 1F

SERVO/SURFACE ACTUATOR

CONFIGURATION STUDY

I. PREMISES OF STUDY

A. Three Axis Stability Augmentation is required to fly the vehicle during most if not all of its mission.

B. It is desirable to stay within the state of the art and use proven techniques wherever possible consonant with other requirements.

C. The following trade-off criteria has been considered as a guide:

Performance	15
Failsafety	20
Mission Success	30
Maintainability	5
Cost	10
Weight	20
	100

II. GROSS CONSIDERATIONS

A. Side Electric Stick vs. Side Electric Stick plus Mechanical Back-Up

1. The airframe has stated that the vehicle must have a fail-operational SAS because SAS is needed in order for the pilot to be able to control the vehicle over a large portion of its mission.

2. This being the case, it becomes hard to justify a mechanical back-up system since the mechanical back-up can not be used (PREMISE A) without SAS, and:

a. 150 - 250 pounds of weight could be eliminated.

b. Trim wheels and triple pick-offs replace non-redundant bulky trim actuators.

c. The X-20 did not have a manual mechanical system.

d. The YF-12 SAS has been more reliable in actual usage than the manual control system.

e. We can eliminate linkage problems associated with cockpit raising.

f. Gear shifts, mixers, etc., can be eliminated.

B. Parallel vs. Series Servos

1. If we use a parallel servo, it must be located near the cockpit so that its disengaged friction will not adversely affect the break-out force of the center stick. This then means a long cable run aft to the surfaces. This in turn will result in additional undesirable non-linear dynamics between the SAS and the surface. This could result in additional surface activity and vehicle motion which is undesirable considering the type of payload.

2. In addition, using only a parallel servo will result in short period damping corrections being reflected at the center stick.

3. Operation of the triple Stability Augmentation System through a single mechanical system control linkages, gear shift and mixer not only degrades the probability of mission success to some extent but makes it possible for a single failure in the mechanical back-up to be catastrophic.

C. Electronic vs. Hydraulic Voting of Servos

The YF-12 and the SR71 use electronic majority voting of redundant servos based on servo position. This scheme is fail operational for first failure and failsafe for a second failure with pilot option for re-cycling. There has not been a "system" failure to date with this system in thousands of flight hours.

C. (cont'd)

The F-111 uses a detection-correction scheme of hydraulic voting as contrasted to hydraulic majority voting. Although this scheme does not offer as good a reliability as a hydraulic majority voting scheme, it weighs less and may offer pilot indication in a simple manner.

Inherently, the hydraulic scheme has the advantage of less dynamic lag in the voting because it doesn't need to wait for the output ram to integrate into position. However, in the electronic scheme of voting there is more flexibility in the adjustment of allowable system errors and thus the capability of adjusting the system optimumly between nuisance disengage and failsafe operation limits to achieve effective operation.

If electric pick-offs (LDVT's) are to be used on the servos regardless of whether hydraulic or electronic voting is used, then the electronic voting will weight considerably less. If mechanical feedback is used, there will still be a slight weight advantage with electronic servo voting.

The electronic (solid state) voting is subject to random failures as is the hydro-mechanical voting. However, the hydro-mechanical voting is also subject to wear which will require much more maintenance to keep the system in a ready status.

III. CONCLUSIONS DRAWN FROM GROSS CONSIDERATIONS

- A triple redundant electronic system should be employed without mechanical back-up.
- If a mechanical back-up were to be used, series servos located as far aft as possible are preferable to parallel servos located near the cockpit.
- Electronic Servo voting is probably more advantageous than hydro-mechanical voting, but final selection need be made for a specific servo/surface actuator combination.

IV. SERVO/SURFACE ACTUATOR CONFIGURATIONS CONSIDERED IN DETAIL STUDY

A. Present System

Figure 1 shows a simplified block diagram of the present system. This system has a manual back-up system. Three multiple input parallel servos are located close to the cockpit and provide for all SAS and Autopilot Inputs.

B. System "A"

System A shown in the block diagram form in Figure 2 uses one multiple input valve dual ram servo in each of the three major axes. The center stick, cockpit linkage extender, trim actuators and the bulk of the control system linkages would be deleted. The servos would be located in the aft portion of the vehicle. The mixer and the gear shifter (elevon/elevator and pitch gimble) would be retained. Trim would be accomplished in the triple electronics.

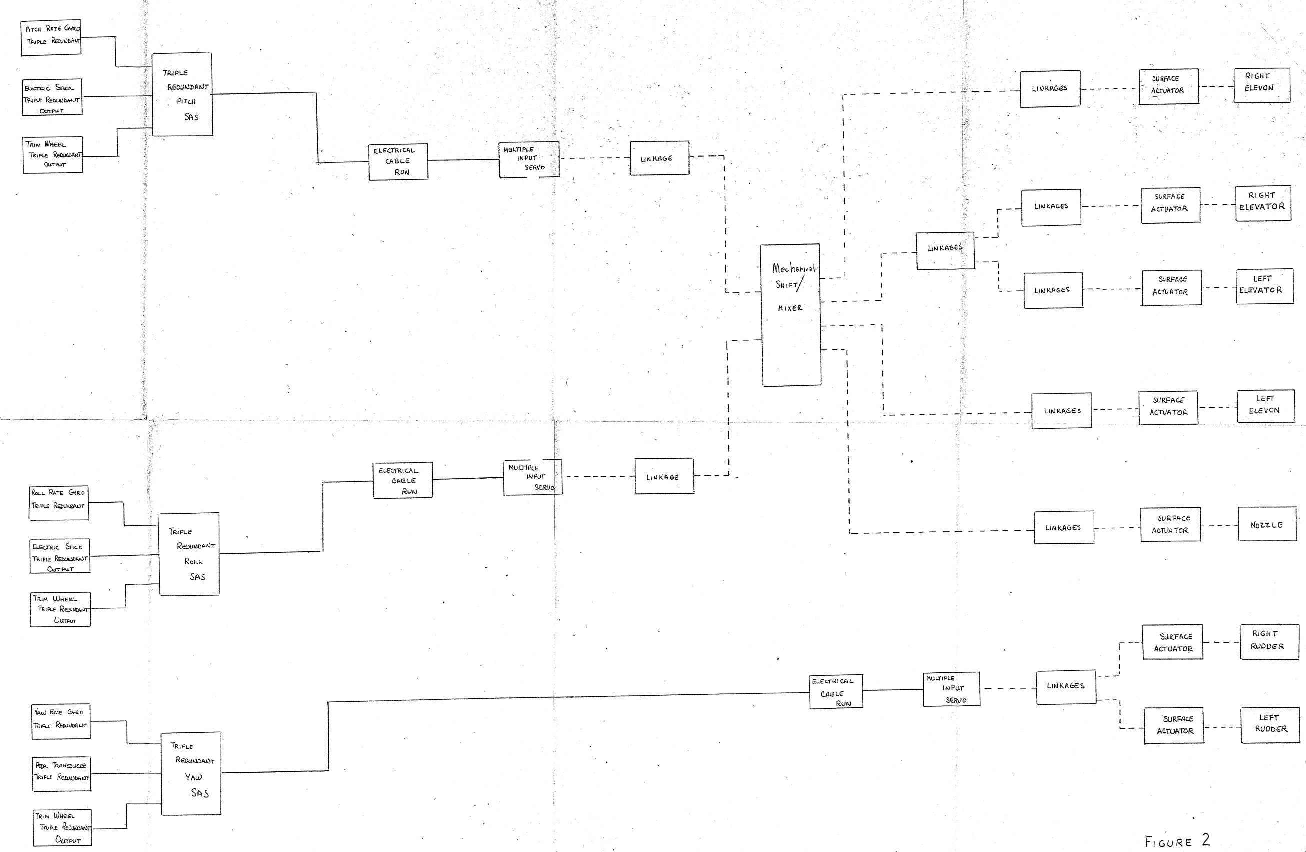

Figure 2

Proposed Configuration A

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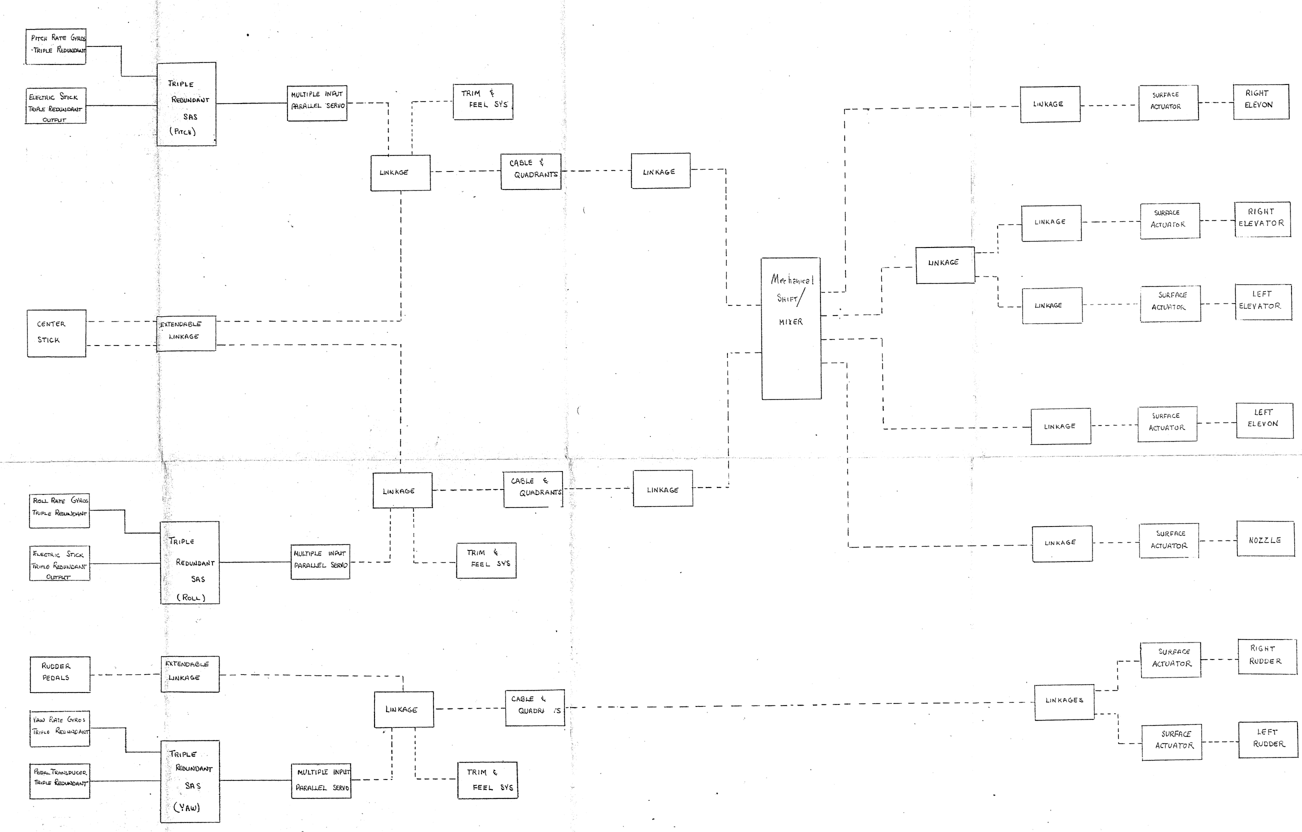


FIGURE 1
PRESENT CONFIGURATION

C. System B

System B is shown in the block diagram of Figure 3. System B uses one multiple input valve directly on each of the seven surface actuators. The center stick, cockpit linkage extender, trim actuators, mixer, gear shifter and all of the mechanical control system linkages would be removed. Mixing, shifting, and trim would be accomplished in the triple redundant electronics.

D. System C

System C is shown in the block diagram of Figure 4. System C is configured as follows:

1. One multiple input servo drives both rudder surface actuators.
2. One multiple input servo drives each elevon actuator.
3. One multiple input servo drives both elevator actuators.
4. One multiple input servo drives the gimbled engine nozzle.

The center stick, cockpit linkage extender, trim actuator, mixer, gear shifter and nearly all of the control linkages are removed. Only the short linkages between servo and its associated actuators remain. All mixing, shifting, and trim would be accomplished in the triple redundant electronics.

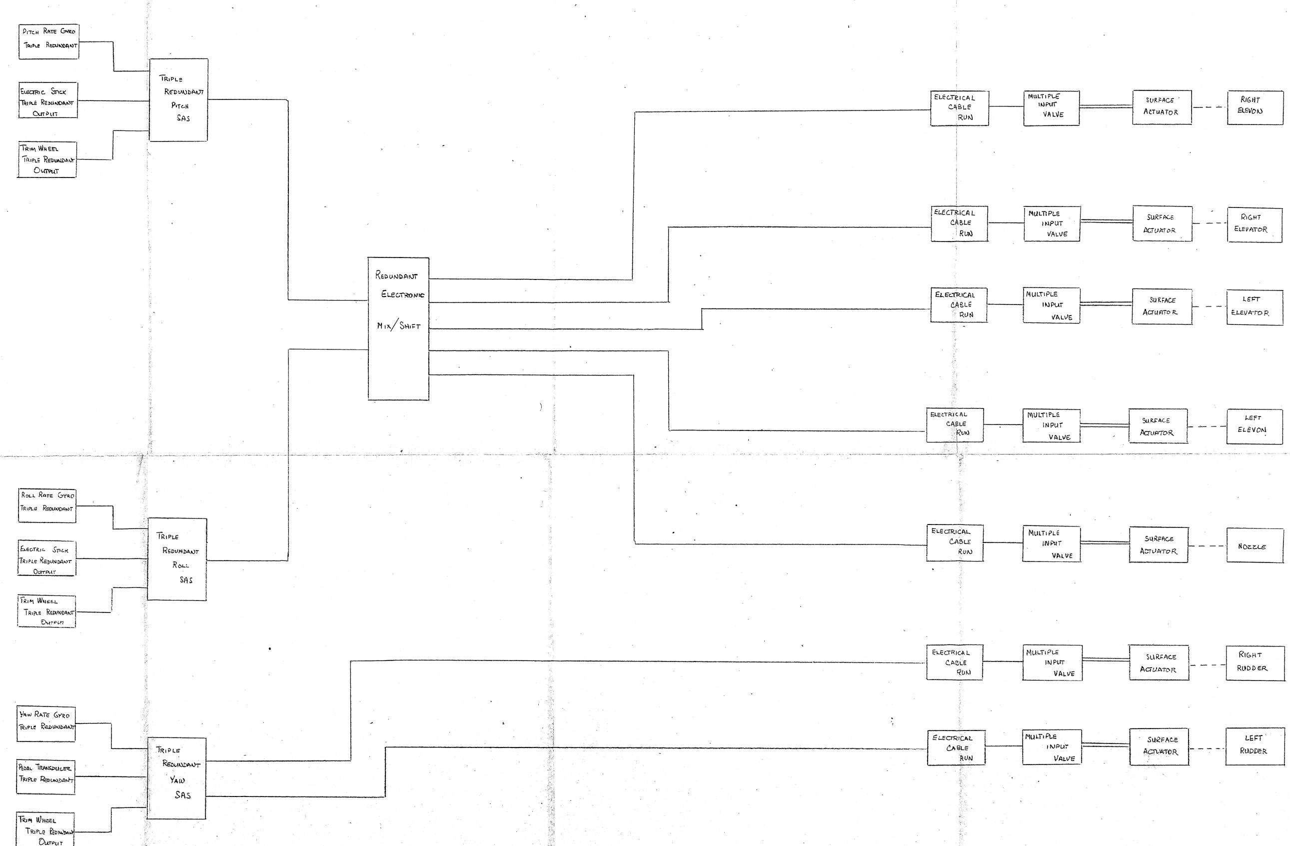


FIGURE 3
PROPOSED CONFIGURATION B

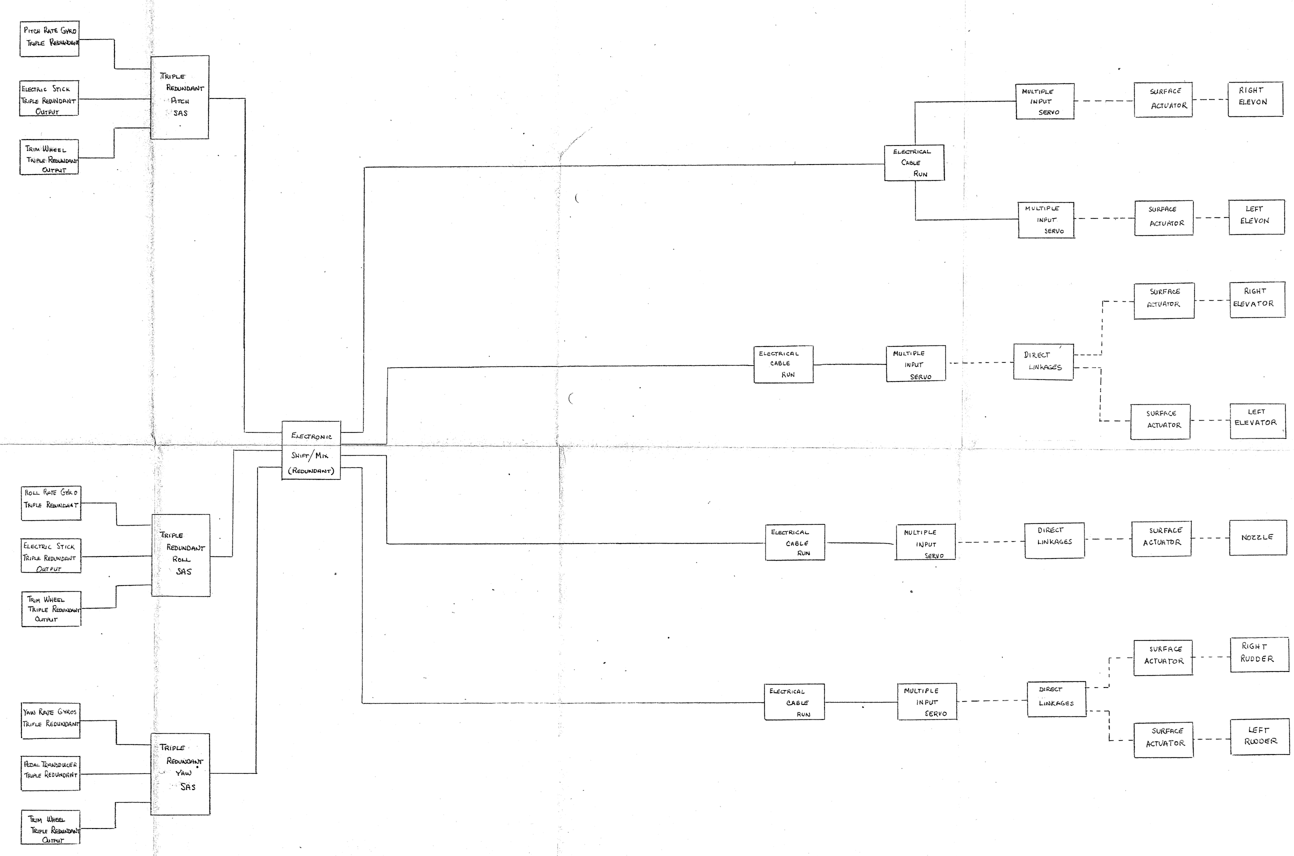


Figure 4
Proposed Configuration C

V. EVALUATION OF SYSTEM WEIGHT AND RELIABILITY

The Table below presents a tabulation of the system relative weights and reliability for the four system configurations being considered.

TABLE I

	Present System	Proposed Systems		
		A	B	C
Weight	377 #	224 #	127 #	163 #
Probability of Success for a one hour mission	0.999962	0.999968	0.999966	0.999961
Mean Time Between Failure	26,196 hrs.	31,188 hrs.	29,766 hrs.	25,345 hrs.

It is to be noted that all of the proposed systems weigh less than the present system (from 150 to 250 pounds less) and are at least comparable in reliability.

Table II gives a detail breakdown of the weight estimates used at arriving at these system weights. Conservative figures have been used so that even more weight savings are likely.

Figures 5 through 8 inclusive show the reliability models for each of the systems under consideration.

TABLE II
RELATIVE WEIGHT COMPARISON

UNIT DESCRIPTION	PER UNIT WEIGHT	PRESENT CONFIGURATION		CONFIGURATION A		CONFIGURATION B		CONFIGURATION C	
		Am't Used	Weight	Am't Used	Weight	Am't Used	Weight	Am't Used	Weight
1. Multiple Input Servo	14 lbs.	3	42 lbs	3	42 lbs	N/A	–	5	70 lbs
2. Multiple Input Valve	10 lbs	N/A	–	N/A	–	7	70 lbs	N/A	–
3. Trim & Feel System	14 lbs	3	42 lbs	Not Used	–	Not Used		Not Used	–
4. Mechanical Cable Run (1)	3/8 lb/ft	180 ft	67 lbs	Not Used	–	Not Used		Not Used	–
5. Electrical Cable Run (2)	1/8 lb/ft	Not Used	–	180 ft	22 lbs	420 ft	52 lbs	300 ft	37 lbs
6. Center Stick	7 lbs	1	7 lbs	Not Used	–	Not Used	–	Not Used	–
7. Linkage Extender	5 lbs	3	15 lbs	Not Used	–	Not Used	–	Not Used	–
8. Shift / Mix	80 lbs	1	80 lbs	1	80 lbs	Not Used	–	Not Used	–
9. SAS Additions (3)	2½ lb/unit	N/A	–	N/A	–	2	5 lbs	1	2 lbs
10. Linkages (4)	6 lbs/unit	19	114 lbs	15	90 lbs	Not Used	–	9	54 lbs
11. Other	–	Same weight is applicable to all configurations							
	TOTALS		367 lbs		234 lbs		127 lbs		163 lbs

(1) Includes quadrants, tension springs etc averaged over cable run length

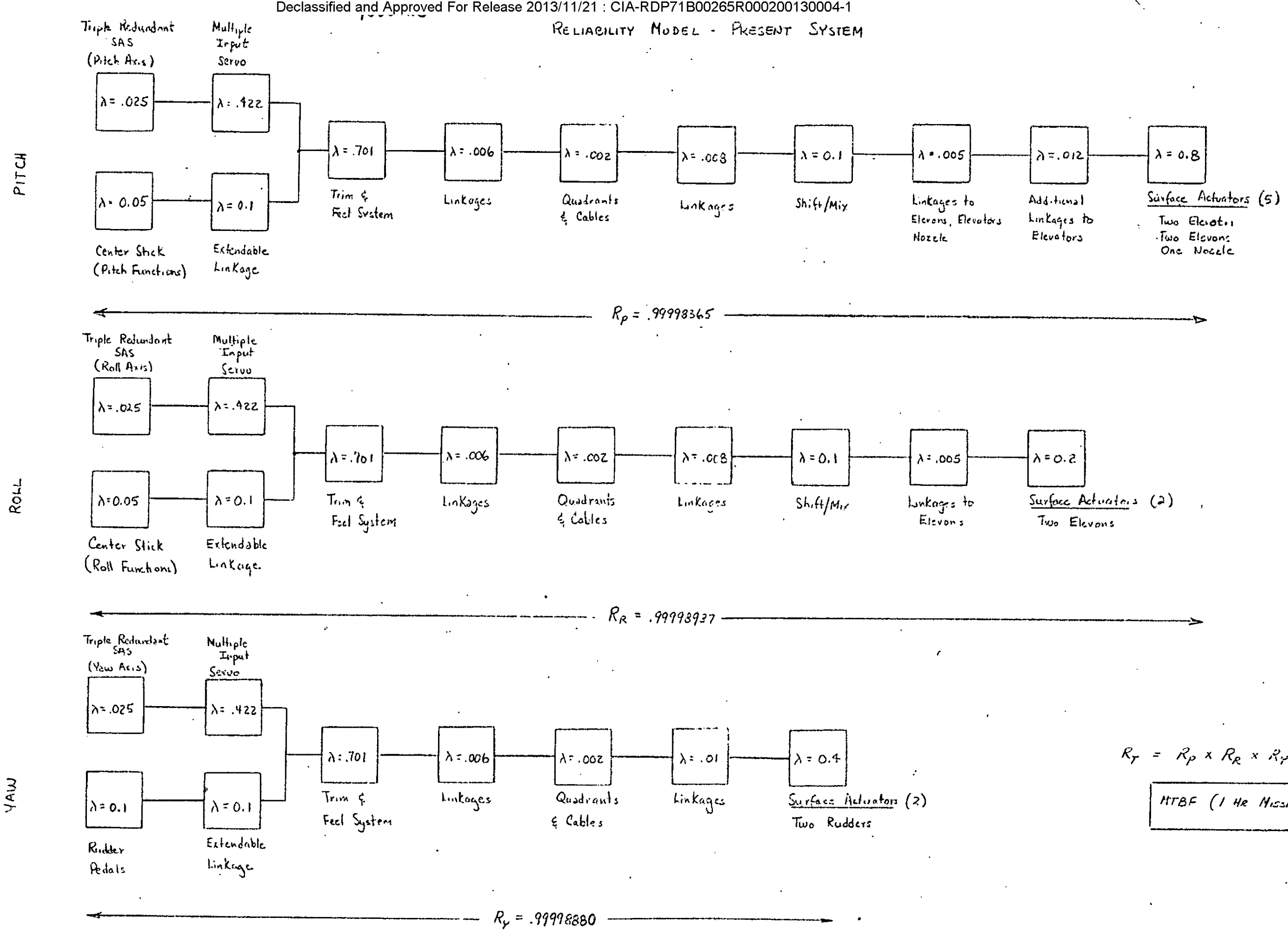
(2) Includes connectors averaged over cable run length

(3) Includes servo amps, electrical trim, electrical mixer

(4) Includes bellcranks, rods, mounts, connectors

λ= %FAILURE

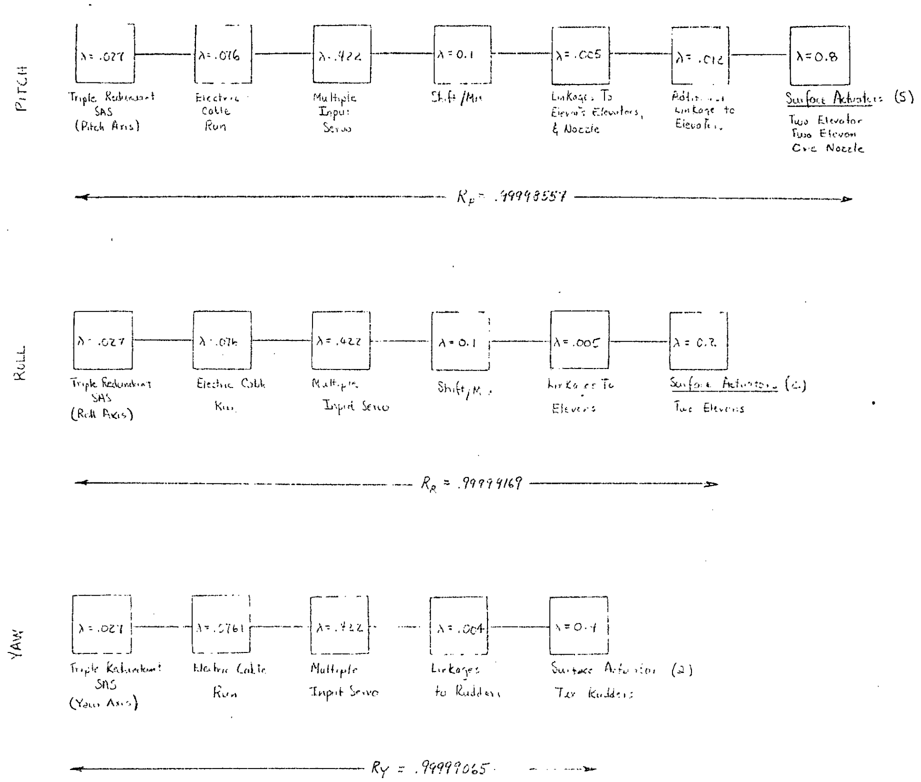
RELIABILITY MODEL - PRESENT SYSTEM



$R_T = R_P \times R_R \times R_Y = .99996182$

MTBF (1 Hr Mission) = 26,191 Hrs.

RELIABILITY MODEL - PROPOSED CONFIGURATION A

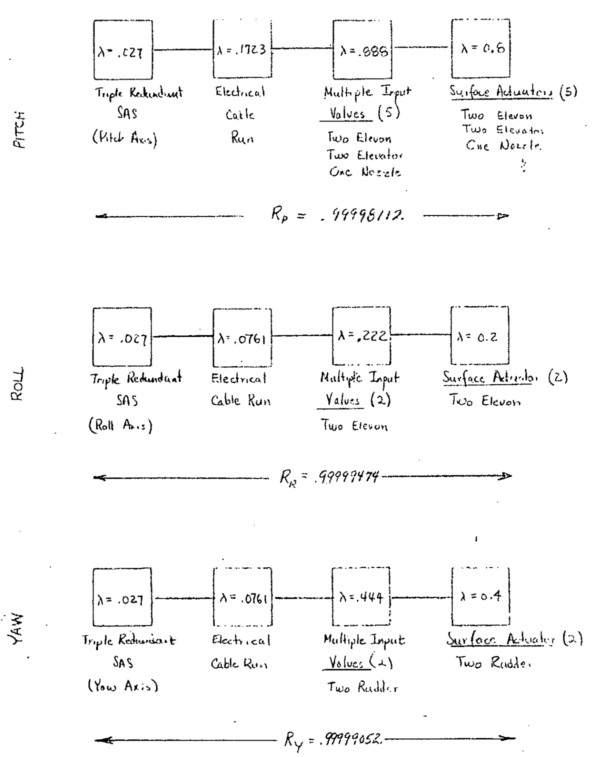


$R_T = R_P \cdot R_R \cdot R_Y = .99996794$

MTBF (1 HR. MISSION) = 31, 188 HRS

FIGURE 1

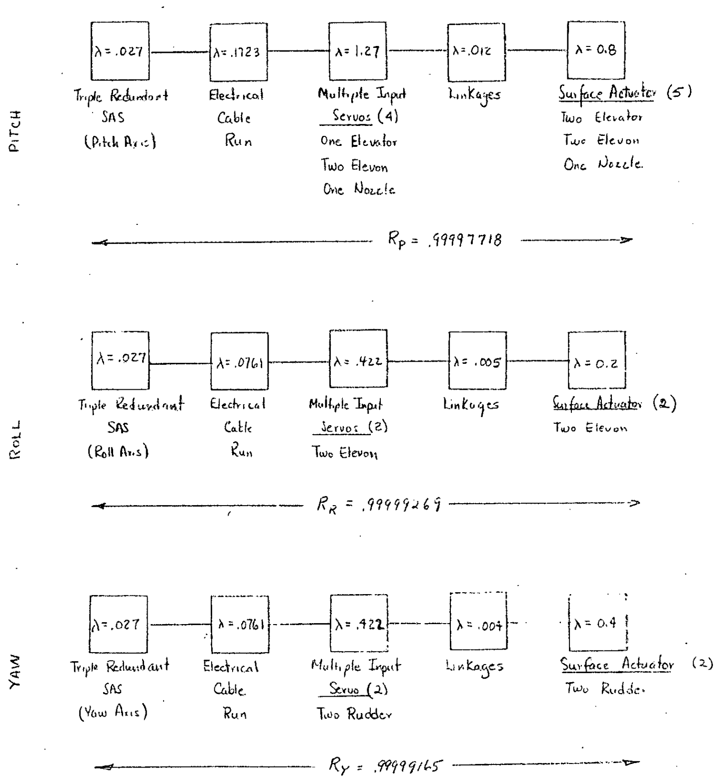
RELIABILITY MODEL - PROPOSED CONFIGURATION B



$R_T = R_P \times R_R \times R_Y = .99996640$

MTBF (1 HR MISSION) = 29,766 HRS

RELIABILITY MODEL - PROPOSED CONFIGURATION C



$R_T = R_P \times R_R \times R_Y = .99996054$

MTBF (1 HR. MISSION) = 25,345 HRS.

V. (cont'd)

The failure rates used in deriving these models have been gathered from WADD, NAVY, and Honeywell sources.

VI. WEIGHTED VALUE TRADE-OFFS OF THE SYSTEMS BEING CONSIDERED

Based on the foregoing information presented, the following system trade-off table was prepared.

TABLE III

System Trade-Off Results

			Proposed System		
	Weight	Present System	A	B	C
Performance	15	5	10	15	12
Failsafety	20	12	16	19	18
Reliability	30	21	25	24	19
Maintainability	5	4	5	3	2
Cost	10	7.4	7.9	7.5	7.3
Weight	20	10	14	17	16
Total		59.5	77.9	85.5	74.3

It is to be noted that all of the proposed systems are better than the present system in total, and indeed in almost every sub-category being rated.

VII. CONCLUSIONS

The conclusions of this detail study are as follows:

- No mechanical back-up system should be employed.
- Full authority, series-command, multiple input, redundant servos or valves should be employed and located as far aft as possible consonant with other considerations.
- Selection of System A, B, or C should be made after refinement of weight and cost figures by the airframe supplier.
- Type of servo voting to be employed should be made after detail discussions by the airframe supplier and the flight control supplier.