REPORT NUMBER 140

JANUARY 1964

PRIMARY FLIGHT CONTROL SYSTEMS STRUCTURAL ANALYSIS

XV-5A

LIFT FAN FLIGHT RESEARCH AIRCRAFT PROGRAM

CONTRACT NUMBER DA44-177-TC-715

GENERAL ELECTRIC

DDC AVAILABILITY NOTICES

1. Distribution of thid document is unlimited.

2. This document is subject to special report controls and each transmittal to foreign governments or foreign nationals may be made only with prior approval of US Army Aviation Materiel Laboratories, Fort Eustis, Virginia 23604.

3. In addition to security requirements which must be met, this document is subject to special export controls and each transmittal to foreign governments or foreign nationals may be made only with prior approval of USAAVLABS, Fort Eustis, Virginia 23604.

4. Each transmittal of this document outside the agencies of the US Government must have prior approval of US Army Aviation Materiel Laboratories, Fort Eustis, Virginia 23604.

5. In addition to security requirements which apply to this document and must be met, each transmittal outside the agencies of the US Government must have prior approval of US Army Aviation Materiel Laboratories, Fort Eustis, Virginia.

6. Each transmittal of this document outside the Department of Defense must have prior approval of US Army Aviation Materiel Laboratories, Fort Eustis, Va.

7. In addition to security requirements which apply to this document and must be met, each transmittal outisde the Department of Defense must have prior approval of US Army Aviation Materiel Laboratories, Fort Eustis, Virginia 23604.

8. This document may be further distributed by any holder only with specific prior approval of US Army Aviation Materiel Laboratories, Fort Eustis, Va. 23604.

9. In addition to security requirements which apply to this document and must be met, it may be further distributed by the holder only with specific prior approval of US Army Aviation Materiel Laboratories, Fort Eustis, Virginia 23604.

DISCLAIMER

10. The findings in this report are not to be construed as an official Department of the Army position unless so designated by other authorized documents.

11. When Government drawings, specifications, or other data are used for any purpose other than in connection with a definitely related Government procurement operation, the United States Government thereby incurs no responsibility nor any obligation whatsoever; and the fact that the Government may have formulated, furnished, or in any way supplied the said drawings, specifications, or other data is not to be regarded by implication or otherwise as in any manner licensing the holder or any other person or corporation, or conveying any rights or permission, to manufacture, use, or sell any patented invention that may in any way be related thereto.

12. Trade names cited in this report do not constitute an official endorsement or approval of the use of such commercial hardware of software.

Report Number 140

PRIMARY FLIGHT CONTROL SYSTEMS STRUCTURAL ANALYSIS

XV-5A LIFT FAN
FLIGHT RESEARCH AIRCRAFT PROGRAM

JANUARY 1964

Advanced Engine and Technology Department
General Electric Company
Cincinnati, Ohio 45215

CONTENTS

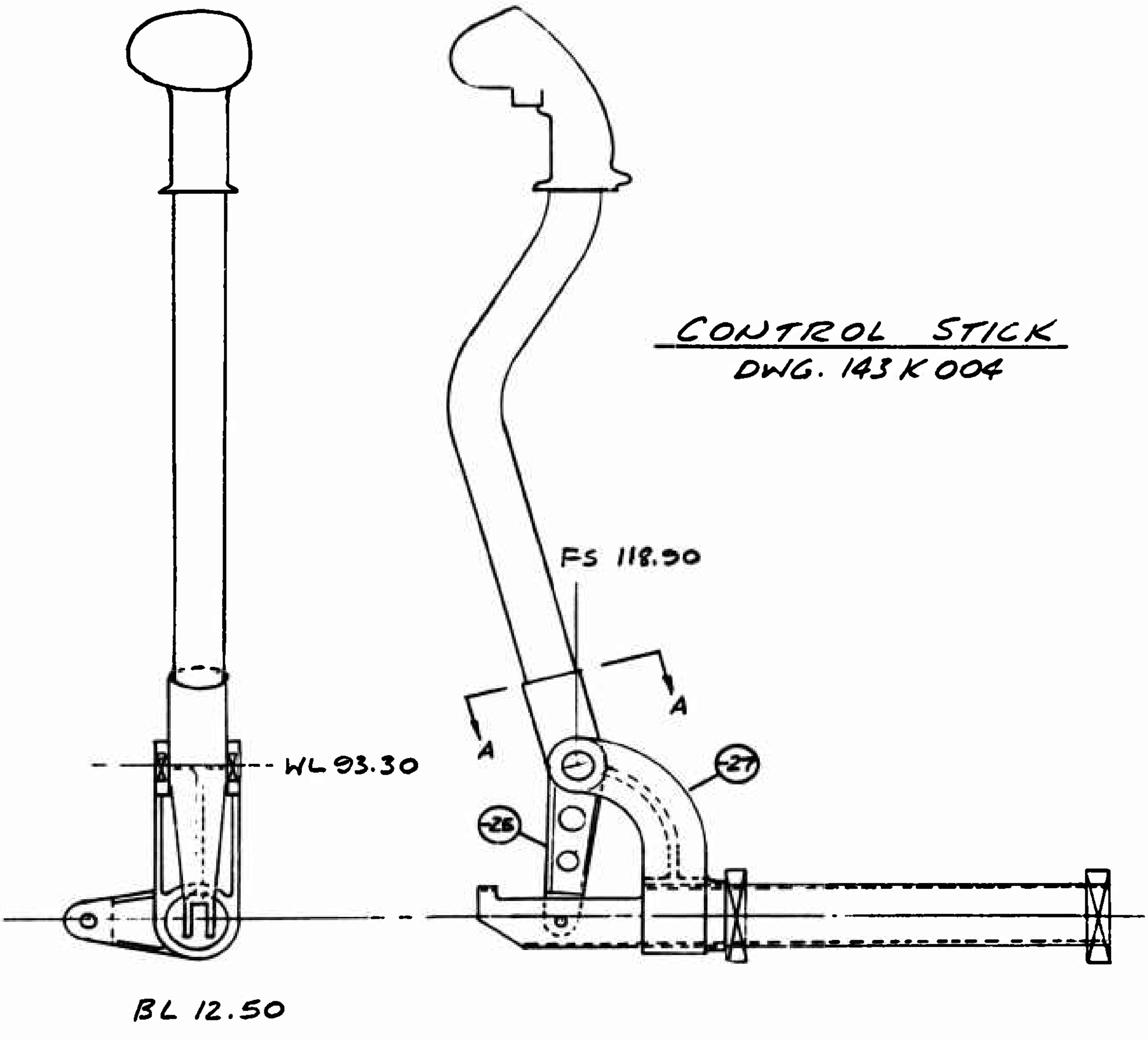
I. INTRODUCTION

The structural analysis of Model XV-5A primary flight control systems is presented in this report. The primary flight control systems consist of conventional stick and rudder pedals mechanically connected to rudder, elevator, and to servo actuators, which control the ailerons, wing-fan exit louvers and nose-fan thrust modulator. The structural analysis is primarily intended to provide load information for the major components.

The conventional flight control systems were satisfactorily tested in the airplane by applying limit load to the cockpit controls and reacting the load by locking the surfaces. The wing-fan louver and nose-fan modulator actuating mechanisms were satisfactorily proof tested on the simulator.

All loads shown in this report are ultimate values, unless otherwise stated.

II. CONVENTIONAL FLIGHT CONTROL SYSTEMS



CONTROL STICK

STICK – SECT. A-A

1.625 × .065 2024-T3 TUBE

ELEVATOR CONTROL LOAD PRODUCES CRITICAL BENDING

MAX. B.M. = 18.5 × 300 = 5550 "#

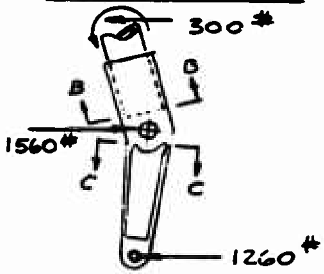
$I/y = .1195$ $D/t = 25$

$f_b = 5550/.1195 = 46400$ psi

$F_b = 1.03\ F_{tu}$
$= 1.03 \times 63000 = 65000$ psi } MIL HDBK 5, PGS. 3.4.2 & 3.2.3.0

$$M.S. = \frac{65000}{46400} - 1 = \underline{+.40}$$

-25 FITTING



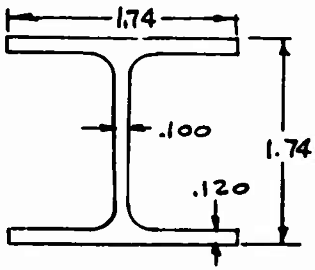
SECT B-B: 1.74 OD 1.60 ID

$I = \frac{\pi}{4}(.87^4 - .80^4) = 1.27$

B.M. = 20.75 × 300 = 6220 "#

$$f_b = \frac{6220 \times .87}{1.27} = 42600 \text{ psi}$$

SECT C-C:



7075-T651 PLATE
$F_{tu} = 78000$ psi

I = .304

B.M. = 4.85 × 1260 = 6110 "#

$$f_b = \frac{6110 \times .87}{.304} = 17500 \text{ psi}$$

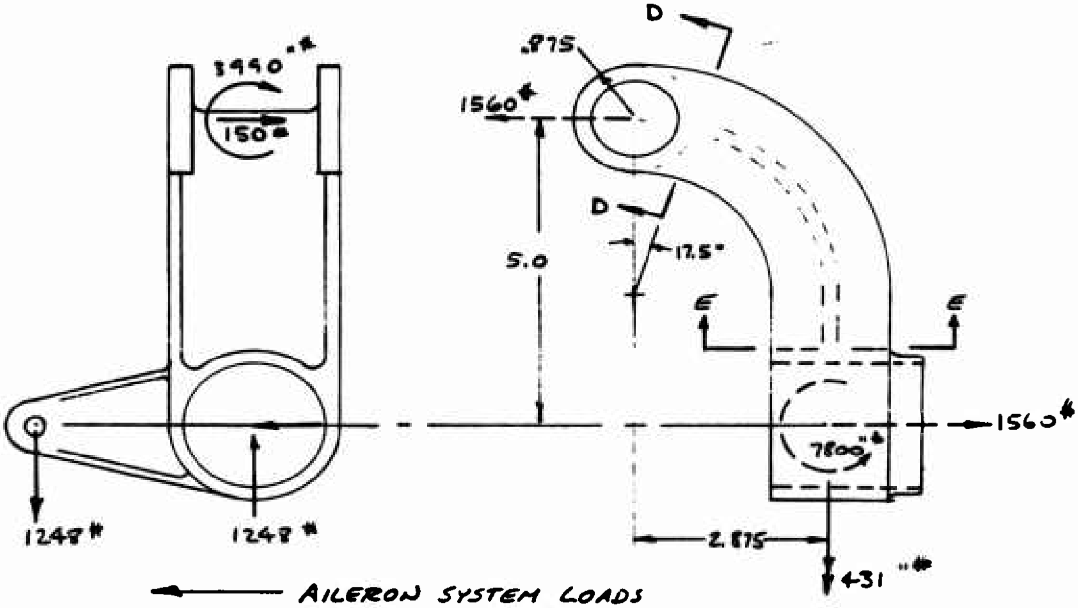
$$\text{CRITICAL } M.S. = \frac{78000}{42600} - 1 = \underline{+.83}$$

CONTROL STICK

-27 PIVOT FITTING

MADE FROM 7075-T651 PLATE

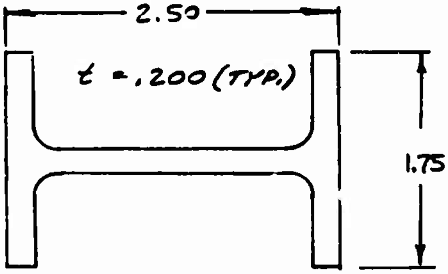
F_{tu} = 66000 psi F_{su} = 40000 psi



AILERON SYSTEM LOADS

ELEVATOR SYSTEM LOADS

SECT D-D



I_x = .179 IN^4

I_y = 1.08 IN^4

CONTROL STICK

-27 PIVOT FITTING

SECT D-D

$T = 3990 \cos 17.5° = 3800$ "#

$M_Y = 3990 \sin 17.5° + 150 \times .875 = 1330$ "#

ALLOW. T (PLASTIC TORSION) $= (\frac{1}{2}At - \frac{1}{6}t^3)F_s'$

WHERE $F_s' = .75 \times$ TORSIONAL MODULUS OF RUPTURE

$F_s' = .75\,(1.54\,F_{su})$

$F_s' = .75 \times 1.54 \times 40000 = 46200$ psi

ALLOW. $T = (.5 \times 1.12 \times .2 - \frac{.20^3}{6})46200 = 5110$ "#

$R_T = 3800/5110 = .743$

$f_b = \frac{1330 \times 1.25}{1.08} = 1540$ psi

$R_B = 1540/66000 = .023$

$R_T + R_B = 1$

$M.S. = \frac{1}{.743 + .023} - 1 = +\underline{.30}$

SECT. E-E (SAME CROSS SECTION AS D-D)

FOR ELEVATOR SYSTEM LOAD:

$M_Y = 1560\,(5 - 1.25) = 5850$ "#

$f_b = \frac{5850 \times .875}{.179} = 28600$ psi

$M.S. = \frac{66000}{28600} - 1 = +\underline{1.31}$

CONTROL STICK

-27 PIVOT FITTING

SECT E-E   FOR AILERON SYSTEM LOAD:

$M_y = 3990 + 150(5 - 1.25) = 4550$ "#

$T = 150 \times 2.875 = 431$ "#

ALLOW. $T = 5110$ "#

$R_T = 431/5110 = .084$

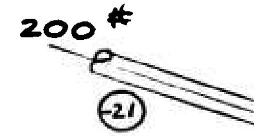
$f_b = \frac{4550 \times 1.25}{1.08} = 5260$ psi

$R_B = 5260/66000 = .079$

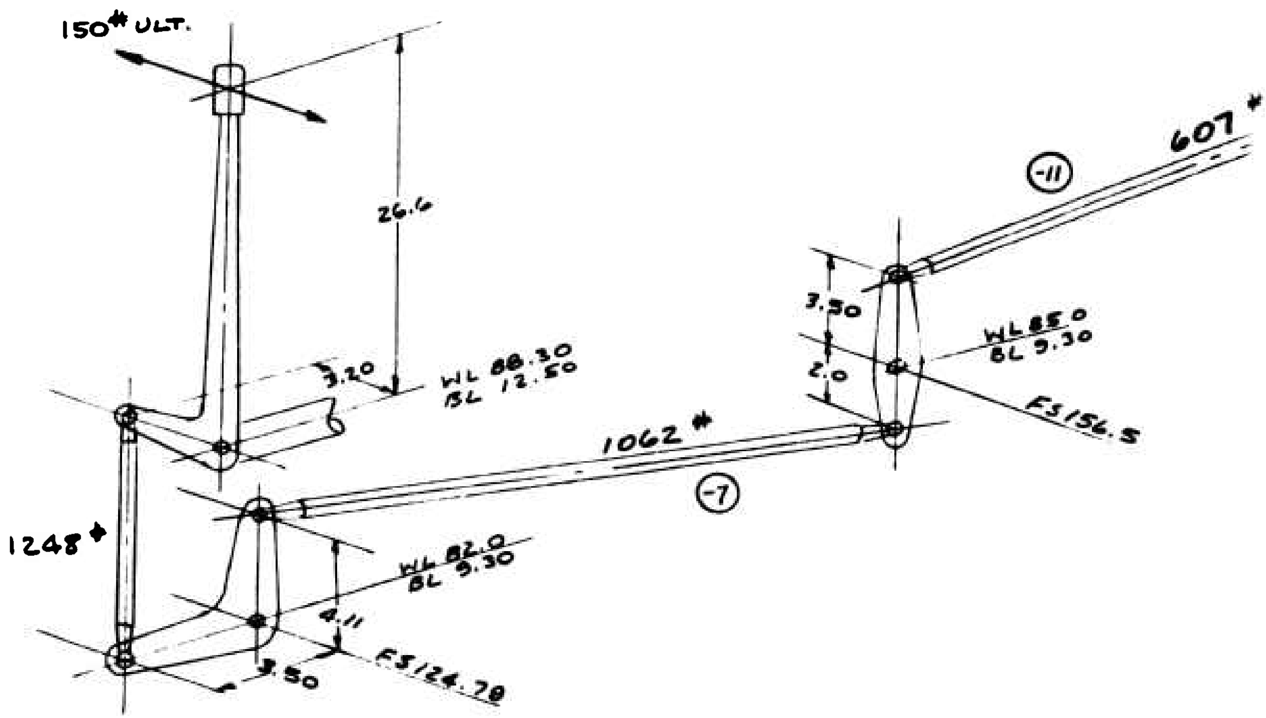
M.S. HIGH

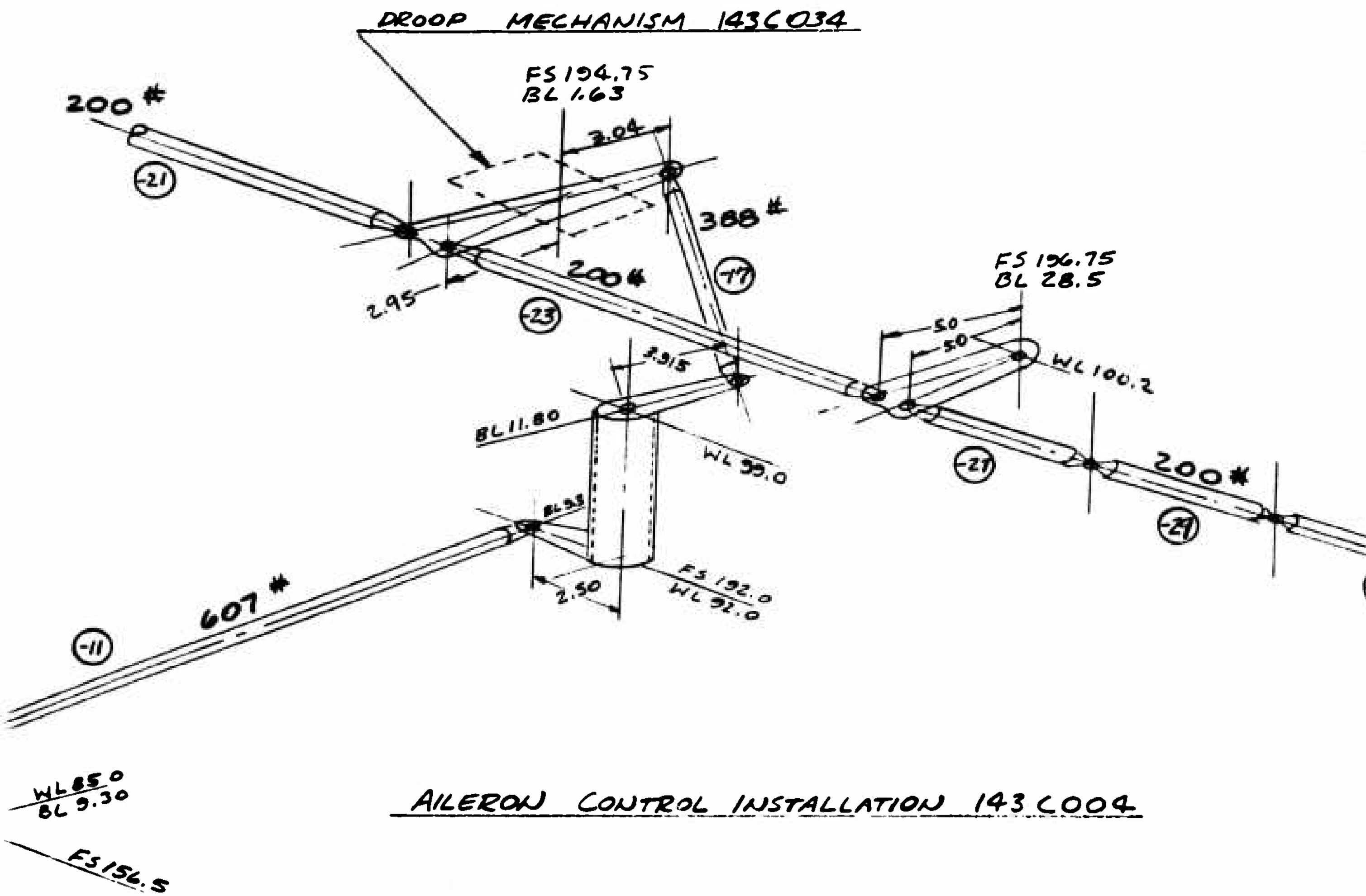
AILERON CONTROL SYSTEM

The ailerons are actuated by servo boost actuators and control tabs. The system is actuated by the pilot by lateral movement of the control stick. Stick movement is transmitted to the servo and tab by a network of push-rods and bellcranks. The output controls the boost actuator servo valve, and also deflects the tab. Loads reacting the tab hinge moment provide pilot feel at the stick. A droop mechanism, incorporated in the system, allows the ailerons to be deflected down simultaneously to augment the flaps. Pilot effort load is divided equally to the push-rods in each wing.



STICK INSTALLATION 143 K 004





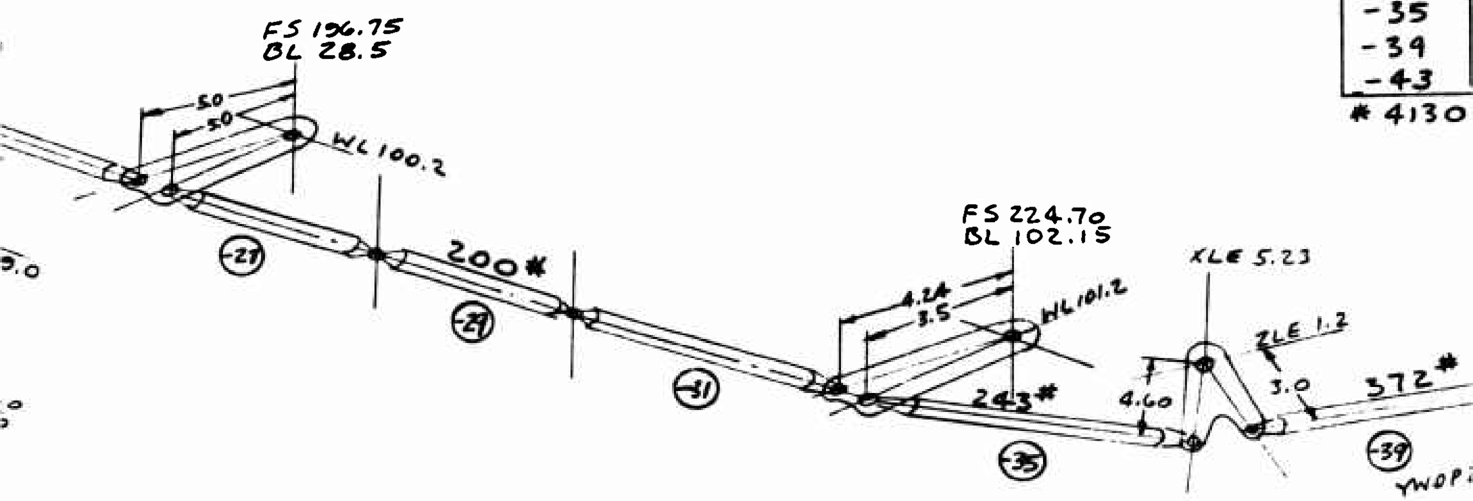
AILERON CONTROL SYSTEM

ULTIMATE LOADS - SYSTEM NEUTRAL - ACTU

C034

-NO.
-7
-11
-17
-21
-23
-27
-29 *
-31
-35
-39
-43

* 4130



USTALLATION 143 C004

WIN

AILERON CONTROL SYSTEM

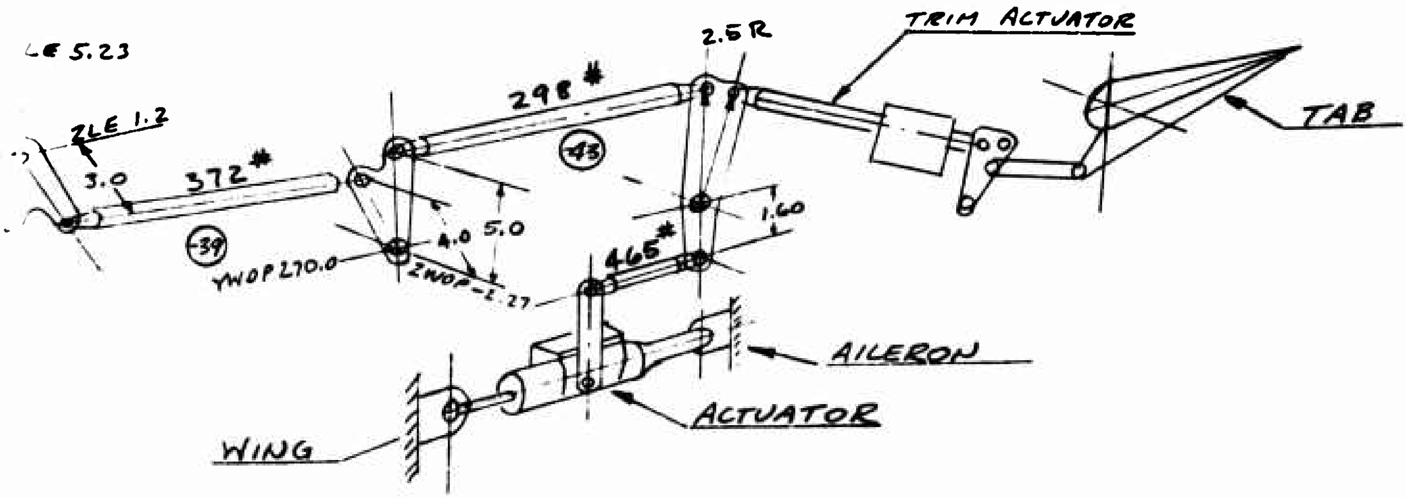
E LOADS - SYSTEM NEUTRAL - ACTUATOR JAMMED

C

CONTROL ROD M.S.

-NO.	L	D	t	P_c	P	M.S.
-7	31.26	1	.035	1293*	1062*	+.22
-11	36.00	7/8	.035	646	607	+.06
-17	13.64	1/2	.035	766	388	+.98
-21	26.43	5/8	.035	421	200	+1.10
-23	29.37	5/8	.035	344	200	+.72
-27	24.50	5/8	.035	486	200	+1.43
-29*	17.28	9/16	.049	2490	200	HIGH
-31	35.95	3/4	.035	409	200	+1.05
-35	19.14	1/2	.035	388	243	+.60
-39	33.22	3/4	.035	471	372	+.27
-43	33.33	3/4	.035	460	298	+.54

* 4130 N STEEL — ALL OTHER TUBES ARE 2024-T3



AILERON CONTROL SYSTEM

Control Rod Loads

Loads are computed with system in neutral position, assuming the actuator is jammed in the neutral position. Ultimate stick load is 150 lbs. (Ref. Ryan Report 62B094, Pg. 31)

$$150 \times \frac{26.6}{3.2} = 1248 \text{ lbs.}$$

$$1248 \times \frac{3.5}{4.11} = 1062 \text{ lbs.}$$

$$1062 \times \frac{2.0}{3.5} = 607 \text{ lbs.}$$

$$607 \times \frac{2.5}{3.915} = 388 \text{ lbs.}$$

$$388 \times \frac{3.04}{2.95} \times 1/2 = 200 \text{ lbs.}$$

$$200 \times \frac{4.24}{3.5} \times 1/2 = 243 \text{ lbs.}$$

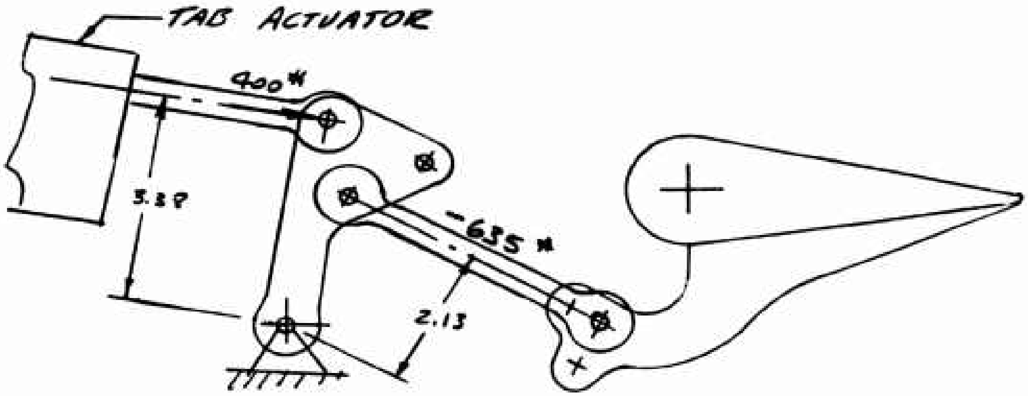
$$243 \times \frac{4.6}{3.0} \times 1/2 = 372 \text{ lbs.}$$

$$372 \times \frac{4.0}{5.0} \times 1/2 = 298 \text{ lbs.}$$

$$298 \times \frac{2.5}{1.6} \times 1/2 = 465 \text{ lbs.}$$

AILERON CONTROL SYSTEM

Tab Control System Loads



CRITICAL LOADS ARE DEVELOPED WHEN TAB IS USED FOR TRIM.

ACTUATOR ULT. CAPACITY = 400#

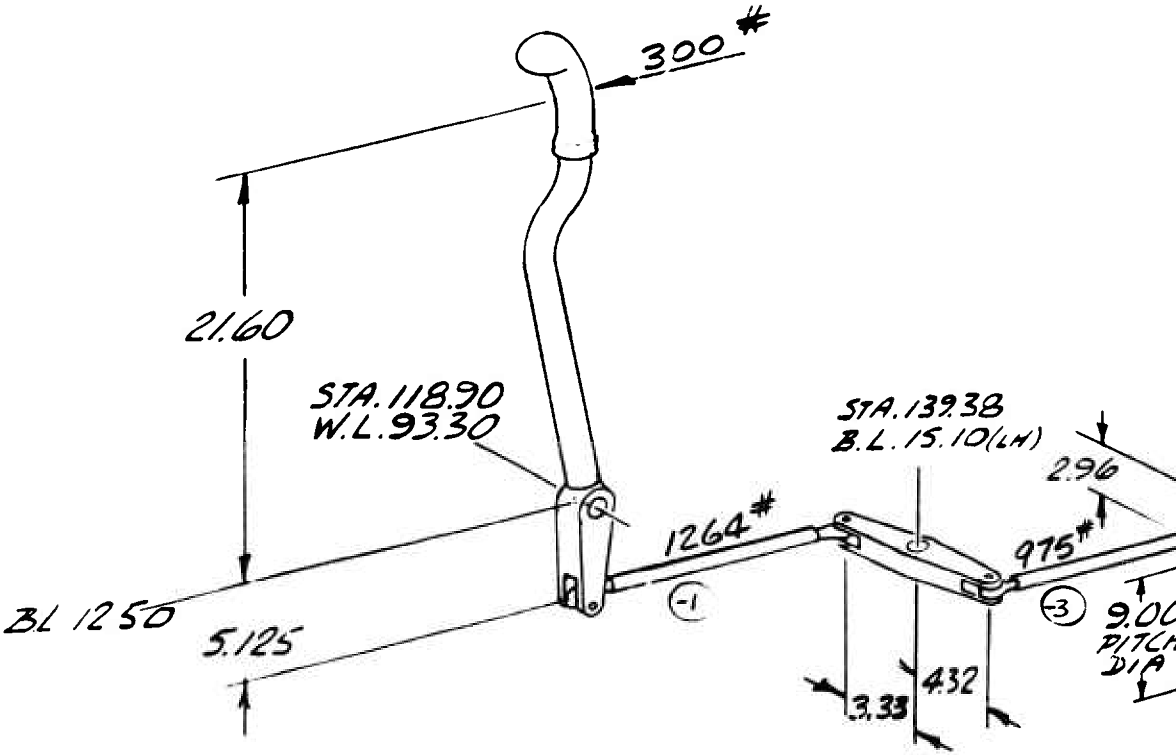
LINK LOAD = $\frac{400 \times 3.38}{2.13}$ = 635#

ELEVATOR CONTROL SYSTEM

Elevator actuation is accomplished mechanically through a push-rod/cable system. Cable tension is maintained by a tension regulating cable drum. Movement resulting from longitudinal input at the stick is applied to the elevator control horn, which is attached to the elevator torque tube.

DWG.	-N
143C038	-1 -3
143C024	-5

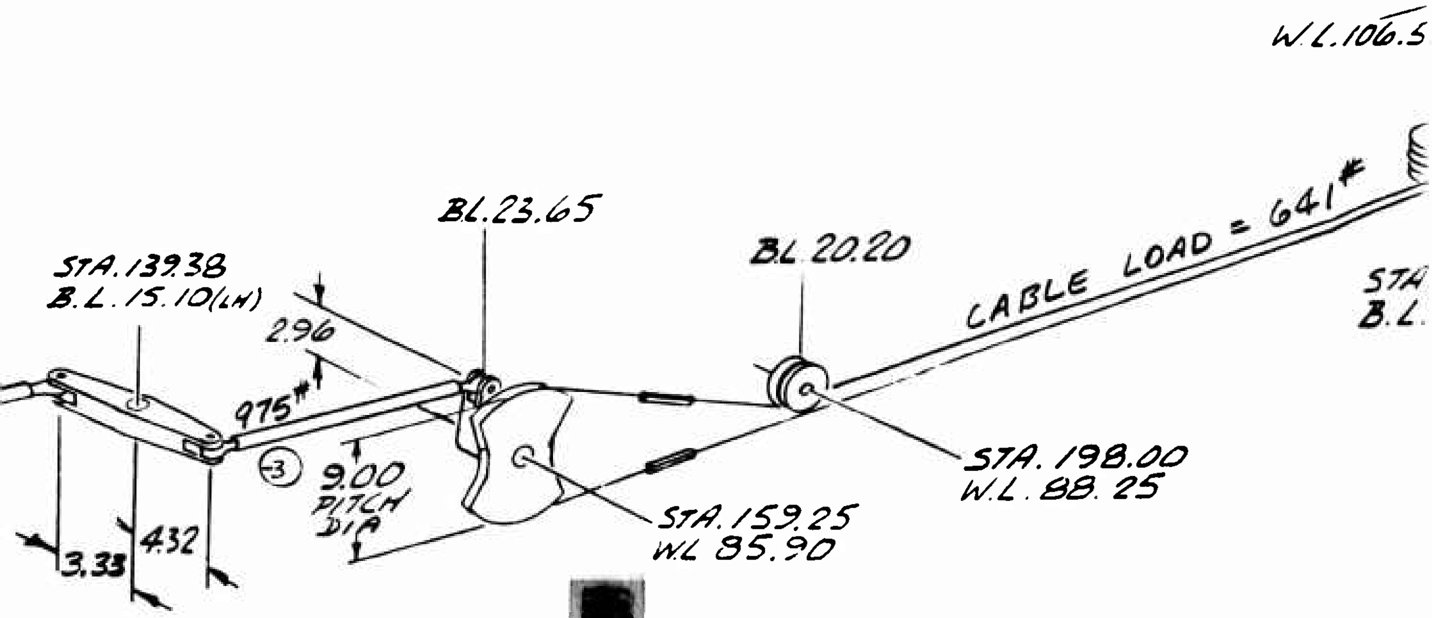
-1 4130N ST



CONTROL ROD M.S.

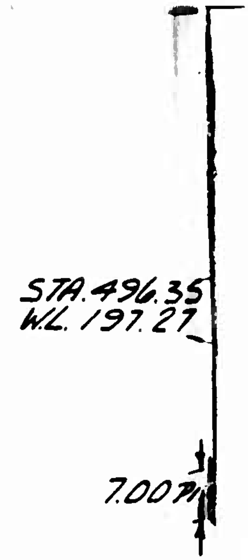
DWG.	-NO	L	D	t	P_c	P	M.S.
143C038	-1	21.7	9/16	.049	1580	1264	+.25
	-3	19.75	3/4	.035	1306	975	+.34
143C024	-5	22.02	3/4	.049	1400	1122	+.25

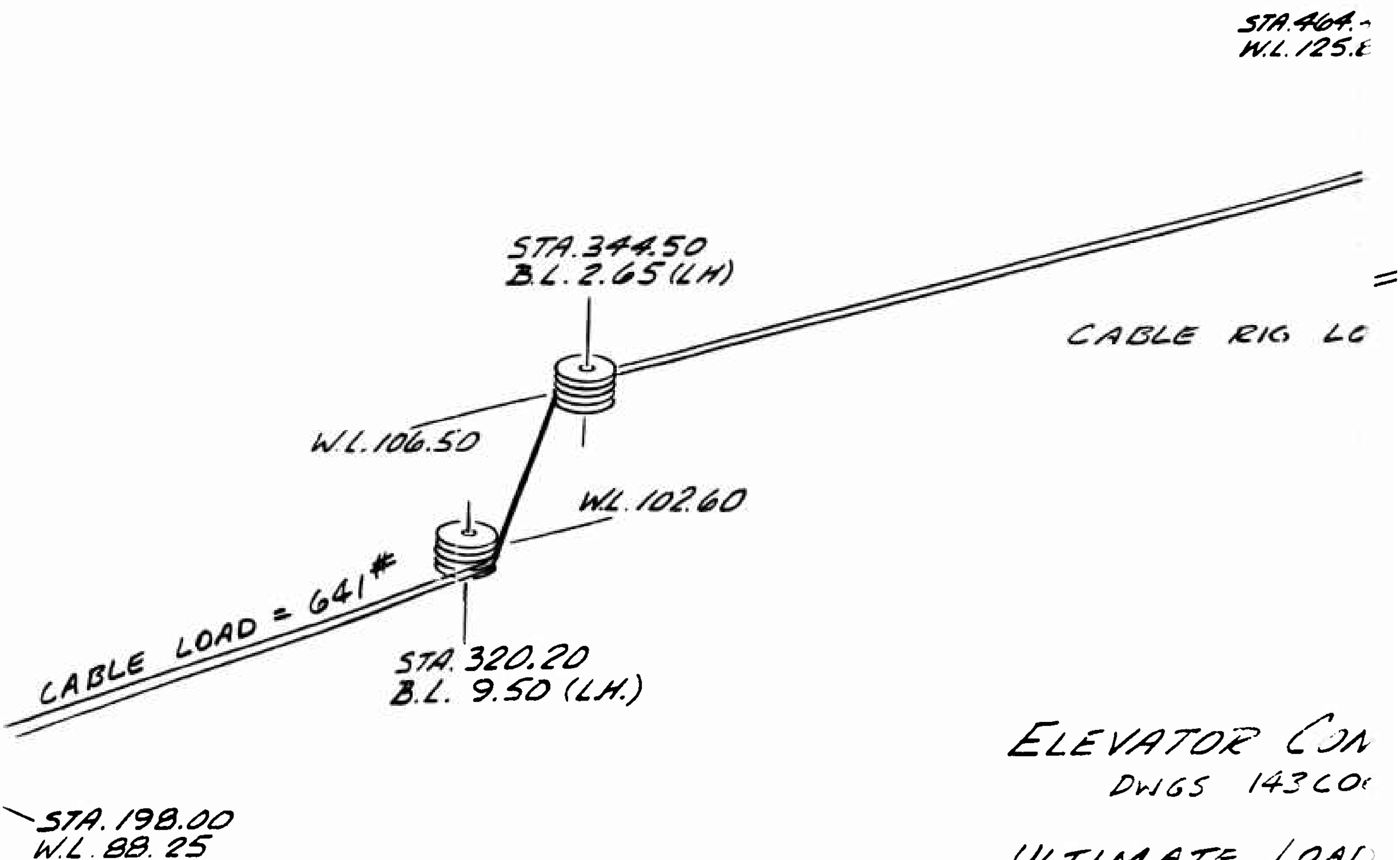
-1 4130 N STEEL , -3 & -5 2024 T3



M. S.

	P	M. S.
30	1264	+.25
06	975	+.34
00	1122	+.25

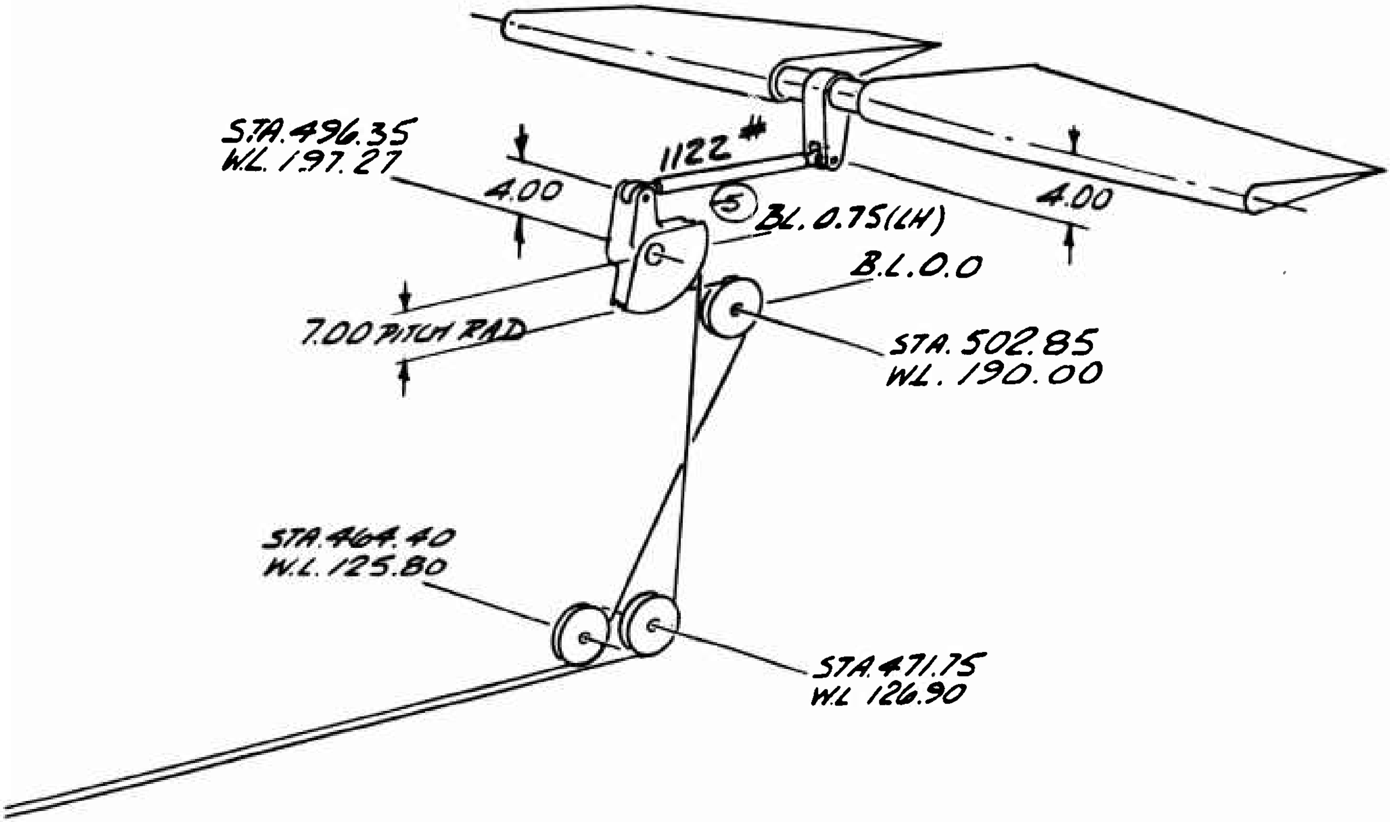




ELEVATOR CON
DWGS 143C0

ULTIMATE LOAD

C



CABLE RIG LOAD = 70#

ELEVATOR CONTROL SYSTEM

DWGS 143C001 & 143K004

ULTIMATE LOADS - SYSTEM NEUTRAL

D

ELEVATOR CONTROL SYSTEM

Control rod and cable loads are computed below, assuming the stick load is reacted by the elevator in the neutral position. Ultimate stick load is 300 lbs. (Ref. Ryan Report 62B094 Pg. 31)

$$300 \times \frac{21.6}{5.125} = 1264 \text{ lbs.}$$

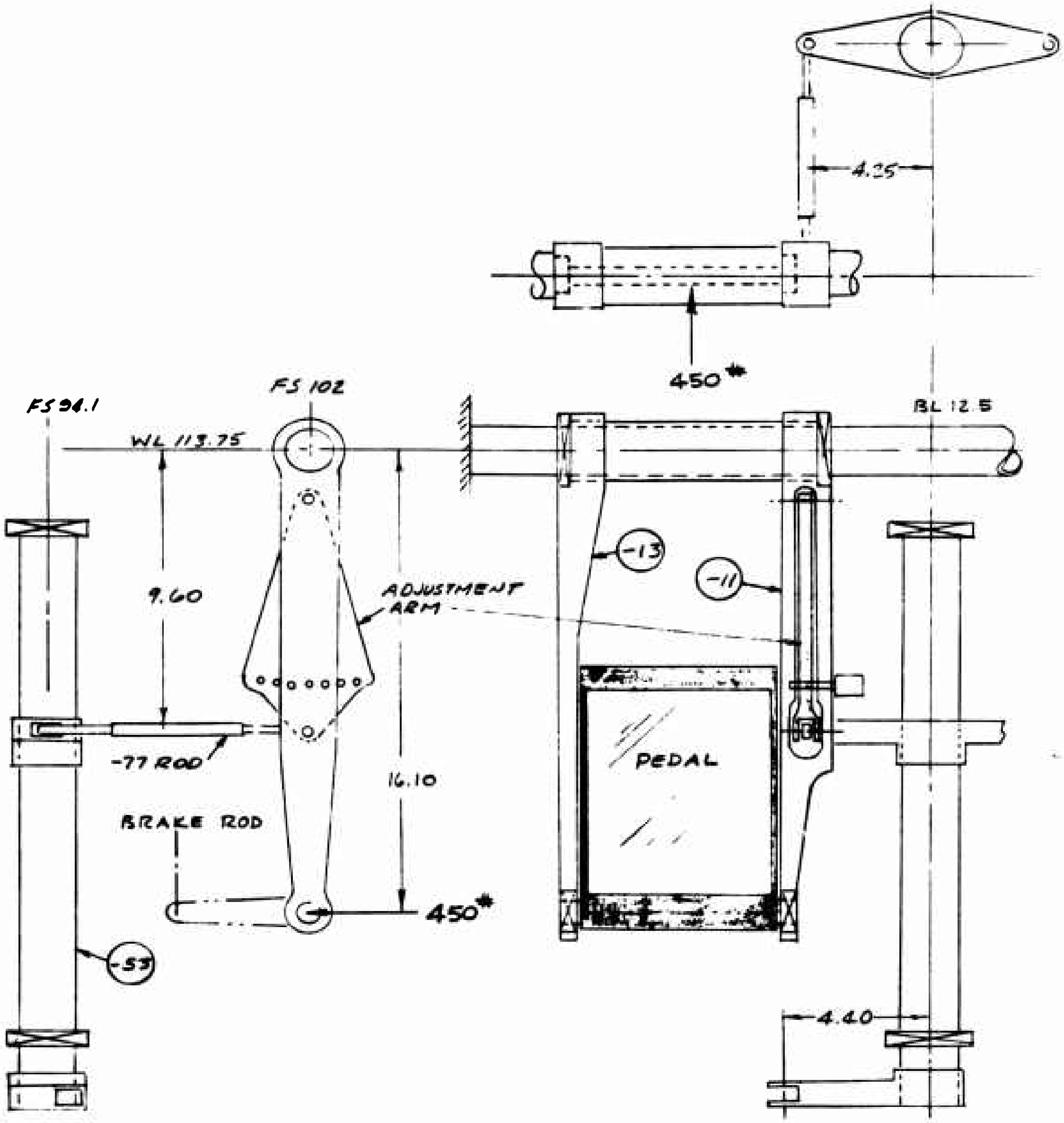
$$1264 \times \frac{3.33}{4.32} = 975 \text{ lbs.}$$

$$\text{Cable Load} = 975 \times \frac{2.96}{4.5} = 641 \text{ lbs.}$$

$$\text{Load @ Elevator Horn} = 641 \times \frac{7.0}{4.0} = 1122 \text{ lbs.}$$

Cable Rig Load = 70 lbs.

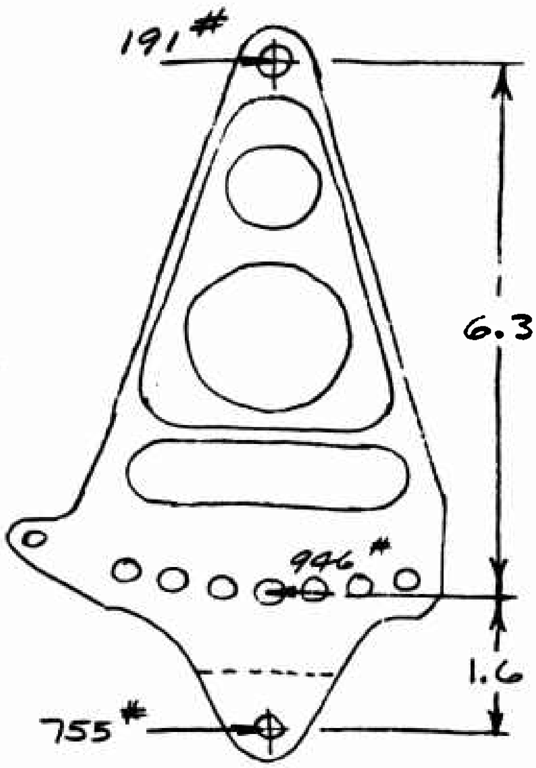
RUDDER PEDAL (DWG. 143K010)



RUDDER PEDAL

Rudder control results from the foot loads applied to the bottom of the pedal. The moment about the pivot axis is balanced by a load in -77 control rod, which is attached to the lower end of the adjustment arm. The adjustment arm is locked to the pedal inner support arm in one of seven possible locations. The brake is actuated by applying toe pressure to the top of the pedal. Loads are computed for rudder in neutral position, and the pedal in the normal, mid-adjustment position.

-77 CONTROL ROD LOAD $= 450 \times \frac{16.1}{9.6} = 755^{\#}$

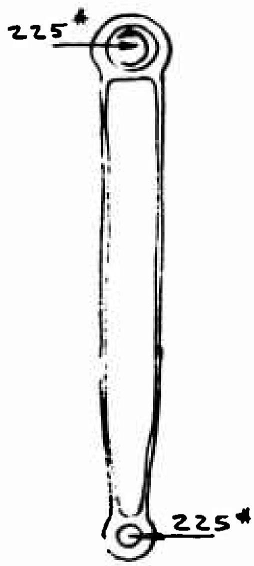


LOCK PIN LOAD $= 755 \times \frac{7.9}{6.3} = 946^{\#}$

PIVOT LOAD $= 946 - 755 = 191^{\#}$

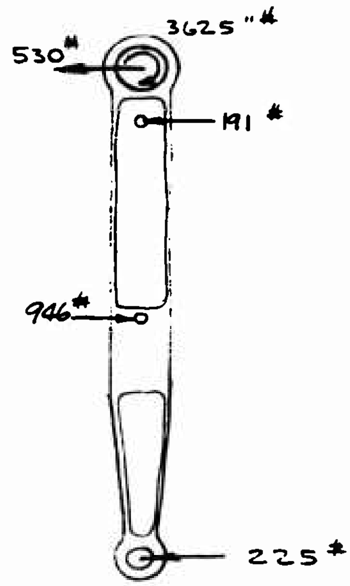
-15 ADJUSTMENT ARM

RUDDER PEDAL SUPPORT ARMS



OUTER ARM (-13)

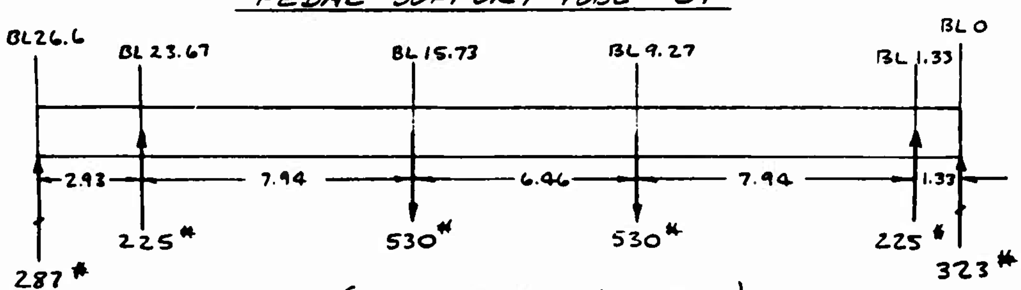
T = 225 × 16.1 = 3625"#



INNER ARM (-11)

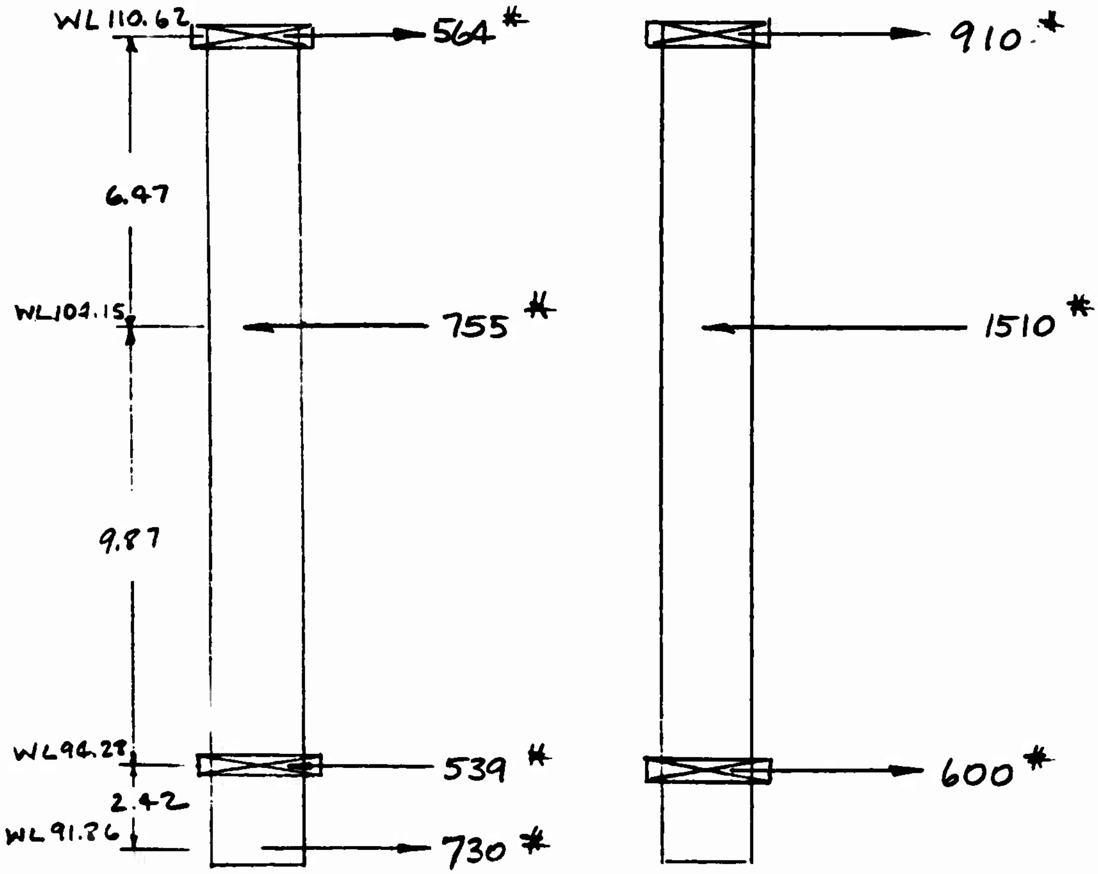
R = 946 − 225 − 191 = 530#

PEDAL SUPPORT TUBE -51



(BOTH PEDALS LOADED)

RUDDER PEDAL LEVER SUPPORT TUBE -53

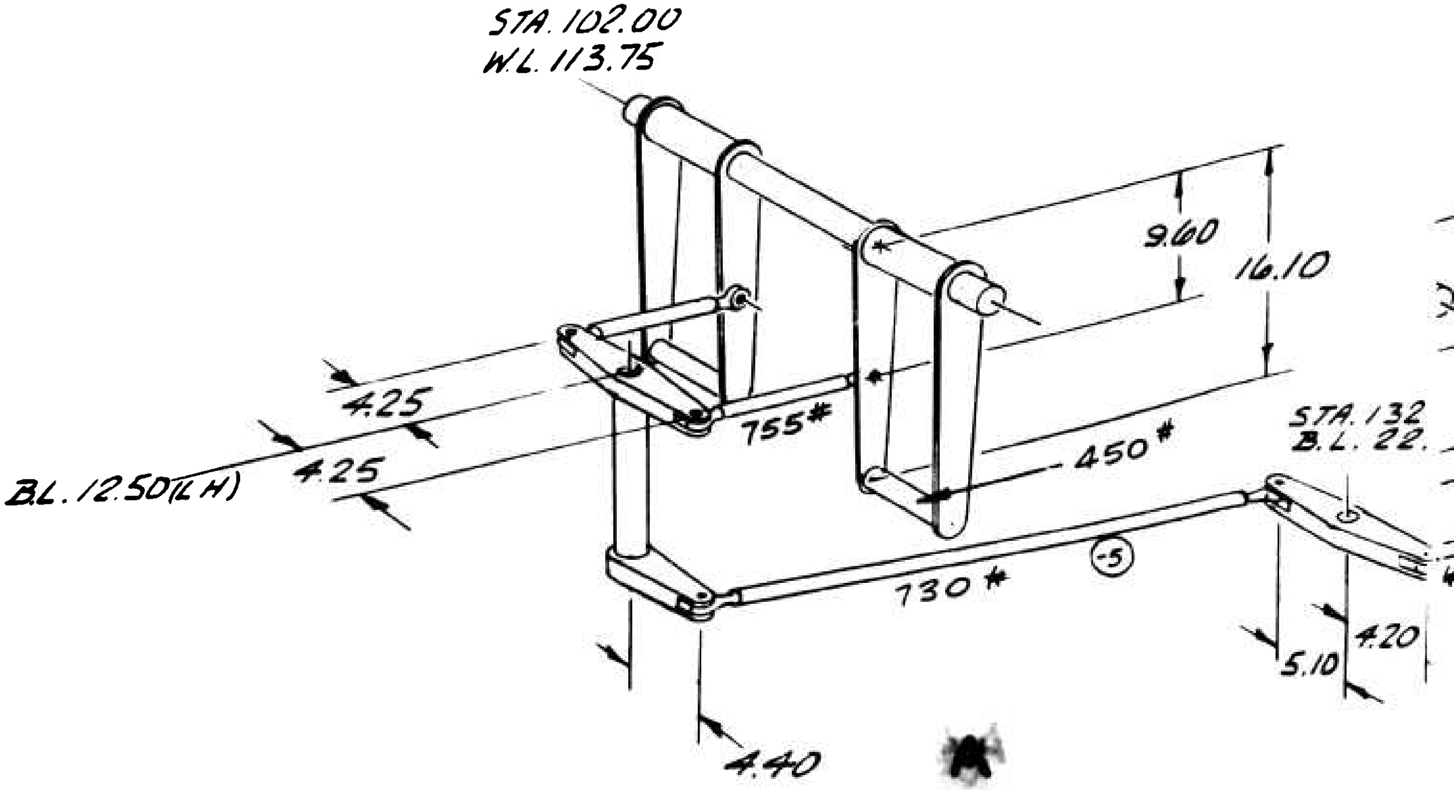


I
PILOT LOAD REACTED BY RUDDER

II
BOTH PEDALS LOADED

RUDDER CONTROL SYSTEM

The rudder is mechanically actuated by a push-rod/cable system. A tension regulator is incorporated in the system to maintain cable tension. The rudder pedals are also used to apply the wheel brakes by applying load to the upper portion of the pedal. Loads are applied simultaneously to each pedal when critical.



STA. 102.00
W.L. 113.75
9.60
16.10
4.25
4.25
B.L. 12.50(LH)
755#
450#
STA. 132
B.L. 22.
-5
730#
5.10
4.20
4.40

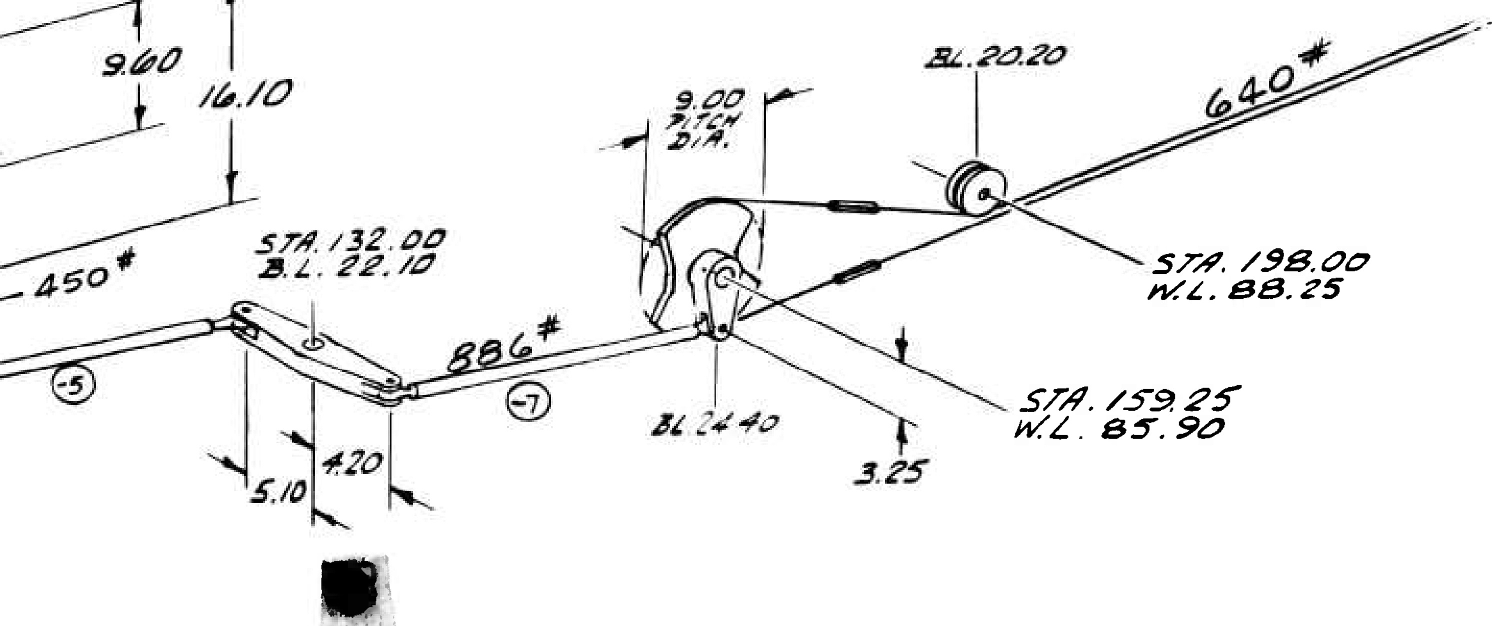
CONTROL ROD M.S.

DWG 143 C038

-No	L	D	t	P_c	P	M.S.
-5	38.72	1	.049	1142	730	+.57
-7	27.10	3/4	.049	928	886	+.05

2024-T3 TUBES

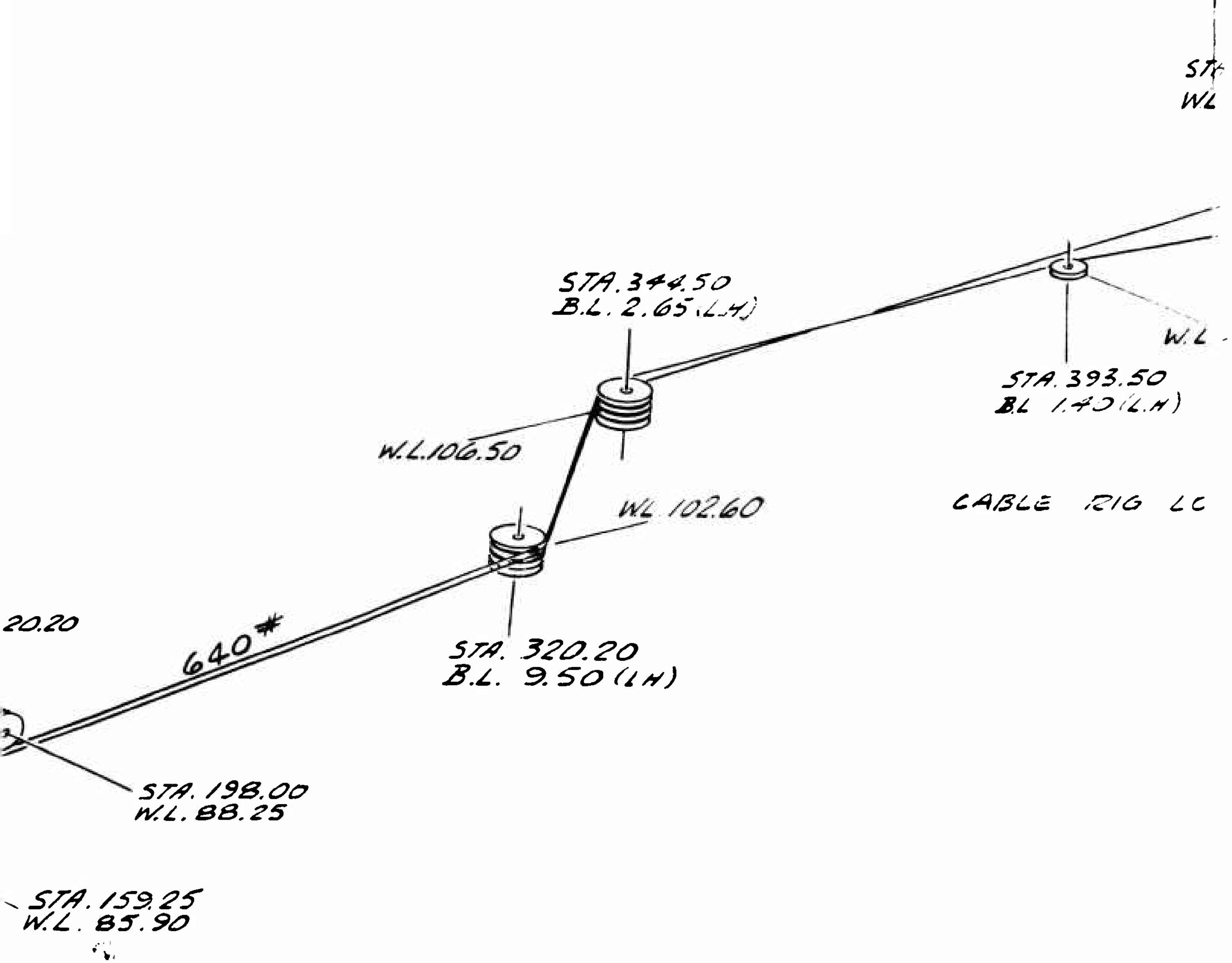
W.



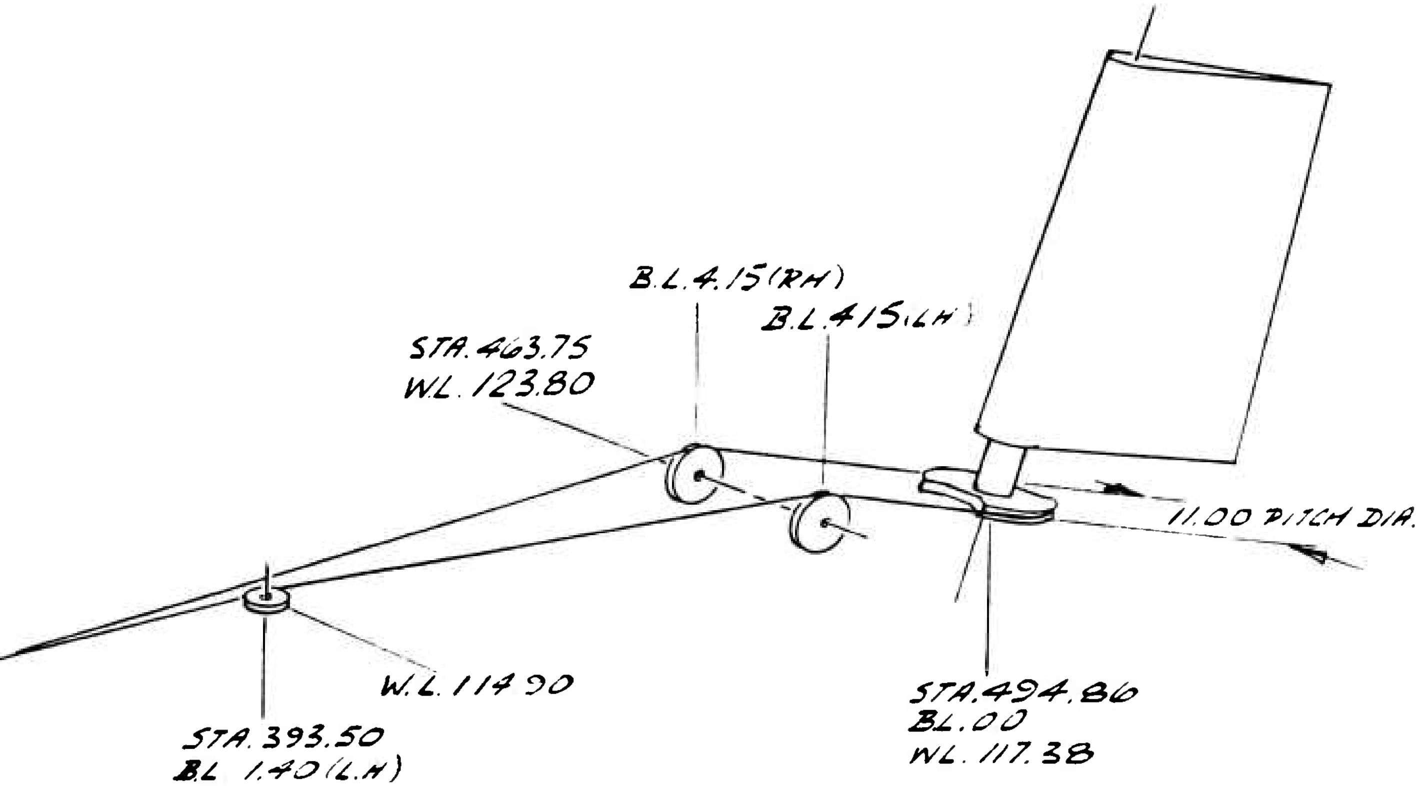
OL ROD M.S.

. 143 C038

t	P_c	P	M.S.
.049	1142	730	+.57
.049	928	886	+.05



C



CABLE RIG LOAD = 80#

RUDDER CONTROL SYSTEM.

DWGS. 143C001 & 143K010

ULTIMATE LOADS - SYSTEM NEUTRAL

D

RUDDER CONTROL SYSTEM

Control rod and cable loads are computed below, assuming the pilot applied load is reacted at the rudder which is in neutral position. Ultimate pedal load is 450 lbs. (Ref. Ryan Report 62B094 Pg. 31)

$$450 \times \frac{16.1}{9.6} = 755 \text{ lbs.}$$

$$755 \times \frac{4.25}{4.4} = 730 \text{ lbs.}$$

$$730 \times \frac{5.10}{4.20} = 886 \text{ lbs.}$$

$$\text{Cable load} = 886 \times \frac{3.25}{4.5} = 640 \text{ lbs.}$$

Rudder Cable Rig Load = 80 lbs.

III. V/STOL FLIGHT CONTROL SYSTEMS

The fan-powered flight primary control system is a fully powered, irreversible system consisting of a collective (lift) stick in addition to the conventional cockpit controls, which mechanically control hydraulic servo valve tandem actuators. These actuators, two located in each wing and one located in the nose of the aircraft, position exit louvers under the wing fans,and exit doors under the nose fan. They modulate high velocity exit gases to control force magnitude and direction.

In conjunction with the fan-powered flight control system, automatic flight control is available in the form of stability augmentation to provide attitude stabilization of the aircraft. This system is in parallel with the manual servo system so that automatic stab. electrical inputs to a first stage flapper motor add or subtract to the manual inputs at the second stage spool of each servo valve. The stab. system can always be manually overriden by manual input to the servo valves.

The only significant forces applied to the mechanical systems from the pilot control to the servo valves result from the pilot feel spring packages. Since these forces are relatively small, no load analyses are shown for the mechanical systems.

WING EXIT LOUVER CONTROL

The main linkage component between the pilot controls and the wing servos is the mechanical mixer assembly (Ryan Drawing No. 143C013-1) located on the aft side of the center section of the forward wing spar. This assembly sums up independent pilot mechanical commands of roll, yaw, and lift and electrical commands of thrust vectoring. Output displacements of the assembly are fed through push-pull rods to fore and aft torque tubes located spanwise in each wing. Each torque tube is subsequently linked to a servo valve actuator (see Drawings 143C029 and 143H003).

To provide artificial pilot feel during hovering, the mixer contains feel springs in the roll and yaw modes. In conjunction with these spring packages, roll and yaw electrical trim actuators are provided. Each trim actuator aligns the spring package zero force position with the pilot's stick or pedal position, thereby relieving the force at the stick or pedals, respectively. This trim capability is approximately fifteen to twenty per cent of the full stick or pedal authority. Trim position readout at the pilot's instrument panel is on the VTOL trim indicator positioned by signal voltage from a linear pot on each actuator.

The mixer contains a thrust vectoring electrical actuator for pilot control of thrust vector angle. Concurrent with vector angle change, this unit mechanically changes roll, yaw and pitch gain ratios as a function of exit louver vector position. As the louvers are vectored aft, all three outputs are reduced to zero magnitude through ratio changers. The pitch control output is varied or reduced to zero magnitude by means of a flexible push-pull cable (Ryan Drawing No. 143C021) between the mechanical mixer and pitch mixer (described below).

With continued aft vectoring, the vectoring actuator provides synchronized closing of the nose fan exit doors and wing exit louvers. An integral potentiometer permits continuous exit louver readout on the pilot's vector angle indicator.

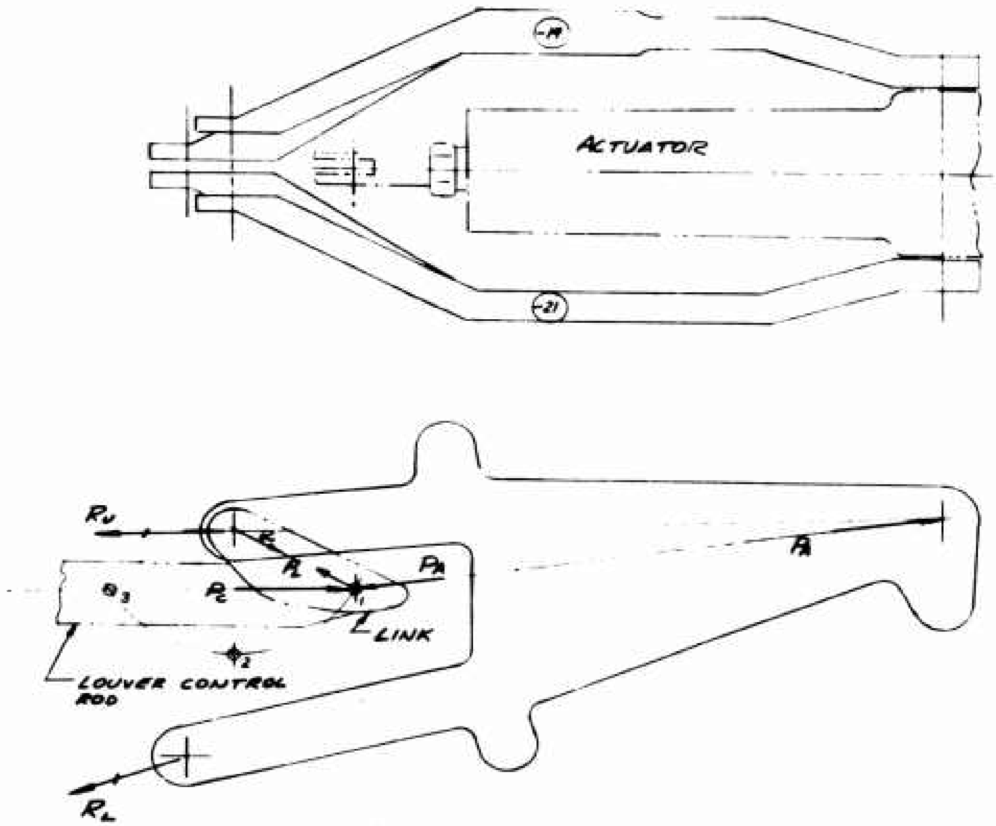
An internal cam and an override spring in the lift system linkage of the mechanical mixer prevents wing exit louver tip clash upon louver closure regardless of lift stick position. This override spring also permits full roll authority at maximum and minimum lift commands.

Provision is also made in the mixer to automatically eliminate adverse roll forces, caused by yawing the aircraft with exit louvers in any fan-powered vectored position (0 to $45^\circ \beta_V$).

WING EXIT LOUVER CONTROL (DWG. 143H003)

Loads on the actuator support bracket and louver control rod are developed for actuator capacity. Three actuator positions are considered: retracted, extended and midway.

Ultimate Actuator Load = 3300 x 1.5 = 4950 lbs. (Ref. SCDH0002)



AFT ACTUATOR

WING EXIT LOUVER CONTROL

R_U and R_L are assumed to pass through the actuator pivot.

The link keeps the louver control rod parallel to the horizontal reference axis.

The link load, P_L, is reacted by the lug on fan structure.

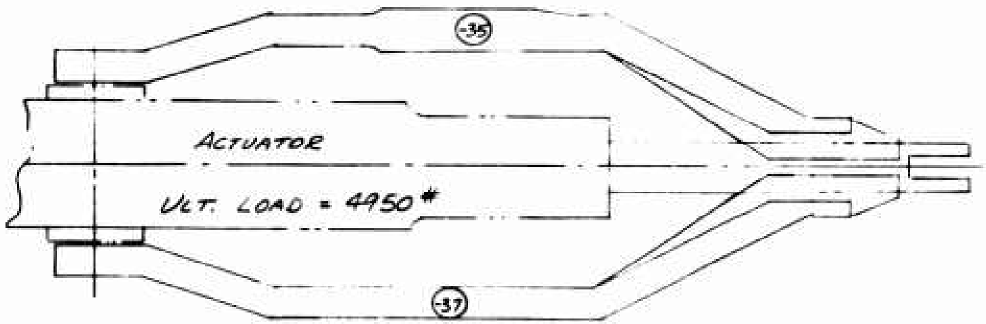
V and H are loads applied to the fan structure lugs. + V is up and + H is aft with respect to airplane reference axes.

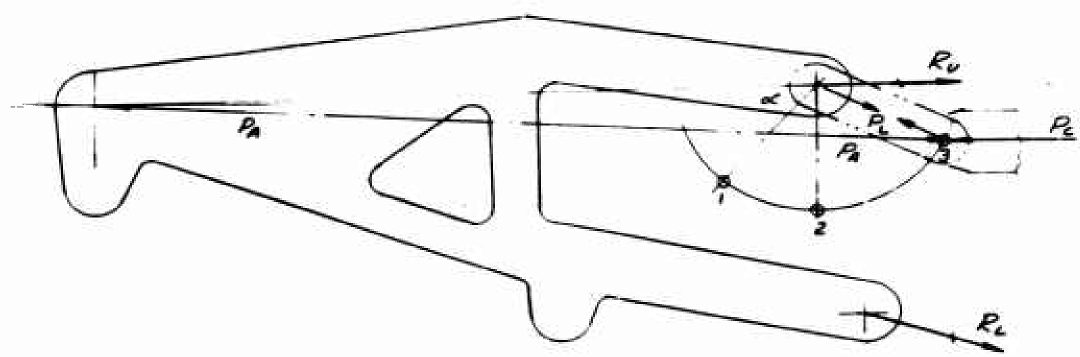
R_U, R, P_L and P_C are determined graphically.

TOTAL LOADS (BOTH BRACKETS)
AFT ACTUATOR

ITEM		ACTUATOR POSITION		
		1	2	3
R_U	1	3180	2000	3770
R_L	2	1840	3020	1230
P_L	3	1280	1000	880
P_C	4	6040	4860	4180
α	5	28.5°	90°	150°
$-P_L \sin \alpha$	6	-611	-1000	-440
$P_L \cos \alpha$	7	1127	0 0	-762
$R_U \sin 1.5°$	8	83	52	99
$R_U \cos 1.5°$	9	3180	2000	3770
V_U 6 + 8	10	-528	-948	-341
H_U 7 + 9	11	4307	2000	3008
$V_L = R_L \sin 20°$	12	630	1032	421
$H_L = R_L \cos 20°$	13	1730	2840	1157

WING EXIT LOUVER CONTROL (DWG. 143H003)





FWD. ACTUATOR

WING EXIT LOUVER CONTROL

TOTAL LOAD (BOTH BRACKETS)
FWD. ACTUATOR

ITEM		ACTUATOR POSITION 1	2	3
R_U	1	2470	2100	3800
R_L	2	2510	2900	1200
P_L	3	890	800	580
P_C	4	5490	4880	4430
α	5	50°	90°	153°
$-P_L \sin \alpha$	6	-681	-800	-263
$-P_L \cos \alpha$	7	-572	0	516
$-R_U \sin 2°$	8	-86	-73	-133
$-R_U \cos 2°$	9	-2470	-2100	-3800
V_U 6 + 8	10	-767	-873	-396
H_U 7 + 9	11	-3042	-2100	-3284
$V_L = +R_L \sin 17°$	12	735	850	352
$H_L = -R_L \cos 17°$	13	-2400	-2770	-1148

V and H are load applied to fan structure lugs (+V is UP and +H is AFT).

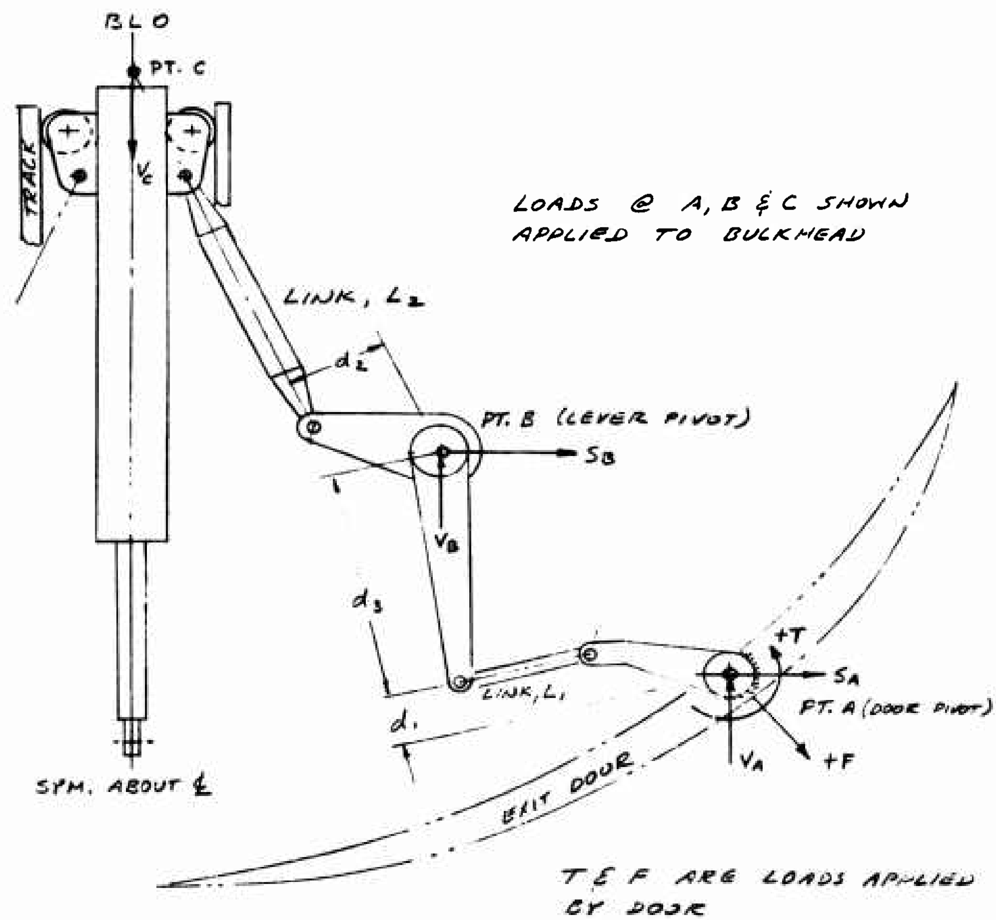
PITCH FAN EXIT DOOR CONTROL

The main linkage component between the pilot controls and the pitch fan exit door servo is the pitch mixer assembly (Ryan Drawing 143C008-3) located centrally in the fuselage underneath the electrical compartment at Sta. 142 to Sta. 154. This assembly sums up independent mechanical inputs of pitch and lift control. Output displacements of the pitch mixer are fed through push rods to the nose exit door servo (see Ryan Drawing 143H004), located approximately at fuselage Sta. 91.00.

To provide artificial pilot feel for pitch during hovering, the mixer contains a feel spring package. In conjunction, an electrical pitch trim actuator is provided to align the spring package zero position with the pilot's conventional (pitch) stick within the trim band. The actuator also has a linear pot for position readout on the instrument panel (VTOL trim indicator). Limit switches are also installed for integrator cutout of the pitch stability augmentation channel when large pitch commands are made.

The servo actuator is located on the center-line and controls both doors through mechanical linkage as shown on the following page. The upper end of the actuator rolls on a track and the lower end is attached to the fuselage. The only stops in the system are contained within the actuator, and therefore, the only loads applied to the mechanism result from airload on the doors. Two conditions are considered; maximum torque at 45° open and an intermediate condition.

PITCH FAN EXIT DOOR CONTROL (DWG. 143H004)



PISTON AREA = 1.17 IN² (TWO IN TANDEM)

ULT. CAPACITY = 2 × 1.17 × 3000 × 1.5 = 10500 #

PITCH FAN EXIT DOOR CONTROL

COND. I — DOOR 45° OPEN

$F = 1500^{\#}$ $T = 6000''^{\#}$

$d_1 = 3.95$ $d_2 = 4.55$ $d_3 = 7.03$

$L_1 = 6000/3.95 = -1520^{\#}$

$L_2 = 1520 \times \frac{7.03}{4.55} = -2345^{\#}$

ACTUATOR LOAD $= 2 \times 2345 \cos 20° = -4410^{\#} = V_C$

$V_A = 176^{\#}$ $V_B = -3227^{\#}$
$S_A = 804^{\#}$ $S_B = -310^{\#}$

COND. II — DOOR 81° OPEN

$F = 750^{\#}$ $T = 4500''^{\#}$

$d_1 = 3.25$ $d_2 = 4.50$ $d_3 = 7.48$

$L_1 = 4500/3.25 = -1383^{\#}$

$L_2 = 1383 \times \frac{7.48}{4.50} = -2300^{\#}$

ACTUATOR LOAD $= 2 \times 2300 \cos 24° = -4200^{\#} = V_C$

$V_A = 868^{\#}$ $V_B = -3220^{\#}$
$S_A = 438^{\#}$ $S_B = 123^{\#}$

COLLECTIVE (LIFT) STICK (DWGS. 143C043 and 143K002)

The pilot's collective stick is mechanically linked to both mixers so as to apply pilot lift commands simultaneously to wing exit louvers and pitch fan exit door. The collective stick has no direct linkage connection to the conventional system. During transition to conventional flight, its output linkage to the pitch and mechanical mixer is made ineffective by the interconnect cable (Ryan Drawing 143C 021) to the thrust vector actuator and the cam and override spring arrangement in the mechanical mixer.

The maximum load applied by the pilot is reacted at the idler stop. Stop condition loads are shown on the following page. Loads in the mechanical linkage from the idler to the mixers are relatively small.

COLLECTIVE STICK (DWGS. 143K002 and 143C043)