than 2 minutes.

b) Flight Control Freedom of Motion Test

A crew activated freedom of motion test shall be provided that confirms proper operation of the FCS without flight crew monitoring of the control surface indicators. (MIL-F-9490D 3.1.3.9.1)

c) Maintenance Test

A maintenance test shall be provided and interfaced with the central on-board maintenance control and display panel. (MIL-F-9490D 3.1.3.9.1.2)

Control Transients (F.C.S.7)

Failures

The following events shall not cause dangerous or intolerable flying qualities: (MIL-F-8785C 3.5.5)

a) Complete or partial loss of any function of the augmentation system following a single failure.

b) Failure-induced transient motions and trim changes either immediately after failure or upon subsequent transfer to alternate control mode.

c) Configuration changes required or recommended following failure.

Failure Induced Transients

With controls free, the airplane motions due to failures described above shall not exceed the following limits for at least 2 seconds following the failure, as a function of the level of flying qualities after the failure transient has subsided: (MIL-F-8785C 3.5.5.1)

NORMAL (after failure): ±0.5g incremental normal or lateral acceleration at the pilot's station and ±10 degrees per second roll rate, except that neither stall angle of attack nor structural limits shall be exceeded.

MINIMUM ACCEPTABLE (after failure): No dangerous attitude or structural limit is reached, and no dangerous alteration of the flight path results from which recovery is impossible.

Transfer to Alternate Control Modes

The transient motions and trim changes resulting from the intentional engagement or disengagement of any portion of the primary flight control system by the pilot shall be such that dangerous flying qualities never result. (MIL-F-8785C 3.5.6)

Transfer Transients

With controls free, the transients resulting from the situations described above shall not exceed the following limits for at least 2 seconds following the transfer: (MIL-F-8785C 3.5.6.1)

Within the Normal Operational Flight Envelope: ±0.1g normal or lateral acceleration at the pilot's station and ±3 degrees per second roll rate.

Within the Permissible Flight Envelope: ±0.5g at the pilot's station, ±5 degrees per second roll rate, the lesser of ±5 degrees sideslip and the structural limit.

Control Force Harmony & Coordination (F.C.S.8)

The pitch and roll control force and displacement sensitivities and breakout forces shall be harmonious so that inputs to one control axis will not cause inadvertent inputs to the other. (MIL-F-8785C 3.4.4)

The following control forces are considered to be maximum for temporary application of simultaneous forces: (MIL-F-8785C 3.4.4.1 & FAR 25.143)

TYPE CONTROLLER	PITCH	ROLL	YAW
Sidestick	50 Lbs	25 Lbs	
Wheel controller	75 Lbs	40 Lbs	
Pedal			150 Lbs

Control Surface Position Indication (F.C.S.9)

Control surface position indication shall be provided for those control surfaces necessary for safe takeoff, flight and landing unless the failure of a surface to respond to a pilot input can be detected by other means from within the flight deck. (FAR 25.1309(c), FAR 25.1329(b))

Flight Control System Caution and Warning (F.C.S.10)

A clear distinguishable caution/warning indication shall be provided for any failure in the flight control systems which could result in an unsafe condition if the pilot were not aware of the failure. (FAR 25.672(a))

Control System Invulnerability (F.C.S.11)

a) Invulnerability to Environment

1) The control system shall retain normal performance when subjected to ambient or induced environment extremes established for the system including the effects of temperature, vibration, shock, and EMI. (FAR 25.1309)
2) The control system shall retain minimum acceptable performance or better when subjected to lightning or static electricity discharge extremes established for the airplane and systems. Wiring shall be shielded and protected to limit the lightning induced transient level to less than 600 volts. The control system shall be protected against the effects induced by the multiple high current pulses or strokes associated with a lightning flash. (FAR 25.1309, FAR 25.581)

b) Invulnerability to Electrical Power Transients

The FCS electronics shall continue to operate satisfactorily during normal or abnormal temporary disruptions in the electrical power system such as those caused by transfer of power from ground to airplane sources and transfers caused by electrical failures which cause circuit breaker trips and consequent reconfiguration of electrical power source and routing to alternative airplane electrical power buses. (MIL-F-9490D 3.2.4.1.1)

Operational Exposure Requirement (F.C.S.12)

The flight control system shall operate correctly through all phases of flight and ground handling exposure including:

a) Power up in any combination or sequence of circuit breaker or switch selection.

b) Power up with degraded ground power supplies.

c) Engine or APU start in any sequence.

d) System cockpit checks.

e) Pushback.

f) Taxi, including high speed taxi and turns.

g) Brake release and rejected takeoff.

h) Takeoff, climb, cruise, descent, hold, approach, go-around, land and rollout.

i) Engine or APU shutdown in any combination or sequence.

j) Storage or park for any length of time in environment extremes established for the system.

k) Exposure to continuous maintenance operation or troubleshooting.

l) Exposure to simulated in-air operation on the ground without causing an unusual or unindicated personnel hazard exposure.

m) System functional checks.

Longitudinal Control Reliability Requirements with Failure Conditions (F.C.S.13)

a) The following failure conditions shall be extremely improbable: (FAR 25.1309)

1) Elevator or stabilizer surface hardover or slowover
2) Oscillatory failure in excess of structural limits
3) Loss of flutter preventive actuation stiffness
4) Loss of core system control of both elevators
5) Asymmetric elevator in excess of limit load
6) Feel forces greater or less than those required for minimum acceptable control.

b) No single failure, including jams, shall cause loss of elevator command capability from both pilot's stations. (FAR 25.671, FAR 25.1309)

c) With controls free, the airplane motions due to any single failure shall not exceed $\pm$ .5 g normal acceleration at the pilot's station for at least 2 seconds following the failure. (MIL-F-8785C 3.5.5.1)

Lateral Control Reliability Requirements with Failure Conditions (F.C.S.14)

a) No single hydraulic or electrical power source failure shall result in an uncommanded deflection of aileron or spoiler panels. (FAR 25.671(c))

b) No single failure including jams shall cause loss of command capability from both pilot stations. (FAR 25.671(c))

c) No single failure shall allow a control surface to assume a hardover position unless it can be shown that the hardover is controllable and does not produce unacceptable excursions. (FAR 25.671(c))

d) Oscillatory aileron or spoiler failures shall be extremely improbable. (FAR 25.1309)

e) No single failure or combination of failures shall result in a trim runaway unless it can be shown to be extremely improbable. (FAR 25.1309)

Directional Control Reliability Requirements With Failure Conditions (F.C.S.15)

a) No single failure, excluding jams, shall result in complete loss of rudder command capability (including trim) from both pilot stations. (FAR 25.671(c))

b) No single failure or combination of failures not shown to be extremely improbable shall result in the following: (FAR 25.1309)

1) Trim runaway.
2) Sustained rudder surface hardover to blowdown.
3) Oscillatory rudder surface at critical frequency and amplitude.

Directional Control System (F.C.S.16)

The directional control system shall be configured such that pilot use of rudder pedals for maneuvering including crosswind and engine-out control shall be consistent with conventional piloting techniques.

High Lift Control Reliability Requirements with Failure Conditions (F.C.S.17)

a) With full loss of drive system power all leading edge and trailing edge devices shall remain in the last position attained at the time of failure. (FAR 25.697(a), FAR 25.697(b))

b) No single failure in the drive system shall cause a flap segment to depart the airplane. (FAR 25.671(c))

c) For probable failures, full extension and retraction of all high lift devices shall be available, using normal procedures to the greatest extent practical, although the actuating time may be increased. (FAR 25.671(c))

d) The failure of one set of high lift devices, leading edge or trailing edge, shall not preclude control of the other set.

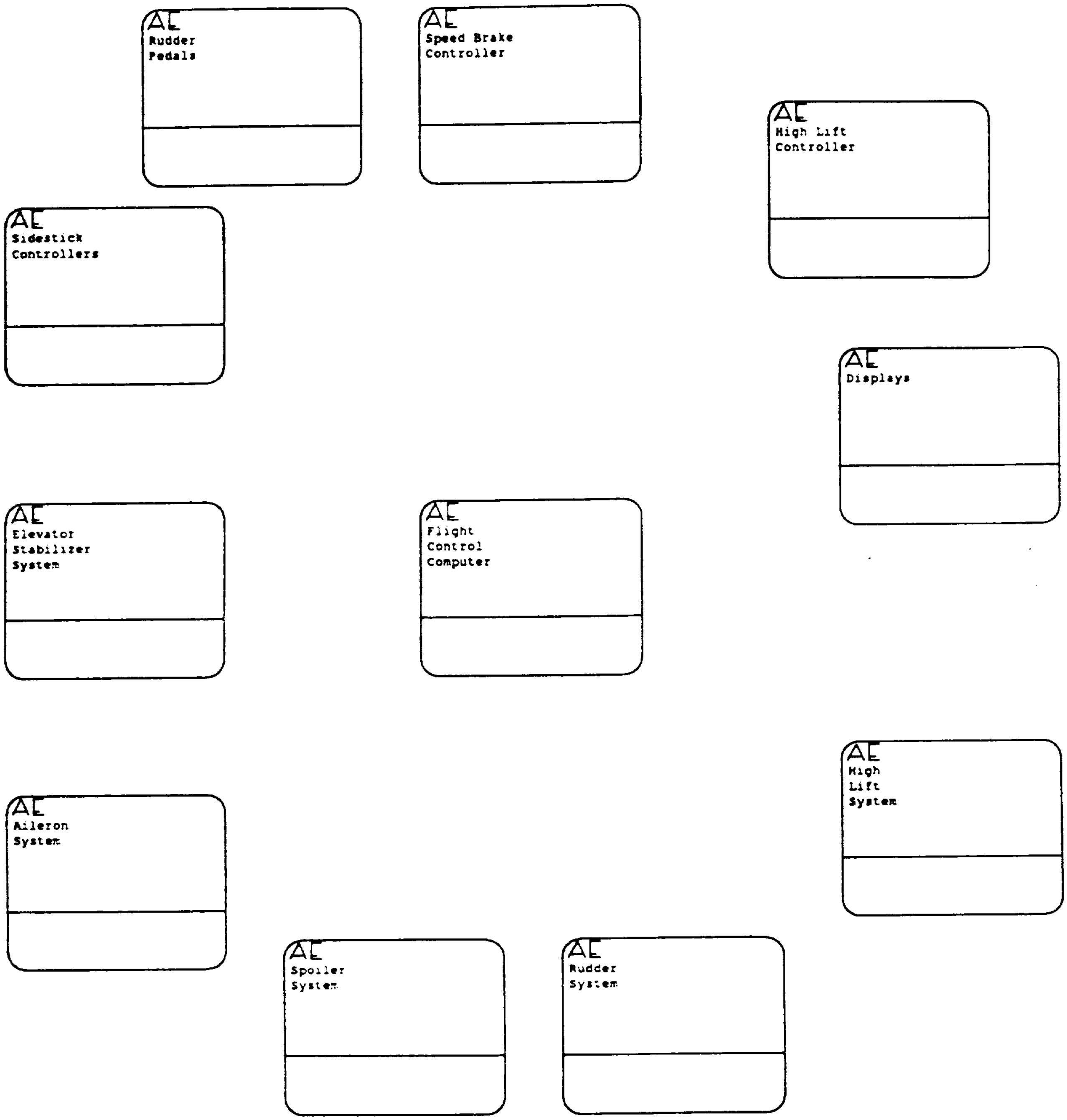
e) No single failure or combination of failures that cannot be shown to be extremely improbable shall cause inadvertent retraction or extension or missequencing of any of the high lift devices if it requires unusual pilot skill or strength for continued safe flight and landing. (FAR 25.697(b), FAR 25.671(c))

f) No single failure or combination of failures that cannot be shown to be extremely improbable shall cause asymmetric operation of leading edge or trailing edge devices if it requires unusual pilot skill or strength for continued safe flight and landing. (FAR 25.1309)

Aerodynamic Braking Reliability Requirements with Failure Conditions (F.C.S.18)

a) No single failure or combination of failures not extremely improbable shall result in hazardous symmetric or asymmetric speed brake operation in response to a speed brake command. (FAR 25.671)

b) No single failure or combination of failures not shown to be extremely improbable shall result in an uncommanded speed brake operation which would have an unacceptable effect on airplane performance or controllability. (FAR 25.671)



Flight Control System
Created by: RMcLees
Revised by: RMcLees
Date changed: 01-SEP-88
Product Name:

Architecture Element Requirements
Flight Control System

Expl name	I-L Reference
Aileron System	A.S.1
Displays	
Elevator Stabilizer System	E.S.S.1 E.S.S.2
Flight Control Computer	F.C.C.1
High Lift Config. Controller	H.L.C.C.1
High Lift System	H.L.S.1 H.L.S.2
Rudder Pedals	R.P.1
Rudder System	R.S.1
Sidestick Controllers	S.C.1 S.C.2
Speed Brake Controller	S.B.C.1
Spoiler System	S.S.1 S.S.2

Aileron Mechanical Travel, Design Hinge Moments and Rates (A.S.1)

1) The lateral control system shall be designed to give the following rate, deflection and hinge moment capabilities with all hydraulic or electrical systems operating normally.

The aileron actuators shall be sized to give full deflection at TBD speed and shall give 90% of full deflection in TBD seconds.

2) Aileron peak rates shall not reduce more than TBD% with only one actuator active.

Longitudinal Control System (E.S.S.1)

The following control system requirements are for airplanes where longitudinal control is provided by an elevator and stabilizer (if required).

a) The elevators shall be capable of reaching 90% of maximum travel in TBD seconds with all hydraulic systems operating and with consideration of utilization of the controls on the other axes. Peak rates shall not reduce more than TBD% with only one actuator active.

b) There shall be sufficient design hinge moment to obtain elevator deflection at V_{DF}/M_{DF} to perform the 1.5 g mistrim dive recovery specified in FAR 25.255(f).

Trim Control System Actuation (E.S.S.2)

The stabilizer shall remain in the last selected position under the full range of operating loads following complete failure of all power sources. (FAR 25.677(c))

Control System Computation (F.C.C.1)

a) The FCS computation and sample rates shall be established at a level which ensures that the digital computation process will not introduce unacceptable phase shift, round off error, nonlinear characteristics or aliasing into the system response. At the time of system acceptance, the total time used in flight control computations for worst case conditions shall not exceed 75 percent of the available computation time allocated for flight control use. Physical memory shall be sized such that at least 25 percent is available for growth at the time of acceptance. (MIL-F-9490D 3.2.4.3.2)

b) Flight critical computation shall utilize dissimilar hardware and software to meet the FCS safety requirements.

c) Software utilized in the FCS electronics shall be designed, tested and documented in a manner to show compliance with RTCA/DO-178A "Software Considerations in Airborne Systems and Equipment Certification".

Manual High Lift Control (H.L.C.C.1)

a) Wing leading edge and trailing edge devices shall be normally controlled through a single flap/slat controller.

b) The high lift device controls shall be designed and located to provide convenient operation and to prevent confusion and inadvertent operation. (FAR 25.777(a))

Trailing Edge Flaps Design Deflection and Rates (H.L.S.1)

a) Flaps shall have a maximum deflection of TBD degrees under operating load.

b) High lift extend/retract rates shall give satisfactory flight and performance characteristics under steady or changing conditions of airspeed, engine power and airplane attitudes. High-lift system operating rates shall be chosen in conjunction with the choice of speed schedules for flap extension and retraction, the stall warning speed schedules, and the flap placard and flap load alleviation speeds, to provide:

At least level flight capability after complete retraction of the high-lift devices from the maximum landing flap position has been initiated from steady, straight, level flight at 1.2Vs, with simultaneous application of full take-off thrust, with the gear extended, and at critical combinations of landing weights and altitudes. (FAR 25.145(c))

c) Any single engine failure shall not significantly affect flap extension and retraction times.

Leading Edge High Lift Device Actuation Rate (H.L.S.2)

a) High lift extend/retract rates shall give satisfactory flight and performance characteristics under steady or changing conditions of airspeed, engine power and airplane attitudes. High-lift system operating rates shall be chosen in conjunction with the choice of speed schedules for flap extension and retraction, the stall warning speed schedules, and the flap placard and flap load alleviation speeds, to provide:

At least level flight capability after complete retraction of the high-lift devices from the maximum landing flap position has been initiated from steady, straight, level flight at 1.2Vs, with simultaneous application of full take-off thrust, with the gear extended and at critical combinations of landing weights and altitudes. (FAR 25.145(c))

b) Any single engine failure shall not significantly affect slat extension and retraction times.

Pilot Yaw Control (R.P.1)

The pilot inputs shall be applied through a pair of pedals for each pilot. Individual pilot-to-pedal adjustments to accommodate pilots ranging in heights from 5'2" to 6'3" shall be provided. (FAR 25.777(c))

Crew trim control shall be provided via trim switches accessible to both pilots.

Rudder System (R.S.1)

Ninety percent of full deflection shall be available in no more than TBD seconds at the highest speed design condition with TBD utilization of the lateral control surfaces and TBD utilization of the elevator.

System Performance with Failure Conditions (FAR 25.671(c))

a) The rudder power actuation system shall be designed with sufficient redundancy such that with any single hydraulic or electrical system inoperative there shall be no degradation in minimum control speeds or crosswind takeoff and landing capability.

b) Sufficient rudder capability shall remain with two hydraulic or electrical systems inoperative to maintain heading at the takeoff safety speed, V_2, with the most critical engine inoperative in the takeoff configuration.

Pilot Longitudinal Control (S.C.1)

Control inputs shall be provided by a small controller at each pilot station.

Normal crew trim control shall be provided by means of trim switches on each pilot controller.

An alternate crew trim command path shall be provided by means of trim switches accessible to both crew members. (MIL-F-9490D 3.1.3.5)

Pilot Lateral Control (S.C.2)

Control inputs shall be provided by a small controller at each pilot station.

Crew trim control shall be provided via trim switches accessible to both pilots.

Speed Brake Controller (S.B.C.1)

Control of speed brakes during in-flight and on-ground operation shall be provided by a single speedbrake control accessible to both pilot and copilot.

Spoiler Deflections (S.S.1)

The flight spoilers shall be capable of simultaneous deflection on both wings for use as inflight and ground speed brakes with modulation about this operating point for roll control.

Spoiler Mechanical Travel, Design Hinge Moments and Rates (S.S.2)

The lateral control system shall be designed to give the following rate, deflection and hinge moment capabilities with all hydraulic or electrical systems operating normally.

The spoiler actuators shall be sized to provide the control capability required to satisfy Paragraphs C.M.F.17. The roll sensitivity with full speedbrake command shall meet the requirements of Paragraph T.R.D.C.1. They shall give 90% of full deflection in TBD seconds at the low speed design condition with TBD utilization of the rudder and TBD utilization of the elevator.

5.0 ESML Problems, Deficiencies, and Recommendations

During this study functional requirements for an advanced flight control system were derived using a structured approach based on the Extended Systems Modeling Language (ESML). The functional requirements were decomposed from the top-level function, Fly Mission. Detailed performance requirements were then added to these functional requirements based on existing regulatory agency requirements and specifications. This effort provided valuable experience with this particular technique for the design and validation of critical systems. Some observations are discussed in this section.

There were problems applying the performance requirements to the decomposed functions. It was relatively easy to apply the regulatory agency requirements to high-level functions, but decomposing the system-level performance requirements into lower level requirements that would ensure that the high-level needs were satisfied proved difficult. Additionally, many of the detailed requirements resulted from implementation considerations associated with specific design choices or decisions. This is unavoidable because many of the regulatory agency requirements are based on traditional or conventional system implementations. It should be noted that the organization of the performance requirements resulting from their allocation to the decomposed functional requirements is less concise and more repetitive than the organization of the same requirements in the source documents.

It is useful to discuss the set of structured requirements in terms of the IAPSA II study. In that effort major control functions were defined with applicable sensors, actuating devices, and update rates. These control functions were allocated to a candidate architecture concept, and key performance and reliability evaluations were accomplished. To perform these evaluations it was necessary to relate the operation of the major control functions to their purpose in the system; these evaluations were feasible only because the major control functions were clearly tied to certain operational capabilities. The current set of structured requirements suffers by comparison because the functions are not as obviously connected to an operational concept. This could be remedied by finding a way to more closely relate the mission analysis results to the decomposed functions.

At some point in the design process, control laws must be designed in accordance with the structured functional and performance requirements. During this effort, standard control law analysis techniques are used to satisfy the high-level performance requirements. The resulting control laws may be organized by operational modes to satisfy the needs found during the mission analysis. The functional and performance requirements resulting from the control law design are suitable for the performance and reliability evaluation of the type accomplished for IAPSA II.

One weakness of the set of structured requirements in terms of design for validation principles is the lack of visibility into the specific design decisions that drive the design. For example, the defined envelope protection functions do not involve the use of thrust control. This is the result of a design decision or ground rule that cannot be traced through the structured set of requirements. Similarly, an autoflight control function clearly interfaces with the flight control system, but the design decision to allocate to the flight control system responsibility for limiting the autoflight maneuver demands is not explicit. Methods that allow traceability of requirements to design decisions within the structured technique framework need to be explored.

Some functions that are candidates for implementation in an advanced flight control system involve aircraft-level tradeoffs with nonavionic functions. For example, incorporation of an active control function such as wing load alleviation has an impact on the vehicle structural requirements. The current set of structured requirements does not contain the functional requirements or supporting performance requirements for nontraditional active control functions. If any such alternative designs are to be considered, their high-level requirements should be included in the baseline requirement set.

The structured approach handles the flightcrew functions and responsibilities somewhat awkwardly. The handling qualities performance requirements are based on the direct pilot-in-the-loop control of the aircraft flightpath. Thus this crew role is implicitly allocated very early in the function decomposition process. On the other hand, the pilot and copilot appear as architectural elements in the flight control system roll, pitch, and yaw context diagrams much later in the function decomposition process. As a result, several transforms are added that are associated with crew interface functions.

This brings up a significant point with respect to the structured approach. If the vast majority of traditional flightcrew roles are assumed to be unchanged in the advanced aircraft, it might be more effective to consistently treat the crew as a dataflow "terminator." In this scheme only crew functions or roles that fall into a well-defined "domain for change" would need to be decomposed in detail. The key point is that the flightcrew plays a dominant role as systems integrator and manager in traditional aircraft operation. Therefore a great deal of effort is required to decompose all the flightcrew functions. If allocation of all the flightcrew functions is deferred until after the function decomposition process, then all traditional aircrew functions must be described in the high-level diagrams for explicit allocation. The latter approach would dramatically increase the scope of the functional decomposition effort compared to the current structured requirements set. If the flightcrew role changes are minor, this will largely be wasted effort.

The set of structured requirements includes several numerical reliability allocations. The current set does not support traceability of these allocations to their source requirements. Qualitative reliability allocations (probable, improbable) or criticality assessments (safety critical, mission critical, etc.) might be more appropriate until the functions are allocated to architectural elements. Numerical reliability allocations are usually more meaningful in the content of a specific implementation design. A supporting reliability tool such as SURE, CARE III, FTREE, or HARP can then be used to demonstrate that the reliability allocations would ensure that the implemented function can meet the system needs.

6.0 Excelerator Problems, Deficiencies, and Recommendations

In addition to the experience gained using the ESML approach to define advanced flight control requirements, this effort also provided experience using the Excelerator tool in an ESML environment. Some of the key problems, deficiencies, and recommendations that came to light during this effort are described in this section.

1. The tool should have the capability to flag any elements on a transform graph that have not been described (i.e., defined and entered into the project database).

2. The tool should be able to check for the lack of a given type of detailed requirement (i.e., performance, availability, reliability, safety) for any type of transform graph entity (i.e., transforms, data flows, control flows). This would force the user to be rigorous and to address all the types of detailed requirements for each entity on a transform graph.

3. The tool should have some artificial intelligence built into the system so that it can check for features such as balancing and assuring that all elements are described. In other words, it should automatically generate some of the the reports the engineer might produce and then check these automatically for inconsistencies and omissions. It would be active in the background at all times and would continually monitor the database and alert the engineer to possible problems in a timely manner.

4. If a transform graph has several transforms that use the same external data flows, the user must currently define an external interface for that data flow for each of the transforms. It should be possible to specify only one external interface for the data flow and have it flow to each of the transforms using it. Similarly, if several transforms produce the same data flow, it should be possible to have these merge into one external interface as opposed to having to define an interface for each transform. Such a feature would greatly enhance manual balancing of transform graphs.

5. Balancing of data flows from the parent transform graph to the child transform graph should not only work for data flows that are elements but also for data flows that are a record of elements. Thus, if roll angle is an interface to a child transform, and there is a data flow control variable that is a record of elements including roll angle into the parent transform, the tool should consider them balanced. Currently the tool does not make this kind of check.

6. Graphics could be greatly improved. Currently, what you see is not what you get. To see what will be printed it is necessary to zoom in to particular sections of the figure. It should be possible to see the entire figure on the screen as it will be printed. This is particularly important with respect to the placement of labels for data flows.

7. The menu-driven capability could be greatly enhanced by allowing the user to move from one kind of analysis directly to another without always having to go back to the main menu. An even better approach is to allow the user to have several processes running concurrently with a different capability in each, so that the user can pop back and forth between capabilities without always having to back out of one before entering the next.

8. It should be possible to explode an expansion document graph fragment to the appropriate document graph in the same manner as a transform is exploded to another transform graph.

9. The tool should allow one to do analysis not only on a given transform graph but also on a tree of transform graphs. For example, one might want to generate an entity list for a given transform graph and all the transform graphs below that level (i.e., all its children).

10. The tool should have a provision to allow the user to generate generic templates of a report. The user would specify a key word that would generate a unique report with the report name, entity list, transform graph name, header for the report, etc., based on the key word.

11. The tool should have a provision to generate document graphs for all children of a given transform graph based on the document graph defined for the parent. That is, the tool would automatically generate the document graphs of the same form as that defined for the parent for each child and would change transform graph name, entity lists, and report headers as appropriate.

12. The tool does not currently support all the graphical elements that may appear on a transform schema. In particular, it does not support intermittently available flows, signals and prompts.

13. The tool does not currently balance control transforms against control specification, nor does it balance flow transforms against primitive specifications.

14. The tool needs the capability to provide a template for specifying flow transform primitive specifications using text, tables, pseudocode, block diagrams, functions, PDL, etc.

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A STRUCTURED APPROACH TO SYSTEM DESIGN

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Abstract

Current approaches to systems design frequently result in large, incremental costs during system integration testing and service introduction to remove design errors that were introduced during the requirements and design phases of the life-cycle. This study was conducted to assess the possibility of reducing system development cost by elimination or early detection of design errors through the use of a systematic design approach. The study indicates that such possibilities do exist and should be exploited.

Introduction

As avionics and flight systems become ever more complex the problems of systems design become more pronounced. The most nagging problems appear to be; 1) making the system meet the real operational requirements of the user and; 2) making sure that the system behaves in a predictable manner to changing operational conditions. When reviewing design data from existing projects there appears to be a lack of integration between user requirements and system design requirements. This is a contributing cause to the first problem. When design requirements are documented primarily as textural material, supplemented by an assortment of figures, it is difficult to be precise and rigorous, and to establish traceability. This lack of an effective means of documenting systems engineering work is a contributing cause to both classes of system design problems.

Figure 1 illustrates how a major airline views these problems. Most design errors are introduced early in the development cycle and removed late in the development cycle or after the product is put into service. This supports the observations regarding the lack of integration between user requirements and system design requirements and the lack of rigor in the requirements formulation. Coding errors are those errors that result from a lack of attention to detail when implementing a system design. Although this chart addresses software development it is representative at the system level as well since most advanced flight system designs are based on the extensive use of digital processors.

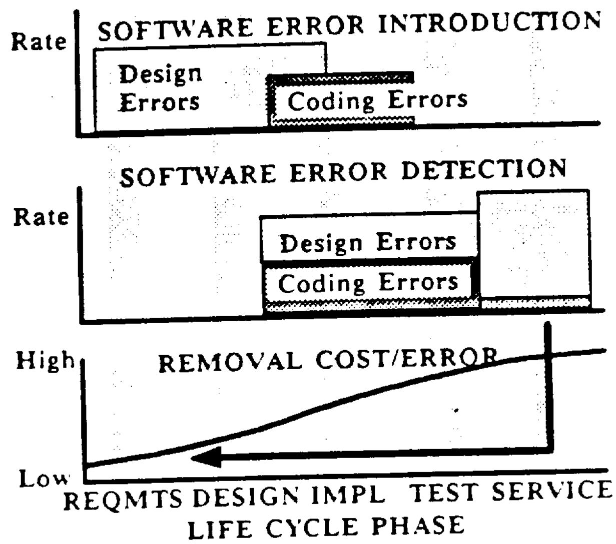

Figure 1 Development Error Characteristics

If design errors could be avoided or detected early in the development cycle, when removal costs are low, rather than late in the development cycle, when removal costs are high, considerable development cost reductions could be realized. A systematic approach to system design can accomplish this. A key ingredient to a systematic design approach is an in-depth analysis of the process at hand, e.g. to operate an aircraft. The analysis results are used to evolve a system architecture design and design requirements for the components that make up the system. The other key ingredient is an integrated project data base where all engineering design data is stored in a common format that promotes rigor and traceability, analogous to that used in machine design or software design.

Approach, Notation, and Rules

This paper will concentrate on introducing an approach, a notation, and a set of rules that are candidates for use in system design. A simple example will illustrate the concepts. It will illustrate that user requirements and system design requirements can be captured using the same approach, notation, and set of rules.

The first step is to identify the task, e.g. fly mission, for which a system will be developed to provide crew support. The task will be analyzed to identify each component process with its output and input flows, the need to store flows, and the need for process control, i.e. the need to activate/de-activate processes. In most cases the output flows from one process are used as input flows to other processes. At this point it is immaterial if a process is to be performed by the crew or by onboard systems that support the crew. That decision will be made later.

The results are documented using a notation that is graphic since it has been proven that pictorial representations of concepts are more easily understood than written descriptions. Figure 2 shows an example of how one small part of the "fly mission" task analysis is documented using a graphic notation where shapes are used to represent processes, input and output flows, and stores where flows are held for future use. A complete definition of a notation and a set of rules is published in [1].

Each process is given a descriptive label that indicates what it does. Each flow and store is given a descriptive label that indicates what it is. The use of graphics shortens the time needed to document the results of a process analysis. It would take a rather lengthy prose statement to describe everything that is documented in Figure 2. Likewise, documents relying extensively on graphics require less effort to comprehend. The bold-lined shape will be referenced later in this paper.

Once processes, flows, and stores, have been defined requirements can be levied against each of these entities. For example the requirements levied against flows may address attributes like range of a parameter measurement or resolution and update rate. For more complex flows simple attributes like range, resolution and update rate will not suffice. If a flow represents a report then requirements on the subject of that report must be documented. The term **domain** is used to mean what is to be included in a flow. As the domain of the flow becomes more expansive, quality requirements become more complex than simply defining a few parameters. Requirements levied against processes may address process performance and safety. Conceptually this is shown in Figure 3. It must be made very clear that the requirements levied against a process, or flow, or a store must

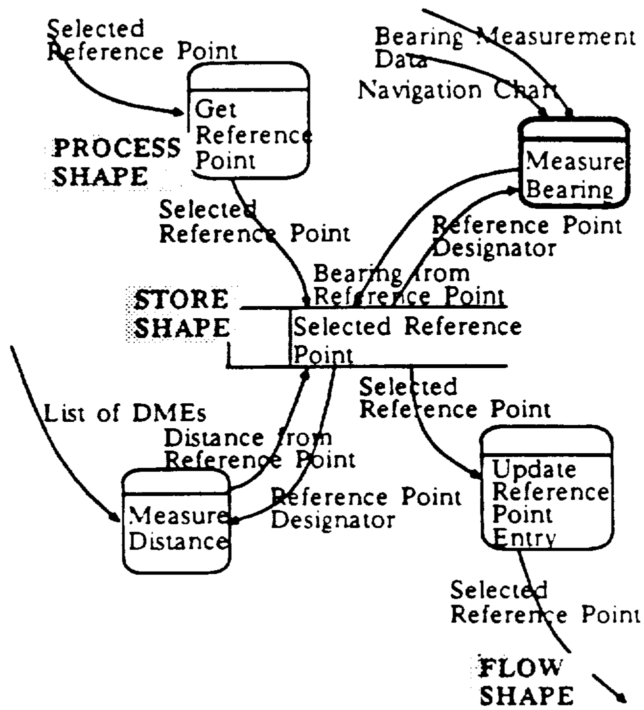

Figure 2 Example of Graphic Notation for Process Analysis Documentation

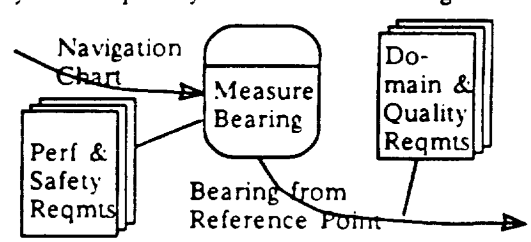

Figure 3 Examples of Requirements Levied Against Flows and Processes

be chosen to suit the needs of the project. The requirements classes used in this example were selected as representative.

In most cases the first set of processes identified in an analysis are top level abstractions. Each of these processes can, in turn, be the subject of an analysis that results in a more detailed definition of the original processes in terms of component processes, flows, and stores. Figure 4 shows the

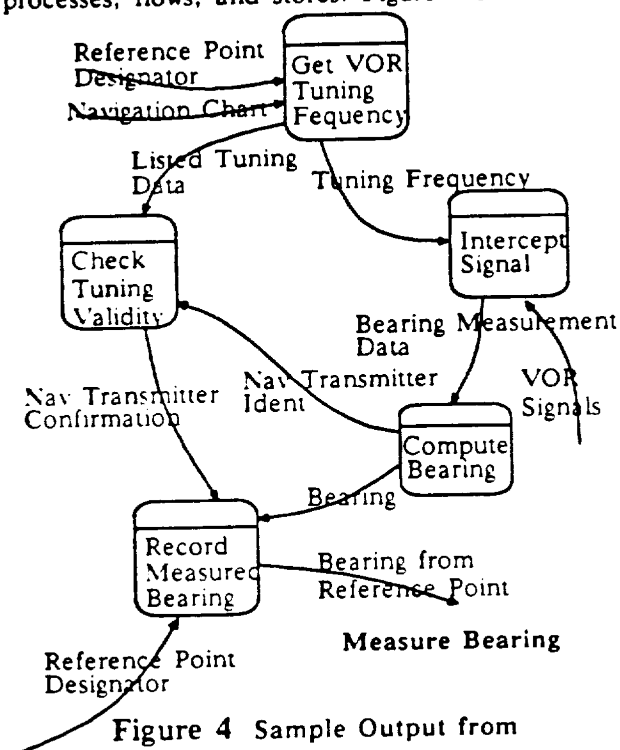

Figure 4 Sample Output from Process Analysis

results of an analysis of the process "Measure Bearing" which was shown in Figure 2. All requirements pertaining to a process, subject to a process analysis, must be considered when formulating the process definition. The successive analyses of processes and flows resulting in ever more detailed levels of requirements lead to the commonly used term Structured Analysis for this approach.

The concept of repetitive structured analysis is illustrated in Figure 5. Each new "level" adds detail to the design requirements. Requirements, e.g. a performance requirement, levied against a higher level process are "distributed" as more detailed requirements amongst the lower level processes once these processes are defined.

Since the graphical notation very precisely identifies processes and stores and how they are connected by flows, rules can readily be established for permissible constructs on a diagram as well as for traceability between a process with its input and output flows and the diagram that further details it. By enforcing notation and rules the probability of omitted requirements, unsupported requirements, or inconsistent requirements can be greatly reduced as will the risk for mis-communication between organizations and individuals.

When the task under analysis, i.e. fly mission is adequately detailed in terms of component processes, stores, and flows a design study can be conducted to determine which of the processes will be performed by a man-made system and which processes will be performed by the crew. Assume the processes involved in measuring a bearing (Figure 4), as a result of a design study, are as-

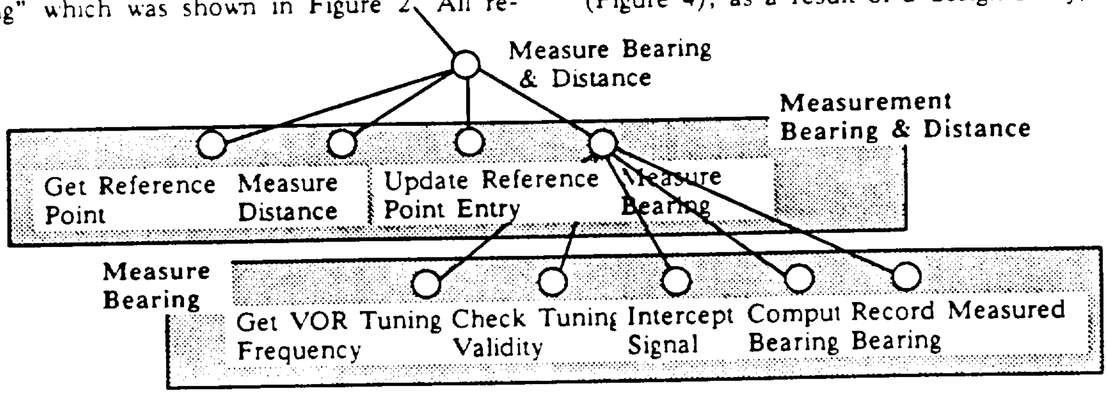

Figure 5 Illustration of the Repetitive Structured Analysis Concept

signed to the pilot and to an airborne navigation receiver.

The pilot and the airborne navigation receiver are classified as architecture entities, and are represented by graphic shapes on an architecture interconnect diagram as shown in Figure 6. Line segments are used to indicate the existence of functional interfaces between the architecture entities, i.e. interconnect indicators. The process assignment is listed next to the architecture entities. There is a tendency by engineers to make assumptions about the human (user) part of the problem that are not necessarily founded on a thorough analysis. The importance of understanding the processes to be performed by the user of the system is just as great as understanding the processes to be performed by the system, particularly when the process assignments result in complex functional interfaces between the user and the system.

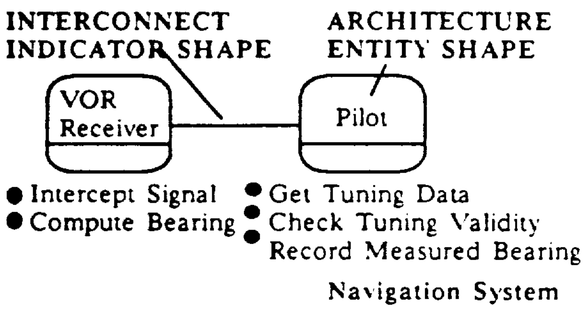

Figure 6 Example of Graphic Notation for Architecture Design Documentation

Architecture entities, once defined, may have requirements and drawings associated with them as summarized in Figure 7. For example environmental requirements may be levied against each architecture entity of the system. In some cases requirements to use a certain technology may be levied against architecture entities.

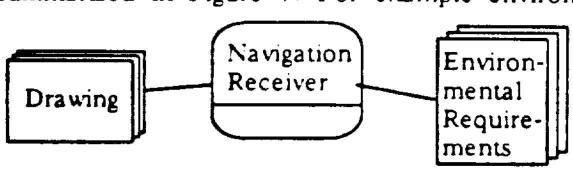

Figure 7 Example of Requirements Levied Against Architecture Entities

When the process assignment is completed the interface definition between the architecture entities can be extracted from data already generated as is illustrated in Figure 8. By conceptually drawing a line around the process(es) and/or stores assigned to an architecture entity, sets of processes and/or stores are defined. The functional interface requirements between the architecture entities are defined by the flows that connect each of the sets. For example, the tuning frequency must be passed between the pilot and the receiver. Tuning validation data and bearing must be passed from the receiver to the pilot. This establishes the interface between the pilot and the receiver. In general the interface definition becomes a fall-out of the architecture design process.

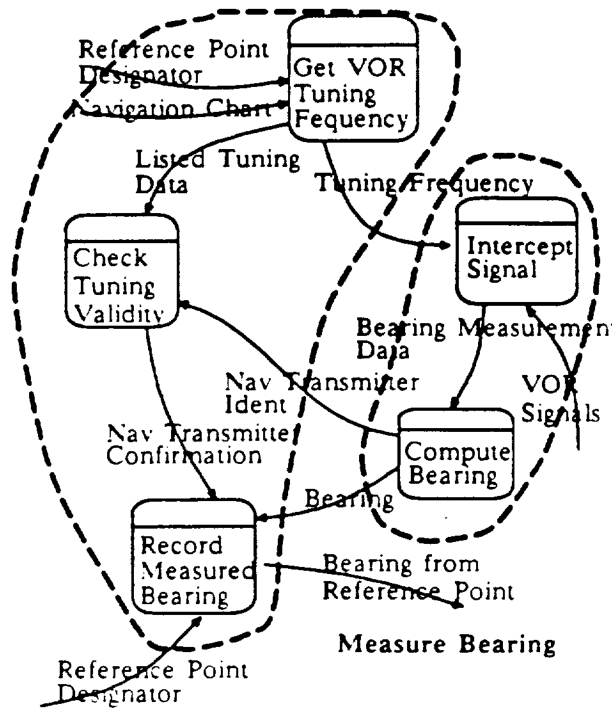

Figure 8 Sample Output from Process Analysis

Depending on the selected system architecture, additional processes may have to be added to make the system function. For example, Interception of VOR Signals and Processing of Bearing Measurement Data were assigned to the navigation receiver. Part of the design process must address the physical implementation of information flow. Decisions on this issue must be made and documented. For example the physical representation of the Tuning Frequency in the mind of the Pilot is different from the physical representation of that same information in the Receiver. To accommodate this a design decision is made to let the pilot rotate a tuning knob to indicate to the system that the tuned frequency must change. The system will display the instantaneous, tuned frequency to the pilot as part of the Bearing Measurement Display. It will also display the measured bearing and a signal quality indicator. Another design decision requires the addition of a process that outputs an audio signal that carries a Nav Transmitter Ident. As a result three processes, Convert Pilot Entry, Display Bearing Measurement Data, and Sound VOR Ident have been added as required processes to make the system perform its intended function, see Figure 9.

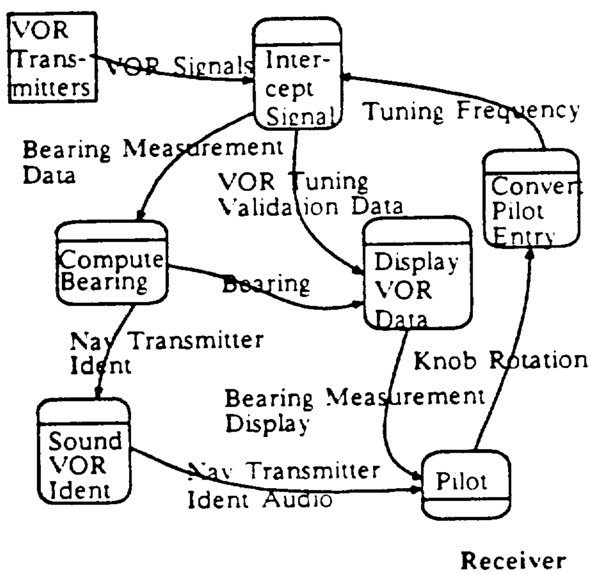

Figure 9 Examples of Flow Format Conversion Processes

This leads to another concept of a structured design approach. There are processes that are generic, i.e. they are part of the overall task irrespective of the system architecture and process assignment and there are processes that are dictated by architecture design decisions. The generic processes will change only when the overall task changes while the architecture dependent processes may change each time the architecture is changed due to technology advances or other reasons. Since the generic processes can readily be identified, they can be re-used each time a new, advanced version of a product is to be developed thereby reducing the overall effort. If the navigation receiver were made part of a larger system where the access of tuning frequencies and the recording of measurement data were automatic the added processes of Figure 9 would differ. Other processes that might get added are processes for redundancy management, maintenance, built in test etc.

Figure 10 graphically represents the systematic approach to system design. It also hints of the structure of a project data base. Set A, in Figure 10, represents the documentation of a task analysis and is the requirements statement for that task. Each "level" symbolizes the definition of one or several processes in terms of constituent components as was illustrated in Figures 2 and 4. The solid lines between process shapes indicates that a lower level process is a component of a higher level process. Although not shown flows and stores also constitute components.

Based on the requirements statement a system architecture is defined in terms of its major components, i.e architecture entities, as represented by Set B. In this example there are three architecture entities in Set B. Each of these has assigned processes as indicated by the dashed lines. These sets of assigned processes form the staring points for requirements statements for each of the architecture entities. The requirements statement for architecture entity A is illustrated by Set C. In order to maintain traceability once architecture entity requirements statements have been formed, provisions must be made to trace each architecture entity, process, flow, and store as it gets partitioned off as an independent entity. This is illustrated by the dotted lines. Periodic checks are made to assure that each occurrence of an architecture entity, a process, a flow, or a store in the project data base have identical definitions.

Once separate requirements statements are defined for each architecture entity processes can be added as represented by the encircled process symbol. The concept of how the need for additional processes can be dictated by an architecture design was discussed in conjunction with Figure 9.

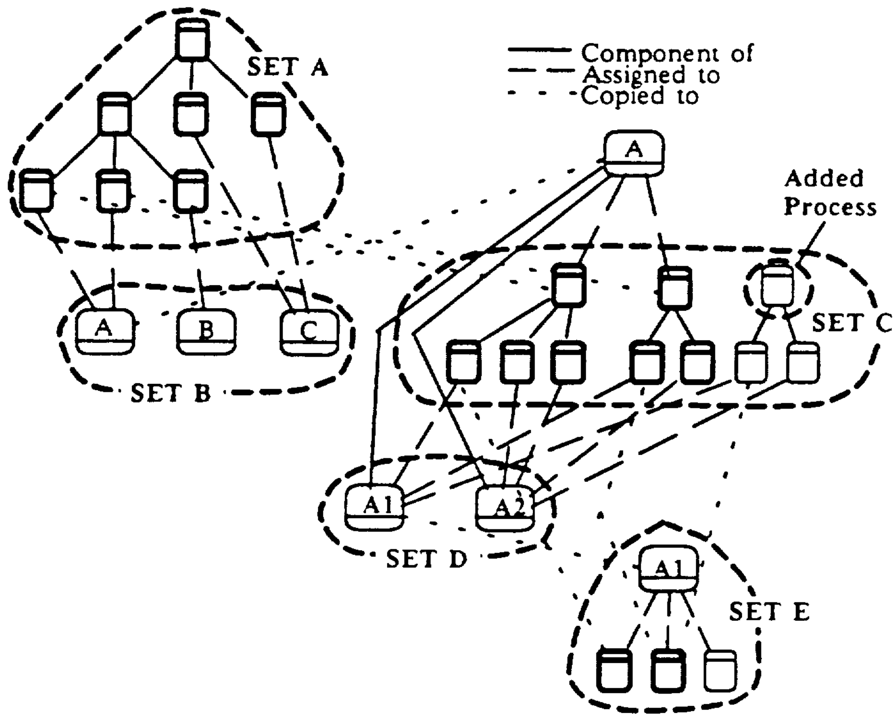

Figure 10 Summary of Systematic Approach to System Design

A series of process analyses may be performed to further detail the top level requirements statement for architecture entity A, i.e. the assigned and added processes are analyzed and defined in terms of their components.

The requirements statement for architecture entity A is used as an input to a design process to define the components of architecture entity A. Conceptually this is illustrated by Set D where the components of architecture entity A are shown. Set E illustrates the result of a second cycle of process assignment. When a projects engineering design data base is organized as outlined above it is possible to systematically trace a high level system requirement all the way down to the lowest level design requirement for an architecture entity.

The systematic partitioning and the establishment of traceability will simplify management of the multi-organizational support of large system development projects. Frequently sub-systems are contracted out to participating organizations. Subsequent work by these organizations can routinely be integrated, system wide, for analysis to uncover traceability and interface problems.

To this point the notion has been that architecture entities represent physical entities. There is no reason to impose such restrictions on the concept of an architecture entity. It can very well represent a software entity, e.g. a Package, Sub-Program, or Task. Figure 11 illustrates the expanded concept of the architecture entity. The architecture entity labeled A1 is the same as the architecture entity A1 appearing in Figure 10. Its requirements statement is represented by the processes included in Set A. Assuming that a digital implementation is selected a top level software architecture can evolve based on this requirements statement. This is illustrated by the two Packages in Set B. The processes of the requirements statement represented by Set A are assigned to Packages #1 and #2. Each of these Packages can then be treated as an independent entity with its own requirements statement, based on the assigned processes as illustrated by Set C. Additional processes can be added as represented by the encircled process symbol. This cycle of formulating a

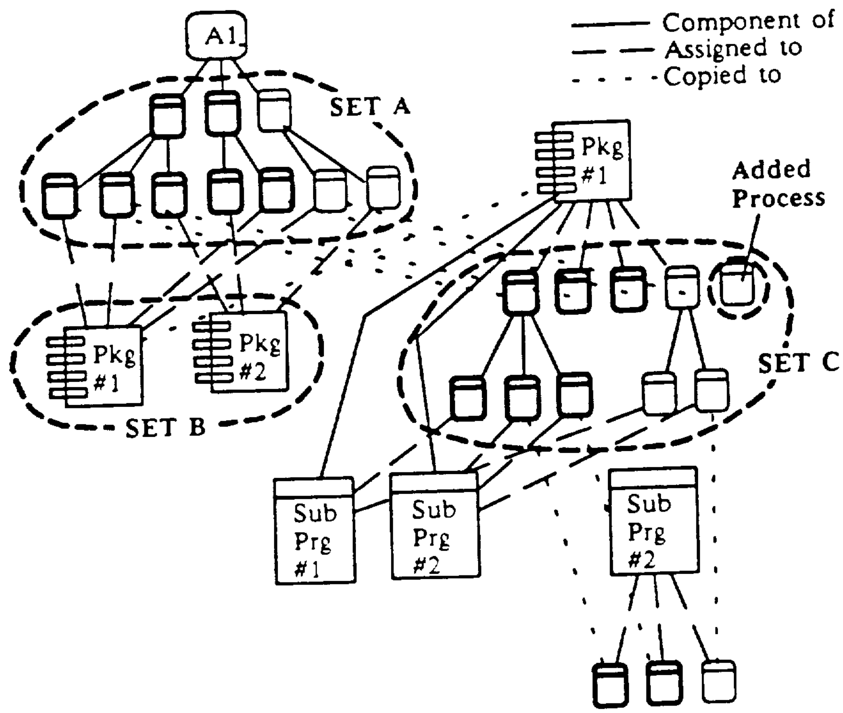

Figure 11 Illustration of "Leveled" Approach to Software Design

requirements statement, basing an architecture on the requirements, assigning processes, and formulating component requirements statements can be repeated. This is illustrated by the definition of Package #1 in terms of component Sub-Programs as shown in Figure 11.

The important conclusion to draw is that the same basic approach that is used for a hardware system architecture design can be used for a software architecture design. In so doing the design is arrived at systematically and traceability is established. A large number of design errors may be eliminated before detailed design of hardware or software coding takes place.

Standardization Efforts

Efforts are under way to develop a notation and set of rules that are suitable for systems engineering. A number of notations and sets of rules have been developed and are documented in CASE literature [2], [3], and [4]. To date they have addressed software engineering problems, not necessarily systems engineering problems. To remedy this an ad hoc team was formed, by representatives from aerospace companies, to derive a notation and rules set from previous work in this discipline that had the additional features required to support systems engineering. This undertaking has become known as the ESML initiative. The acronym ESML stands for Extended Systems Modeling Language. One paper that proposes a notation and set of rules to be used in the formulation of requirements for system processes and process control has been released at a conference. A paper defining a notation and set of rules for documenting an architecture design is planned for this year.

The team that is pursuing this task has not been chartered by any organization to develop an industry standard. The extent to which this work will tend to standardize notations and rules will depend on the following that it receives. If it gains support in the industry it can become a candidate for a standard at some future date.

The Role of Systems Engineering Tools

Data contained in diagrams like those in Figures 2, 4, and 6 can be converted to tabular form. In tabular form the data can be analyzed using set operations, e.g. sorts, selects, unions, and intersections. The analyses can be tailored to detect lack of rigor, e.g. flows without a defined source, requirements statements for architecture entities that cannot be traced to higher level requirements. Analyses can be tailored to detect inconsistencies, e.g. an interfacing flow is defined differently at the source and destinations. The progress in developing a system design definition can be measured by periodically taking inventory of the project data base. If the requirement for rigor and traceability is enforced throughout the design process a lot more data will have to be generated in the requirements and architecture design phases of the life cycle than is the case today. The proposed approach will probably be unmanageable if applied to a large project without the assistance of automation, i.e. software tools hosted on computers that are appropriately networked. Computer graphics tools can be used to draw the diagrams that this approach is based on. The computer can be used to convert the graphical data into tabular form and load it in a data base. Once the engineering design data is in the data base, the computer can be used to perform the set operations needed to analyze the data base.

Once a computer-based project data base exists, automation can be extended to support documentation. Engineering documents contain engineering data selected for a specific purpose. In a large project the same document format is often used, repeatedly, but the specific data will vary. Document templates can be used to define the document format and contain boilerplate text. These can be copied to become the starting point for each occurrence of the document. References to data in the project data base are used to finalize the template. At publishing time the document template will be used to automatically produce the document by accessing up-to-date engineering data in the project data base and including it with the boilerplate text. Automation of the documentation process has the potential for considerable cost savings.

Software tools that have the capability to support the systematic system engineering approach are available on the CASE tool market. They are hosted on a variety of PCs, engineering workstations, and mainframe computers. Most tools support the drawing of diagrams and entering of data contained on the diagrams into a data base. To varying degrees they support rules enforcement, analysis of the data base, and documentation. Most still lack the capability to be tailored to the needs of a particular project.

The Cost of Introduction

The issue of recovering the cost of introducing this approach and its supporting automation appears to be an impediment to a full commitment. The cost of introduction is driven by the need for training and re-documentation of existing engineering design data or reverse engineering. The need for training is reduced by notation and rules set commonality and simplicity. It is also reduced by tool designs that are user friendly and adaptable to the needs of a project. Some degree of reverse engineering is inevitable to any organization with a well established product line that opts to introduce a systematic approach to systems engineering. Waiting for a brand new project to be launched where the whole development process will start from "square one" may be putting off the commitment indefinitely. In many cases companies with established product lines may benefit from a reverse engineering process to get the design requirements for current products consolidated in support of derivative and new product commonality.

The cost of automation can be minimized if a common notation and set of rules can be agreed upon. That will require fewer varieties of systems engineering tools, each lining up behind a favored notation, and give tool suppliers a broad customer base. It will also facilitate the transfer of engineering data between participating organizations with a minimum of data conversion tools.

The cost recovery will have to come from the shift of design error detection and correction from the system integration and product introduction phases to the requirements and architecture design phases as is indicated in Figure 1. The cost of late design error detection and correction is high. Expensive integration test facilities and test vehicles must be operated for long periods of time to support detection of design errors and to re-test the revised system. Each design error correction involves a lengthy process of problem reporting, re-design, document revision, and testing. The correction of design errors after service introduction carries the added cost of fleet revision. An analysis of cost per late design error correction may show that the cost savings of even a modest reduction in the design error count may pay for the introduction and automation costs.

Conclusion

The combination of a systematic approach, a graphic notation, an associated set of rules, and computer bases tools for systems engineering provide the potential for reducing the development cost of complex systems. This is done by elimination or early detection of design errors thereby reducing the high cost of detecting and removing these errors during integration testing and service introduction. Developments in the areas of notation and rules standardization and computerized engineering tools provided the key ingredients needed to pursue a systematic approach to system design. These developments should be exploited.

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ESML: An Extended Systems Modeling Language Based on the Data Flow Diagram

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Abstract: ESML (Extended Systems Modeling Language) is a new system modeling language based on the Ward-Mellor and Boeing structured methods techniques, both of which have proposed certain extensions of the DeMarco data flow diagram notation to capture control and timing information. The combined notation has a broad range of mechanisms for describing both combinatorial and sequential control logic.

1. Introduction. A modification of the data flow diagram notation to capture control and timing information was proposed by Ward and Mellor [1] and later extended by Ward [2]. The modification encompasses extended graphic notation, specification rules, and balancing rules. The notation and formation rules for this method have been incorporated into several commercially available CASE tools, and prototypes of the executable model have been demonstrated on a TI Explorer in Flavors [3], in the Vax environment on the ADAS CASE tool [4], and in OPS5 [5].

Within the same time period, another modification of the data flow diagram to capture control and timing information was proposed by Hatley [6]. The Boeing structured methods technique is based on the notation described in reference [6]. The notation and formation rules for this modification have also been incorporated into commercial CASE tools.

A substantial body of experience now exists on the use of these two notations. Furthermore, a number of developers, including developers in two of the authors' organizations (Honeywell Inc. and Hughes Aircraft Company), have succeeded with the use of combinations of elements from the two notations. The basis for this combination has been discussed by Ward and Keskar [7]. The present paper is a detailed proposal for a notation extending features of the two original ones. The extended notation has a more comprehensive and flexible set of constructs for representing control logic than either of the original notations. We propose that the new notation together with its formation and execution rules be called the Extended Systems Modeling Language (ESML).

2. Transform Schema Objects. The flow diagram extension used in ESML is called the **transform schema** as in [1]. Figure 1 shows the objects that can appear in a transform schema.

Transforms represent units of work or control within the system. Each transform carries a label describing the unit of work or control performed. The same transform can appear in more than one transform schema. A **flow transform** represents a unit of work performed

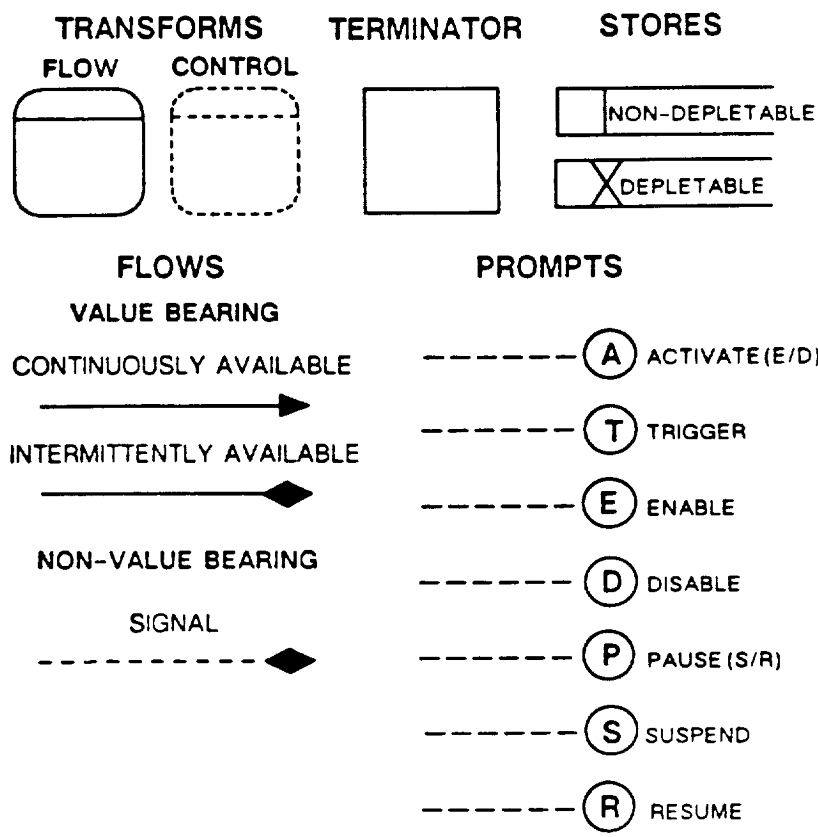


Figure 1 ESML Transform Schema

to produce a set of output flows from a set of input flows, e.g. accepting, manipulating, producing, storing, transporting, and retrieving flows. A **control transform** represents a unit of control logic that determines when, and for how long, other transforms are active.

Terminators represent a physical entity or system that provides flows (information, material, energy) to, or receives flows from, the schema and should be thought of as a transform or group of transforms whose details are of no interest within the schema. *Each terminator carries a label describing the real-world entity or system it represents.* The same terminator can appear on more than one transform schema.

Flows represent the "things" on which transforms operate. **Value bearing flows** represent variable-content information, material, or energy, that flows within the system or between the system and interfacing physical entities or systems. *Each value bearing flow carries a label describing what it is.* The same value bearing flow can appear on more than one transform schema. A **continuously available flow** represents information, or material, or energy, or any other item that moves within a system, or between a system and terminators, which is available at every point in time. An **intermittently available flow** represents information, material, energy, or any other item that moves within a system, or between a system and terminators, but is not available at every point in time.

Non-value bearing flows, also called **signals**, represent the recognition of the occurrence of events. *Each signal carries a label describing the event it represents.* The same non-value bearing flow can appear on more than one transform schema.

Prompts represent control imposed by one control transform on another transform. There are five distinct prompts, distinguished by a letter placed in the small circle at the end of the line segment. A **trigger** activates a transform to perform a time-discrete action. A triggered transform terminates under its own control. The **enable** prompt initiates the activity of a transform. The **disable** prompt terminates the activity of a transform. When the activity of a transform is terminated, it "forgets" any intermediate results and starts anew when enabled or triggered. The **activate** prompt is a combination of the enable and disable prompts. The **suspend** and **resume** prompts are similar to the enable and disable prompts, except that a suspended transform remembers its intermediate results and the system context. The resumed transform continues where it left off when suspended. The **pause** prompt is a combination of the suspend and resume prompts.

Stores represent value bearing flows within the system that are held for future access. A transform that uses a stored flow controls its accesses to the flow. *Each store, like each flow, carries a label describing what it is.* The same store can appear on more than one transform schema.

A **non-depletable store** represents information flow, held for future use, that is not "consumed" when accessed.

A **depletable store** represents flow, held for future use, that is "consumed" when accessed.

3. Transform Schema Connections. The connection rules for the objects defined above are stated in the following figures. The "X" in those figures indicates legal connections. In summary, transforms, terminators, and stores are connected by flows.

At least one end of each flow in a transform schema must be connected to a transform. Connections are not allowed between terminators, between stores, or between terminators and stores.

Flows from multiple sources and to multiple destinations may be represented by a split/merge notation as described in reference [1].

A flow transform must have at least one output flow. A flow transform normally has at least one input flow or a prompt.

A control transform must have at least one input flow and one output prompt, or output signal.

A terminator must have at least one input or one output flow.

A store must have at least one input or one output flow. The input flow can represent all elements of the store, or a sub-set of them. In the first case the input flow label will be the same as the store label *or it may be omitted*. In the second case the input flow label will differ from the store label. The output flow can also represent all elements of the store, or a sub-set of them. In the first case the output flow label will be the same as the store label *or it may be omitted*. In the second case the output flow label will differ from the store label.

Continuously available flows connect transforms, terminators, and stores as shown in Figure 2. A continuously available flow can originate from a control transform only if

FROM \ TO	FLOW TRANS-FORMS	CONTROL TRANS-FORM	NON-DEPL STORE	DEPLETABLE STORE	TERMINATOR
FLOW TRANSFORMS	X	X	X	Energy or Material	X
COMBINATORIAL CONTROL TRANSFORM	X	X	X		X
NON-DEPL STORE	X	X			
DEPL STORE	Energy or Material				
TERMINATOR	X	X			

Figure 2 Connection Rules for Continuously Available Flows

that control transform represents a combinatorial controller. The controller types will be addressed later.

Intermittently available flows connect transforms, terminators and stores as shown in Figure 3.

FROM \ TO	FLOW TRANS-FORMS	SEQUENTIAL CONTROL TRANSFORM	NON-DEPL STORE	DEPLETABLE STORE	TERMINATOR
FLOW TRANSFORMS	X		X	X	X
SEQUENTIAL CONTROL TRANSFORM	X		X	X	X
NON-DEPL STORE					
DEPL STORE	X	X			
TERMINATOR	X				

Figure 3 Connection Rules for Intermittently Available Flows

Signals connect transforms and terminators as shown in Figure 4. There is one special

FROM \ TO	FLOW TRANS-FORMS	CONTROL TRANSFORM	NON-DEPL STORE	DEPLETABLE STORE	TERMINATOR
FLOW TRANSFORMS	X	X			X
CONTROL TRANSFORM	X	X			X
NON-DEPL STORE					
DEPL STORE					
TERMINATOR	X	X			

Figure 4 Connection Rules for Signals

case identified. A signal can only be destined for a flow transform or a control transform that represents a sequential controller.

Prompts connect control transforms to flow and control transforms as shown in Figure 5.

FROM \ TO	FLOW TRANS-FORMS	CONTROL TRANSFORM	NON-DEPL STORE	DEPLETABLE STORE	TERMINATOR
FLOW TRANSFORMS					
CONTROL TRANSFORM	X	X			
NON-DEPL STORE					
DEPL STORE					
TERMINATOR					

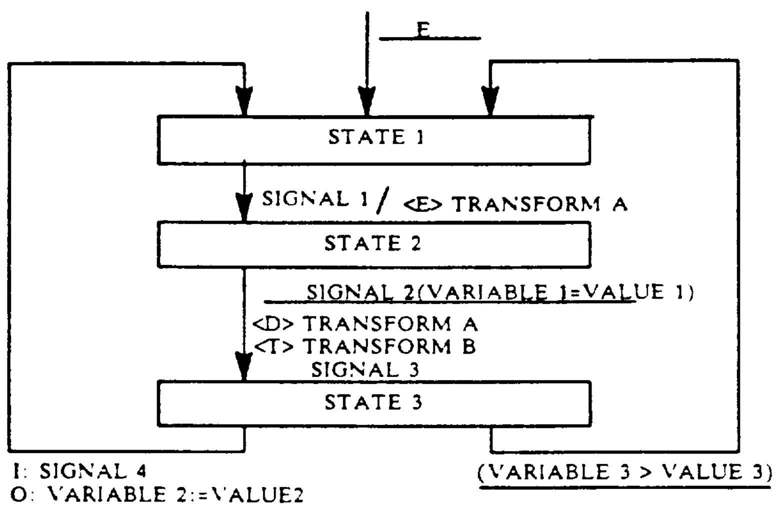
Figure 5 Connection Rules for Prompts

Control transforms may not exchange prompts. Transforms activated by a prompted control transform are deactivated when the prompted control transform is deactivated. When a transform is de-activated, each element in a continuously available output flow will have a defined default value. The default value can be the last value, a constant, an initial value, an expression, or a null value.

4 Object Specification. An object must be specified either in terms of sets of objects or in terms of an object specification. The rules for specifying an object in terms of sets of objects will be discussed in the following paragraphs. Formats for individual object specifications will be presented.

Each **flow transform** must be specified either by a transform schema, *i.e. a set of related transforms, flows and stores, or a transform specification. A flow transform specification describes in detail the transformation of input flows to the corresponding output flows.* A flow transform specification may be procedural, non-procedural, graphical, textual, PDL, psuedocode, or tabular.

Each **control transform** must be specified by a control specification. *A control specification describes in detail the control logic that the control transform represents.* If the control transform logic is at least partly sequential (i.e. it depends on a time sequence of discrete occurrences as well as knowledge of its current state) a **state transition diagram** or a **state transition matrix** format is used to specify control. Examples of each are shown in Figure 6.



EVENT / STATE	E	SIGNAL 1	SIGNAL 2 (VARIABLE1= VALUE 1)	SIGNAL 4	(VARIABLE 3> VALUE 3)
STATE 1		<E> TRANS-FORM A / STATE 2			
STATE 2	STATE 1		<D> TRANSFORM A <T> TRANSFORM B SIGNAL 3 / STATE 3		
STATE 3	STATE 1			VARIABLE 2:= VALUE 2 / STATE 1	STATE 1

Figure 6 Examples of State Transition Diagram and State Transition Matrix

The transition inputs on the diagram can be shown above a horizontal line, to the left of a slash (/), or prefixed by an **I:**, and be located next to the transition vectors. A transition input can be a signal, one or more logical expressions, or both. A prompt may serve as a transition input for the entry transition. Permissible logical expressions consist of two continuously available flows, separated by a relational operator or a continuously available flow and a constant separated by a relational operator.

When a transition can occur due to one or more transition inputs, each input is entered as a separate expression starting with an I:, e.g. *I: (X>=critical)*
I: Stop(Y=20)

Alternately the expressions are entered on one line and separated by a vertical bar, e.g. (X>=critical)|Stop(Y=20). A third alternative is to use multiple transition vectors, each with a unique input condition and all having the same output action.

The transition outputs on the diagram are shown below a horizontal line, or to the right of a slash (/), or prefixed by an O:, and located next to the associated transition vectors. During a transition zero or more actions may be taken. These may be to issue prompts signals or assign values to an intermittently available flows. Prompts are indicated by a prompt label enclosed in "< >", followed by the label of the transform affected by the prompt. Signaling an event is indicated by a signal label. Assigning a value to an intermittently available flow is indicated by the flow label followed by a colon, an equal sign, and the assigned value. Examples of each are shown in Figure 6.

If the logic of a control transform is purely combinatorial -- the control exerted during a time period depends only on a combination of values of continuously available flows that hold during the period an **activation table** format is used to specify control. An example is shown in Figure 7. The left columns represent the possible sets of input flow

INPUTS		TRANSFORMS		OUTPUTS	
FLOW 1	FLOW 2	T1	T2	SIGNAL 1	FLOW 3 =
ON	1	D	?	Y	5
ON	2	D	?	N	10
ON	3	E	T	N	15
OFF	1	E	?	Y	20
OFF	2	E	?	N	25
OFF	3	E	?	N	1000

Figure 7 Activation Table

conditions, the center columns represents the control action imposed on other transforms as a function of combinations of input flow conditions, and the right columns represent outputs that are set as a result. The activation table must account for all possible input flow combinations

Each input column is headed by the label of a continuously available flow. The row entries represent mutually exclusive sets of flow conditions. The range of conditions for each flow must fall within its domain as specified in the flow specification. Each transform column is headed by the label of a controlled transform. The row entries specify the control action performed at the time of the transition. As with a sequential control specification, if there is no change in the control state for a transform, no control action is specified. Each output column is headed by the label of a signal or a continuously available flow. The row entries for a signal will specify whether or not that signal is broadcast. The row entry for a continuously available flow represents the value assigned to that flow during the time period of a control state.

Prompt sequencing rules are defined in Figure 8. Note that two of the prompt sequences

CURRENT PROMPT / PREVIOUS PROMPT	TRIGGER	ENABLE	DISABLE	SUSPEND	RESUME
TRIGGER	TRIGGER ▷	NOT LEGAL	DISABLE	SUSPEND	NO ACTION
ENABLE	NOT LEGAL	NO ACTION	DISABLE	SUSPEND	NO ACTION
DISABLE	TRIGGER	ENABLE	NO ACTION	NO ACTION	NO ACTION
SUSPEND	NO ACTION	NO ACTION	DISABLE	NO ACTION	RESUME
RESUME	TRIGGER ▷	NO ACTION	DISABLE	SUSPEND	NO ACTION

▷ Only if transform is completed after previous trigger

Figure 8 Prompt Sequencing

are illegal.

Each **value-bearing flow** must be specified either by its composition, i.e. a set of component flows or by a flow specification. A flow specification defines in detail what a flow is. A flow specification may be textual, graphical, or tabular. There can be several classes of flows in a transform schema, e.g. information, material, or energy. The format for a flow specification must be tailored to the class with which it is used.

An abstract continuously available flow, can consist of a set of continuously available flows, intermittently available flows, and signals. An abstract, intermittently available flow, can only be specified as a set of intermittently available flows. The notation of DeMarco [8] for the composition of abstract flows is recommended.

Each **signal** *must have its meaning specified.*

Each **store** must be specified either by its composition, i.e. a set of component stores or by a stored flow specification. A store specification defines in detail what a stored flow is. A stored flow specification may be textual, graphical, or tabular. There can be several classes of stored flows in a transform schema, e.g. stored information, material, or energy. The format for a stored flow specification must be tailored to the class with which it is used. *An abstract non-depletable store consists of a set of non-depletable stores and depletable stores. An abstract depletable store consists of a set of depletable stores.*

5. **Balancing.** Balancing is an analysis process used to assure consistency and rigor within a project.

Level balancing *assures that the input and output flows of a transform are completely accounted for in its transform schema or transform specification. This means that the union of all input flow decompositions of the parent transform shall map onto the union of all input flow decompositions on the child transform schema, i.e. the two sets shall be identical. Likewise, the union of all output flow decompositions of the parent transform shall map onto the union of all output flow decompositions on the transform schema or transform specification, i.e. the two sets shall be identical. Level balancing also applies to control specifications. If the components of a flow decomposition are optional then the input and output flow decompositions on the transform schema must map into the input and output flow decompositions of the parent transform. If the components of a flow decomposition are mutually exclusive then the input and output flow decompositions on the transform schema must map into one of the mutually exclusive input and output flow decompositions of the parent transform.* Figure 9 illustrates the concept of a flow

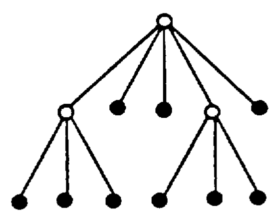

The filled nodes represent the de-composition of a flow

Figure 9 The Concept of Flow Composition

decomposition.

Flow merge/branch balancing *assures that the union of all flow decompositions entering a merge, maps onto the flow decomposition leaving a merge. Likewise, the flow decomposition entering a branch, must map onto the union of the flow decompositions leaving a branch.*

Store balancing is performed to assure that the union of all flow decompositions for flows listed as outputs from a store must map onto the flow decomposition for the flow that the store represents, i.e. the two sets must be identical. The union of all flow decompositions for flows listed as inputs to a store must map into the flow decomposition for the flow that the store represents, i.e. the input set must be a sub-set of the store set.

6. **Example.** Consider a very simple automotive cruise control system, whose driver interface is shown in Figure 10. The functions to be performed by this system are limited to capturing and storing the actual speed for use as the desired speed; maintaining the desired speed by comparing the desired and actual speeds and adjusting the throttle

setting to minimize the deviation; and increasing the speed at a constant rate by gradually increasing the throttle setting.

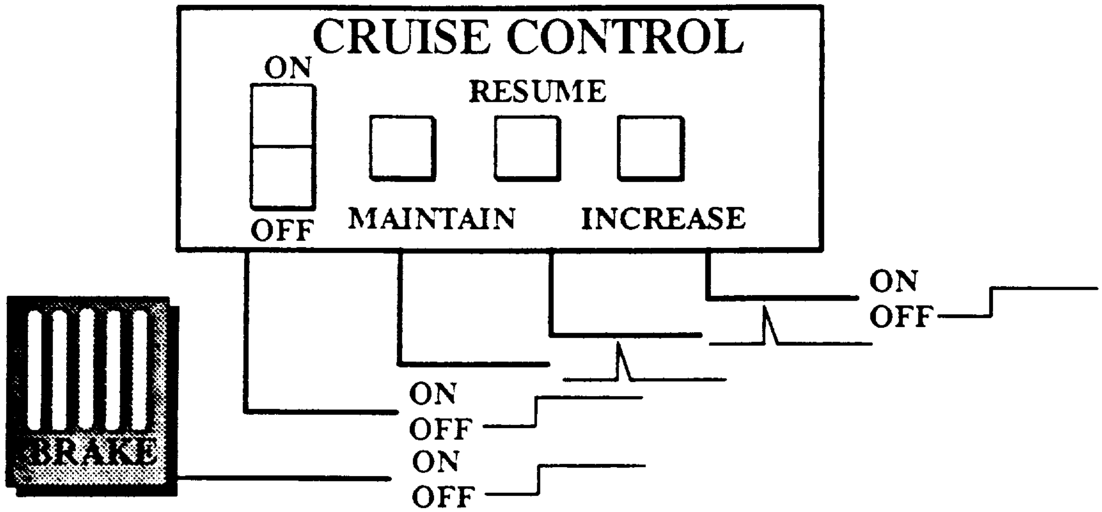


Figure 10 Driver Interface

Figure 11 is a transform schema that models the operation of this cruise control system. There are two levels of control. The upper level, performed by the "Monitor CC Status" transform, enables the lower level of control while the engine is running and disables them otherwise.

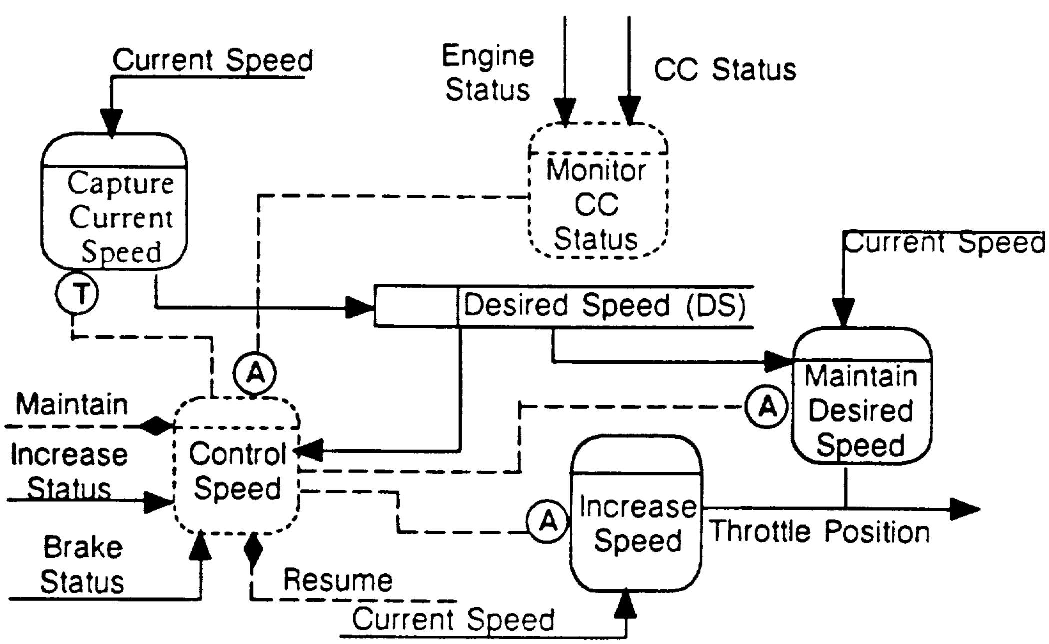


Figure 11 Transform Schema for Cruise Control Example

Monitor CC Status

ENGINE STATUS	CRUISE CONTROL STATUS	CONTROL SPEED STATUS
ON	ON	ENABLE
ON	OFF	DISABLE
OFF	ON	*
OFF	OFF	DISABLE

Figure 12 Sample Activation table

The control specification for the transform "Monitor CC Status" is an activation table and is shown in Figure 12. This transform enables the lower level of control, "Control Speed" when the engine is running and the cruise control on/off switch is in the on state. It is specified by the state transition diagram of Figure 13. The control transform "Monitor CC Status" assures that after the engine is turned off and then back on, the cruise control on/off switch has to be returned to off before and then back on to re-activate the cruise control system.

Control Speed

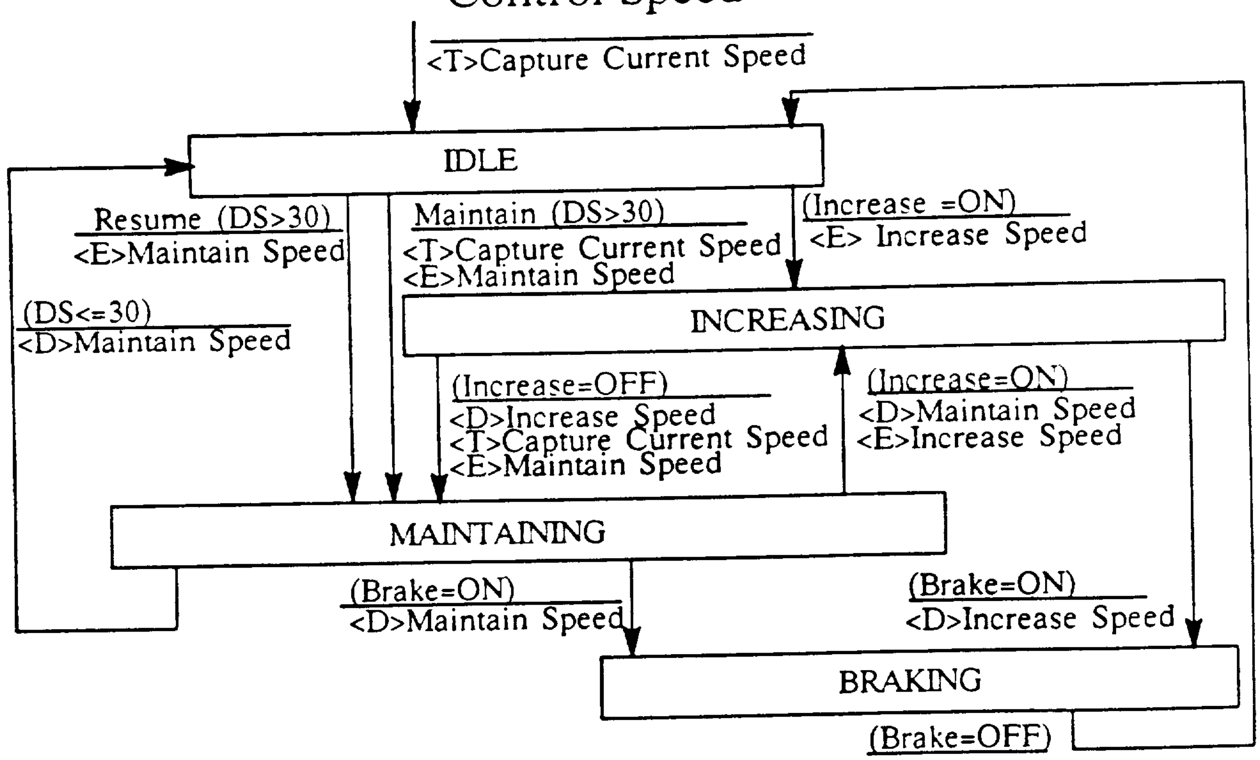


Figure 13 Sample State Diagram

The lowest level of control on Figure 11, when enabled, carries out driver commands subject to conditions on the speed and the brake status. It is specified by the state transition diagram of Figure 14. An equivalent state transition matrix is shown in Figure 15. Notice that a driver request to maintain the current speed is obeyed only if the speed is over 30 mph and if the brake pedal is not currently depressed.

Since Figure 11 contains flow transforms and also represents control of those transforms, it is fairly "busy". To allow the creation of simplified views of such schemas different "views" may be used. For example, one subset could show only flow transforms with their inputs and outputs (Figure 15) and another subset could show control transforms with their inputs and outputs, along with the flow transforms connected to the control transforms but minus any inputs and outputs other than control transform connections (Figure 16).

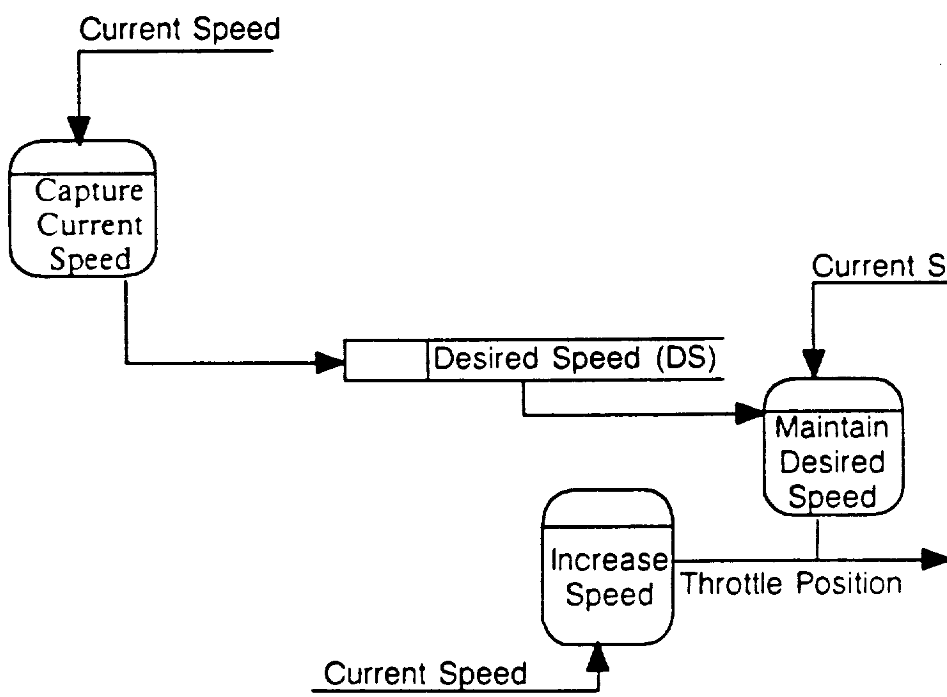


Figure 15 Transform Schema - Flow Transform View

8. Execution of the Model. A model built with the notation described here is executable in essentially the same sense as a model built with the notation described in [2]. However, the use of continuous flows and of stores as inputs to and outputs from control transforms requires that the tokens associated with these flows be assigned values so that transition inputs can be evaluated. Also, the use of composite enable/disable and suspend/resume flows requires that tokens placed on these flows be given values to distinguish which prompt is being sent.

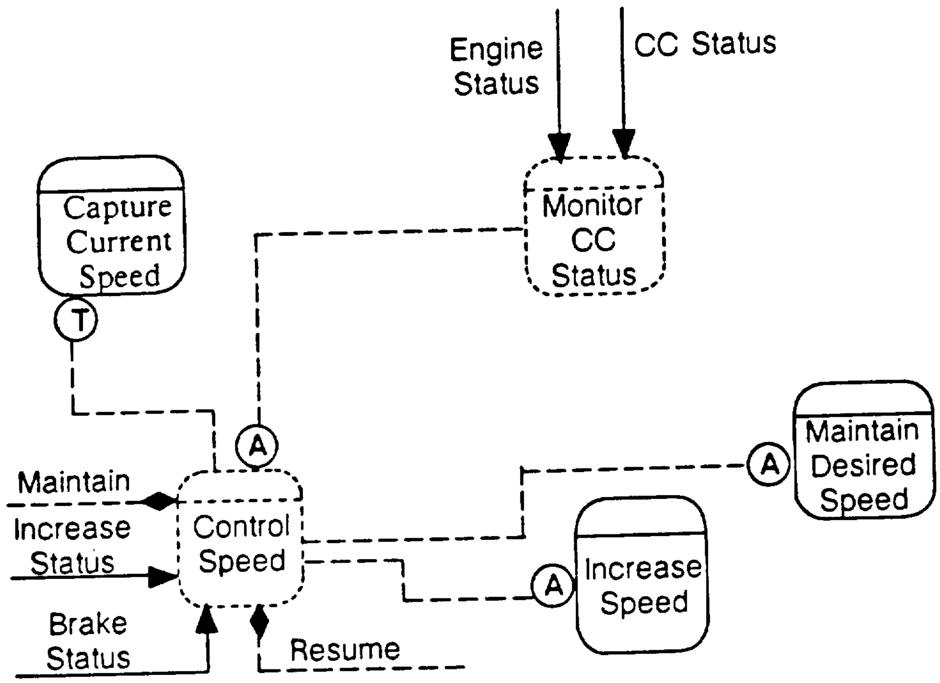


Figure 16 Transform Schema - Control Transform View

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Appendix C

System Architecture Model

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1. Introduction. A transform schema defines the transforms, stores, and flows needed to perform a task. It also defines in what way the task must adjust to external and internal events and condition. A transform schema is created during a structured analysis of a task for which a mechanization or organization is to be developed.

An architecture is the physical arrangement of a mechanization or organization in terms of its components. An architecture is defined in terms of entities that "host" transforms and stores or convey value-bearing flows between "host" entities. An architecture definition should include the user(s) as entities, i.e. those entities that will directly interface with the mechanization or organization being considered. The architecture concept may also be used to group transforms and stores into abstract entities in order to gain different views of the design. A software architecture is an example of an architecture of abstract entities.

An architecture definition is captured in an architecture diagram. The architecture diagram is composed of objects representing entities and value-bearing flows. An architecture diagram is created during a design study and must be fully traceable to a transform schema.

2. Architecture Diagram Objects. Three object can appear on an architecture diagram. These are architecture entity, terminator, and value-bearing flows as shown in Figure 1.

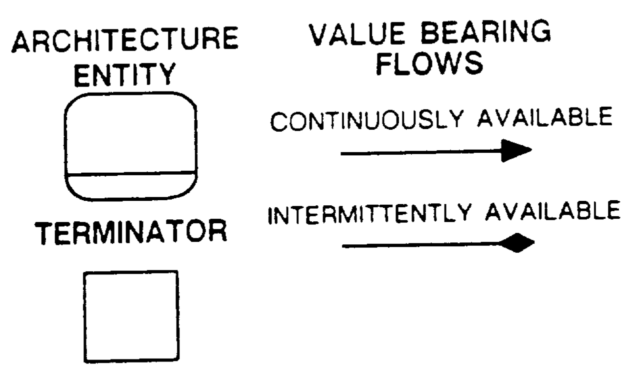

Figure 1 Architecture Diagram Objects

Terminators represent architecture entities that provide flows (information, material, energy) to, or receives flows from, the system under study but where the behavior and processing characteristics are unknown. A terminator carries a label describing the system that it represents. The same terminator can appear on more than one architecture diagram.

Architecture entities represent the embodiment of transforms and stores. Each architecture entity carries a label describing its purpose. The same architecture entity can appear in more than one architecture diagram. An architecture entity can be physical or abstract. It can represent a computer, a software module, or an organization. Each architecture entity carries a descriptive label. The symbol for an architecture entity may be tailored to more closely illustrate what it represent. For example symbols resembling a processor, a key-board, or a software entity may be used in lieu of the generic symbol of Figure 1.

Value bearing flows represent variable-content information, material, or energy, that flows within the system or between the system and interfacing physical entities or systems. Each value bearing flow carries a label describing what it is. The same value bearing flow can appear on more than one transform schema. A **continuously available flow** represents information, or material, or energy, or any other item that moves within a system, or between a system and terminators, which is available at every point in time. An **intermittently available flow** represents information, material, energy, or any other item that moves within a system, or between a system and terminators, but is not available at every point in time.

3. **Architecture Diagram Connections.** The connection rules are shown in Figure 2. The "X" indicates legal connections. In summary, sets of

TO / FROM	SINGLE ARCHITECTURE ENTITY	TERMINATOR	MULTIPLE ARCHITECTURE ENTITIES
SINGLE ARCHITECTURE ENTITY	X	X	X
TERMINATOR	X		X
MULTIPLE ARCHITECTURE ENTITIES	X	X	X

Figure 2 Architecture Entity Connection Rules

architecture entities can be connected by value-bearing flows. An architecture entity can be connected to a terminator. However, terminators cannot be connected together.

4. Object Specification. The rules for object specification are discussed in the following paragraphs.

Each **architecture entity** must be specified by an architecture diagram i.e. a set of related architecture entities and flows or a detailed design definition. Each architecture entity must have its functionality specified by a transform schema. Hardware drawings or source code are examples of detailed design definitions. Each architecture entity that is specified by an architecture diagram may have an overview drawing that shows the assembly of components on the architecture diagram, i.e the architecture diagrams may be used as an index to the system drawings.

In those cases when an architecture entity represents a simple conduit that has no active components, it need not be functionally specified by a transform schema.

Each **value-bearing flow** must be specified either by its composition, i.e. a set of component flows or by a flow specification. A flow specification defines in detail what a flow is. A flow specification may be textual, graphical, or tabular. There can be several classes of flows in a transform schema, e.g. information, material, or energy. The format for a flow specification must be tailored to the class with which it is used.

An abstract continuously available flow, can consist of a set of continuously available flows and intermittently available flows. An abstract, intermittently available flow, can only be specified as a set of intermittently available flows.

Level balancing assures that the input and output flows of an architecture entity are completely accounted for in its architecture diagram. Level balancing also assures that the input and output flows of an architecture entity are completely accounted for in its related transform schema.

Level balancing architecture entity to architecture diagram means that the union of all input flow decompositions of the parent architecture entity shall map onto the union of all input flow decompositions on the child architecture diagram, i.e. the two sets shall be identical. Likewise, the union of all output flow decompositions of the parent architecture entity shall map onto the union of all output flow decompositions on the architecture diagram, i.e. the two sets shall be identical. Figure 3 illustrates the concept of a flow decomposition.

Level balancing architecture entity to transform schema means that the union of all input flow decompositions of the architecture entity shall map onto the union of all input flow decompositions on the related transform schema. i.e. the two sets shall be identical. Likewise, the union of all output flow

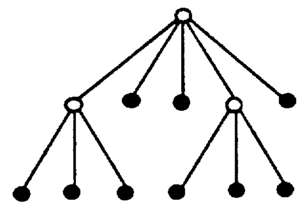

Figure 3 The Concept of Flow De-composition

decompositions of the architecture entity shall map onto the union of all output flow decompositions on the related transform schema, i.e. the two sets shall be identical.

6. Assignment. Each transform and store in a transform schema must be assigned to an architecture entity. If a transform must be split between two or more architecture entities, it must first be specified by a transform schema. The transforms on that transform schema may then be assigned to two or more architecture entities. If a store must be split between two or more architecture entities, it must first be specified by its composition. The store components may then be assigned to two or more architecture entities. Figure 4 illustrates the concept of transform and store assignment. Set A represents a

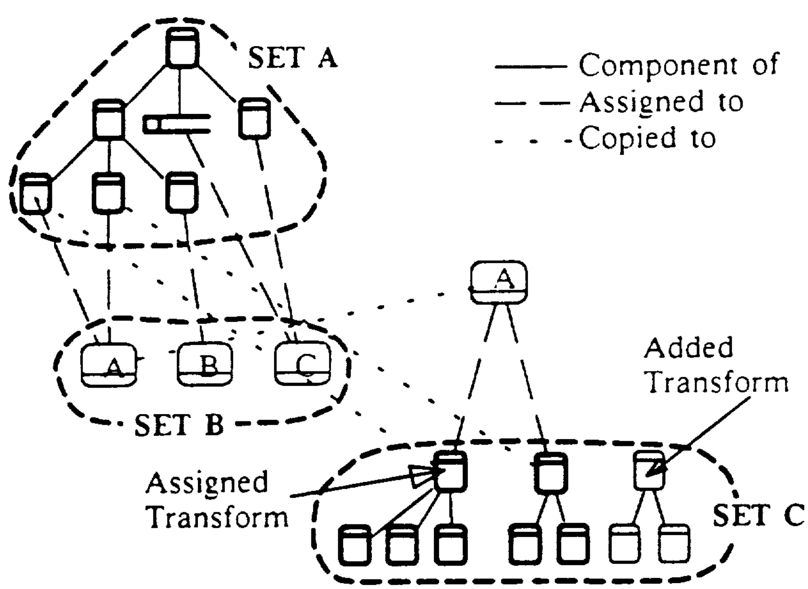

Figure 4 Illustration of Assignment and Traceability

hierarchy of transforms and stores, constituting the functional requirements for a system. The components of the system are defined as architecture entities A.B. and C. These are shown as Set B. The transforms and stores of the functional requirements are assigned to the "host" architecture entities. As a result each architecture entity will have a set of processes assigned to it. If applicable it will have stores assigned to it. Each set must be entered in a transform schema that constitutes the functional requirements for the related architecture entity. Transforms and stores can be added to the transform schema as dictated by the chosen architecture. This is illustrated in Set C. These additions may establish requirements for I/O processing, redundancy management etc.

7. **Traceability**. Each transform or store that has been assigned has in reality been copied into the transform schema for the "host" architecture entity. Throughout the project, traceability must be maintained. This means that the flow interfaces to an assigned transform or store must be identical in each transform schema where the transform or store appears, i.e. one definition must map onto the other. Likewise, the specification of a transform or store must be identical wherever the transform or store appears, i.e. one specification must map onto the other.

8. **Example**. The functional interface requirement between two architecture entities is specified by the flows that connect the sets of transforms and stores assigned to each architecture entity. This is illustrated in Figure 5a. In many designs the functional interface flows are "packaged" by some process into composite flows and later "unpacked". This is illustrated in Figure 5b. If interface flows are routed from one processing entity to another via some conduit entity this is indicated as shown in Figure 5c.

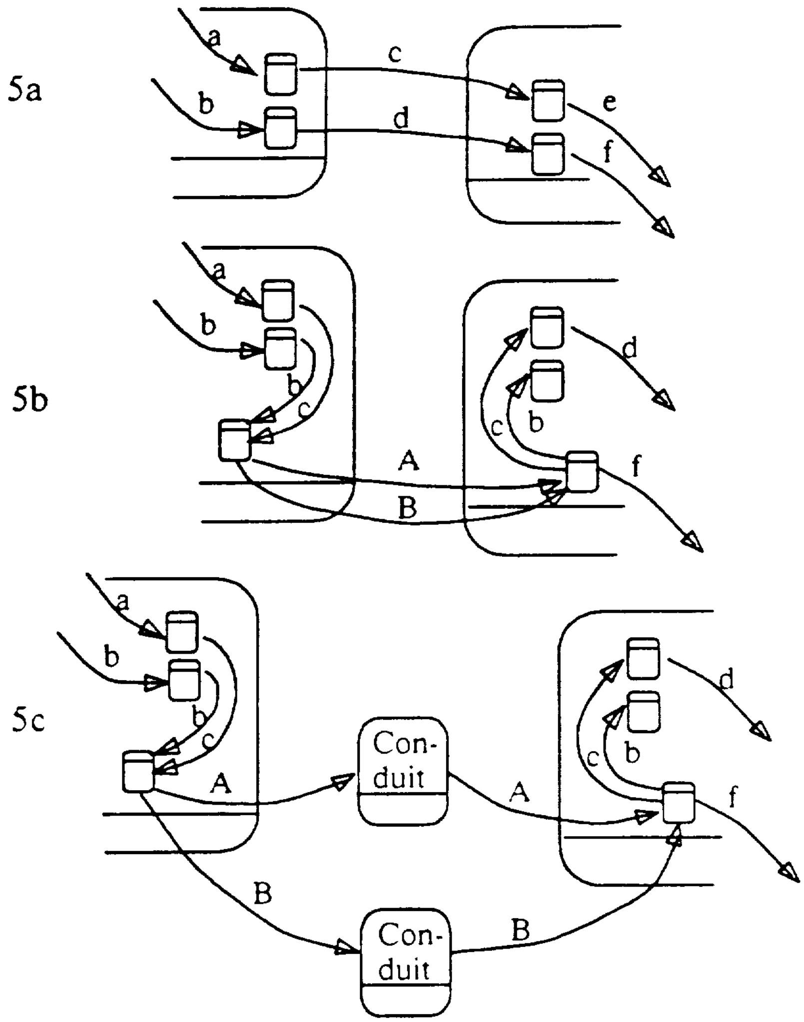

Figure 5 Illustration of Interface Definition

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16. Abstract
The requirements contained in this report are for an Advanced Subsonic Civil Transport (ASCT) flight control system and were generated using structured techniques. The requirements definition starts from initially performing a mission analysis to identify the high level control system requirements and functions necessary to satisfy the mission flight. The result of this study is an example set of control system requirements partially represented using a derivative of Yourdon's structured techniques. This document can also provide a research focus for studying structured design methodologies and in particular design-for-validation philosophies.

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