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PRESENTATION OF FLIGHT CONTROL DESIGN AND HANDLING QUALITY COMMONALITY BY SEPARATE SURFACE STABILITY AUGMENTATION FOR THE FAMILY OF COMMUTER AIRPLANES

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Prepared For: NASA Grant NGT-~~8001~~ 50001

Prepared By: Douglas Hensley

University of Kansas
AE 790 Design Team
May 13, 1987

Team Leader: Thomas Creighton

Team Members:
Raphael Haddad
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LIST OF SYMBOLS

SYMBOL	DEFINITION	UNITS
b	Wing Span	ft
C.G.	Center of Gravity	
c	Mean Geometric Chord	ft
CL	Lift Coefficient	
Cm	Pitching Moment Derivative	/rad
Des	Desired, Design	
EHA	Electrohydrostatic Actuator	
Ixx, Iyy, Izz	Moment of Inertia	Slug ft^2
K	Gain	
L,M,N	Dimensional Derivative of Moment Variation	
P	Roll Rate	1/sec
P.dot	Roll Acceleration	$1/sec^2$
q	Dynamic Pressure	psf
S	Surface Area	ft^2
SSSA	Separate Surface Stability Augmentation	
T	Time Constant	sec
t	Time	sec
U1	Velocity	fps
Xac	Aerodynamic Center location	
Xcg	Center of Gravity Location	
y	Moment Arm	in
Y	Dimensional Derivative of Side Force Variation	
Z	Dimensional Derivative of Zs Force Variation	

Greek Symbols

α	Angle of Attack	deg,rad
δ	Deflection Angle	deg,rad
η	Eta, Efficiency	
τ_{ϵ}	Elevator Effectiveness	
σ	Gust Speed	fps
ω_n	Frequency	rad/sec
ζ	Zeta, Damping Ratio	

Subscripts

D	Dutch-Roll	
E	Elevator	
H	Horizontal Tail	
q	Pitch Rate	/sec
r	Yaw Rate	/sec
R	Rudder	
SP	Short Period	
V	Vertical Tail	

1. INTRODUCTION

This is the sixth in a series of seven reports required for partial fulfillment of the requirements of NASA Grant NGT-8001. The first report (Reference 1) presented the results of the Class I design for the Family of Commuter Airplanes. The second report (Reference 2) determined the preliminary structure designs and weight penalties due to commonality for the Family of Commuter Airplanes. The third report (Reference 3) presented the structural component designs common to the Family of Commuter Airplanes. The fourth report (Reference 4) contained the methodology and results of a cost analysis for the Family of Commuter Airplanes. The fifth report (Reference 5) presented a study of advanced prop fans for the Family of Commuter Airplanes. The seventh report (Reference 6) contains the Class II design update for the Family of Commuter Airplanes.

This report contains the methodology and results for a flight control design and implementation for common handling qualities by Separate Surface Stability Augmentation (SSSA) for the Family of Commuter Airplanes.

Chapter 2 will present the open and closed loop dynamics and the design results of augmenting for common handling qualities.

Chapter 3 will present the physical and technology requirements for implementing the SSSA system.

Chapter 4 will discuss the conclusions of this report and recommendations for changes or improvement.

1.1 Background History

The Separate Surface Stability Augmentation (SSSA) concept was first implemented on a general aviation airplane by Donald J. Collins and Willard R. Bolton, JR. as the requirements for their doctoral thesis (References 7, 8).

This SSSA system was originally designed to improve the undesirable lateral-directional handling in approach and cruise flight conditions and poor ride qualities in turbulence at all speeds. This improvement in handling and ride qualities was to be gained without the mechanical feedback to the pilot that was inherent with traditional stability augmentation systems (Reference 8). The system was implemented by dividing the normal control surface into two surfaces. The larger surface was the new primary control surface and was connected to the pilot's controls in the conventional manner. The smaller surface, the SSSA surface, was driven by electric actuators whose signals were sent by a computer. The computer, in turn, derived its signals from the gyroscopes and from pilot commands through the pilot controls. In this way, the SSSA surfaces were not connected directly to the pilot's controls and a force feedback from the SSSA system was not transmitted to the pilot (Reference 7).

1.2 Incorporating Flight Control Design and Handling Quality Commonality

In order to achieve the desired commonality goals for this Family of Commuter Airplanes, it was necessary not only to implement a common stability augmentation system, but to obtain through this system common handling quality characteristics throughout the family. Thus, the commonality goals could be met on a system level - for cost and maintenance purposes - and on a personnel level through cross-certification of the flight crews among the entire Family of Commuter Airplanes.

This level of commonality, incorporating a common physical system that must produce stability augmentation tailored to the individual airplane's inherent qualities and to induce the airplane's response characteristics to a level that is perceived by the pilot to be similar to the rest of the family's characteristics is ideal for SSSA. A common separate surface size could be chosen and simple changes in the gain required for stability augmentation could tailor the response of the system to each airplane. By implementing a desired command level into the gain of the normal feedback loop, this system can then be used to drive each airplane to a common level of handling quality characteristics. Because this entire system operates separate from the primary control surfaces, the pilot perceives that the handling qualities of each airplane is similar throughout the Family of Commuter Airplanes.

In order to achieve a common "feel" for the forces required for the primary control surfaces, the stick force gradients of each airplane were modified through a stick force gain box. Because this report is focused exclusively on the stability augmentation system and its use to gain common handling quality characteristics, it will not present the methodology and results of the modification of the maneuver and velocity stick force gradients. These results are presented in Reference 6.

1.3 Design Objectives

It was mandatory for the augmentation system to meet certain minimum criteria for this design project. In the Longitudinal, Lateral-Directional and Roll modes, each airplane was required to meet the Class I handling qualities for all flight conditions at both the forward and aft C.G. locations. In addition, this SSSA system must have sufficient control power to maintain these Class I handling qualities in gust conditions for all flight phases. This requirement is to reduce pilot work load and to ensure that the system will be reliable and safe in up to 1 percent probability gusts and in thunderstorm gust conditions.

The stick forces for the primary flight control surfaces must have common maneuver and velocity gradients in all flight conditions at the forward and aft C.G. locations. These conditions are presented in Reference 6.

The physical constraints require that all SSSA surfaces must be of common size and geometry. The actuators for all control surfaces must be common; this may require that the surfaces requiring greater control forces for deflection will have a greater number of actuators. This may incur certain weight penalties in favor of commonality requirements.

2. DESIGN RESULTS OF AUGMENTING FOR COMMON HANDLING QUALITIES

The purpose of this section is to present the unaugmented characteristics and the augmented design results of the handling qualities for the Family of Commuter Airplanes. These results will be presented for the Longitudinal, Lateral-Directional and the Roll modes.

2.1 Longitudinal Open and Closed Loop Dynamics

From Figures 2.1 and 2.2, it can be seen that the critical minimum and maximum ωn_{sp} and ζ_{sp} for Level I handling qualities in the longitudinal mode occurs at:

TABLE 2.1 Critical Short-Period Frequencies and Damping Ratios

ζ_{sp} = 0.3 for all conditions.

Cruise Speed:

Min. ωn_{spmax}: 7.3 rad/sec 50 Pax - Fore C.G.

Max. ωn_{spmax}: 1.75 rad/sec 75 Pax - Aft C.G.

Min. Control Speed:

Min. ωn_{spmax}: 3.6 rad/sec 50 Pax - Fore C.G.

Max. ωn_{spmax}: 1.2 rad/sec 75 Pax - Aft C.G.

And from Table 2.2, it can be seen that all of the airplanes in the family meet the Level I handling qualities in the longitudinal mode in all flight conditions except for the 50 Pax - Aft C.G. at both the cruise and min. control speed.

Therefore, the primary requirement of the augmentation system was to drive the handling qualities of each airplane to a level of commonality.

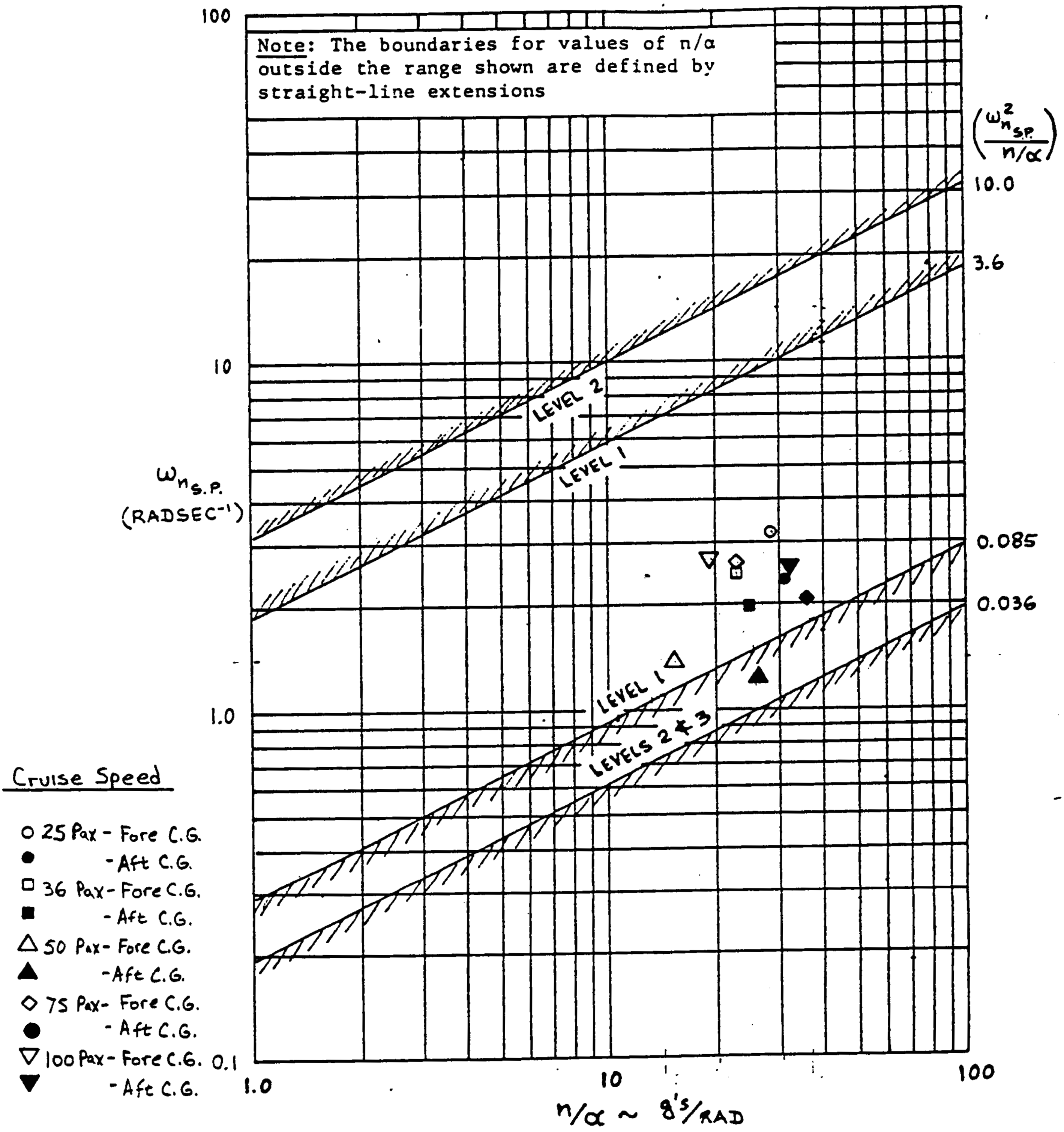
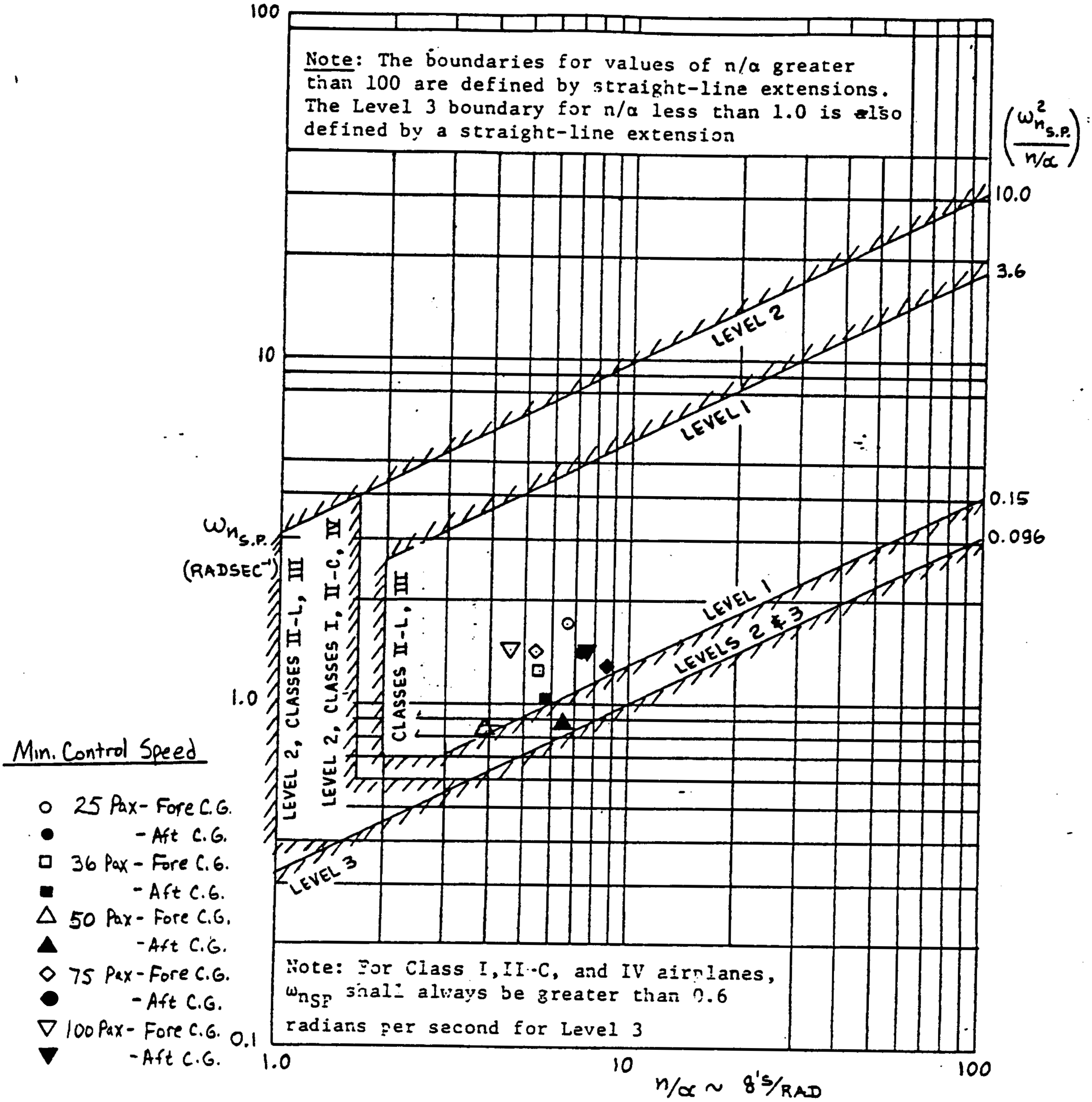


FIGURE 2.1 Cruise Speed Longitudinal Short Period Frequency Requirements



Note: The boundaries for values of n/α greater than 100 are defined by straight-line extensions. The Level 3 boundary for n/α less than 1.0 is also defined by a straight-line extension

Note: For Class I, II-C, and IV airplanes, $\omega_{n_{SP}}$ shall always be greater than 0.6 radians per second for Level 3

FIGURE 2.2 Min. Control Speed Longitudinal Short Period Frequency Requirements

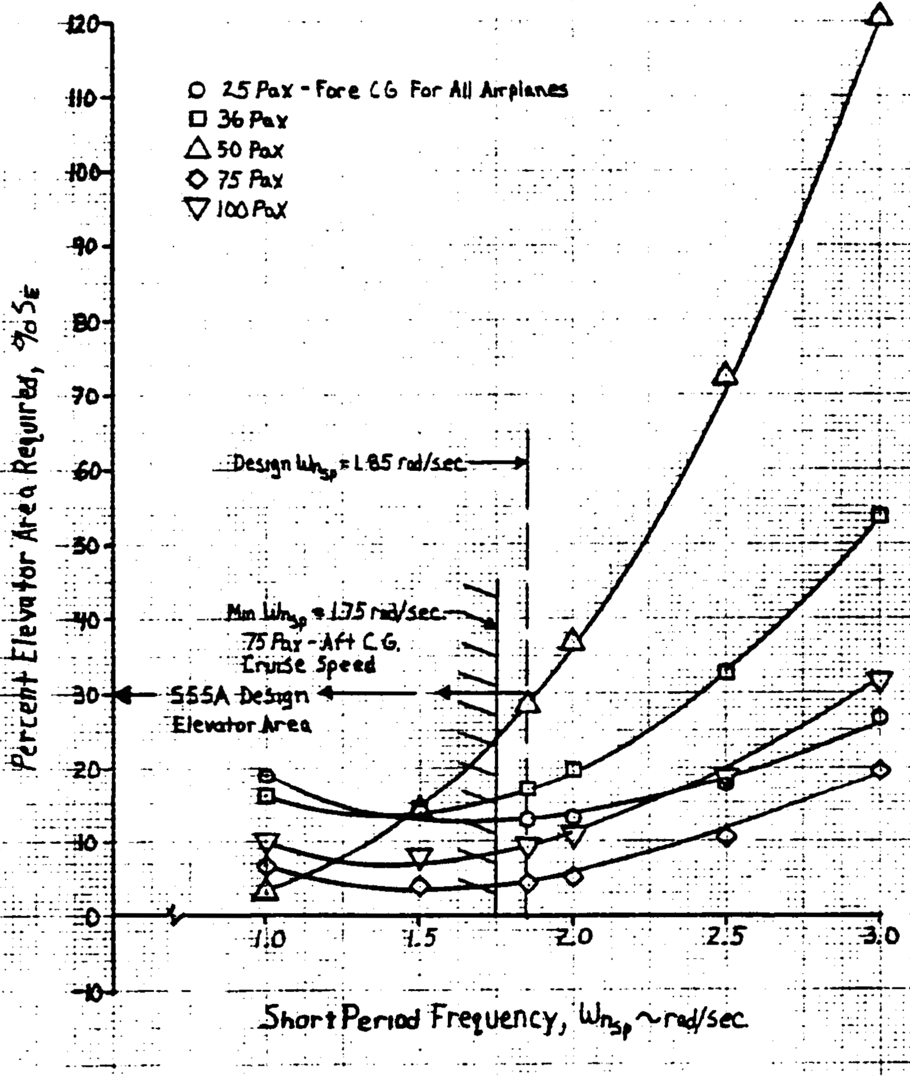
TABLE 2.2 Longitudinal and Lateral-Directional Handling Qualities

LEVEL OF FLYING QUALITIES

Airplane	Flight Condition C.G. Location	$W_{n_{sp}}$	ζ_{sp}	W_{n_D}	ζ_D	$W_{n_D}\zeta_D$
			Level Satisfied			
	fwd @ cruise	1	1	1	1	1
25	aft @ cruise	1	1	1	1	1
	fwd @ Vmc	1	1	1	1	1
	aft @ Vmc	1	1	1	1	1
	fwd @ cruise	1	1	1	1	1
.36	aft @ cruise	1	1	1	1	1
	fwd @ Vmc	1	1	1	1	1
	aft @ Vmc	1	1	1	1	1
	fwd @ cruise	1	1	1	1	1
50	aft @ cruise	2	1	1	1	1
	fwd @ Vmc	1	1	1	1	1
	aft @ Vmc	2	1	1	1	1
	fwd @ cruise	1	1	1	1	2
75	aft @ cruise	1	1	1	1	1
	fwd @ Vmc	1	1	1	1	2
	aft @ Vmc	1	1	1	1	1
	fwd @ cruise	1	1	1	1	2
100	aft @ cruise	1	1	1	1	1
	fwd @ Vmc	1	1	1	1	2
	aft @ Vmc	1	1	1	1	1

Using the analysis presented in Appendix A for the longitudinal dynamics, a trade study was performed to observe the effects changing the design short period frequency had on required elevator area. The graphical results of this study are presented for the critical forward C.G. locations for all airplanes in the family in Figure 2.3. It can be seen that as the ωn_{sp} is raised to high levels, the required elevator area to cause the airplane to react with the desired quickness increased sharply for the most critical airplane. As the ωn_{sp} was lowered to very slow response characteristics, the elevator area required once again began to increase as this control power was required to make the airplane react more sluggishly than its inherent short period frequency. While it is obvious that the minimum required elevator area occurs in the region of ωn_{sp} = 1.5 rad/sec, this could not be chosen as a design point. This is because the critical maximum ωn_{spmin} for all of the airplanes is at 1.75 rad/sec for the 75 Pax airplane Aft C.G. at cruise speed. In order to have qualities that exceeded the minimum Class I handling requirements by a reasonable margin, a design point of ωn_{sp} = 1.85 rad/sec and ζ_{sp} = 0.5 was chosen. The location of this design point in relation to the open loop characteristics is shown on the root loci in Figures 2.4 and 2.5.

From the spreadsheet analysis presented in Appendix A, this design point resulted in minimum gain and SSSA elevator surface area size requirements for the longitudinal SSSA system (Table 2.3).



All Airplanes Critical For Fore C.G.
And Min. Control Speed, U_W = 21 FPS

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FIGURE 2.3 Required Elevator Area Variation due to Short Period Frequency

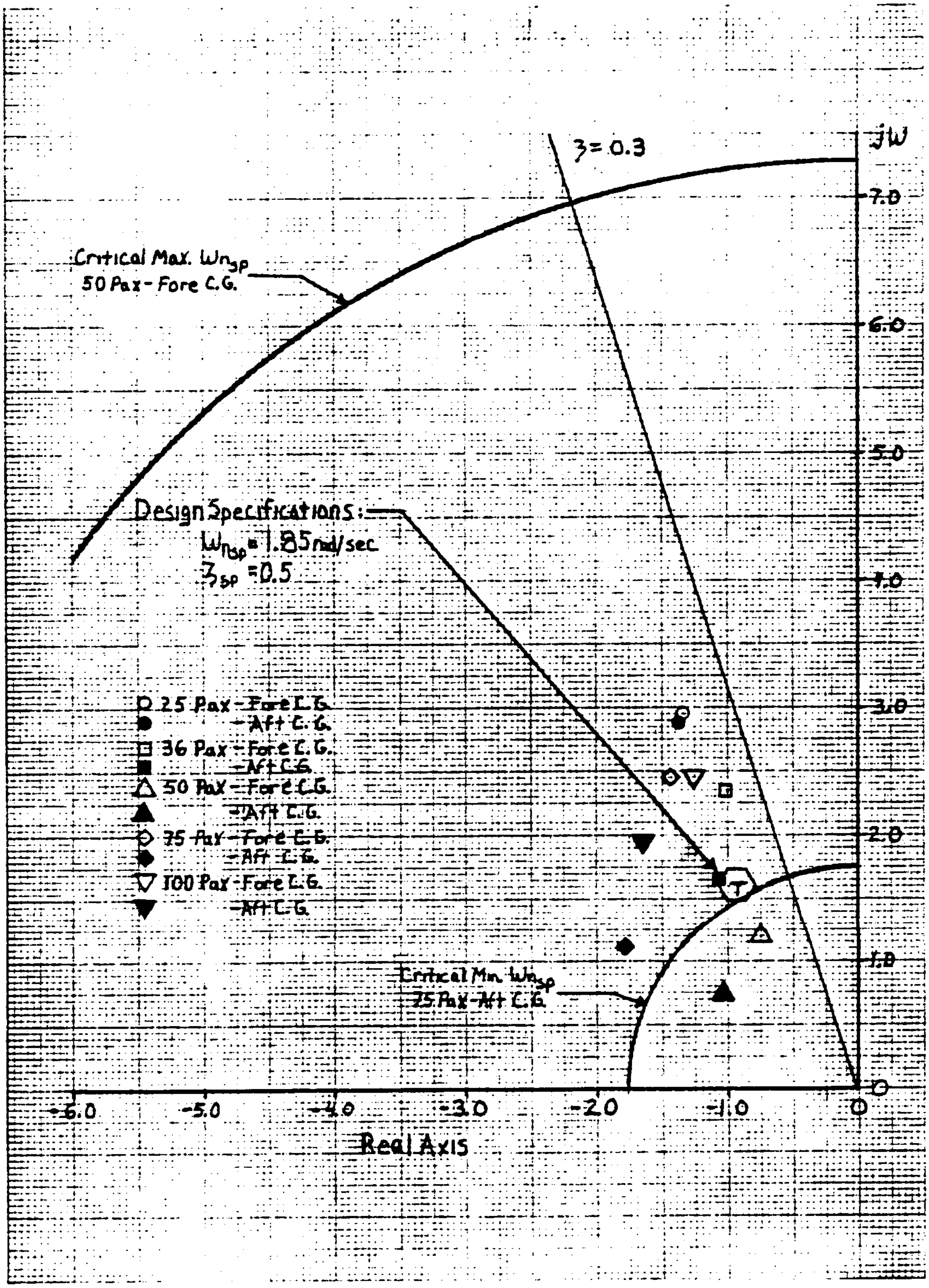

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FIGURE 2.4 Cruise Speed Longitudinal Short Period Root Locus

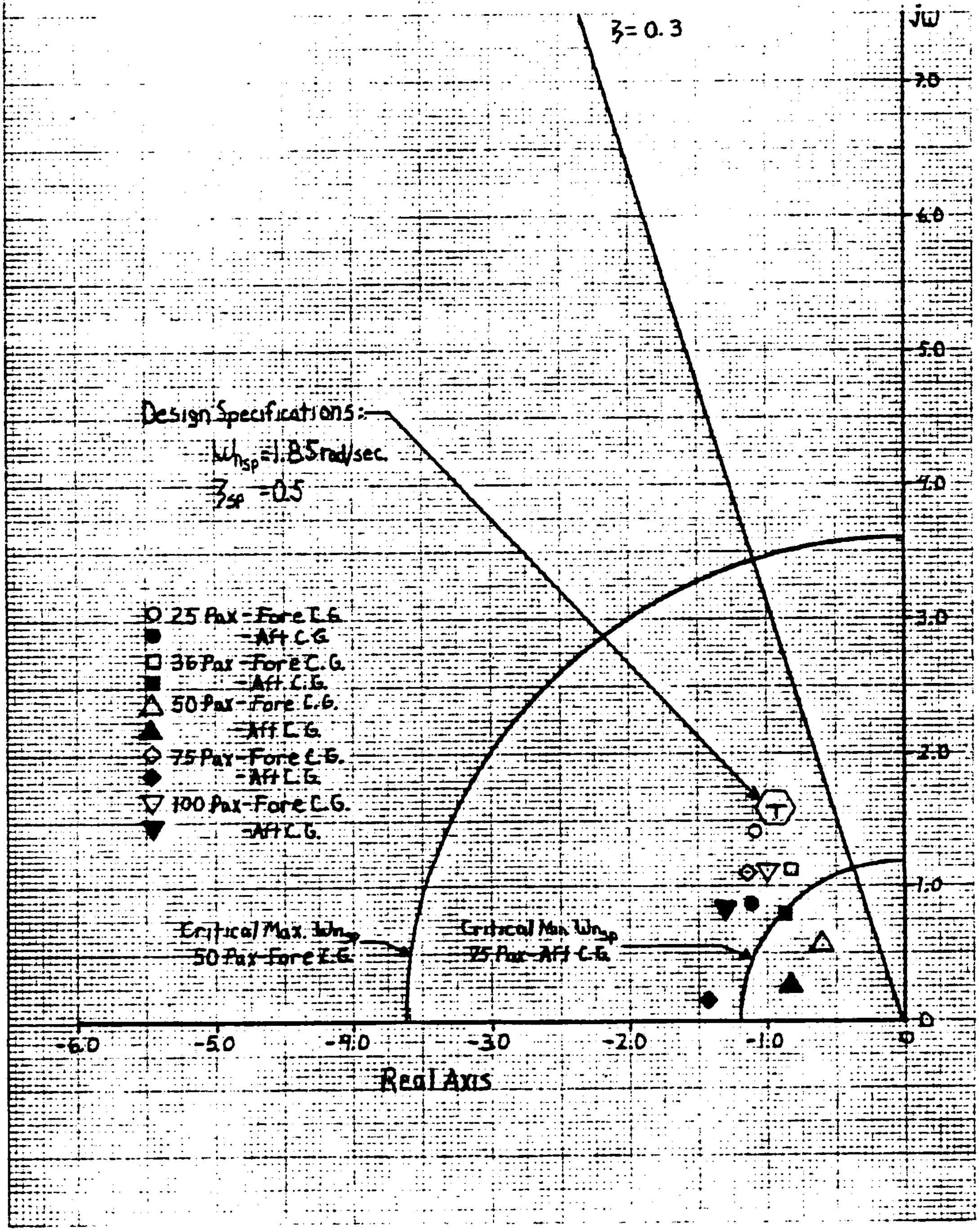

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FIGURE 2.5 Min. Control Speed Longitudinal Short Period Root Locus

TABLE 2.3 Longitudinal SSSA Requirements for Critical Conditions

Design $\omega_{n_{sp}}$ = 1.85 rad/sec
Design ζ_{sp} = 0.5
Critical Conditions: Min. Control Speed, σ_w = 21 fps

	25 Pax		36 Pax		50 Pax		75 Pax		100 Pax	
	Fore	Aft	Fore	Aft	Fore	Aft	Fore	Aft	Fore	Aft
K_α	-.314	-.261	-.179	-.071	.642	.312	-.263	-.386	-.225	-.407
Kq	-.146	-.180	.189	.094	.923	.136	-.105	-.370	.039	-.317
Percent S_E required:	12.7	1.8	16.8	8.9	28.4	13.9	4.2	-8.6	9.0	-2.8

The critical requirements occurred for the 50 Pax - Fore C.G. which required 28.4 percent of the elevator to be designated for SSSA. This was rounded to 30 percent which resulted in each airplane being able to safely compensate for the following gust conditions at the Min. Control Speed.

TABLE 2.4 Longitudinal SSSA Gust Performance

SSSA S_E = 30 Percent or 12.6 ft^2 - 25, 36, 50 Pax
43 ft^2 - 75, 100 Pax

	25 Pax		36 Pax		50 Pax		75 Pax		100 Pax	
	Fore	Aft	Fore	Aft	Fore	Aft	Fore	Aft	Fore	Aft
Gust Speed (fps), σ_w	49.5	345.3	37.4	70.7	22.2	45.3	149.2	-73.4	69.8	-221.9

Typical gain schedules for the critical airplane - 50 Pax - Fore C.G. are presented for K_α in Figure 2.6 and Kq in Figure 2.7.

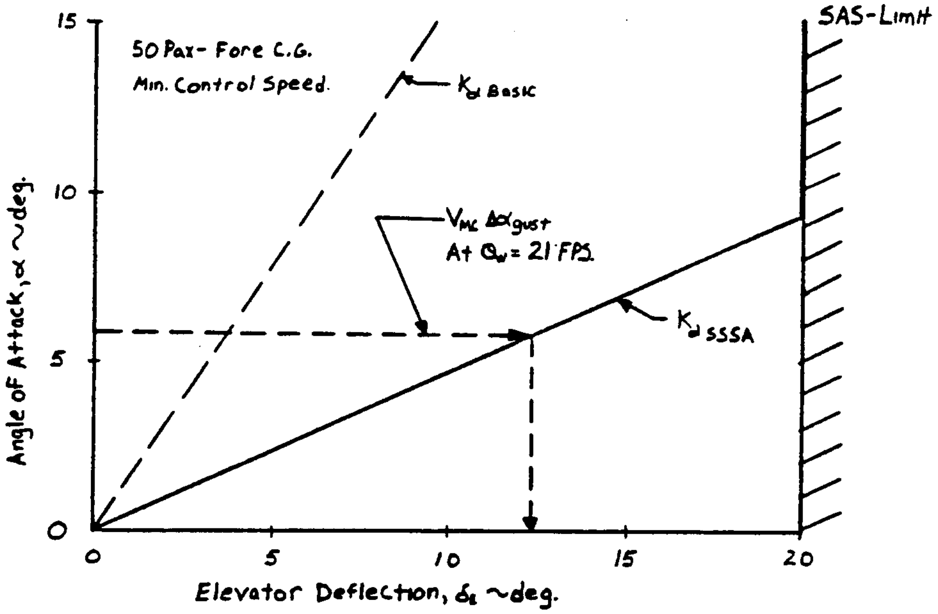

FIGURE 2.6 Typical Kα Gain Schedule for Longitudinal Dynamics

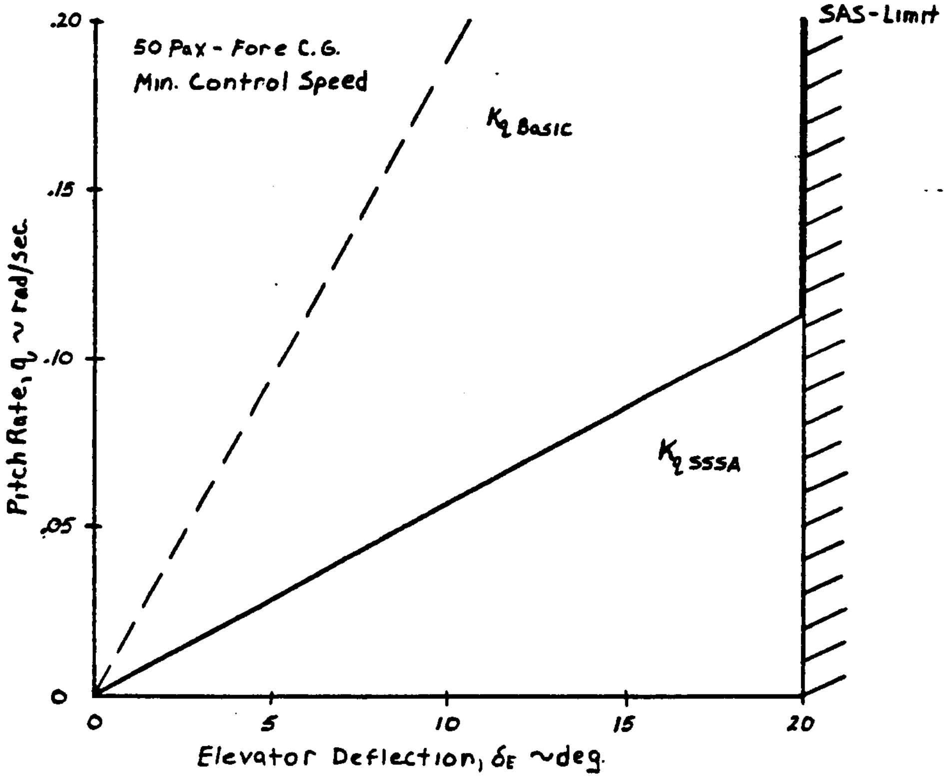

FIGURE 2.7 Typical Kq Gain Schedule for Longitudinal Dynamics

2.2 Lateral-Directional Open and Closed Loop Dynamics

The lateral directional open loop dynamics for the Family of Commuter Airplanes are presented for forward and aft C.G. at cruise and min. control speed in Figures 2.8 and 2.9. From these figures, and from Table 2.2, it is obvious that all of the airplanes - in their basic state - meet the Level I Lateral-Directional handling requirements except for the 75 and 100 Pax - Fore C.G. at both cruise and min. control speed.

Due to the indirect manner in which the augmentation system affects the lateral directional Dutch roll frequency and Dutch roll damping, and because of the extensive interaction that occurs in this mode, it was decided to drive each airplane to a common Dutch roll damping and to let the Dutch roll frequency "fall-out" of the calculations. Using the spreadsheet methodology presented in Appendix B, basic calculations revealed that the minimum acceptable ζ_D that resulted in Class I handling qualities for all airplanes in all flight conditions was $\zeta_D = 0.27$. A conservative, but more realistic figure of $\zeta_D = 0.29$ was chosen as the design goal.

The resulting handling qualities are shown in Figures 2.8 and 2.9. The spreadsheet analysis also resulted in the minimum gain and SSSA rudder control surface area requirements for the Lateral-Directional SSSA system presented in Table 2.5.

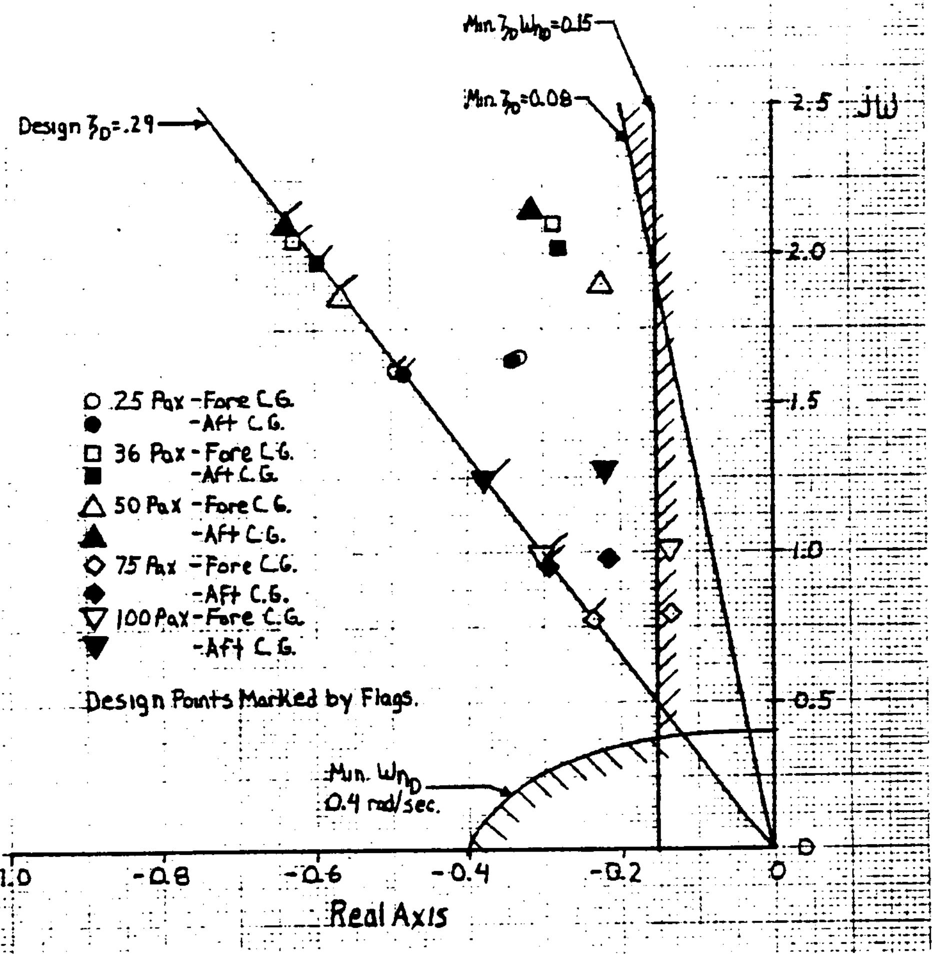

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FIGURE 2.8 Cruise Speed Lateral-Directional Root Locus

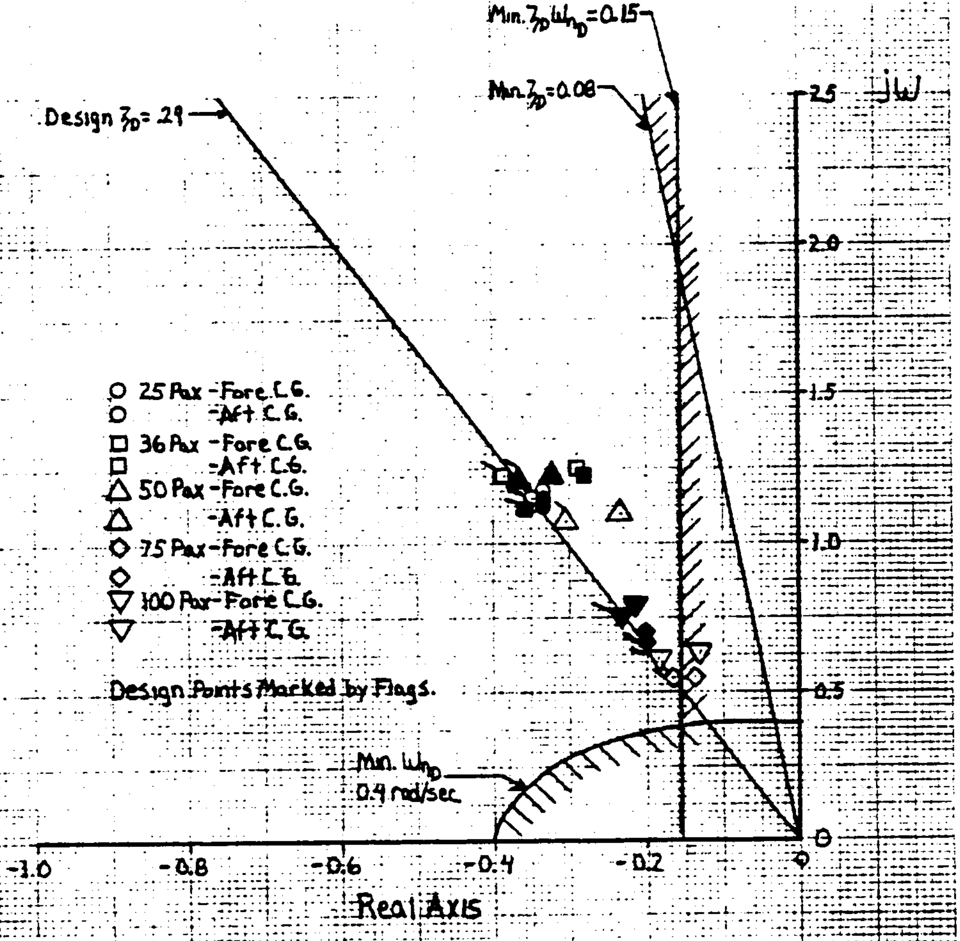

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FIGURE 2.9 Min. Control Speed

Lateral-Directional Root Locus

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TABLE 2.5 Lateral Directional SSSA Requirements for Critical Conditions

Design ζ_D = 0.29

Critical Conditions: Min. Control Speed, σ_v = 21 fps

	25 Pax		36 Pax		50 Pax		75 Pax		100 Pax	
	Fore	Aft	Fore	Aft	Fore	Aft	Fore	Aft	Fore	Aft
Kr	.156	.179	.026	.052	-.074	.167	.218	.445	.021	.319
Percent S_R required:	15.4		24.0		28.2		15.7		20.4	

The critical requirements occurred for the 50 Pax which required 28.2 percent of the rudder to be designated for SSSA. This was rounded to 30 percent which resulted in each airplane being able to safely compensate for the following gust conditions at the min. control speed.

TABLE 2.6 Lateral-Directional SSSA Gust Performance

SSSA S_E = 30 percent or 18 ft^2 - 25, 36, 50 Pax
35.7 ft^2 - 75, 100 Pax

	25 Pax	36 Pax	50 Pax	75 Pax	100 Pax
Gust Speed (fps), σ_v	40.8	26.2	22.3	40.2	30.8

A typical gain schedule for the 50 Pax - Fore C.G. is presented in Figure 2.10.

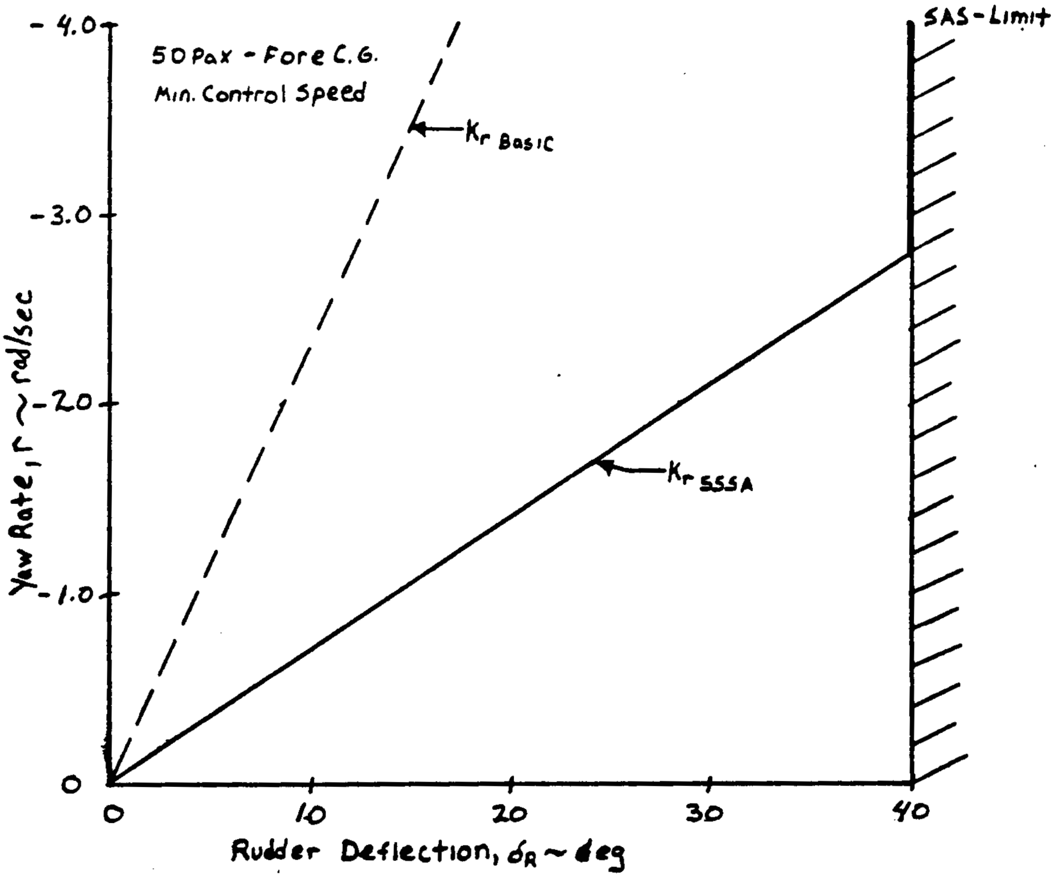

FIGURE 2.10 Typical Kr Gain Schedule for Lateral-Directional Dynamics

2.3 Roll Mode Dynamics

The critical open loop dynamics in the Roll mode consists primarily of the roll time constant, T_R, and the time requirement to reach a minimum roll angle. These minimum Level I requirements are presented in Table 2.7.

Table 2.7 Roll Mode Minimum Requirements

Flight Condition	T_{Rmax} (sec)	t (sec)	Phi (deg)
Cruise	1.4	1.9	45
Min. Control	1.4	1.8	30

From the spreadsheet analysis of Appendix C, these values were calculated for each airplane at cruise and min. control speeds at fore and aft C.G. locations. The results of these calculations are presented in Table 2.8

Table 2.8 Roll Mode Dynamics

	25 Pax		36 Pax		50 Pax		75 Pax		100 Pax	
	Fore	Aft	Fore	Aft	Fore	Aft	Fore	Aft	Fore	Aft
Cruise:										
T_R,(sec)	.145	.221	.152	.267	.305	.157	.533	.299	.648	.349
Phi,(deg)	112.2	107.3	111.7	104.4	102.0	111.4	55.8	64.6	51.9	62.7
P,(sec^{-1})	1.12	1.12	1.12	1.11	1.11	1.12	0.68	0.70	0.67	0.70
P.dot,(sec^{-2})	2E-5	9E-4	3E-5	3E-3	7E-3	4E-5	3E-2	4E-3	5E-2	8E-3
Min. Control:										
T_R,(sec)	.223	.341	.234	.411	.470	.243	.838	.470	1.018	.549
Phi,(deg)	60.7	56.2	60.3	53.6	51.6	59.9	34.9	44.1	31.4	41.8
P,(sec^{-1})	.67	.67	.67	.66	.65	.67	.50	.56	.47	.55
P.dot,(sec^{-2})	9E-4	1E-2	1E-3	2E-2	3E-2	1E-3	8E-2	2E-2	9E-2	4E-2

It is apparent that within each group of airplanes with the same planform - single body and twin body - that these critical characteristics are inherently very similar. For the following reasons:

1) The similarity of the open-loop dynamics within each group of common planform.
2) The magnitude by which the family inherently exceeded the Level I minimum requirements.
3) That the perception of the pilots in the twin-bodies would be unpredictably affected in the roll-mode due to their location away from the axis of rotation.

it was decided that a roll-damper SAS would not be used in this Family of Commuter Airplanes.

3. REQUIREMENTS OF SYSTEM IMPLEMENTATION

The purpose of this Section is to present the physical and technology requirements for implementing a Separate Surface Stability Augmentation System. A typical arrangement and block diagrams for the control systems will then be presented.

3.1 Separate Surface Control Surface Requirements

The surface areas required for the SSSA control surfaces in the Longitudinal, Lateral-Directional and the Roll modes can be summarized from Sections 2.1, 2.2, and 2.3 of the report as:

TABLE 3.1 Summary of Control Surface Requirements

	Longitudinal Elevator Area	Lateral-Directional Rudder Area	Roll Aileron Area
SSSA Percent of Primary Surface	30	30	N/A
25,36,50 Pax (ft^2)	12.6	18	N/A
75, 100 Pax (ft^2) (Twin Bodies)	43	35.7	N/A

As explained earlier in this report, the design goal of commonality being the primary design driver rather than individual optimization for each airplane is the reason a common control surface size was chosen for each airplane. The selected surfaces that will be controlled by the SSSA system for each airplane are represented in Figures 3.1, 3.2, and 3.3. A note for Figure 3.2, the surface areas indicated on the aileron or the spoiler are suggested locations that could

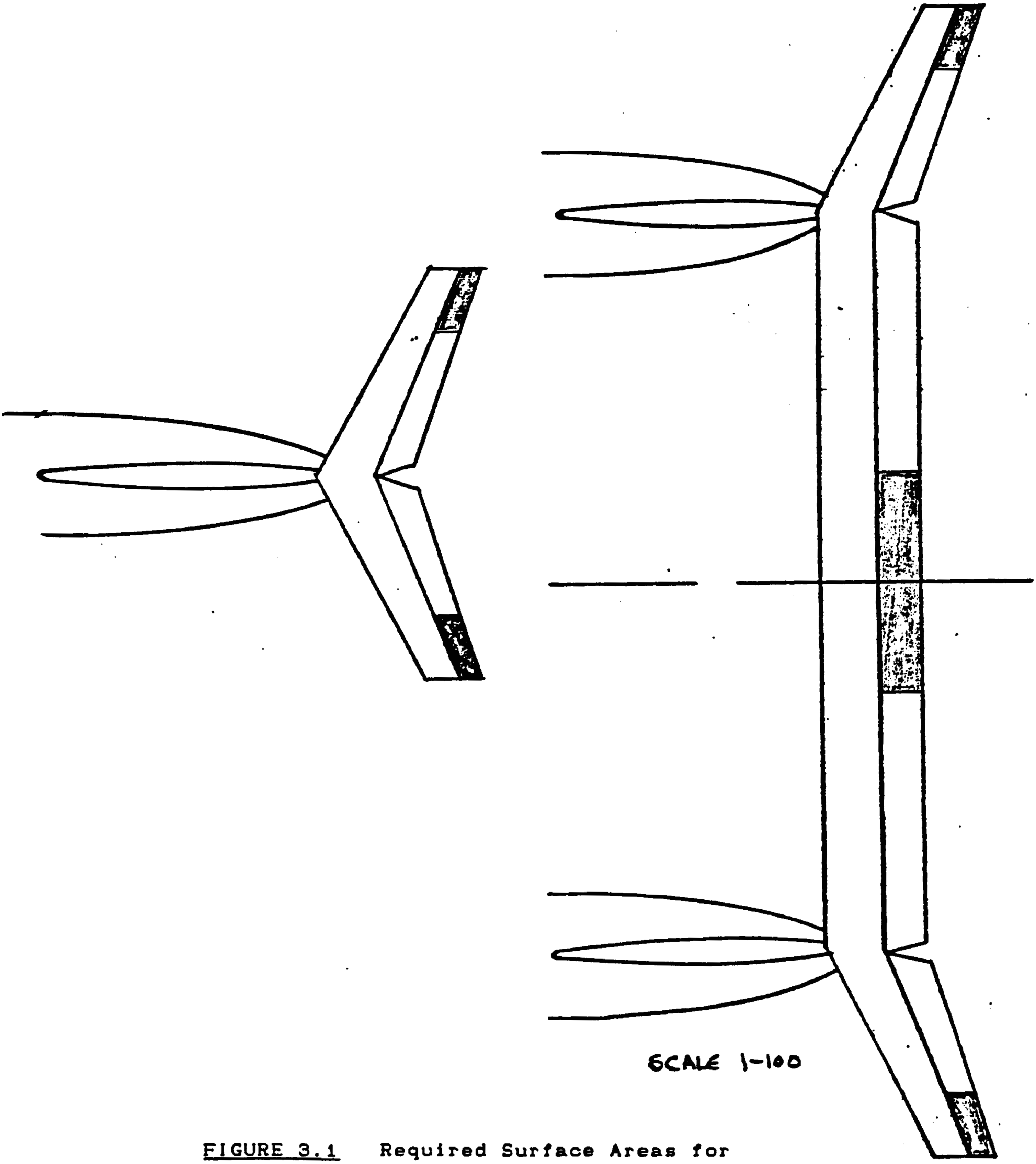

FIGURE 3.1 Required Surface Areas for Longitudinal Dynamics

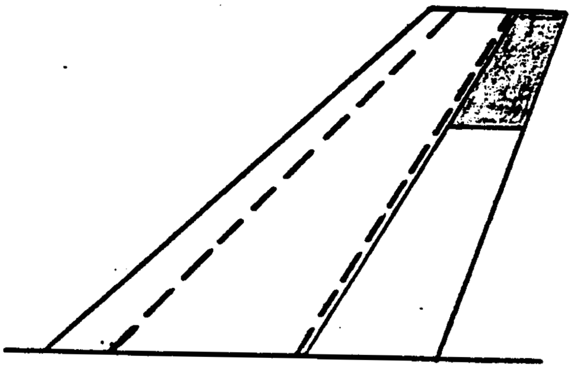

FIGURE 3.2 Required Surface Area for Lateral-Directional Dynamics

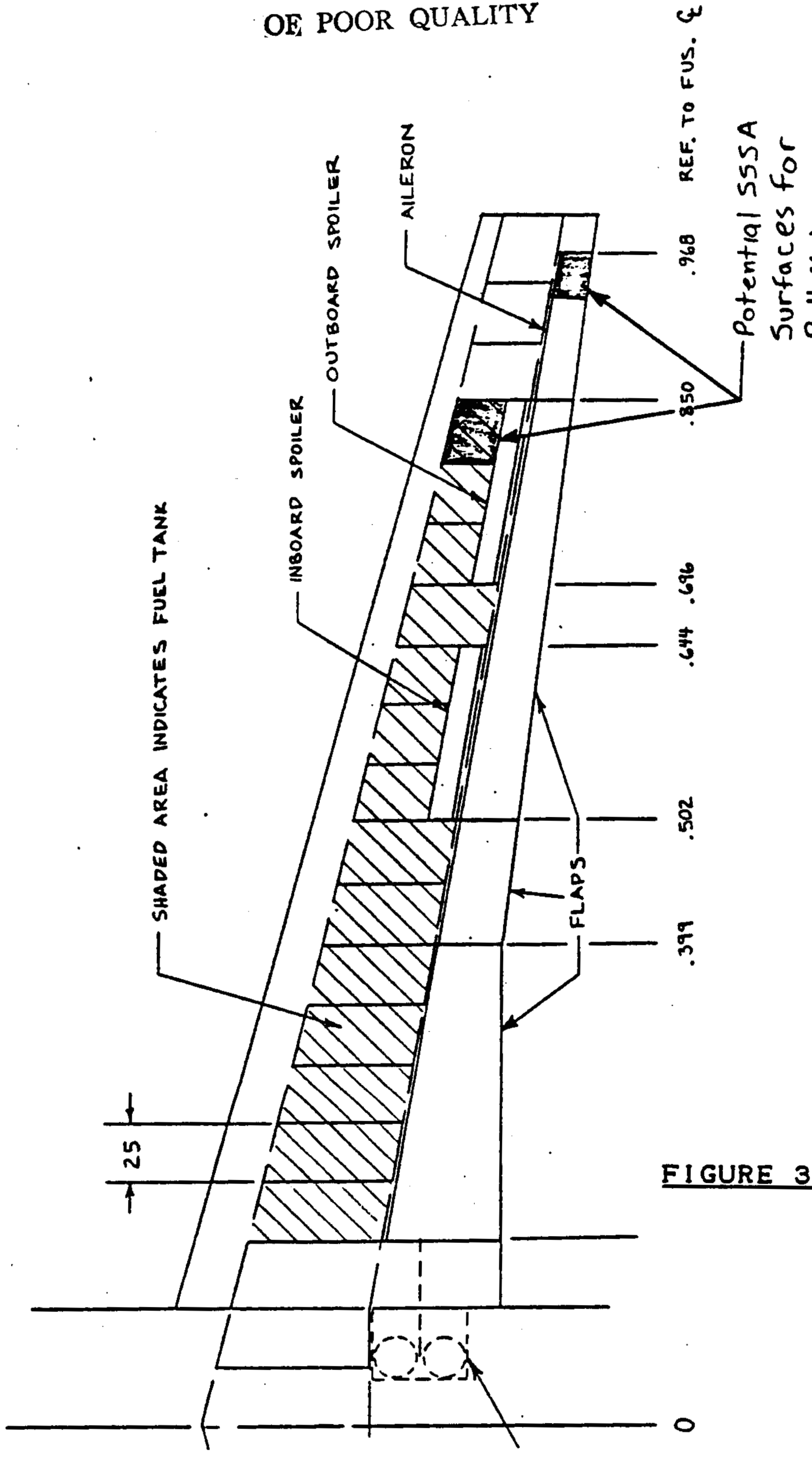

FIGURE 3.3 Suggested Surface Areas for Roll-Mode Dynamics

be retro-fitted as SSSA control surfaces if pilot perceptions indicate that such a system would be required to achieve greater common handling characteristics in the Roll mode.

3.2 Technology Requirements

In order to meet the goal of maximizing commonality throughout the Family of Commuter Airplanes, it was crucial for the entire stability and handling qualities augmentation system to be similar. This ruled-out the use of mechanical or hydraulic linkages for this system as such linkages would require a system specifically tailored for the physical constraints of each airplane. According to Reference 9, a control system driven by electric signals avoids the complexity and individual design required by a fully mechanical or hydraulic system. It also avoids the non-recurring cost required by mechanical/hydraulic systems for a Vehicle System Simulator (or "Iron Bird"). The result of using a system driven by electric signals is a decrease in the design and development costs as well as the installation and testing costs for the system.

The ideal actuator to be used for this system, and that is available through current technology, would be electrohydrostatic actuators (EHA's). As described in References 10 and 11, these actuators are driven by a localized hydraulic system pressurized by a high-power-(rare earth) magnet electric motor. They can be activated by electric or light signals and are ideal for usage with the primary flight control system elements such as the elevators, ailerons and rudder. Figure 3.4 shows an example of an Electrohydrostatic actuator.

Figures 3.5 and 3.6, courtesy of Reference 12, demonstrate additional characteristics of EHA's. Figure 3.5 shows typical hinge moments, rates, horsepower, estimated weights and electrical bus power requirements for a control

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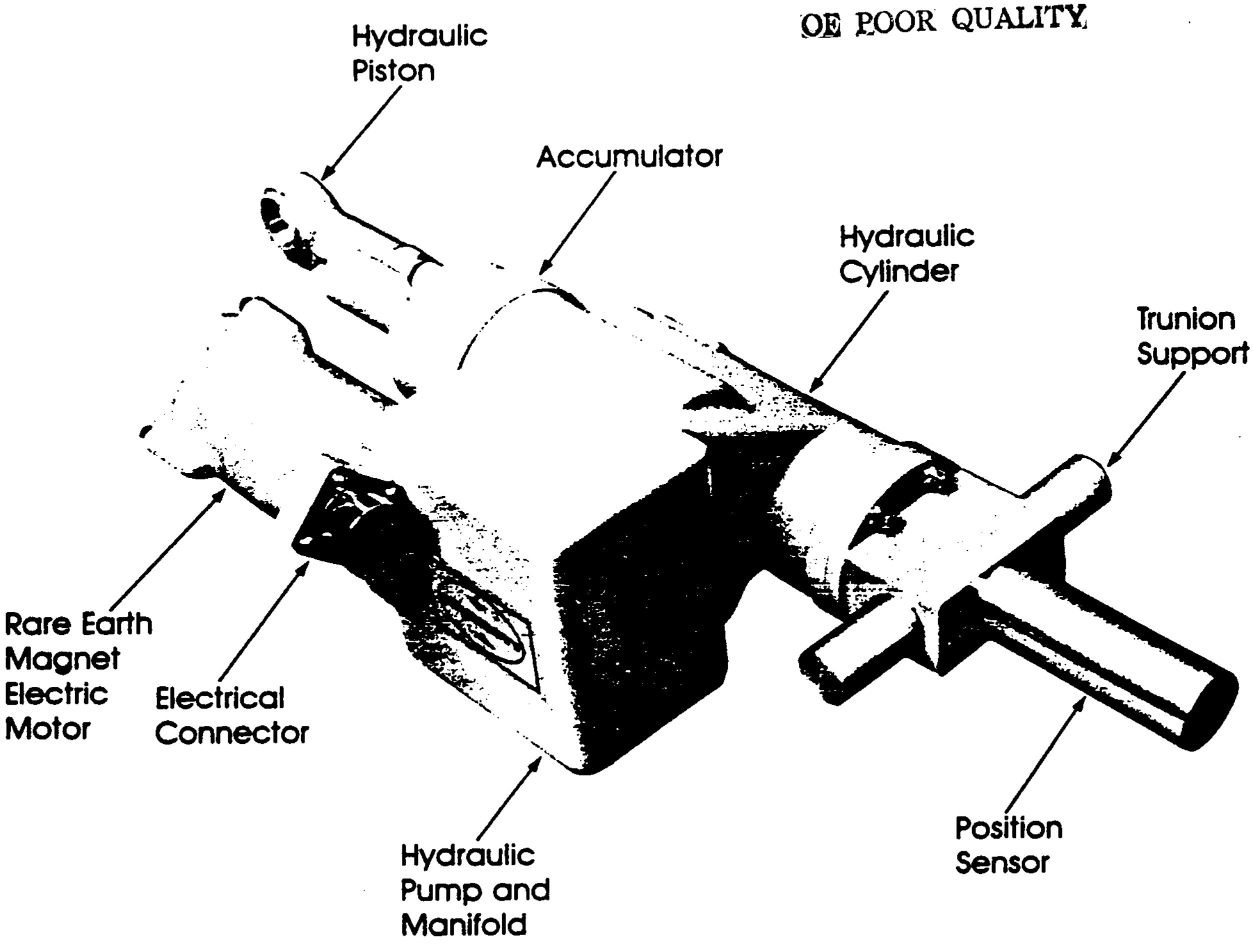


FIGURE 3.4 Example Electrohydrostatic Actuator

TABLE 1
BUS SUMMARIES

ACTUATOR & #		CONNECTED ACTUATOR HORSEPOWER OUTPUT			Max. Rate	Max Act. H.M.	ESTIMAT ACTUATO WEIGHT
		BUS LOCATION					
		L	C	R	°/S	FT - LBS.	LBS
L. AILERON	1			.88	30	925	15-20
L. AILERON	2		.88		30	925	
R. AILERON	1	.88			30	925	
R. AILERON	2		.88		30	925	
L. SPOILER	1	3.70			60	1945	20-25
L. SPOILER	2		4.79		60	2516	
L. SPOILER	3	5.35			60	2812	
L. SPOILER	4			6.28	60	3300	
R. SPOILER	9			6.28	60	3300	20-25
R. SPOILER	10	5.35			60	2812	
R. SPOILER	11		4.79		60	2516	
R. SPOILER	12	3.70			60	1945	
STABILIZER	1		15.63		5	98500	40-60
STABILIZER	2			15.63	5	98500	
L. ELEVATOR	1	2.48			30	2600	20-25
L. ELEVATOR	2		2.48		30	2600	
L. ELEVATOR	3			2.48	30	2600	
R. ELEVATOR	1	2.48			30	2600	20-25
R. ELEVATOR	2		2.48		30	2600	
R. ELEVATOR	3			2.48	30	2600	
RUDDER	1	1.99			35	1790	20-25
RUDDER	2		1.99		35	1790	
RUDDER	3			1.99	35	1790	
Total Connected Bus H.P.		25.93	33.92	36.02			
Bus Power In kW.		26.77	35.02	37.19			
Est. Cont. Load kW		2.68	3.50	3.72			

$$HP = \frac{(RATE)\,(HM) \times 60}{360 \times 5252}$$

$$Pbus = \frac{HP \times .746}{.85 \times .85} = 1.033 \times HP \ \ (kW)$$

FIGURE 3.5 Performance Characteristics of Typical EHA's

NOTES:
1 - CONTROLLERS FOR THESE ACTUATORS WOULD WEIGH 5-10 POUNDS EACH.
2 - STAB TRIM IS EMA. CONTROLLER WT IS 10-15 POUNDS.

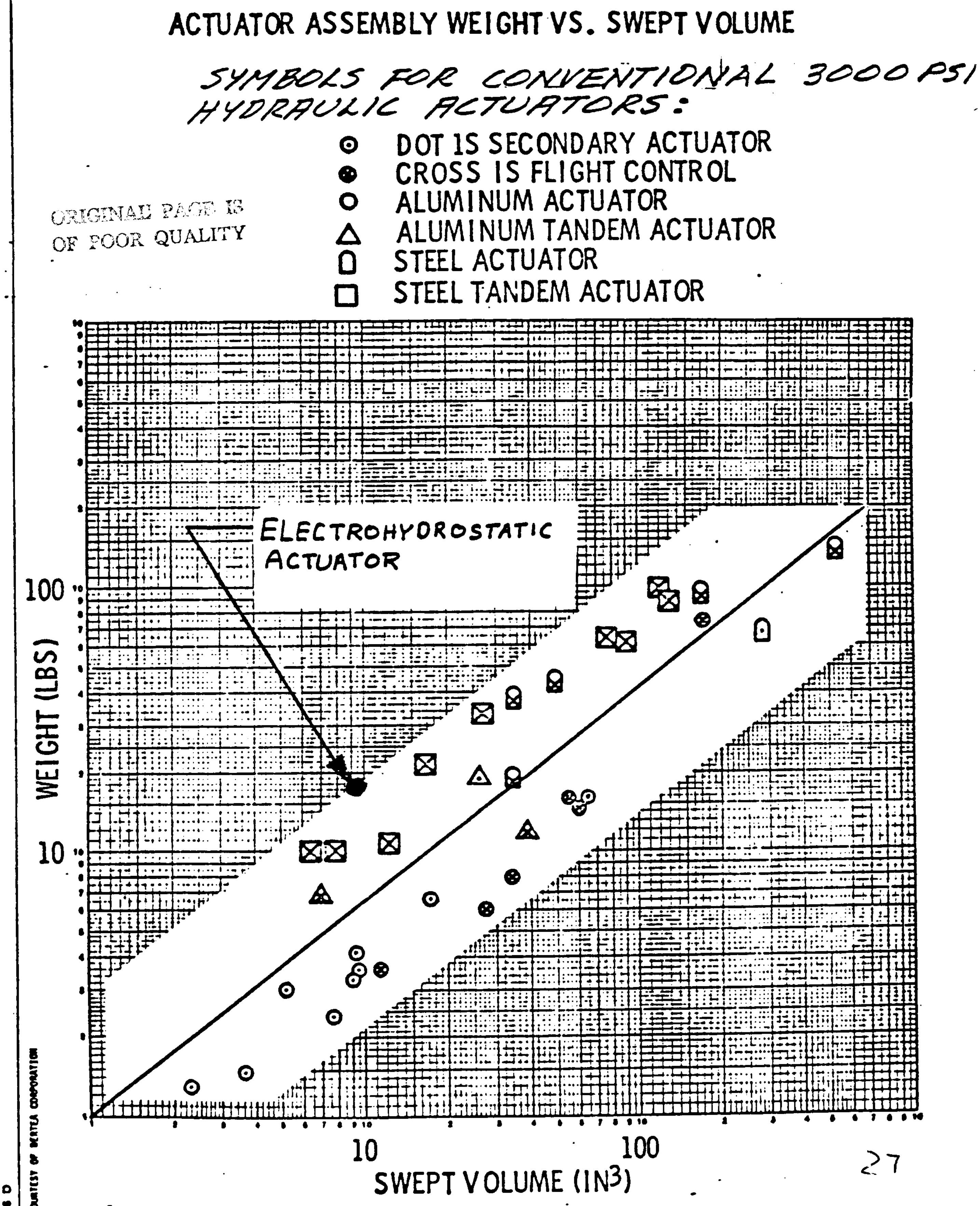


FIGURE 3.6 EHA Weight to Swept-Volume Comparison

system for a similar airplane. Figure 3.6 shows a comparison of the weight of an EHA as a function of swept volume with conventional hydraulic actuators. While this figure indicated - 11.5 lbs for a 95 in^3 swept volume - appears to be high compared to conventional hydraulic actuators, each EHA is a self-contained unit and their use will save weight on the overall system by eliminating the need for a central hydraulic system and long runs of redundant high-pressure tubing required by conventional hydraulic systems.

The system will also require typical controllers driven by electric signals. As stated previously in Section 1.2 of this report, simple adjustments in the gain requirements for these controllers can be used to tailor the handing qualities of each airplane to achieve the desired goal of common Level I handling characteristics.

The requirements for the stick force gain box, previously mentioned in Section 1.3 of this report, to achieve common stick force gradients for the primary control surfaces are detailed in Reference 6.

3.3 System Implementation

As noted in Reference 12 and the characteristics presented in Figure 3.5, the performance of EHA's is similar to standard hydraulic actuators. For this reason, the concern noted in Section 1.3 of this report concerning the possible need for an undue number of actuators driving the surfaces requiring greater control forces is apparently unfounded. Figure 3.7 demonstrates a typical physical arrangement of actuators, controllers and control surface areas for a horizontal tail.

Figures 3.8, 3.9 and 3.10 represent the block diagrams for the controllers. They are for an angle of attack controller, pitch damper and yaw damper respectively.

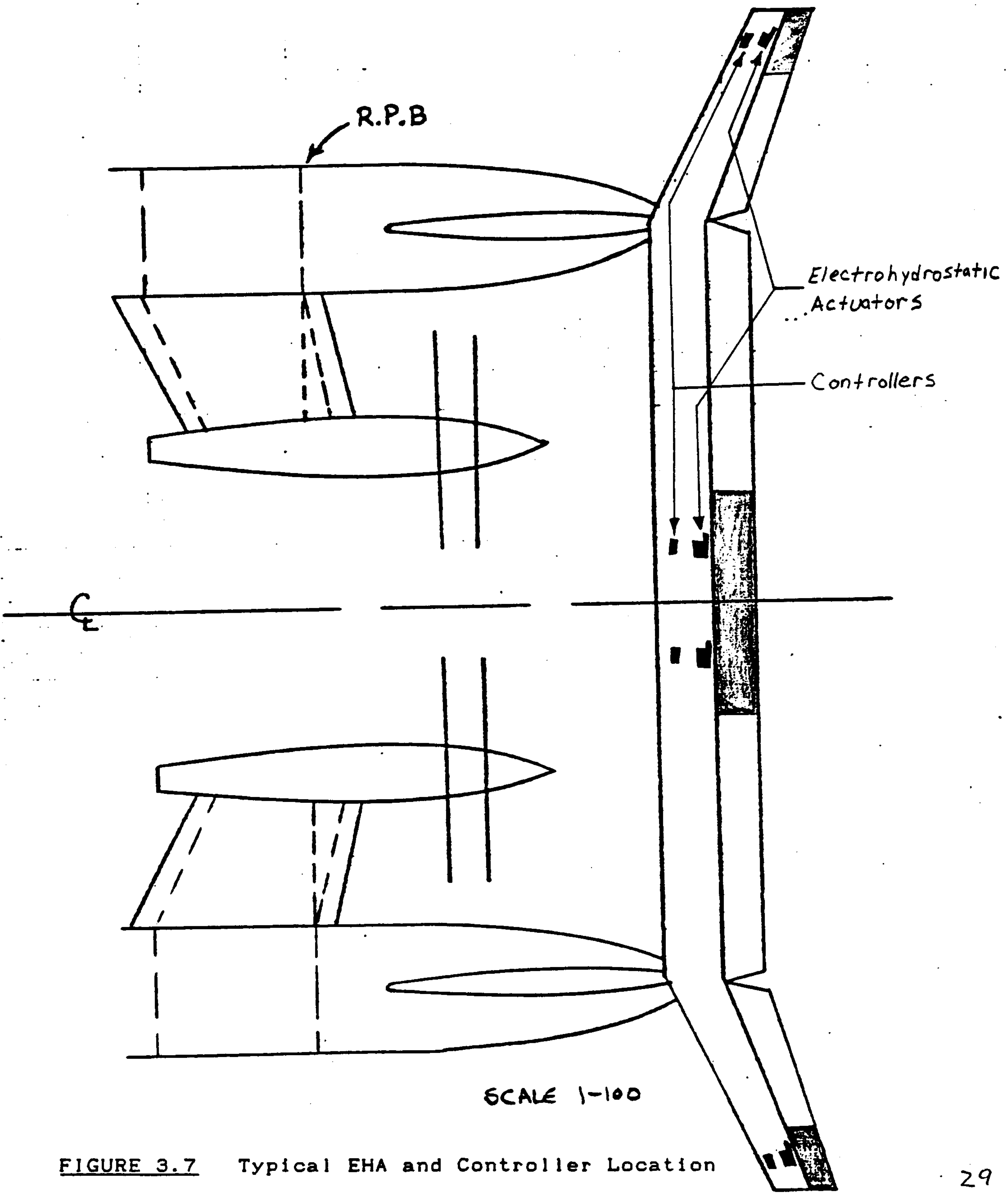
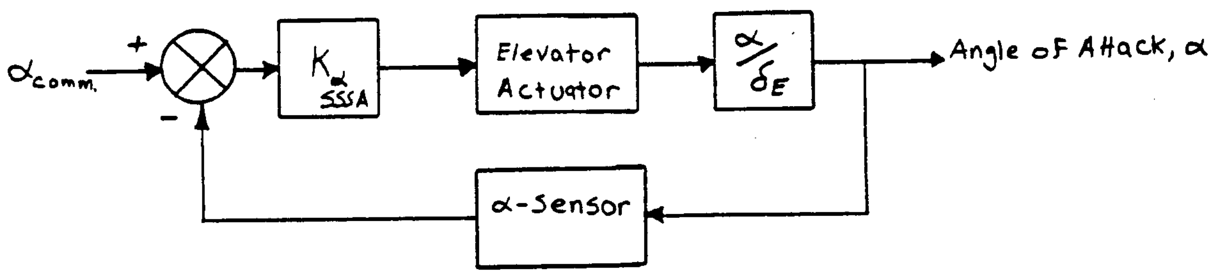
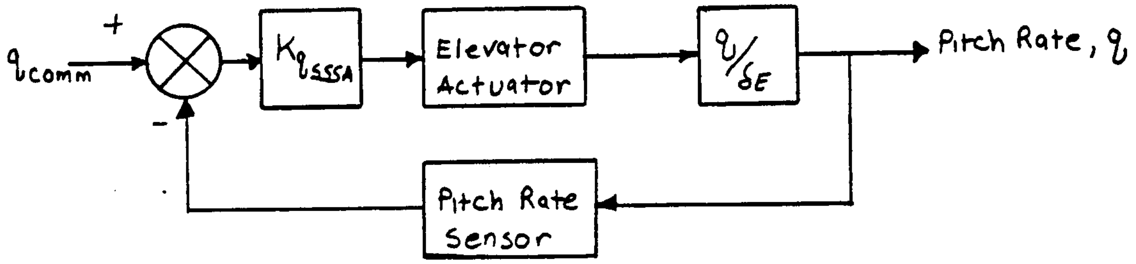


FIGURE 3.7 Typical EHA and Controller Location For SSSA System



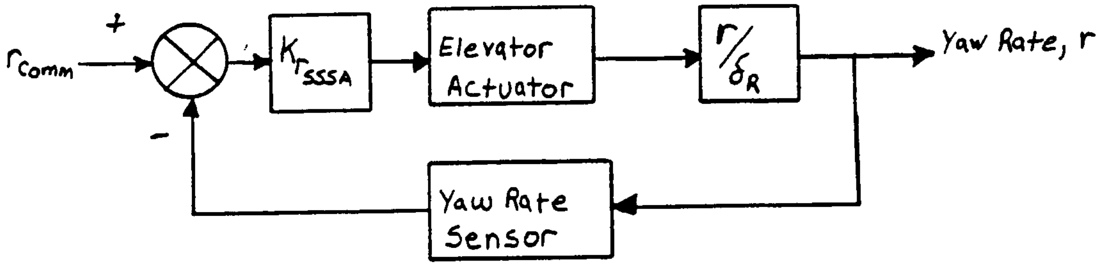
Where $K_{\alpha_{SSSA}}$ Follows The Gain Schedule depicted in Figure 2.6

FIGURE 3.8 SSSA Angle of Attack Compensator



Where $K_{q_{SSSA}}$ Follows the Gain Schedule depicted in Figure 2.7

FIGURE 3.9 SSSA Pitch Damper



Where $K_{r_{SSSA}}$ Follows the Gain Schedule depicted in Figure 2.10

FIGURE 3.10 SSSA Yaw Damper

4. CONCLUSIONS AND RECOMMENDATIONS

The purpose of this report was to present the results of a design study for implementing a flight controller and achieving handling quality commonality by Separate Surface Stability Augmentation for a Family of Commuter Airplanes. Stability

4.1 Conclusions

Stability augmentation by independently controlled surfaces is a feasible manner to achieve Level I handling qualities and to tailor the performance of each airplane to achieve common handling qualities throughout the Family of Commuter Airplanes. It was also demonstrated that this system was robust, for the most critical airplane and flight condition it can safely handle gusts up to thunderstorm intensity.

This form of stability and performance augmentation is a unique method to achieve commonality on a system and personnel level throughout the Family. Variations of the gain schedule allows for the use of common control surface sizes and common handling qualities allows for cross-certification of flight crews throughout the Family of Airplane. Acquisition and design costs are decreased due to the design flexibility allowed by a system driven by electric signals. These costs are further decreased due to the use of Electrohydrostatic actuators, which eliminate the need for a central hydraulics system and the complex tubing a central hydraulics system would require. Maintenance costs are also decreased as each surface is driven by a common actuator that is a self-contained unit.

4.2 Recommendations

While this designer believes that the results and conclusions reached through this study generally indicated the feasibility and advantages that use of a Separate Surface Stability Augmentation system could gain in terms of system, personnel and handling quality commonality, some recommendations for future consideration are in order.

1) A detailed analysis of the control forces required to drive the larger control surfaces would be required to ascertain whether these surfaces would need a disproportionate number of EHA's.
2) Tests would be needed to ensure that the primary control surfaces have enough control power to maintain acceptable handling qualities in the event of a hard-over system failure in any of the modes augmented.
3) A more detailed analysis could be done to augment for a common Dutch-roll frequency in addition to the common Dutch-roll damping achieved in this study.
4) A more advanced study using all six degrees of freedom rather than the approximations used in this study would provide definitive conclusions concerning the feasibility and advantages of using this form of stability augmentation and handling characteristics tailoring.
5) Pilot reactions to the roll mode will be needed to determine if a roll damper will be required to drive these characteristics to a closer level of commonality. In particular, the pilot's perception of the differences in Lateral acceleration in the roll mode between the single body airplanes and the twin-body airplanes will be required.

5. REFERENCES

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APPENDIX A: SEPARATE SURFACE CALCULATIONS FOR LONGITUDINAL DYNAMICS

The purpose of this Appendix is to present a summary of the method and results used to determine the elevator area and gain requirements for a SSSA system to achieve the commonality design goals.

A.1 Angle of Attack and Pitch Rate Gain Requirements

From Section 6.2.3 of Reference 13, the 2-Dimensional short period approximation was found to be:

$$\omega n_{sp} = Z\alpha \, Mq \,/\, U1 - M\alpha \qquad (A.1)$$

$$\zeta_{sp} = -(Mq + Z\alpha/U1 + M\alpha) \,/\, 2\omega n_{sp} \qquad (A.2)$$

Where $M\alpha$ is the dominant term for short period frequency and Mq is the dominant term for short period damping.

From Table 6.3 of Reference 13,

$$M\alpha = \bar{q} \; S \; \bar{c} \; Cm\alpha \,/\, Iyy \; (sec^{-2}) \qquad (A.3)$$

$$Mq = \bar{q} \; S \; \bar{c}^2 \; Cmq \,/\, 2 \; Iyy \; U1 \; (sec^{-1}) \qquad (A.4)$$

The relationships for angle of attack and pitch rate gains were found in Reference 13 to be:

$$K\alpha = \Delta Cm\alpha \,/\, Cm\delta E \qquad (A.5)$$

$$Kq = (\Delta Cmq \,/\, Cm\delta E) \; \bar{c}/2U1 \qquad (A.6)$$

where $Cm\alpha$ was determined as:

$$\Delta Cm\alpha_{des} = [Z\alpha Mq/U1 - (\Delta\omega n_{sp})^2] \,/\, (\bar{q} \; S \; \bar{c}/Iyy) \qquad (A.7)$$

where $\Delta\omega n_{sp} = \omega n_{spdes} - \omega n_{spbasic}$

and

$$\Delta Cmq_{des} = -[2IyyU1/\bar{q} \; S \; \bar{c}^2](2\omega n_{sp}\Delta\zeta_{sp} + Z\alpha/U1 + M\alpha) \qquad (A.8)$$

where $\Delta\zeta_{sp} = \zeta_{spdes} - \zeta_{spbasic}$

The inter-related nature of ωn_{sp} and ζ_{sp} when either is modified was ignored for simplicity of the model.

These gains were calculated based upon the normal control surface sizes and must be multiplied to account for the ratio of Separate Surface sizes to the primary control surface sizes.

A.2 SSSA Longitudinal Surface Sizing Requirements

The minimum required surface areas were determined for one percent probability and thunderstorm gusts. Using the VonKarman scales in Section 9.8.1 of Reference 14, the root-mean-square gust intensity and the resulting change in angle of attack due to gust perturbation were determined to be:

TABLE A.1: Longitudinal Gust and Perturbations

	Clear Air		Thunderstorm	
	Cruise	Min.Control*	Cruise	Min.Control*
σ_w, (fps)	4.6	6.6	21	21
α_{gust}, (rad)	.0066	.0318	.0302	.1012

* At 500 ft. altitude

It is obvious that the critical flight condition that will size the surface required for the SSSA system is for a thunderstorm gust at min. control speed. The required elevator area was determined according to the method of balancing moments in the longitudinal axis as presented in Section 6.6.5 of Reference 13.

$$Cm\alpha\ \Delta\alpha_{gust} = Cm\delta E\ \ \Delta\,\delta E \qquad (A.9)$$

where: $\Delta\delta Emax = \pm\ 20$ deg.

$$Cm\alpha = Cm\alpha_{basic} + Cm\alpha_{des}$$

From Reference 13, Section 4.1.4, the relationship of the elevator to the affected horizontal tail area was determined to be:

$$Cm\delta E = -CL\alpha H\ \eta_H\ Sh/S\ (\bar{X}ach - \bar{X}cg)\ \tau_\epsilon \qquad (A.10)$$

From this, it is obvious that the percentage of required elevator area that must be dedicated to SSSA is:

$$\text{Percent } S_E = -(\ Cm\delta E_{req})(Sh/S)/[(\bar{X}ach-\bar{X}cg)(CL\alpha H)(\eta_H)(\tau_\epsilon)] \qquad (A.11)$$

where: $Cm\delta E_{req} = Cm\alpha(\Delta\alpha_{gust}/\Delta\delta E)$

For a chosen elevator size for the SSSA control surface, the maximum gust intensity that the system can overcome was found as:

$$\sigma_{wMax} = U1(\Delta\delta Emax/\Delta Cm\alpha_{req})(-CL\alpha H)\eta_{H}(Sh/S)(\bar{X}acH-\bar{X}cg)\tau_{\epsilon} \quad (A.21)$$

From these relationships, a spreadsheet analysis was defined to show simultaneously the effect of design choices on the requirements for all of the airplanes. This facilitated the trade study shown in Section 2.1 of this report, from which the design point was chosen. A sample spreadsheet is presented for the design point at the critical min. control speed in Table A.2.

TABLE A.2 Sample Spreadsheet for Longitudinal Dynamics

MIN. CONTROL Gust=21 fps	25-Fore	25-Aft	36-Fore	36-Aft	50-Fore	50-Aft	75-Fore	75-Aft	100-Fore	100-Aft
Z-alpha	-223.3370	-236.3080	-182.1430	-193.3620	-128.0730	-212.6880	-179.7080	-286.4610	-148.2900	-248.9080
M-q	-.8800	-.8750	-.6130	-.6480	-.4810	-.5330	-1.1890	-1.2420	-1.0560	-1.1600
U-1	207.5000	207.5000	207.5000	207.5000	207.5000	207.5000	207.5000	207.5000	207.5000	207.5000
Wn.sp.des	1.8500	1.8500	1.8500	1.8500	1.8500	1.8500	1.8500	1.8500	1.8500	1.8500
Wn.sp.basic	1.7920	1.4130	1.3960	1.1720	.8300	.8740	1.5890	1.4400	1.4940	1.5390
D.Wn.sp	.0580	.4370	.4540	.6780	1.0200	.9760	.2610	.4100	.3560	.3110
q.bar	51.1700	51.1700	51.1700	51.1700	51.1700	51.1700	51.1700	51.1700	51.1700	51.1700
Sh	120.0000	120.0000	120.0000	120.0000	120.0000	120.0000	410.0000	410.0000	410.0000	410.0000
S	592.0000	592.0000	592.0000	592.0000	592.0000	592.0000	1182.0000	1182.0000	1182.0000	1182.0000
C-bar	7.4500	7.4500	7.4500	7.4500	7.4500	7.4500	8.9700	8.9700	8.9700	8.9700
Iyy	130433.0000	122535.0000	235569.0000	209114.0000	465510.0000	408670.0000	505979.0000	440988.0000	771875.0000	655374.0000
Cm.dE.avail	-1.7360	-1.6780	-1.9400	-1.8820	-2.3890	-2.3570	-3.4150	-3.2600	-3.9740	-3.8410
M.alpha.dot	-.2030	-.2020	-.1400	-.1490	-.1080	-.1200	-.2310	-.2410	-.2030	-.2240
Cm.a.basic	-1.3080	-.5430	-1.4720	-.7120	-.8080	-.3950	-1.3940	-.2920	-2.1310	-1.1880
d.Cm.a.des	.5455	.4374	.3465	.1336	-1.5337	-.7357	.8968	1.2571	.8934	1.5641
K-a	-.3142	-.2607	-.1786	-.0710	.6420	.3121	-.2626	-.3856	-.2248	-.4072
d.Cm.a.req	-.7625	-.1056	-1.1255	-.5784	-2.3417	-1.1307	-.4972	.9651	-1.2376	.3761
Zeta.sp.des	.5000	.5000	.5000	.5000	.5000	.5000	.5000	.5000	.5000	.5000
Zeta.sp.res	.3599	.3693	.2718	.2881	.2010	.2797	.3810	.4773	.3289	.4306
D.Zeta.sp	.1401	.1307	.2282	.2119	.2990	.2203	.1190	.0227	.1711	.0694
D.Cmq.des	14.1246	16.8356	-20.4325	-9.8346	-122.8050	-17.8339	16.5285	55.8575	-7.1714	56.2881
K-q	-.1461	-.1801	.1391	.0938	.9228	.1358	-.1046	-.3703	.0390	-.3168
Gust Speed	21.0000	21.0000	21.0000	21.0000	21.0000	21.0000	21.0000	21.0000	21.0000	21.0000
D.a.gust-rad	.1012	.1012	.1012	.1012	.1012	.1012	.1012	.1012	.1012	.1012
D.de.max-deg	20.0000	20.0000	20.0000	20.0000	20.0000	20.0000	20.0000	20.0000	20.0000	20.0000
D.ag/dE.max	.2899	.2899	.2899	.2899	.2899	.2899	.2899	.2899	.2899	.2899
D.Cm.dE.req	-.2210	-.0306	-.3263	-.1677	-.6789	-.3278	-.1441	.2798	-.3588	.1090
Xach.bar	4.1500	4.1500	4.6760	4.6760	6.0400	6.0400	4.2930	4.2530	4.9420	4.9420
Xcg.bar	.1450	.2800	.2010	.3350	.5300	.6030	.6020	.7690	.6590	.8020
Xach-XcgBar	4.0050	3.8700	4.4750	4.3410	5.5100	5.4370	3.6810	3.5140	4.2830	4.1400
CL.alpha.H	3.9610	3.9610	3.9610	3.9610	3.9610	3.9610	4.9530	4.9530	4.9530	4.9530
Tau.E	.5400	.5400	.5400	.5400	.5400	.5400	.5400	.5400	.5400	.5400
D.Sh.req	15.2726	2.1884	20.1812	10.6922	34.1018	16.6868	17.3003	-35.1685	37.0220	-11.6354
% Sh.req	12.7272	1.8237	16.8177	8.9102	28.4182	13.9057	4.2196	-8.5826	9.0298	-2.8379
Percent - Sh	30.0000	30.0000	30.0000	30.0000	30.0000	30.0000	30.0000	30.0000	30.0000	30.0000
Sh - max	36.0000	36.0000	36.0000	36.0000	36.0000	36.0000	123.0000	123.0000	123.0000	123.0000
Gust - Max	49.4843	345.2642	37.4586	70.7076	22.1679	45.3019	149.2483	-73.4014	69.7658	-221.9074

APPENDIX B: SSSA CALCULATIONS FOR LATERAL-DIRECTIONAL DYNAMICS

The purpose of this Appendix is to present a summary of the method and results used to determine the rudder area and gain requirements for a SSSA system to achieve the commonality design goals.

B.1 Yaw Rate Gain Requirements

From Section 6.3.5 of Reference 13, the Dutch Roll approximation for Lateral-Directional dynamic stability was found to be:

$$\omega_{n_D} = \sqrt{1/U1\ (Y_\beta Nr + N_\beta U1 - N_\beta Yr)} \qquad (B.1)$$

$$\zeta_D = -1/2\omega_{n_D}\ (Nr + Y_\beta U1) \qquad (B.2)$$

Because of the inter-related nature of the Dutch roll damping and frequency and the rather common usage of yaw rate sensors, it was decided to choose a design damping ratio and to allow the Dutch roll frequency to result from the nature of the equations.

With the yaw rate as the measured quantity, its relationship to Dutch roll damping and frequency through the dimensional derivative, Nr, was found in Table 6.8 of Reference 13 to be:

$$Nr = \bar{q}\ S\ b^2\ Cnr\ /\ 2\ Izz\ U1 \qquad (B.3)$$

The relationship for the yaw rate gain was found in Reference 13 to be:

$$Kr = (\Delta Cnr\ /\ Cn_{\delta R})\ (b\ /\ 2\ U1) \qquad (B.4)$$

where: $\Delta Cnr = -2\ Izz\ U1/\bar{q}\ S\ b^2(2\omega_{n_D}\Delta\zeta_D + Y_\beta/U1)$ (B.5)

where: $\Delta\zeta_D = \zeta_{Ddesign} - \zeta_{Dbasic}$

This gain was calculated based upon the normal control surface sizes and must be multiplied to account for the ratio of the Separate Surface size to the primary control surface size.

The change in the dimensional derivative, Nr, required a recalculation of the resulting Dutch roll frequency by Equation (B.1). The relationships of $_D$, n_D and $_D$ n_D were then checked to insure all airplanes met Level I handling requirements at all flight conditions and C.G. locations for the chosen design point.

B.2 SSSA Lateral-Directional Surface Sizing Requirements

The minimum required surface area for the rudder was determined for one percent probability and thunderstorm gusts. Using the VonKarman scales of Section 9.8.1 of Reference 14, the root-mean-square gust intensity and the resulting change in sideslip due to gust perturbation was found to be:

TABLE B.1 Lateral-Directional Gusts and Perturbations

	Clear Air		Thunderstorm	
	Cruise	Min.Control*	Cruise	Min.Control*
σ_v, (fps)	4.6	8.71	21	21
β_{gust}, (rad)	.0066	.0419	.0302	.1012

* at 500 ft. altitude

It is obvious that the critical flight condition that will size the surface required for the SSSA system is for a thunderstorm gust at min. control speed. The required rudder area was determined according to the method of balancing moments in the Lateral-directional axis.

$$Cn_\beta \, \Delta\beta_{gust} = Cn_{\delta R} \, \Delta \, \delta R_{max} \qquad \text{(B.6)}$$

or

$$Cn_{\delta R} = Cn_\beta \, (\Delta\beta_{gust} \, / \, \Delta \, \delta R_{max})$$

where: $\Delta\delta R_{max} = \pm 40$ deg

From Reference 15, Sections 12.1 and 12.3, the relationship of the rudder to the affected vertical tail area was determined to be:

$$Cn_{\delta R} = -(Cy_{\delta R_{basic}}/Sv_{basic})\Delta Sv(Lv\cos\alpha + Zv\sin\alpha/b) \qquad (B.7)$$

From this it is obvious that the percentage of the required rudder area that must be dedicated to SSSA is:

$$\%\ SR = (-1/Cy_{\delta R_{basic}})(b/Lv\cos\alpha + Zv\sin\alpha)(Cn_{\beta}\Delta\beta_{gust}/\Delta\delta R_{max}) \qquad (B.8)$$

For a chosen rudder size for the SSSA control surface, the maximum gust intensity that the system can overcome was found as: (B.9)

$$\sigma_{vmax} = U1(\Delta\delta R_{max}/Cn_{\beta})(-Cy_{\delta R_{basic}}/Sv_{basic})(Sv)(Lv\cos\alpha + Zv\sin\alpha/b)$$

From these relationships, a spreadsheet analysis was defined to show simultaneously the effect of design choices on the requirements for all of the airplanes. A sample spreadsheet is presented for the design point at the critical min. control speed in Table B.2.

TABLE B.2 Sample Spreadsheet for Lateral-Directional Dynamics

MIN.CONTROL Lat-Direct	25 - Fore	25 - Aft	36 - Fore	36 - Aft	50 - Fore	50 - Aft	75 - Fore	75 - Aft	100 - Fore	100 - Aft
U-1	207.5000	207.5000	207.5000	207.5000	207.5000	207.5000	207.5000	207.5000	207.5000	207.5000
S	592.0000	592.0000	592.0000	592.0000	592.0000	592.0000	1182.0000	1182.0000	1182.0000	1182.0000
Sv	170.0000	170.0000	170.0000	170.0000	170.0000	170.0000	340.0000	340.0000	340.0000	340.0000
b	84.3000	84.3000	84.3000	84.3000	84.3000	84.3000	132.5000	132.5000	132.5000	132.5000
q.bar	51.1700	51.1700	51.1700	51.1700	51.1700	51.1700	51.1700	51.1700	51.1700	51.1700
Alpha(deg)	9.0000	9.0000	9.0000	9.0000	9.0000	9.0000	9.0000	9.0000	9.0000	9.0000
Lv,Zv,Alpha	23.9500	23.9500	28.3900	28.3900	37.4700	37.4700	26.8600	26.8600	34.8200	34.8200
Weight	24739.0000	23381.0000	30334.0000	28574.0000	43141.0000	25978.0000	71419.0000	44804.0000	85044.0000	50666.0000
m	768.2919	726.1180	942.0497	887.3913	1339.7826	806.7702	2217.9814	1391.4286	2641.1180	1573.4783
Izz	177066.0000	180634.0000	284424.0000	310361.0000	580046.0000	457113.0000	1779161.0000	1124871.0000	2328189.0000	1457505.0000
N.B.basic	1.4120	1.3840	1.6230	1.4870	1.2310	1.5620	.3210	.5070	.4060	.6490
N.r.basic	-.4480	-.4390	-.3910	-.3590	-.3340	-.4240	-.1120	-.1770	-.1430	-.2280
Y.B.basic	-48.5350	-51.3540	-39.5830	-42.0210	-27.8320	-46.2200	-29.7260	-47.3850	-24.5320	-41.1780
Y.r.basic	4.3040	4.5540	4.1600	4.4160	3.8600	6.4100	3.3430	5.3290	3.6080	6.0570
Cn.B.basic	.0980	.0980	.1810	.1810	.2800	.2800	.0710	.0710	.1200	.1200
Cn.r.basic	-.1530	-.1530	-.2150	-.2150	-.3740	-.3740	-.0780	-.0780	-.1310	-.1310
Cy.dR.basic	-.3240	-.3240	-.3240	-.3240	-.3240	-.3240	-.3240	-.3240	-.3240	-.3240
Cn.dR	.0920	.0920	.1090	.1090	.1440	.1440	.0660	.0660	.0850	.0850
Zeta.D.basic	.2790	.2840	.2260	.2270	.2090	.2550	.2220	.2770	.2030	.2600
Wn.D.basic	1.2200	1.2090	1.2900	1.2360	1.1190	1.2680	.5760	.7310	.6450	.8220
Zeta.D*Wn.D	.3404	.3434	.2915	.2806	.2339	.3233	.1279	.2025	.1309	.2137
Basic Class One Qualities										
Zeta.D - min	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
Wn.D - min	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
Zeta*Wn.D-min	yes	yes	yes	yes	yes	yes	no	yes	no	yes
Zeta.D.des	.2900	.2900	.2900	.2900	.2900	.2900	.2900	.2900	.2900	.2900
d.Zeta.D	.0110	.0060	.0640	.0630	.0810	.0350	.0680	.0130	.0870	.0300
d.Cn.r	.0707	.0811	.0141	.0280	-.0527	.1181	.0451	.0920	.0055	.0849
N.r.result	-.2412	-.2064	-.3665	-.3126	-.3816	-.2904	-.0473	.0319	-.1380	-.0808
Kr	.1561	.1791	.0262	.0522	-.0744	.1666	.2184	.4452	.0205	.3191
Zeta.D.des	.2900	.2900	.2900	.2900	.2900	.2900	.2900	.2900	.2900	.2900
Wn.D.cc	1.1996	1.1852	1.2886	1.2323	1.1222	1.2564	.5680	.6976	.6444	.8038
Zeta.D*Wn.D	.3479	.3437	.3737	.3574	.3254	.3643	.1647	.2023	.1869	.2331
SAS - Class One Qualities										
Zeta.D - min	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
Wn.D - min	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
Zeta*Wn.D-min	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
Gust Response										
Gust Speed	21.0000	21.0000	21.0000	21.0000	21.0000	21.0000	21.0000	21.0000	21.0000	21.0000
d.B.gust-rad	.1012	.1012	.1012	.1012	.1012	.1012	.1012	.1012	.1012	.1012
D.dR.max-deg	40.0000	40.0000	40.0000	40.0000	40.0000	40.0000	40.0000	40.0000	40.0000	40.0000
D.Sv.req	26.2371	26.2371	40.8798	40.8798	47.9148	47.9148	53.2803	53.2803	69.4651	69.4651
Percent - Sv	30.0000	30.0000	30.0000	30.0000	30.0000	30.0000	30.0000	30.0000	30.0000	30.0000
Sv.max	51.0000	51.0000	51.0000	51.0000	51.0000	51.0000	102.0000	102.0000	102.0000	102.0000
Gust - max	40.8200	40.8200	26.1988	26.1988	22.3522	22.3522	40.2025	40.2025	30.8356	30.8356

APPENDIX C: CALCULATIONS FOR ROLL MODE DYNAMICS

The purpose of this Appendix is to present a summary of the method and results used to determine the aileron area and gain requirements for a SSSA system to achieve the commonality design goals.

From Section 6.6.3 of Reference 13, the Rolling approximation was found to be:

$$T_R = -1 / Lp \qquad (C.1)$$

And,

$$Phi(t) = -L_{\delta A}\ \delta A/Lp\ t + L_{\delta A}\ \delta A/Lp^2\ (e^{Lpt} - 1) \qquad (C.2)$$

The roll rate and the roll acceleration were also calculated for all airplanes, and the lateral acceleration for the twin-bodies was determined.

$$P(t) = -L_{\delta A}\ \delta A/Lp\ (1 - e^{Lpt}) \qquad (C.3)$$

$$P.dot(t) = L_{\delta A}\ \delta A\ e^{Lpt} \qquad (C.4)$$

and the lateral acceleration was:

$$Lat.acc = (y)[P.dot(t)] \qquad (C.5)$$

where y = fuselage distance from Centerline

y = 289 in.

Due to the nearness of the grouping of time constants and roll rates within each group of similar planform, and the magnitude that these values exceeded the minimum Level I requirements, and augmentation system was not designed for the Roll mode.

These calculations were made in a spreadsheet analysis. A sample spreadsheet demonstrating Level I requirements is demonstrated in Table C.1.

TABLE C.1 Sample Spreadsheet for Roll Mode Dynamics

ROLL MODE

CRUISE *	25-Fore	25-Aft	36-Fore	36-Aft	50-Fore	50-Aft	75-Fore	75-Aft	100-Fore	100-Aft
Lp	-6.9196	-4.5205	-6.5766	-3.7529	-3.2809	-6.3444	-1.8765	-3.3409	-1.5435	-2.8611
L.da	88.4574	57.788	84.0728	47.976	41.9419	81.1047	15.1456	26.9658	12.4659	23.1075
da (deg)	5	5	5	5	5	5	5	5	5	5
Time(sec)	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9
Phi (deg)	112.2070	107.3068	111.7255	104.4271	102.0010	111.3701	55.7787	64.6199	51.9564	62.6734
Level One	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
P (rad/sec)	1.1155	1.1153	1.1155	1.1146	1.1133	1.1155	.6844	.7031	.6672	.7017
P.dot	.00002	.00094	.00003	.00335	.00718	.00004	.03738	.00412	.05793	.00878
Lat Accel (ft/sec^2)							.9003	.0992	1.3952	.2116

APPROACH *	25-Fore	25-Aft	36-Fore	36-Aft	50-Fore	50-Aft	75-Fore	75-Aft	100-Fore	100-Aft
Lp	-4.4867	-2.9311	-4.2643	-2.4334	-2.1274	-4.1138	-1.1936	-2.125	-.9816	-1.8196
L.da	17.2738	11.2847	16.4176	9.3687	8.1903	15.838	2.6191	4.6632	2.1557	3.996
da (deg)	10	10	10	10	10	10	15	15	15	15
Time	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8
Phi (deg)	60.7218	56.2320	60.2759	53.6773	51.5947	59.9465	34.8871	44.0978	31.4699	41.8752
Level One	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
P (rad/sec)	.6717	.6685	.6716	.6635	.6573	.6715	.5074	.5619	.4767	.5532
P.dot	.00094	.01007	.00133	.02048	.03105	.00168	.07999	.02663	.09642	.03955
Lat Accel (ft/sec^2)							1.9263	.6414	2.3222	.9525