HUGHES TOOL COMPANY · AIRCRAFT DIVISION

Culver City, California

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HOT CYCLE ROTOR SYSTEM
VOLUME III
HUB AND CONTROL SYSTEM STRUCTURAL ANALYSIS

March 1962

HUGHES TOOL COMPANY -- AIRCRAFT DIVISION
Culver City, California

For

Commander

Aeronautical Systems Division

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VOLUME III

ROTOR HUB AND CONTROL SYSTEM STRUCTURAL ANALYSIS

CONTENTS

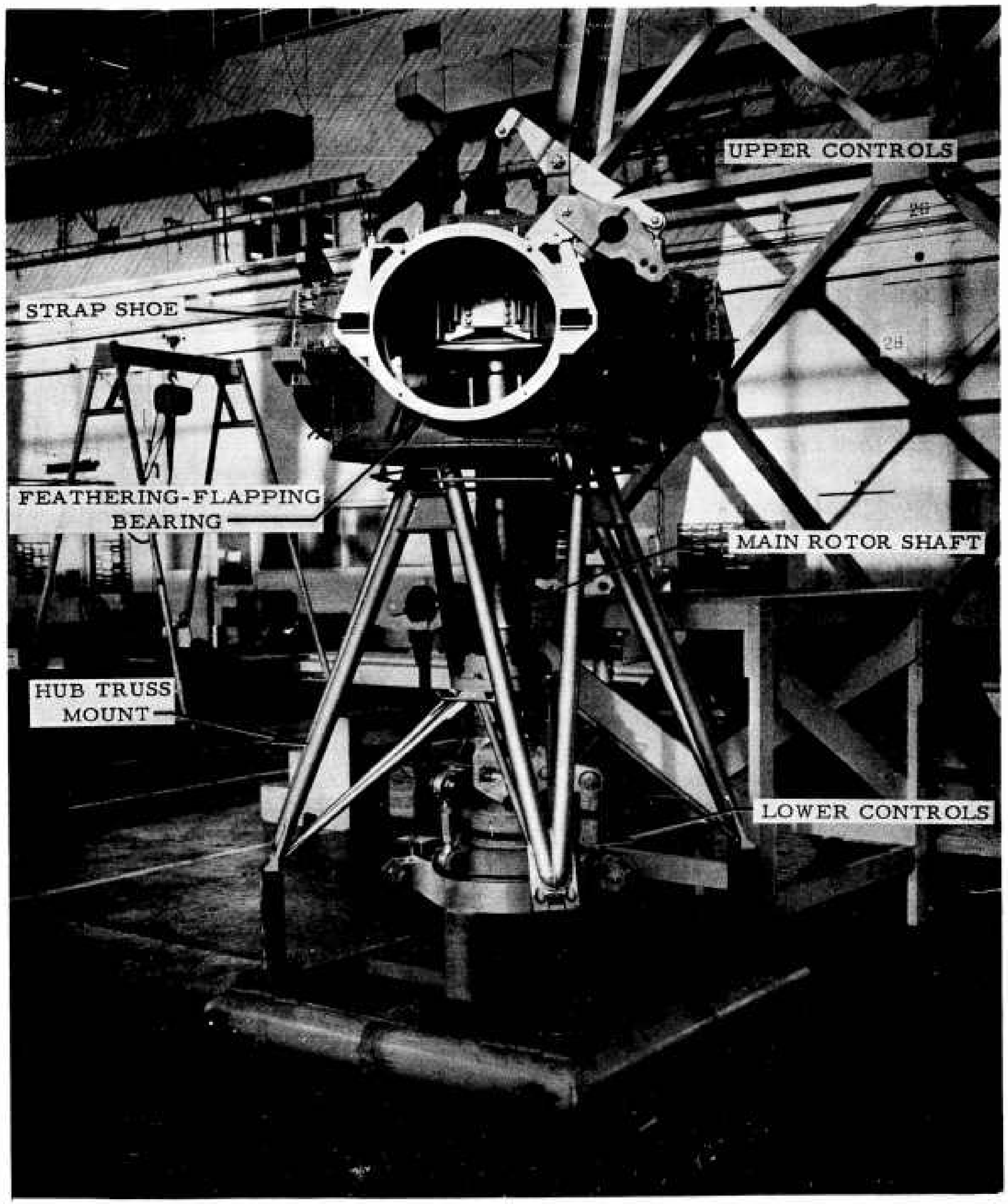


Figure 5. 3-1. Hot Cycle Rotor Hub

5.3 ROTOR HUB

5.3.1 INTRODUCTION

THE ROTOR HUB CONSISTS OF THE HUB STRUCTURE, THE UPPER (ROTATING) AND LOWER (STATIONARY) DUCTS, MAIN ROTOR SHAFT, TRUNNION, GIMBAL FITTINGS, SPOKE AND THE UPPER AND LOWER MAIN ROTOR SHAFT BEARINGS.

THIS SECTION IS DIVIDED INTO 3 SUB-SECTIONS COVERING HUB STRUCTURE ANALYSIS, HUB DUCTS ANALYSIS AND MAIN ROTOR SHAFT ANALYSIS, EACH WITH THEIR RELATED COMPONENTS.

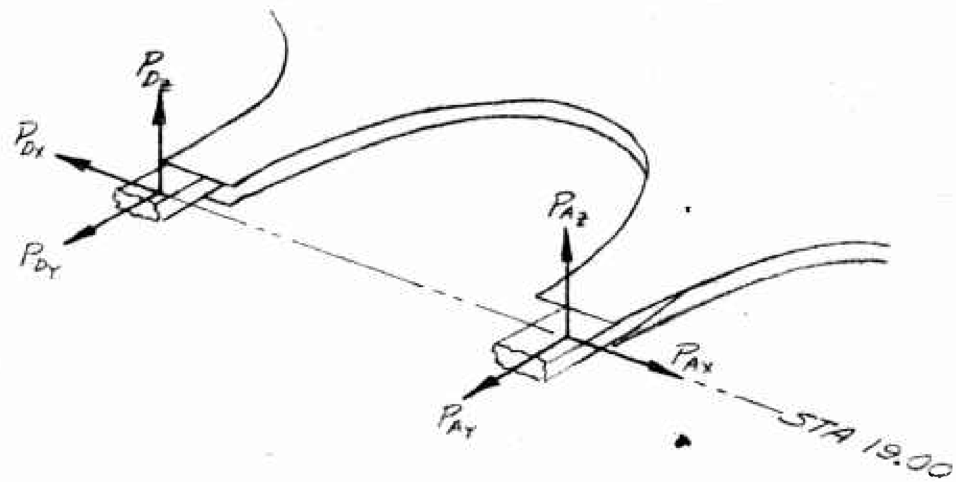
5.3.2 HUB ANALYSIS (HUB STRUCTURE)

THE HUB STRUCTURE PROVIDES THE ROOT MOUNTING STRUCTURE FOR THE ROTOR BLADES, THE INBOARD MOUNTING FOR THE BLADE STRAPS AND ARTICULATING DUCTS AS WELL AS THE FEATHERING BEARING HOUSING.

LOADS, WITH THE EXCEPTION OF THE GROUND FLAPPING CONDITION, ARE APPLIED TO THE HUB FROM EACH BLADE AND BALANCED OUT THRU THE HUB STRUCTURE.

FOR SIMPLIFICATION THE ANALYSIS IS DIVIDED INTO UPPER AND LOWER HUB SECTIONS. ULTIMATE AND WEIGHTED FATIGUE ANALYSES ARE INVESTIGATED AND, WHERE APPLICABLE, THE GROUND FLAPPING CONDITION.

5.3.2.1 LOADING CONDITIONS
LOWER HUB SECTION

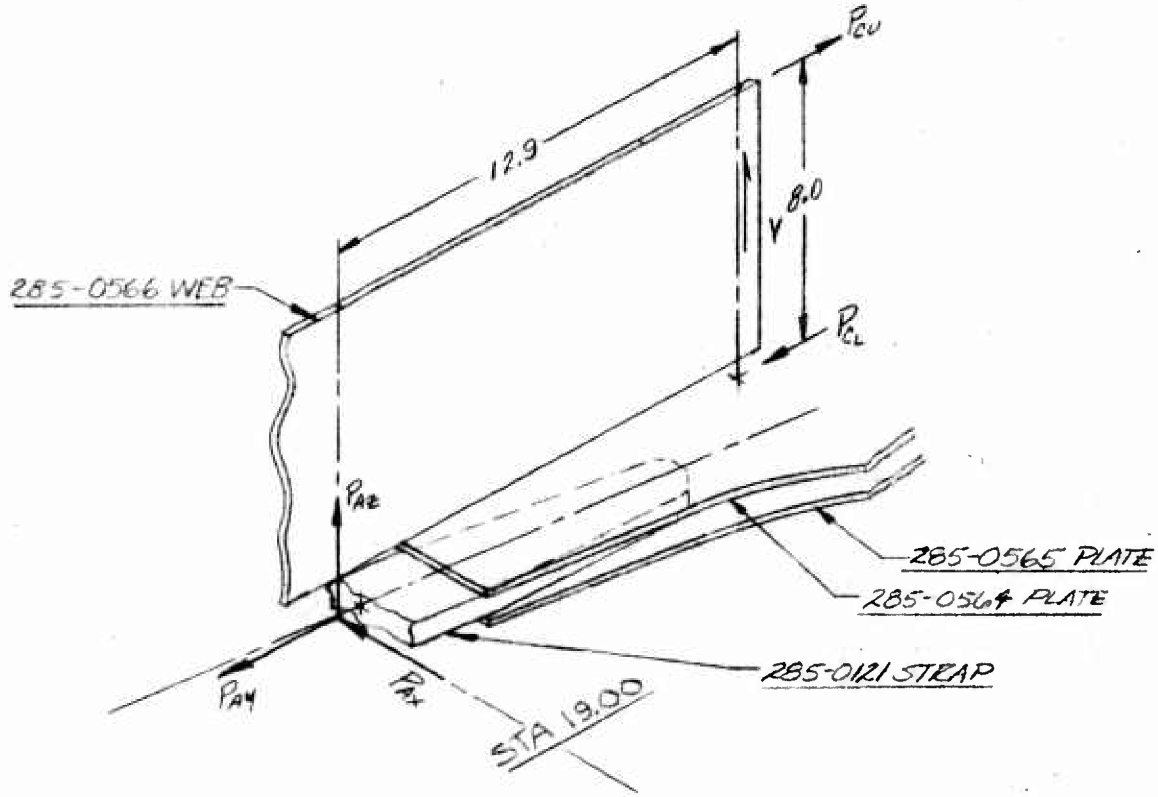


CONDITION	P_{Ax}	P_{AY}	P_{Az}	P_{Dx}	P_{DY}	P_{Dz}
2½ G MANEUVER	+5440 ±1330	+48000 ±11,750	+9900 ±2420	−4160 ±1020	+48000 ∓11,750	+6400 ∓1560
WEIGHTED FATIGUE	+5440 ±432	+48000 ±3820	+7420 ±787	−4160 ±331	+48000 ∓3820	+5760 ∓508

NOTES: REF - STRAPS ANALYSIS, SECTION 4
LOADS INBOARD OF STA 19.00 (REF SECTION 4)
1) WT. FATIGUE - $P_{Ax} + P_{Dx} = 200 \pm 520$ # LIM
2) 2½G MAN - $P_{Ax} + P_{Dx} = 100 \pm 1550$ # LIM
FOR PURPOSES OF THIS ANALYSIS, $P_{Ax} + P_{Dx}$ WILL BE EQUALLY DISTRIBUTED TO EACH SIDE.

HUB ANALYSIS

5.3.2.2 LOADS DISTRIBUTION - LOWER HUB SECTION



$$P_{CU} = P_{CL} = \frac{P_{AZ}(12.9)}{8.0}$$

$2\frac{1}{2}G$ MANEUVER CONDITION

$$P_{CU} = P_{CL} = \frac{(9900+2420)(12.9)}{8.0}(1.5) = 29810\# \text{ ULT}$$

WEIGHTED FATIGUE COND

$$P_{CU} = P_{CL} = \frac{(7420 \pm 787)(12.9)}{8.0} = 11950 \pm 1270\# \text{ LIM}$$

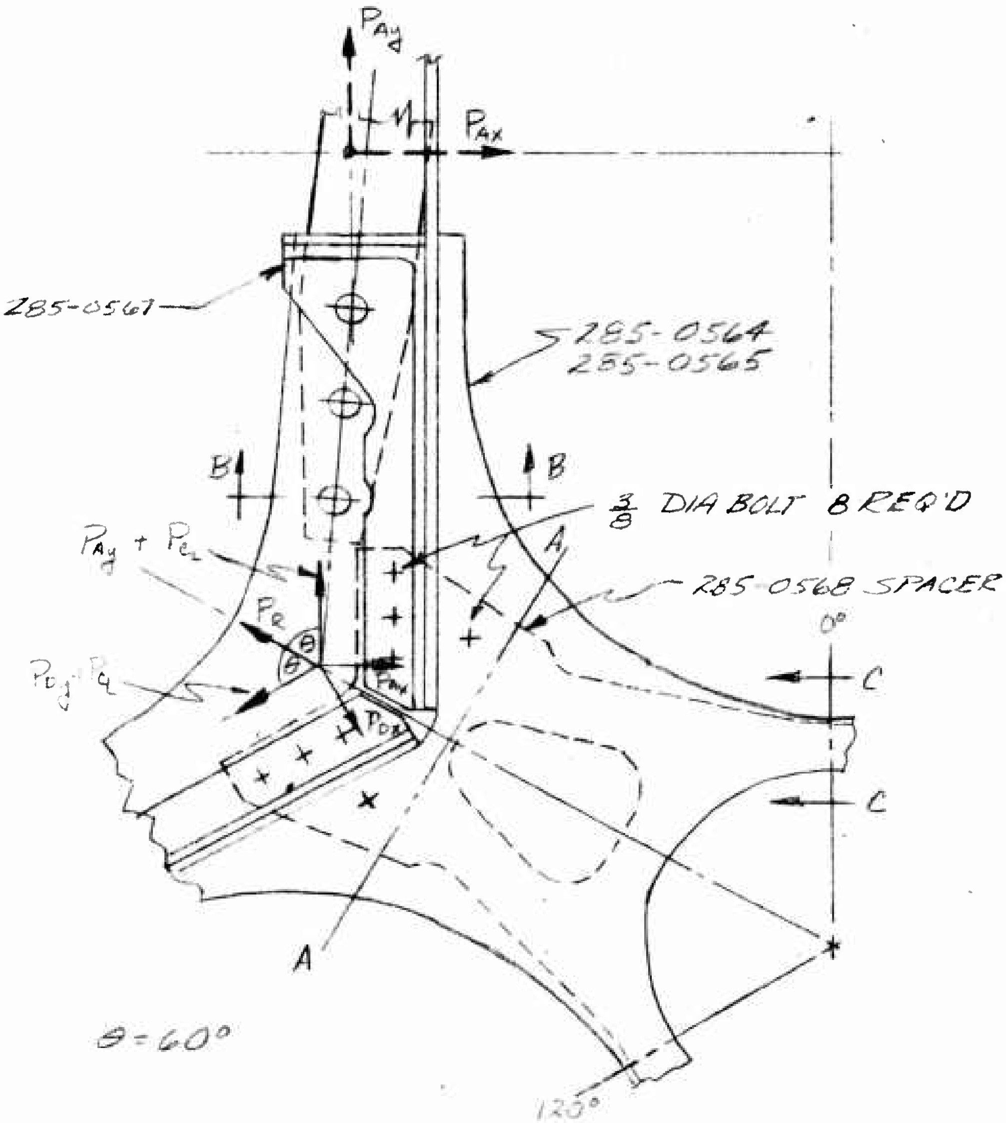
GROUND FLAPPING COND

$$P_{CU} = P_{CL} = \frac{99000}{8.0} = 12,400\# \text{ ULT}$$

HUB ANALYSIS

LOADS DISTRIBUTION - LOWER HUB SECTION

(CONT'D)



CONSIDER THAT AT SECT. A-A THE STRESS LEVELS IN THE DETAIL PLATES ARE BASED ON PLATE THICKNESS. THE LOAD CARRIED BY THE BOLTS IS THEN THAT PORTION OF THE TOTAL LOAD TRANSFERRED TO THE -0568 PLATE THE REST OF THE LOAD REMAINING IN THE OUTER PLATES.

5.3.2.3 2½G MANEUVER COND. - LOWER HUB SECTION

STRAP ATTACH BOLTS ~

ARBITRARILY DISTRIBUTE LOAD TO BOLTS AS FOLLOWS:

AXIALLY { 40% TO END BOLTS
20% TO CENTER BOLT

LATERALLY - 33⅓% TO EACH BOLT

END BOLTS .625 DIA H.T. 160-180 KSI

$$.4P_{A_y} = (.4)(48000 + 11{,}750) = 23{,}900\# \text{ (LIMIT)}$$

$$\frac{1}{3}P_{A_x} = (\tfrac{1}{3})(100 + 1550) = 550\#$$

$$P_{A_{BOLT}} = (23{,}900 + 550)1.5 = 35{,}900\# \text{ (ULT)}$$

$$P_{ALLOW(BOLT)} = 58{,}300\# \text{ (REF 1)} \qquad M.S. = \frac{58{,}300}{35900} - 1 = \underline{.62}$$

BOLT BEARING ON SHEET (MAT'L - 4130 STL H.T. 140-160 KSI)

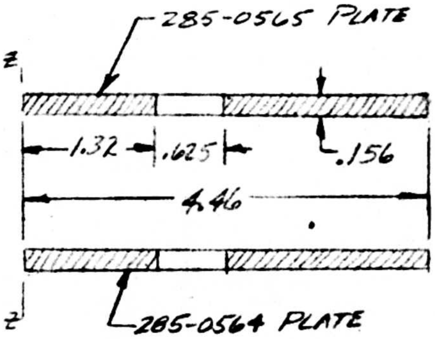
$$t_{SHEET} = 2(.156)$$

$$f_{br} = \frac{35{,}900}{(2)(.156)(.625)} = 184{,}000 \text{ PSI (ULT)}$$

$$F_{bru} = 251{,}000 \text{ PSI (REF 1)}$$

$$M.S. = \frac{251{,}000}{184{,}000} - 1 = \underline{.36}$$

SECTION B-B - PLATE STRESSES ~



SECTION LOADING - COMBINED BENDING & TENSION

MAT'L - 4130 STL H.T. 140-160 KSI

$$A = (.156)(4.46 - .625)(2) = 1.197 \text{ IN}^2$$

$$N.A. = \frac{(4.46)(.312)(2.23) - (.625)(.312)(1.63)}{1.197} = 2.33 \text{ IN}$$

$$I_{zz} = \frac{(.312)(4.46)^3}{3} - (.625)(.312)(1.63^2) = 8.706 \text{ IN}^4$$

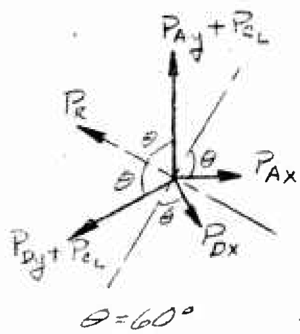
$$I_{NA} = 8.706 - 1.197(2.33)^2 = 2.212 \text{ IN}^4$$

$$f_t = \frac{(48000 + 11{,}750)(1.5)}{1.197} = 74{,}900 \text{ PSI ULT}$$

$$f_b = \frac{P_{Ax}(8.5)(2.33)}{I_{BB}} = \frac{(100 + 1550)(8.5)(1.5)(2.33)}{2.212} = 22{,}160 \text{ PSI (ULT)}$$

$$f_{t_{TOTAL}} = 74{,}900 + 22{,}160 = 97{,}060 \text{ PSI (ULT)} \qquad M.S. = \frac{140{,}000}{97{,}060} - 1 = \underline{.44}$$

2½ G MANEUVER CONDITION - LOWER HUB SECTION (CONT'D)



$$P_{C_L} = \frac{(9900+2420)(12.9)}{8.0}(1.5) = 29{,}810$$

$$P_{Ay} = P_{Dy} = (1.5)(48000+11{,}750) = 89{,}625\# \text{ (ULT)}$$

$$P_{Ax} = P_{Dx} = (1.5)(100+1550) = 2475\# \text{ (ULT)}$$

$$P_R = (P_{Ay}+P_{Dy}+2P_{C_L})\cos 60° - (P_{Ax}+P_{Dx})\sin 60°$$

$$= [(2)(89{,}625)+(2)(29{,}810)](.500) - (2)(2475)(.866)$$

$$P_R = 130{,}150\# \text{ ULT}$$

LOAD DISTRIBUTION TO PLATES ~

-0564 & -0565 PLATES -

$$P_{R_1} = \frac{.31}{(.31+.56)} P_R = .356 P_R$$

-0568 PLATE

$$P_{R_2} = \frac{.56}{.87} P_R = .644 P_R$$

THRU THE BOLT PATTERN ATTACHING PLATES -

$$P_{EXT} = \frac{(.644)(130{,}150)}{8} = 10{,}600\# \text{ ULT}$$

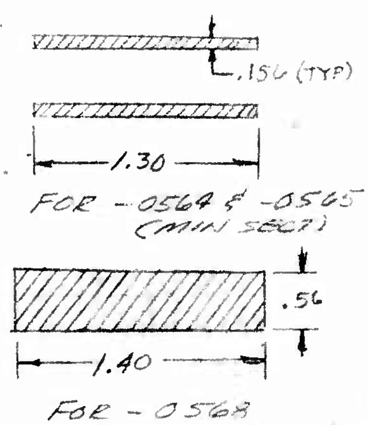
(8) $\frac{3}{8}$ DIA BOLTS H.T. 160-180 KSI

$$F_{ALLOW\,(BOLT)} = 21{,}000\# \text{ (REF 1)}$$

$$M.S. = \frac{21{,}000}{10{,}600} - 1 = \underline{.98}$$

SECTION C-C

AT THIS SECTION, $P = \frac{P_R}{2}$.



-0564 & -0565 PLATES, MAT'L - 4130 STL, H.T. 140-160 KSI

$$P = \frac{(.356)(130{,}150)}{2} = 23{,}170$$

$$f_t = \frac{23{,}170}{(.312)(1.3)} = 57{,}120 \text{ PSI}$$

-0568 PLATE - MAT'L - 4130 STL, H.T. 140-160 KSI

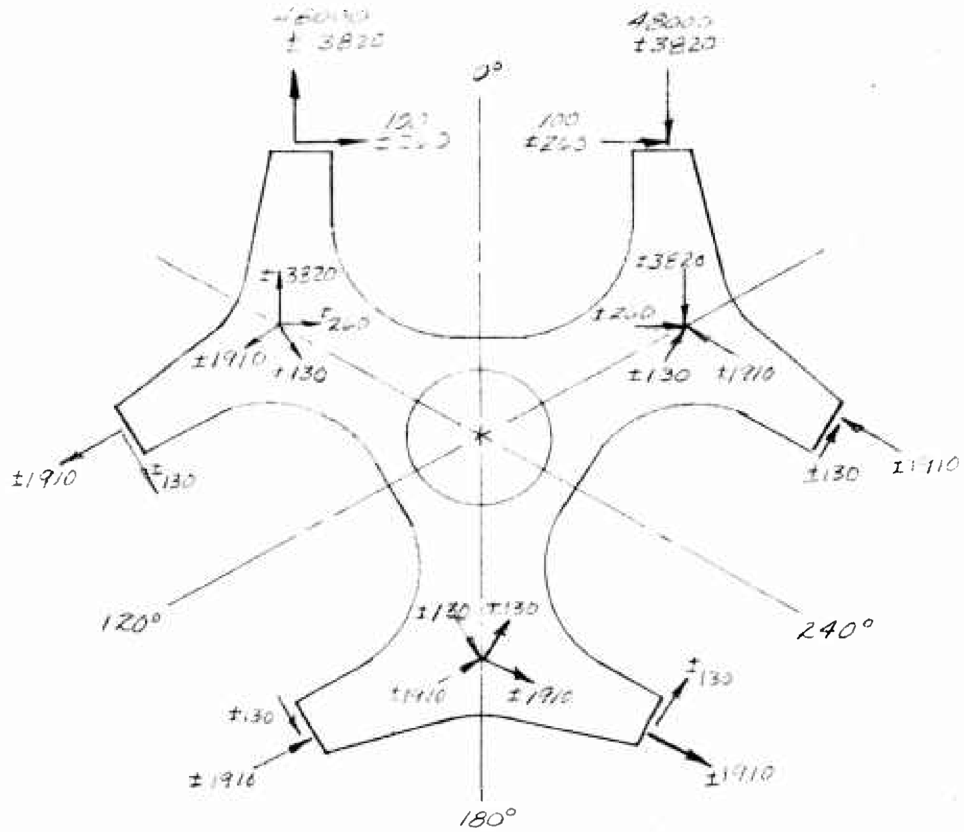
$$P = \frac{(.644)(130{,}150)}{2} = 41{,}900\#$$

$$f_t = \frac{41{,}900}{(.56)(1.4)} = 53{,}500 \text{ PSI}$$

$$M.S. = \frac{140{,}000}{53{,}500} - 1 = \underline{1.62}$$

HUB ANALYSIS

5.3.2.4 WEIGHTED FATIGUE CONDITION - LOWER HUB SECTION



WEIGHTED FATIGUE CONDITION - LOWER HUB SECTION (CONT'D)

STRAP ATTACH BOLTS ~

ARBITRARILY DISTRIBUTE 40% OF AXIALLY LOAD TO END BOLTS AND 20% TO CENTER BOLT LATERALLY, 33⅓% TO EACH BOLT.

END BOLTS ~

$$P_{BOLT} = (.40)(48000 \pm 3820) = 19,200 \pm 1528$$

BOLT BEARING ON SHEET ~

$$A_{br} = 2(.156)(.625) = .195 \text{ IN}^2$$

$$f_{br} = \frac{19,200 \pm 1528}{.195} = 98,461 \pm 7836 \text{ PSI}$$

SECTION B-B

AGAIN, SECTION IS SUBJECTED TO COMBINED BENDING & TENSION

$A = 1.197 \text{ IN}^2$

$I = 2.212$ $\quad P_{Ay} = 48000 \pm 3820$ #

$C = 2.33$ $\quad P_{Ax} = 100 \pm 260$ #

$$f_t = \frac{48000 \pm 3820}{1.197} = 40,100 \pm 3210 \text{ PSI}$$

$$f_b = \frac{(100 \pm 260)(8.5)(2.33)}{2.212} = 45 \pm 2330 \text{ PSI}$$

$$f_{t_{TOTAL}} = 40,150 \pm 5540 \text{ PSI}$$

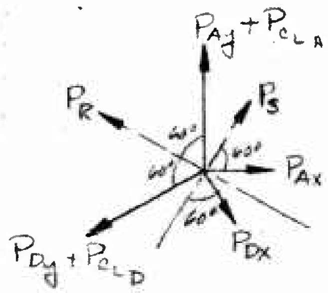
$F_{tc} = \pm 30,000$ PSI (SECT 2.8, FIG 2.8.1)

$K_t = 1.63$ (REF 4, FIG 86)

$$F_a = \frac{\pm 30,000}{1.63} = \pm 18400$$

$$M.S. = \frac{18400}{5540} - 1 = \underline{\underline{2.32}}$$

WEIGHTED FATIGUE CONDITION - LOWER HUB SECTION (CONT'D)



$$P_{C_{LA}} = \frac{(7420 \pm 787)(12.9)}{8.0} = 11{,}950 \pm 1270\#$$

$$P_{Ay} = 48{,}000 \pm 3820\#$$

$$P_{Ax} = 100 \pm 260\#$$

$$P_{Dy} = (48000 \pm 3820) \text{ SIN } 30° = 24000 \pm 1910\#$$

$$P_{Dx} = (100 \pm 260) \text{ SIN } 30° = 50 \pm 130\#$$

$$P_{C_{LD}} = \frac{(5760 \pm 508)(12.9)}{(8.0)} \text{ SIN } 30° = 4640 \pm 410\#$$

$$P_R = (P_{Ay} + P_{C_{LA}} + P_{Dy} + P_{C_{LD}}) \text{ COS } 60° - (P_{Ax} + P_{Dx}) \text{ SIN } 60°$$

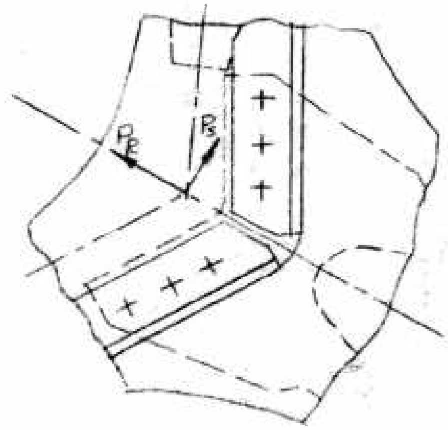
$$= \left[(48000 \pm 3820) + (11950 \pm 1270) + (24000 \pm 1910) + (4640 \pm 410)\right] \text{ COS } 60° - \left[(100 \pm 260) + (50 \pm 130)\right] \text{ SIN } 60°$$

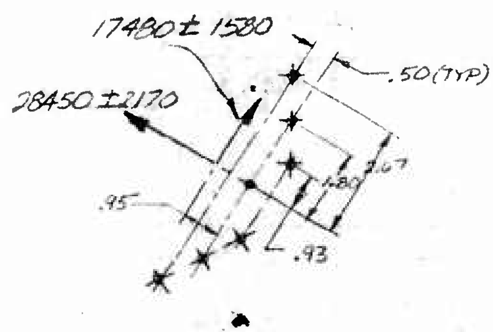
$$= 44{,}170 \pm 3370\#$$

$$P_S = \left[(P_{Ay} + P_{C_{LA}}) - (P_{Dy} + P_{C_{LD}})\right] \text{ SIN } 60° + \left[(P_{Ax} - P_{Dx})\right] \text{ COS } 60°$$

$$= \left[(48000 \pm 3820) + (11{,}950 \pm 1270) - (24000 \pm 1910) - (4640 \pm 410)\right] \text{ SIN } 60° + \left[(100 \pm 260) - (50 \pm 130)\right] \text{ COS } 60°$$

$$27{,}140 \pm 2460\#$$





BOLT PATTERN -

THE LOADS CARRIED BY THE BOLT PATTERN WILL BE THAT PORTION OF THE TOTAL LOADS CARRIED BY THE -0563 PLATE

$$P_{R_2} = \frac{.56}{.87}(44170 \pm 3370) = 28450 \pm 2170\#$$

$$P_{S_2} = \frac{.56}{.87}(27140 \pm 2460) = 17{,}480 \pm 1580\#$$

WEIGHTED FATIGUE CONDITION - LOWER HUB SECTION

DIRECT LOADS TO BOLTS -

$$P_{R/BOLT} = \frac{28,450 \pm 2170}{6} = 4740 \pm 360\#$$

$$P_{S/BOLT} \; \frac{17,480 \pm 1580}{6} = 2920 \pm 265\#$$

$$I_p = \sum(\bar{x}^2+\bar{y}^2) = (2)(.25+7.13)+(2)(0+3.24)+(2)(.25+.87) = 23.48$$

$$M_{\phi} = (.95)(17,480 \pm 1580) = 16,610 \pm 1500 \text{ "\#}$$

$$P_{R_M} = \frac{M\bar{y}}{I_p} \;;\quad P_{S_M} = \frac{M\bar{x}}{I_p}$$

FOR BOLT AT $x = .50$, $y = 2.67$

$$P_{R_M} = \frac{(16610 \pm 1500)(2.67)}{23.48} = 1890 \pm 170\#$$

$$P_{S_M} = \frac{(16610 \pm 1500)(.50)}{23.48} = 350 \pm 35\#$$

$$P_{R_{BOLT}} = (4740 \pm 360) + (1890 \pm 170) = 6630 \pm 530\#$$

$$P_{S_{BOLT}} = (2920 \pm 265) + (350 \pm 35) = 3270 \pm 300\#$$

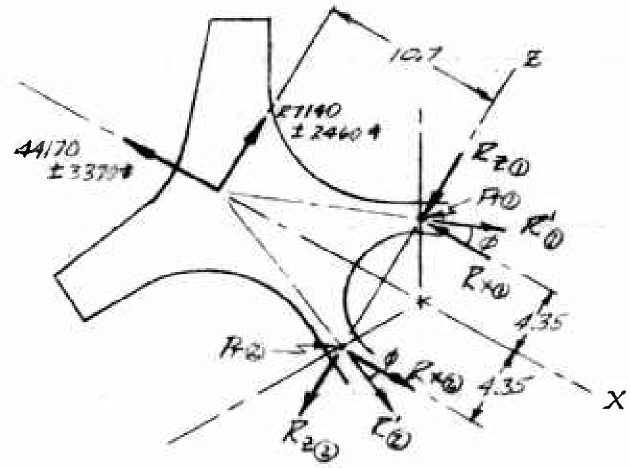
$$P_{BOLT} = (6630 \pm 530) \mapsto (3270 \pm 300) = 7390 \pm 610\#$$

(DOUBLE SHEAR)

$$A_{br} = (.156)(2)(.312) = .097 \text{ in}^2$$

$$f_{br} = \frac{7390 \pm 610}{.097} = 76,200 \pm 6290 \text{ PSI}$$

WEIGHTED FATIGUE COND - LOWER HUB SECTION (CONT'D)

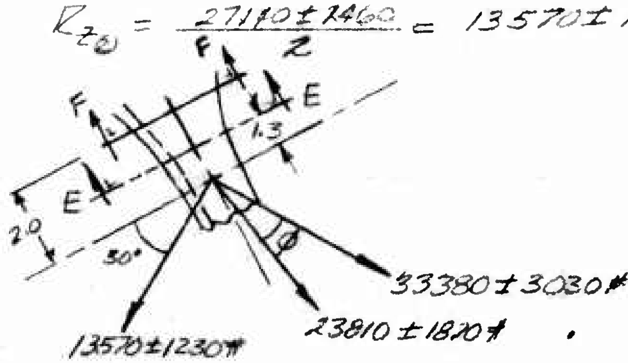


$\phi = 22°$

$$R'_{①} = R'_{②} = \frac{44170 \pm 3370}{2\cos 22°} = 23{,}810 \pm 1820\#$$

$$R_{x②} = \frac{(27140 \pm 2460)(10.7)}{(8.7)} = 33{,}380 \pm 3030\#$$

$$R_{z②} = \frac{27140 \pm 2460}{2} = 13570 \pm 1230\#$$

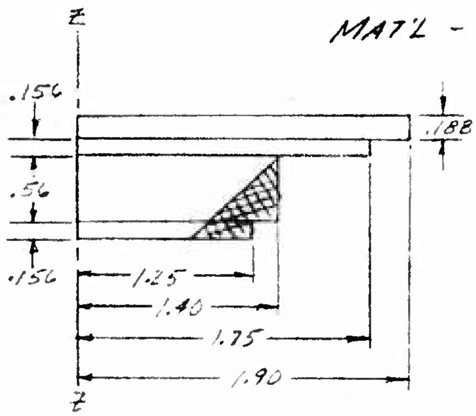


$$P_{t_{EE}} = (13570 \pm 1230)\sin 30° + (33380 \pm 3030)\cos 30° + (23810 \pm 1820)\cos 8°$$
$$= 59360 \pm 5040$$

$$M_{EE} = 1.3\left[(13570 \pm 1230)\cos 30° - (33380 \pm 3030)\sin 30° - (23810 \pm 1820)\sin 8°\right]$$
$$= -10730 \pm 915\ ''\#$$

WEIGHTED FATIGUE COND. - LOWER HUB SECTION (CONT'D)

MAT'L - 4130 STL H.T. 140-160 KSI



SECTION E-E

$A = (.188)(1.9) + (.156)(1.75 + 1.25) + (.56)(1.4)$

$A = 1.609\ IN^2$

$N.A. = \dfrac{(.188)(1.9)(.95) + (.156)(1.75)(.875) + (.56)(1.4)(.7) + (.156)(1.25)(.625)}{1.609}$

$N.A. = .776\ IN$

$I_{zz} = \dfrac{(.156)(1.25)^3 + (.156)(1.75)^3 + (.56)(1.4)^3 + (.188)(1.9)^3}{3}$

$I_{zz} = 1.323\ IN^4$

$I_{NA} = 1.323 - 1.609(.776)^2 = .354\ IN^4$

$f_{t_{ES}} = \dfrac{59360 \pm 5040}{1.609} + \dfrac{(10730 \pm 915)(1.9 - .776)}{.354}$

$f_{t_{ES}} = 70960 \pm 6037\ PSI\ LIMIT$

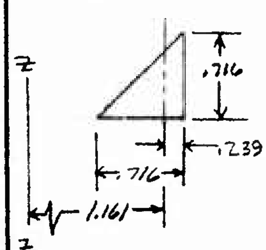
$F_{te} = \pm 22000\ PSI$ (REF FIG 2.8.1)

$M.S. = \dfrac{22000}{6037} - 1 = \underline{2.64}$

ADDENDUM 30 JAN 1961 —

ON INSTALLATION IT WAS FOUND NECESSARY TO CHAMFER A CORNER OF THE ASSEMBY AS INDICATED BY THE SHADED AREA SHOWN —

A 45° CHAMFER USED AND FOR SIMPLICITY ASSUME DIMS AS SHOWN AT LEFT.



$I_o = \dfrac{(.716)(.716)^3}{36} = \dfrac{.262}{36} = .0073\ IN^4$

$A = (.716)\left(\dfrac{.716}{2}\right) = .256\ IN^2$

$A\bar{y} = (.256)(1.161) = .297$

$\Sigma A\bar{y} = (1.609)(.776) - .297 = .950\ IN^3$

$A\bar{y}^2 = .345\ IN^4$ $\qquad A_{TOT} = 1.609 - .256 = 1.353\ IN^2$

$\bar{y} = \dfrac{.950}{1.353} = .701\ IN$

$I_{zz} = 1.353 - .007 - .345 = .971\ IN^4$

$I_{NA} = .971 - (.950)(.701) = .305\ IN^4$

$f_{t_{EE}} = \dfrac{59360 \pm 5040}{1.353} + \dfrac{(10730 \pm 915)(1.9 - .701)}{.305} = 86{,}000 \pm 7320\ PSI$

$F_{te} = \pm 17{,}800\ PSI$ (REF FIG 2.8.1) $\qquad M.S. = \dfrac{17800}{7320} - 1 = \underline{1.44}$

Weighted Fatigue Condition – Lower Hub Section (Cont'd)

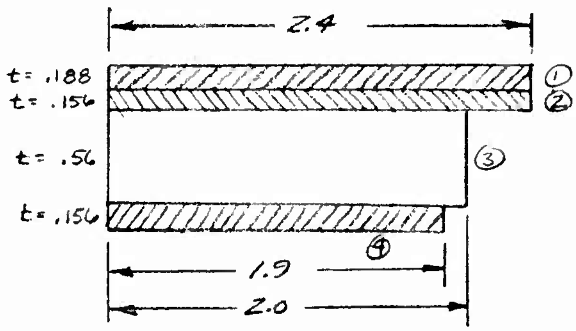
Section F-F at 2.0 in from ℄ – (Ref Pg 5.3.2.4.4)

$P_{T_{FF}} = 53960 \pm 5040$ # (Same as $P_{T_{EE}}$)

$M_{FF} = 2.0\left[(13570 \pm 1230)\cos 30° - (33380 \pm 3030)\sin 30° - (23810 \pm 1820)\sin 8°\right]$

$= 2.0\left[(11730 \pm 1065) - (16680 \pm 1515) - (3310 \pm 253)\right]$

$= -(16520 \pm 1410)$ "#



ITEM	A	AY	I_{BASE}
①	.4512	.5414	.8663
②	.3744	.4493	.7188
③	1.1200	1.1200	1.4933
④	.2964	.2816	.3567
Σ	2.2420	2.3923	3.4351

$\bar{Y} = \frac{2.3923}{2.2420} = 1.07$

$I_{NA} = 3.4351 - 2.3923(1.07) = .8753 \text{ in}^4$

$f_{t_{FF}} = \frac{59360 \pm 5040}{2.2420} + \frac{(16520 \pm 1410)(1.33)}{.8753}$

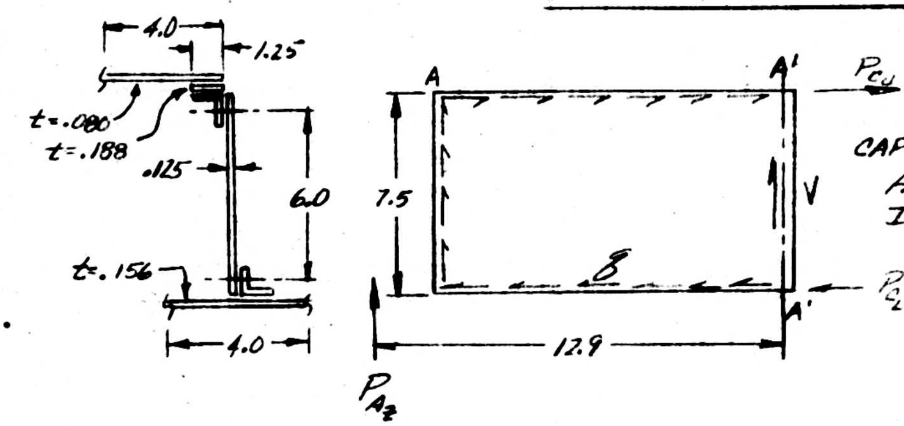
$= 51600 \pm 4390$ PSI

$F_{tc} = \pm 27000$ PSI (Ref Fig 2.8.1)

M.S. = High +

5.3.2.5 285-0566 WEB

MAT'L - 4130 STL H.T. 140-160 KSI



CAPS - 1.25 x 1.25 x .188
$A = .43\ IN^2$
$I = .059\ IN^4$

FOR THE CAPS -
1.25 x 1.25 x .188
$A = .43\ IN^2$
$I = .059\ IN^4$
$\rho = .38\ IN$

2½G MANEUVER CONDITION

$$P_{A_z} = (9900 \pm 2420)(1.5) = 14850 \pm 3630\#\ ULT$$

$$M_{A'-A'} = (9900 \pm 2420)(1.5)(12.9) = 191{,}500 \pm 46800\ ''\#\ ULT$$

$$q = \frac{V}{h} = \frac{14850 + 3630}{7.5} = 2464\ \#/IN\ (ULT)$$

$$f_s = q/t = \frac{2464}{.125} = 20{,}530\ PSI$$

$$f_b = \frac{Mz}{I} = \frac{(191{,}500 + 46{,}800)(3.75)}{28.86} = 30{,}960\ PSI$$

M.S. = HIGH +

WEIGHTED FATIGUE CONDITION

$$P_{A_z} = 7420 \pm 787\ \#$$

$$M_{A'A'} = (7420 \pm 787)(12.9) = 95720 \pm 10{,}150\ ''\#$$

$$q = \frac{V}{h} = \frac{7420 \pm 787}{7.5} = 990 \pm 105\ \#/IN$$

$$F_s = q/t = \frac{990 \pm 105}{.125} = 7920 \pm 840\ PSI$$

$$f_b = \frac{(95720 \pm 10150)(3.75)}{28.86} = 12430 \pm 1320\ PSI$$

$F_{te} = \pm 35000$ PSI (REF FIG 2.8.1)

M.S. = HIGH +

5.3.2.6 285-0567 FITTING – BEAM, SHOE ATTACH

MAT'L 4130 STL H.T. 140-160 KSI

* FITTING IS SUBJECTED TO THE CAP LOAD P_{CL} FROM THE LOWER HUB SECTION LOADS DISTRIBUTION AND FROM THE DIRECT LOAD PORTION OF THE DROOP STOP LOADING CONDITION. THE 2½G MAN. COND IS MAX.

ATTACHMENTS TO -0565 PLATE

SIX 5/16 DIA BOLTS

$q = 2464$ #/IN

$P_{TOTAL} = 12.9 \times 2464 = 31785\#$ ULT

BOLT $P_{ALLOW} = 7300\#$ (REF 1)

TOTAL $P_{ALLOW} = (6)(7300) = 43{,}800\#$

$$M.S. = \frac{43800}{31785} - 1 = \underline{.38}$$

ATTACHMENTS TO -0566 WEB

EIGHT 5/16 DIA BOLTS

OK BY INSPECTION

* NOTE. – INSTALLATION OF THIS PART SHOWN ON PAGE 5.3.2.2.1

5.3.2.7 285-0570 ANGLE MAT'L 4130 STL H.T. 125 KSI MIN

$P_{CAP} = q \times l = 2464(12.9) = 31{,}800$ # ULT (REF PG 5.3.2.5.0)

$A = .43\ IN^2$; $I = .059\ IN^4$; $\rho = .38\ IN$

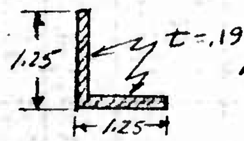
$f_c = \frac{31800}{.43} = 74{,}000$ PSI (ULT)

AS A COLUMN – (NOT INCLUDING SKIN OR WEB)

$F_c = 145{,}000 - 18.36\left(\frac{L'}{\rho}\right)^2$ (REF 1)

(SHORT COLUMN)

$\frac{L'}{\rho} = \frac{L}{\rho\sqrt{C}} = \frac{10.9}{.38\sqrt{1}} = 28.7$



ANGLE SECTION

$F_c = 145{,}000 - 18.36(28.7)^2 = 129{,}880$ PSI

$M.S. = \frac{129{,}880}{74000} - 1 = \underline{.75}$

ATTACHMENTS THRU ANGLE, SKIN & WEB

FASTENERS – $\frac{5}{16}$ DIA BOLTS (8)

$q = 2464$ #/IN (ULT) (REF PG 5.3.2.5.0)

$l = 12.9$ IN

$P_{TOTAL} = 12.9(2464) = 31800$ # (ULT)

$P_{ALLOW} = 8 \times 7300 = 58400$ #

$M.S. = \frac{58400}{31800} - 1 = \underline{.83}$

BOLT BEARING ON SKIN

SKIN $t = .090$

$P_{BOLT} = \frac{31800}{8} = 3973$ # (ULT)

DISTRIBUTE LOAD ACCORDING TO THICKNESS OF DETAILS

TOTAL THICKNESS = .090 + .188 + .188 = .466

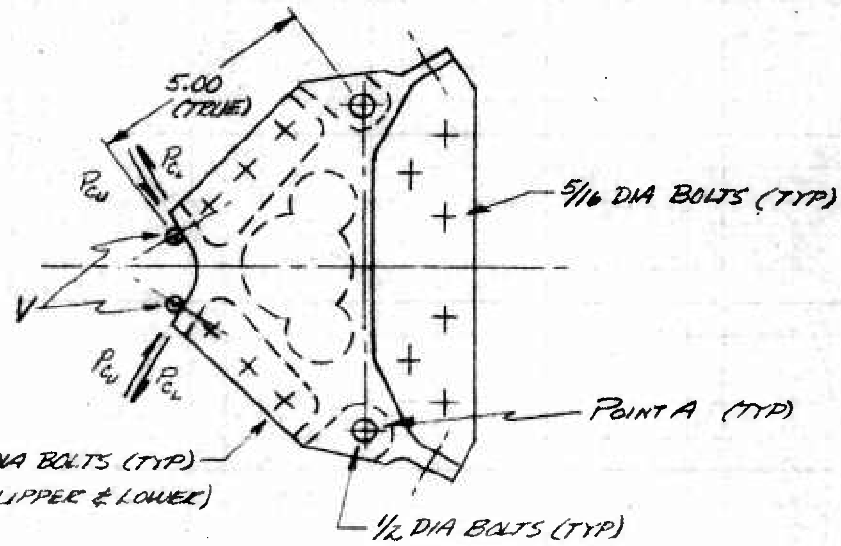
$P_{SKIN} = \frac{.090}{.466} \times 3973 = 767$ #

$A_{br} = .312 \times .090 = .028\ IN^2$

$f_{br} = \frac{767}{.028} = 27{,}400$ PSI ULT M.S. = HIGH +

$F_{bru} = 194{,}000$ PSI (REF 1)

5.3.2.8 285-0562 FITTING MAT'L 4130 STL H.T. 140-160 KSI



LOADS IN THE FITTING UNLOAD TO THE UPPER HUB STRUCTURE THRU THE SIX 5/16 DIA AND TWO 1/2 DIA BOLT ATTACHMENTS. THE VERTICAL LOAD, V, WILL PRODUCE A MOMENT ABOUT THE TWO 1/2 DIA BOLT CENTERS AND CAN BE RESOLVED INTO A COUPLE ADDING TO THE APPLIED COUPLE LOADS.

WEIGHTED FATIGUE CONDITION -

$P_{C_U} = P_{C_L} = 11{,}950 \pm 1270$ # (LIM) (REF PG 5.3.2.2.0)

$V = P_{A_Z} = 7420 \pm 787$ # (LIM) (REF PG 5.3.2.1)

$M_A = (7420 \pm 787)\,5.0 = 37{,}100 \pm 3940$ "# (LIM)

$$P_U = P_L = (11{,}950 \pm 1270) + \frac{37100 \pm 3940}{7.344} = 17{,}000 \pm 1810\text{\# LIM}$$

CYCLIC LOAD IS SMALL AND SO ANALYSIS OF THIS CONDITION IS DISCONTINUED.

$2\frac{1}{2}$ G MANEUVER CONDITION

$P_{C_U} = P_{C_L} = 29810$ # (ULT) (REF PG 5.3.2.2.0)

$$V = \frac{P_{A_Z} + P_{D_Z}}{2}(1.5) = \frac{(9900+2420)+(6400-1560)}{2}(1.5) = 12870\text{\# (ULT)}$$

$M_A = (12870)(5.0) = 64{,}350$ "# (ULT)

$$P_U = P_L = 29810 + \frac{64350}{7.344} = 38570\text{\# (ULT)}$$

285-0562 FITTING (CONT'D)

LOWER BOLT ATTACHMENTS —

SIX 5/16 DIA BOLTS EACH SIDE

$P_{BOLT} = \frac{38570}{6} = 6430\#$ (ULT)

$P_{ALLOW} = 7300\#$ (REF 1)

$M.S. = \frac{7300}{6430} - 1 = \underline{.13}$

UPPER BOLT PATTERN

THREE 5/16 DIA BOLTS ONE ½ DIA BOLT EACH SIDE

TOTAL $P_{ALLOW} = 3 \times 7300 + 18{,}650 = 40550\#$ (REF 1)

$M.S. = \frac{40550}{38570} - 1 = \underline{.05}$

SHEAR STRESS IN SIDE WALLS

MIN WALL THICKNESS = .14 IN

$h = 7.094$ IN

$A_s = (7.094)(.14) = .993 \text{ IN}^2$

$f_s = \frac{V}{A_s} = \frac{12870}{.993} = 12{,}950$ PSI (ULT) $M.S. = \underline{HIGH +}$

ATTACHMENT TO -0566 WEB (5) 5/16 DIA BOLTS

2½ G MAN. COND - ULT

$V = (9900 + 2420)(1.5) = 18{,}500\#$ ULT

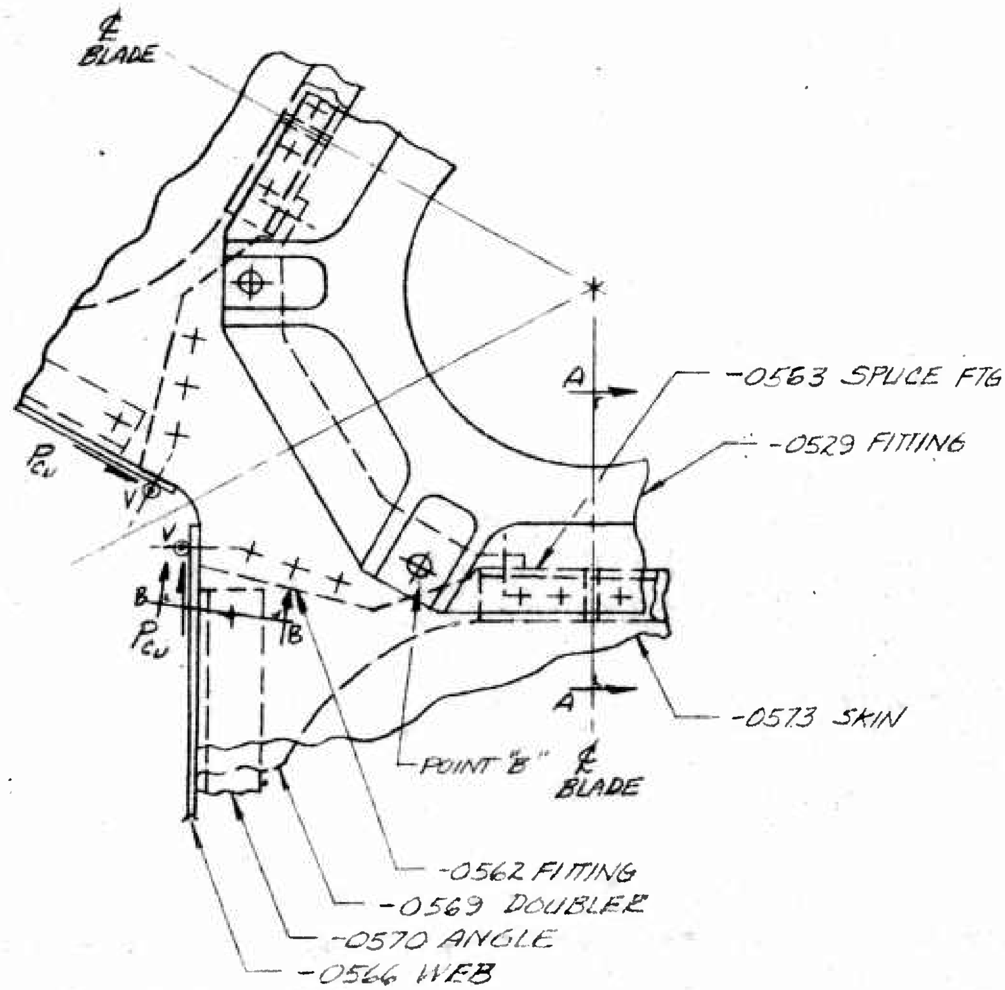
$P_{BOLT} = \frac{18500}{5} = 3700\#$

$P_{ALLOW} = 7300\#$ (REF 1)

$M.S. = \frac{7300}{3700} - 1 = \underline{.97}$

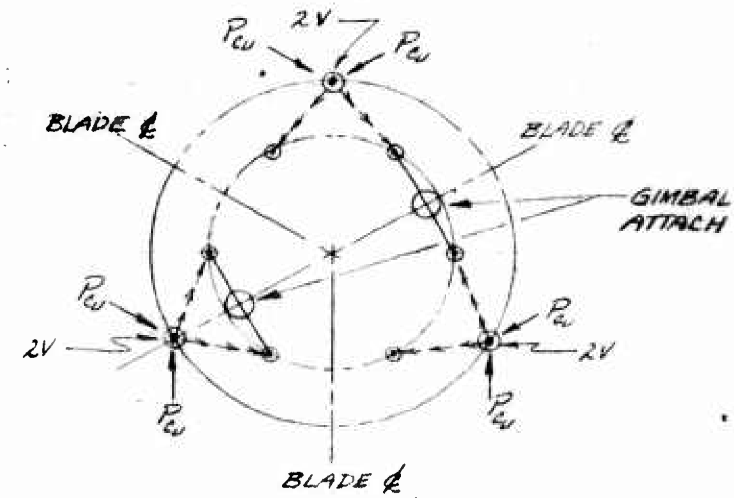
HUB ANALYSIS

5.3.2.9 LOADS DISTRIBUTION - HUB UPPER SECTION

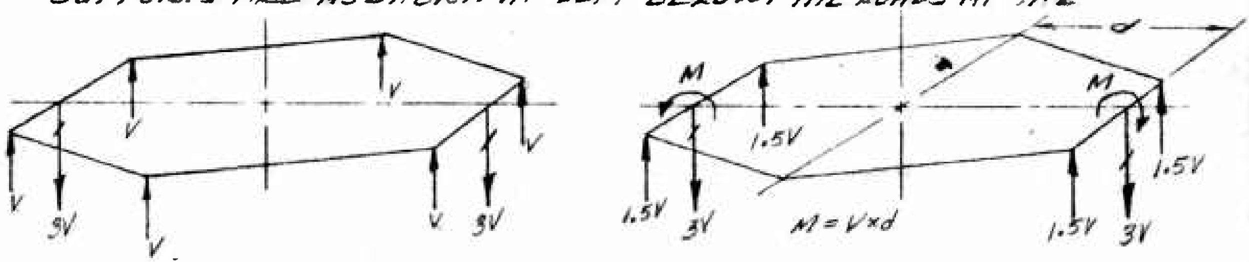


THE DISTRIBUTION ANALYSIS IS BASED ON THE ASSUMPTION LOADS ARE CARRIED THRU THE -0562 FITTING TO THE UPPER HUB STRUCTURE AND ACROSS TO THE BLADE CENTER-LINE WHERE THEY ARE BALANCED BY EQUAL AND OPPOSITE LOADS. ON THE BLADE ℄ THE LOADS WILL BE DISTRIBUTED TO THE SECTION ACCORDING TO THE THICKNESS OF THE FLANGES ON THE -0529 AND -0563 FITTINGS.

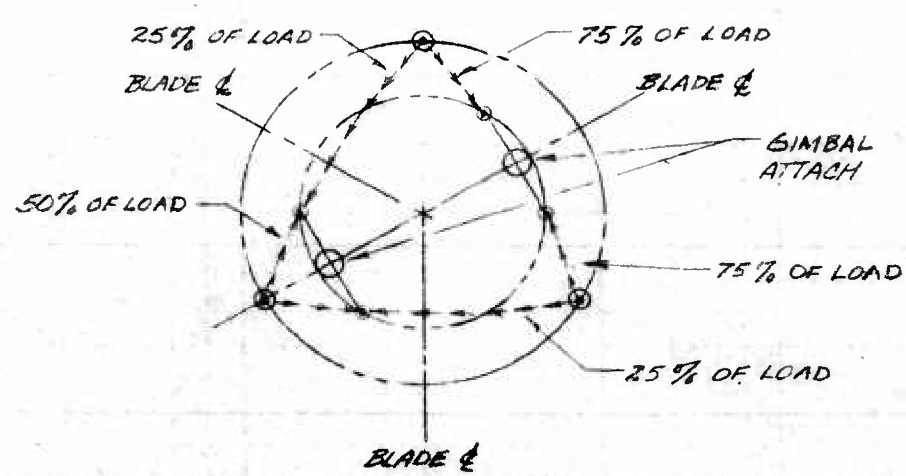
LOADS DISTRIBUTION - HUB UPPER SECTION (CONT'D)



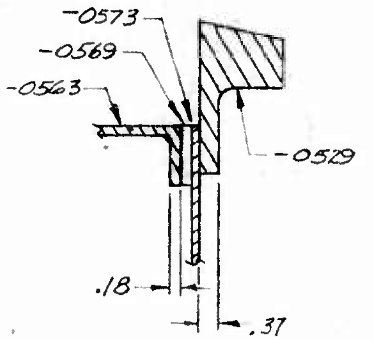
THE VERTICAL LOADS DISTRIBUTION AND REACTIONS AT THE GIMBAL SUPPORTS ARE AS SHOWN AT LEFT BELOW. THE LOADS AT THE



CENTER PLANE BETWEEN THE GIMBAL SUPPORTS ARE TRANSFERRED TO THE ENDS AS SHOWN AT RIGHT. THIS YIELDS A NEW LOADS PATH PICTURE AS SHOWN BELOW, ONE MORE NEARLY REPRESENTING THE ACTUAL LOAD PATHS IN THE STRUCTURE.



LOADS DISTRIBUTION HUB UPPER SECTION (CONT'D)



SECTION A-A
(REF PG 5.3.2.9.0)

AT SECTION A-A THE LOADING IS COMPRESSION. FROM THE ANALYSIS OF THE -0562 FITTING -

$$P_{COMP} = 38{,}570\ \#\ (ULT)$$

DISTRIBUTION OF THE LOAD WILL BE 67% TO THE -0529 FITTING AND 33% TO THE -0563 FITTING

THE VERTICAL LOAD, V, IS TAKEN OUT THRU THE $\frac{1}{2}$ INCH DIAMETER BOLT AT POINT "B."

FOR THE -0529 FITTING, $P_{COMP} = .67(38{,}570) = 25{,}700\#\ (ULT)$

FOR THE -0563 FITTING, $P_{COMP} = .33(38{,}570) = 12{,}860\#\ (ULT)$

SHEAR LOADS ON THE ATTACHMENTS ACROSS BLADE ℄

THRU THE -0529 FITTING -
3 ATTACHMENTS (1) $\frac{1}{2}$ DIA BOLT, (2) $\frac{3}{8}$ DIA BOLTS

DISTRIBUTING THE LOAD ACCORDING TO BOLT DIA:

$$\bar{3}^2 + \bar{3}^2 + \bar{4}^2 = 34$$

FOR THE $\frac{1}{2}$ DIA BOLT -

$$P_{BOLT} = \frac{\bar{4}^2}{34}(25700) = 12{,}100\#$$

$P_{ALLOW} = 18{,}650\#$ (REF. 1) $\quad M.S. = \frac{18650}{12{,}100} - 1 = \underline{.54}$

FOR THE (2) 3/8 DIA BOLTS -

THESE BOLTS CARRY THE REMAINDER OF THE LOAD IN DOUBLE SHEAR

$$P_{BOLT} = \frac{38590 - 12{,}100}{2} = 13{,}245\#$$

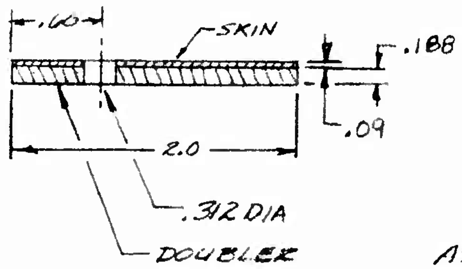
$P_{ALLOW} = 21{,}000\#$ (REF 1)

$$M.S. = \frac{21{,}000}{13245} - 1 = \underline{.58}$$

HUB ANALYSIS

LOADS DISTRIBUTION HUB UPPER SECTION

AT SECTION B-B, A WIDTH OF SKIN AND DOUBLER ARBITRARILY TAKEN AT 2.0 IN WIDE IS INVESTIGATED FOR COMPRESSIVE STRESSES. (REF PG 5.3.2.9.0)



SECTION B-B

MAT'L STEEL 4130
H.T. 140-160 KSI

$A_{SECT} = (2.0 - .312)(.188 + .090) = .469\ IN^2$

ASSUME ENTIRE CAP LOAD HAS UNLOADED INTO SKIN AND DOUBLER.

2½ G MANEUVER CONDITION P = 29810# ULT (REF PG 5.3.2.2.0)

$f_c = \frac{P}{A} = \frac{29810}{.469} = 63{,}560$ PSI ULT

$M.S. = \frac{160{,}000}{29810} = $ HIGH +

WEIGHTED FATIGUE CONDITION

P = 11,950 ± 1270 # LIM (REF PAGE 5.3.2.2.0)

$f_c = \frac{P}{A} = \frac{11950 \pm 1270}{.469} = 25840 \pm 2710$ PSI LIM

$F_{tc} = \pm 35000$ PSI (REF FIG 2.8.1) M.S. = HIGH +

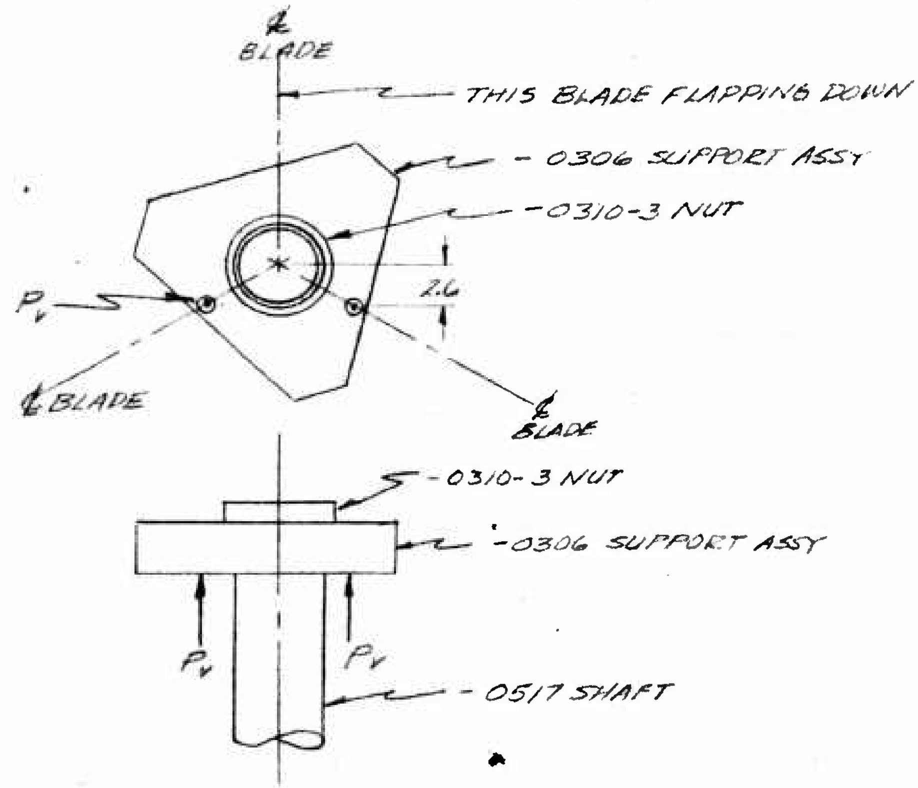
$K_t = 2.44$ (REF 4 FIG 71)

$F_2 = \frac{\pm 32000}{2.44} = \pm 13{,}000$ PSI

5.3.2.10 UPPER HUB SECTION - GROUND FLAPPING COND.

THE GROUND FLAPPING CONDITION, NOT PREVIOUSLY DISCUSSED IN THE HUB ANALYSIS, IS INTRODUCED AT THIS POINT. FOR THE 2° DROOP STOP A 2.0 G LIMIT FACTOR IS USED. THE GROUND FLAPPING MOMENT BASED ON A 2.5 G LIMIT FACTOR IS 125,810 "# (REF BASIC LOADS DATA, SECTION 4)

$$M_{G.F.} = \frac{2.0}{2.5}(125{,}810) = 100{,}650 \text{ "\# LIM}$$



THE BLADE FLAPPING DOWN CAUSES THE HUB TO TILT AND THE 2° STOPS TO CONTACT THE -0306 SUPPORT ASSY APPLYING THE LOADS P_V AS SHOWN. THE SUPPORT ASSY RESISTS FURTHER HUB TILT AND SO THESE LOADS PRODUCE COMPRESSION ON THIS SIDE OF THE UPPER HUB STRUCTURE. THESE LOADS ARE CARRIED BY THE -0529 FITTING ATOP THE UPPER HUB STRUCTURE AS COMPRESSION ON ONE SIDE AND TENSION ON THE OPPOSITE. THE TENSION LOADS ARE ADEQUATELY CARRIED BY THE .500 DIA BOLTS MOUNTING THE FITTING TO THE

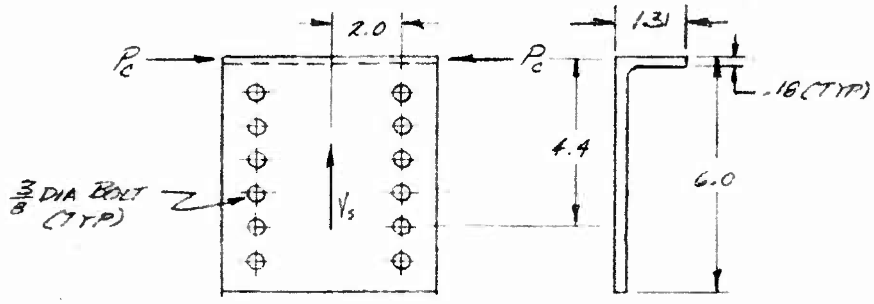
-CONT'D-

UPPER HUB SECTION - GROUND FLAPPING CONDITION

UPPER HUB STRUCTURE. THE COMPRESSION LOADS ARE CARRIED TO THE -0562 FITTINGS AND FROM THERE CARRIED AS SHEAR THRU THE -0563 SPLICE FITTINGS.

$$P_V = \frac{100,650\,(1.5)}{(2.6)\,(2)} = 29000\#\ \text{ULT}$$

5.3.2.11 285-0563 SPLICE FITTING
MAT'L 4140 STL H.T. 140-160 KSI



FROM THE LOADS DISTRIBUTION -

$P_c = 12860\#$ ULT (REF PG 5.3.2.9.2)

FOR THE FLANGE -

$f_c = \frac{12860}{(1.31)(.18)} = 54540$ PSI ULT

$F_a = 160{,}000$ PSI $M.S. = \frac{160{,}000}{54540} - 1 = \underline{1.94}$

SHEAR STRESS IN WEB -

$V_s = 29000\#$ ULT (GROUND FLAPPING COND.) (REF PG 5.3.2.10.1)

$f_s = \frac{(29000)}{(6.0)(.18)} = 26{,}800$ PSI ULT

$F_a = 95000$ PSI (REF 1) $M.S. = \frac{95000}{26800} - 1 = \underline{2.54}$

BENDING IN SECTION -

$M = (29000)(2.0) = 58000$ "# ULT

RESOLVE THE MOMENT INTO A COUPLE ACTING IN THE CAP AND AT THE CENTER OF LOWER SIX BOLTS IN THE BOLT PATTERN (4.4 IN)

$P_{COUPLE} = \frac{58000}{4.4} = 13{,}200\#$ ULT

HORIZONTAL LOAD IN EACH BOLT -

$P_H = \frac{13200}{3} = 4400\#$ ULT

VERTICAL LOAD IN EACH BOLT

$P_V = \frac{29000}{6} = 4840$

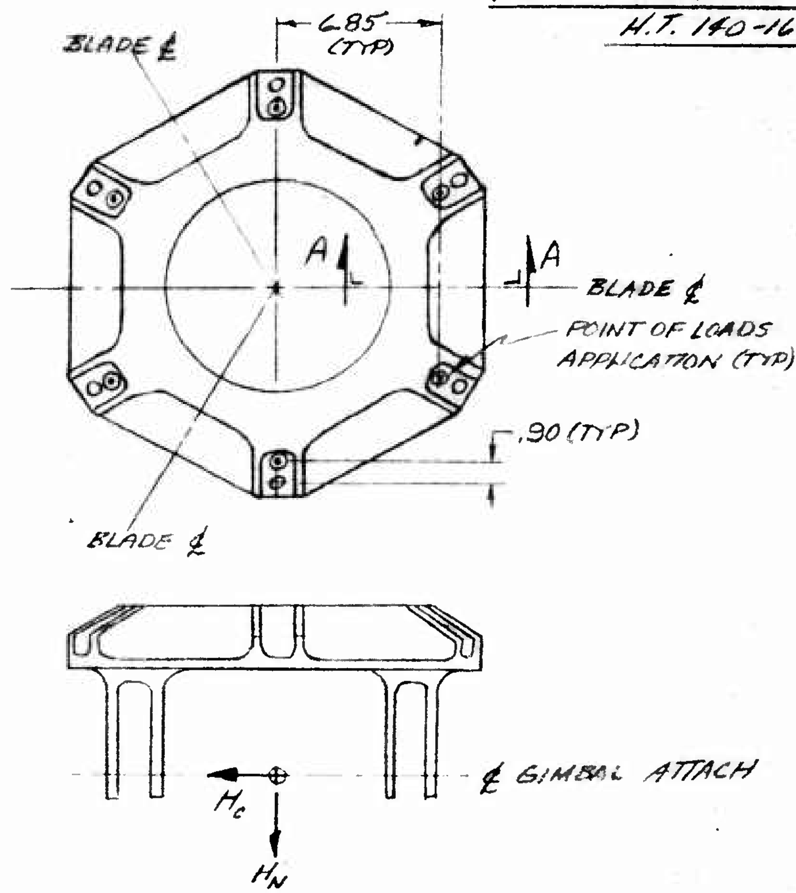
$P_{BOLT} = 4400 + \!\!\!\rightarrow 4840 = 6550\#$ ULT

$P_{ALLOW} = 11{,}500\#$ (REF 1) $M.S. = \frac{11{,}500}{6550} - 1 = \underline{.75}$

5.3.2.12 285-0529 FITTING

MAT'L - 4340 STL

H.T. 140-160 KSI



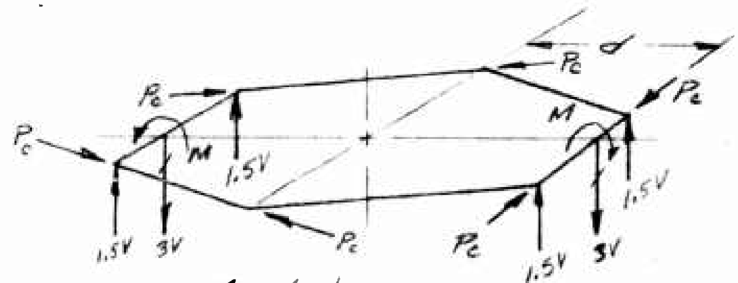
FROM BASIC LOADS - (REF SECTION 4)

2½G MANEUVER COND $H_C = 3675\#$ LIM
$H_N = 32840\#$ LIM

WEIGHTED FATIGUE COND $H_C = \pm 1050\#$ LIM
$H_N = 22950\#$ LIM

FROM THE LOADS DISTRIBUTION OF THE HUB UPPER SECTION THERE IS ALSO A COMPRESSION LOAD CARRIED TO EACH BLADE ℄ $P_{COMP} = 25700\#$ (ULT) (REF PG 5.3.2.9.2)

285-0529 FITTING (CONT'D)

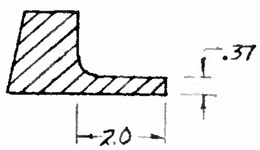


$M = V \times d$

$d = 6.85$ IN

THE UPPER SECTION OF THE FITTING WILL BE TREATED AS A RING WITH NORMAL LOADS AND REACTIONS AS SHOWN AND THE COMPRESSION LOADS CARRIED TO EACH BLADE ℄ AS EXPLAINED IN THE LOADS DISTRIBUTION. ULTIMATE CONDITION ONLY WILL BE ANALYZED.

THE COMPRESSION LOAD P_c ACTS ON SECTION A-A, TYPICAL AT EACH BLADE ℄. CONSERVATIVELY ASSUMING THAT ALL THE LOAD IS IN THE FLANGE –



SECTION A-A

FROM THE LOADS DISTRIBUTION:

$P_c = 25{,}700\#$ ULT (REF PG 5.3.2.9.2)

$A_{FLANGE} = (2.0)(.37) = .74 \text{ IN}^2$

$f_c = \frac{25{,}700}{.74} = 34{,}730\#$ ULT

$M.S. = \frac{160{,}000}{34730} - 1 = \underline{3.65}$

THE VERTICAL LOADS ARE REACTED THRU THE GIMBAL ATTACH LUGS AND INTO THE GIMBAL FITTING. THE TOTAL VERTICAL LOAD (6V) IS EQUAL TO THE LIFT OR THRUST ON THE HUB.

FROM THE BASIC LOADS $H_N = 38{,}840\#$ LIM. (REF SECTION 4)

$6V = 38{,}840\,(1.5)$ (ULT)

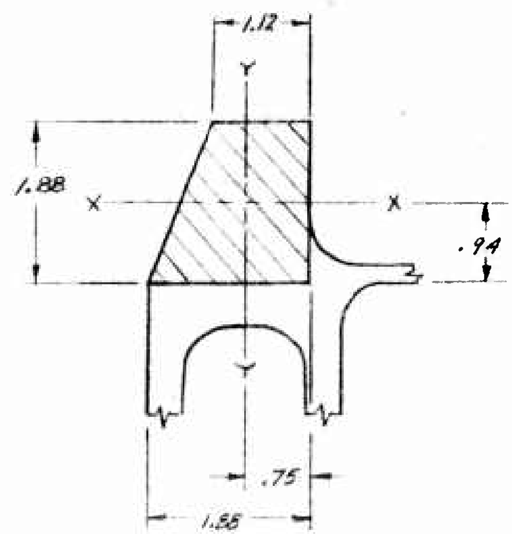
$V = 9710\#$

$M = V \times d = 9710 \times 6.85 = 66{,}500\ ''\#$

THIS MOMENT PRODUCES A TORSION WHICH IS RESISTED BY THE MAIN SECTION OF THE RING.

– CONT'D –

285-0529 FITTING (CONT'D)



$A = \frac{1.12 + 1.88}{2} \times 1.88 = 2.82 \text{ IN}^4$

$I_{xx} = \frac{1.88^3 (1.88^2 + 4 \times 1.88 \times 1.12 + 1.12^2)}{36(1.88 + 1.12} = .7202 \text{ IN}^4$

$I_{YY} = \frac{(1.88)(.75)^3}{3} + \frac{(1.88)(.37)^3}{3} + \frac{(1.88)(.39)^3}{36} + \frac{(1.88)(.39)}{2}(.50)^2 = .3908 \text{ IN}^4$

$I_p = I_{xx} + I_{yy} = .7202 + .3908 = 1.1110 \text{ IN}^4$

$\rho = \sqrt{\frac{I_p}{A}} = \sqrt{\frac{1.111}{2.82}} = .628 \text{ IN}$

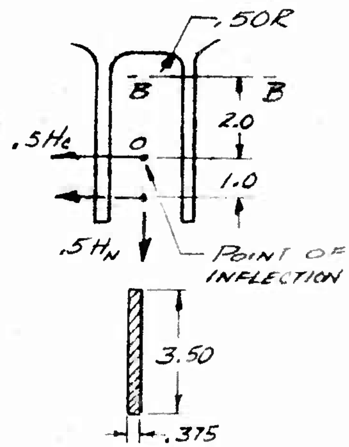
$f_{ST} = \frac{T\rho}{I_p} = \frac{(66\,500)(.628)}{1.111} = 37{,}600 \text{ PSI ULT}$

$F_{SU} = 95000 \text{ PSI}$ (REF 1)

$M.S. = \frac{95000}{37600} - 1 = \underline{\underline{1.60}}$

285-0529 FITTING (CONT'D)

GIMBAL ATTACH LUGS –
ONE-HALF OF LOAD TO EACH SIDE OF FITTING



$I = \frac{(3.5)(.375)^3}{12} = .0155\ IN^4$

$A = (3.5)(.375) = 1.313\ IN^2$

WEIGHTED FATIGUE CONDITION -

$.5H_c = (.5)(\pm 1050) = \pm 525\#\ LIM$

$M_o = (1.0)(525) = \pm 525\ IN\#\ LIM$

RESOLVE M_o INTO A COUPLE

$P_1 = P_2 = \frac{\pm 525}{1.75} = \pm 300\#\ LIM$

MOMENT ABOUT SECTION A-A IS EQUALLY DIVIDED BETWEEN LUGS

$M_{B\text{-}B} = \frac{\pm 525}{2}(2) = \pm 525''\#\ LIM$

$.5H_N = .5(22950) = 11,475\#\ LIM$

$f_{t_1} = \frac{300}{1.313} + \frac{(525)(.188)}{(.0155)} = \pm 6580\ PSI\ LIM$

$f_{t_2} = \frac{11475}{(2)1.313} = 4370\ PSI\ LIM$

$f_t = 4370 \pm 6580\ PSI\ LIM$

* $F_a = 26,000\ PSI$ $M.S. = \frac{26000}{6580} - 1 = \underline{\underline{2.94}}$

$2\frac{1}{2}G$ MANEUVER CONDITION –

$.5H_c = (.5)(3675)(1.5) = 2756\#\ ULT$

$M_o = 2756''\#\ ULT$

$P_1 = P_2 = \frac{2756}{1.75} = 1575\#\ ULT$

$M_{B\text{-}B} = 2756''\#\ ULT$

$.5H_N = (.5)(38,840)(1.5) = 29,130\#\ ULT$

$f_t = \frac{1575}{1.313} + \frac{(2756)(.188)}{.0155} + \frac{29130}{(2)(1.313)} = 45,700\ PSI\ ULT$

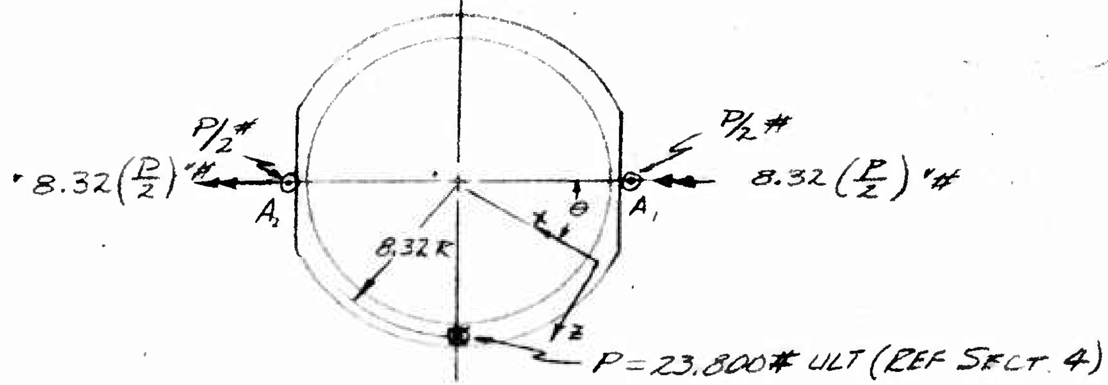
$M.S. = \frac{160,000}{45,700} - 1 = \underline{\underline{2.50}}$

* $F_{tc} = 35000\ PSI$ (REF SECT 2.8, FIG 2.8.1) FOR $K_t = 2.0$
FROM REF 4, $K_t \leq 1.35$ (FIG. 60)

$F_a = \frac{35000}{1.35} = 26,000\ PSI$

5.3.2.13 285-0532 RING MAT'L 4340 STL H.T. 140-160 KSI

THE MAX LOADING CONDITION ON THE RING OCCURS IN THE DROOP STOP COND. THE UPPER HALF OF THE RING IS SUPPORTED BY THE HUB STRUCTURE, THE LOWER PORTION UNSUPPORTED. USING A RING SOLUTION -



UNIT SOLUTION - ASSUMING A CONSTANT SECTION

$P = 10,000\ \#$

$M_{A_1} = M_{A_2} = 8.32 \left(\frac{10,000}{2}\right) = 41,600\ "\#$

$M_x = \frac{P}{2} R \cos\theta - \frac{P}{2} R \sin\theta$

$M_z = \frac{P}{2} R \sin\theta - \frac{P}{2} R (1 - \cos\theta)$ (REF 11)

AT $\theta = 45^\circ$

$M_x = (5000)(8.32)(\cos 45^\circ) - (5000)(8.32)(\sin 45^\circ) = 0$

$M_z = (5000)(8.32)(\sin 45^\circ) - (5000)(8.32)(1 - \cos 45^\circ) = 17,200\ "\#$

AT $\theta = 90^\circ$

$M_x = (5000)(8.32)(\cos 90^\circ) - (5000)(8.32)(\sin 90^\circ) = -41,600\ "\#$

$M_z = (5000)(8.32)(\sin 90^\circ) - (5000)(8.32)(1 - \cos 90^\circ) = 0$

MAXIMUM DEFLECTION

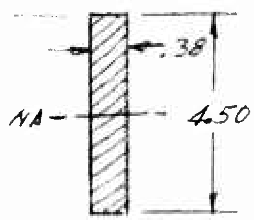
$\Delta_{MAX} = .376 \frac{PR^3}{EI_x}$ (REF 11)

MAXIMUM DEFLECTION OCCURS AT POINT OF APPLICATION OF LOAD P.

- CONT'D -

285-0532 RING (CONT'D)

MAXIMUM DEFLECTION -(CONT'D)



CROSS SECTION AT A_1 & A_2

$$I_{NA} = \frac{(.38)(4.50)^3}{12} = 2.886\ IN^4$$

$$\Delta_{MAX} = .376\ \frac{(10,000)(8.32)^3}{(30 \times 10^6)(2.886)} = .067\ IN\ (UNIT)$$

$$DESIGN\ \Delta_{MAX} = (2.38)(.067) = .159\ IN$$

DEFLECTION IS OF LITTLE CONSEQUENCE IN THIS ANALYSIS.

MAXIMUM BENDING STRESS

MAXIMUM BENDING STRESS OCCURS AT A_1 & A_2

$$f_b = \frac{Mc}{I} = \frac{(23,800)(8.32)(2.25)}{2.89} = 77,100\ PSI\ (ULT)$$

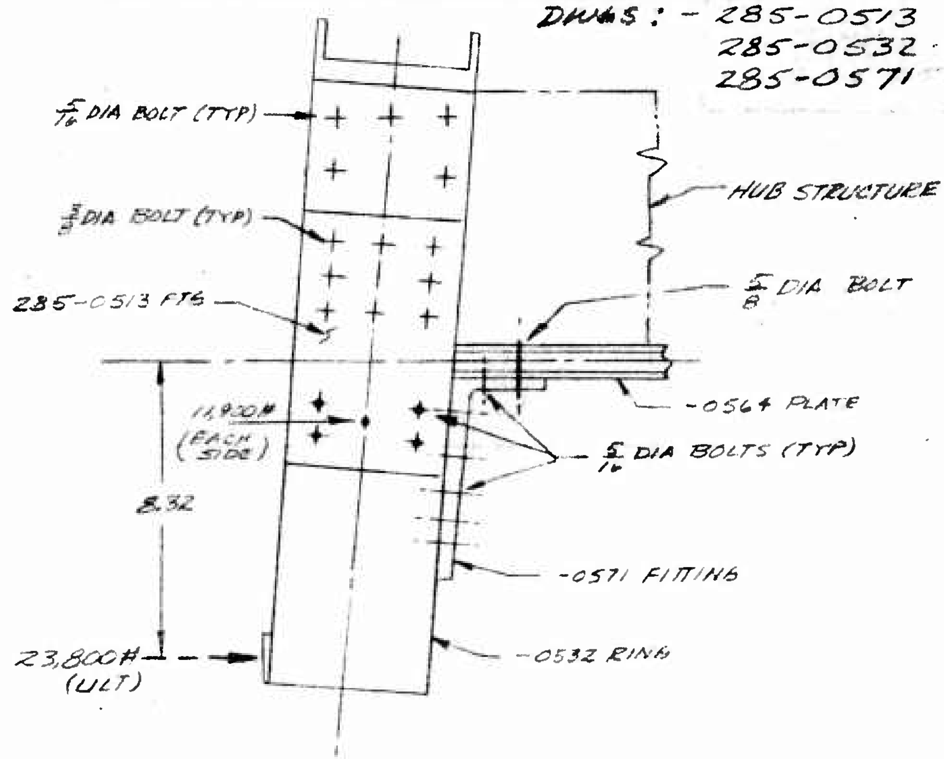
$$M.S. = \frac{160,000}{77,100} - 1 = \underline{\underline{1.08}}$$

MAXIMUM TORSIONAL STRESS

DUE TO THE STIFFNESS OF THE RING SECTION, THE STRESSES DUE TO THE MAX. TORSIONAL MOMENT, M_Z, ARE LOW COMPARED TO THE BENDING STRESSES AND ARE NOT CALCULATED.

5.3.2.14 FEATHERING BEARING HOUSING ASSY ATTACHMENT TO HUB STRUCTURE

DWGS: - 285-0513
285-0532
285-0571



THE -0532 RING IS MOUNTED TO THE HUB STRUCTURE BY (4) 5/16 DIA BOLTS AND (8) 3/8 DIA BOLTS IN THE PATTERN AS SHOWN.

THE FOUR BOLTS IN THE LOWER PATTERN CARRY THE 11,900 # LOAD DIRECTLY INTO THE -0513 FITTING. THE -0513 FITTING IN TURN CARRIES THE LOAD TO THE HUB STRUCTURE THRU THE TWO BOLTS ATTACHING IT TO THE -0564 PLATE.

FOR THE FOUR BOLT PATTERN IN THE -0513 FITTING -

$P_{BOLT} = \frac{11900}{4} = 2975$ # ULT

$P_{ALLOW} = 7300$ #/BOLT (REF 1)

$M.S. = \frac{7300}{2975} - 1 = \underline{\underline{1.45}}$

FOR THE -0571 TO -0564 ATTACHMENT

$P = 11,900$ # ULT

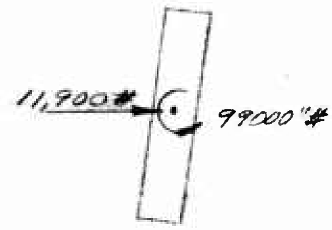
$P_{ALLOW} = 7300 + 29,150 = 36,450$ # (REF 1)

$M.S. = \frac{36450}{11,900} - 1 = \underline{\underline{2.05}}$

- CONT'D -

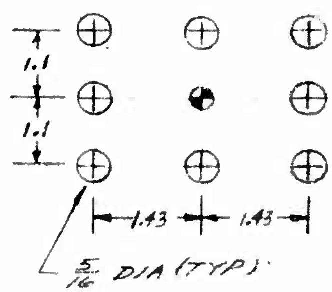
FEATHERING BEARING HOUSING ASS'Y ATTACHMENT TO HUB STRUCTURE

CONT'D



THE MOMENT PRODUCED BY THE APPLIED LOAD IS CARRIED INTO THE -0513 FITTING AND FROM THERE APPLIED TO THE HUB STRUCTURE AS A COUPLE.
THE DIRECT LOAD IS CARRIED DIRECTLY INTO THE -0567 FITTING.

ATTACHMENTS TO THE -0513 FITTING -



$I_p = 6(1.1)^2 + 6(1.43)^2 = 19.50\ IN^4$

FOR THE EXTREME BOLTS IN THE PATTERN -

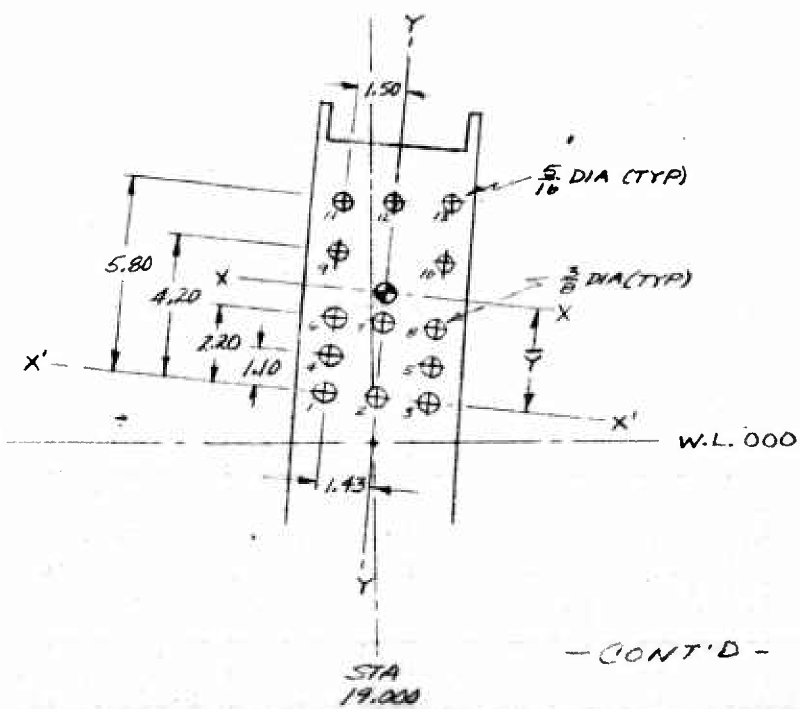
$r = \sqrt{1.43^2 + 1.10^2} = 1.8$

$P_{BOLT} = \frac{Tr}{I_p} = \frac{99000(1.8)}{19.5} = 9140\#$

$P_{ALLOW} = 11500\#$ (REF 1)

$M.S. = \frac{11500}{9140} - 1 = \underline{.21}$

ATTACHMENT TO THE HUB STRUCTURE - LOAD CARRIED TO WEB AND CAPS



- CONT'D -

HUB ANALYSIS

FEATHERING BEARING HOUSING ASSY ATTACHMENT TO HUB STRUCTURE

CONT'D

BOLT	K	Y	KY	Y^2	KY^2	X	X^2	KX^2
1	36	0	0	0	0	1.43	2.03	73.08
2	36	0	0	0	0	0	0	0
3	36	0	0	0	0	1.43	2.03	73.08
4	36	1.1	39.6	1.21	43.56	1.43	2.03	73.08
5	36	1.1	39.6	1.21	43.56	1.43	2.03	73.08
6	36	2.2	79.2	4.84	174.24	1.43	2.03	73.08
7	36	2.2	79.2	4.84	174.24	0	0	0
8	36	2.2	79.2	4.84	174.24	1.43	2.03	73.08
9	25	4.2	105	17.64	441.0	1.50	2.25	56.25
10	25	4.2	105	17.64	441.0	1.50	2.25	56.25
11	25	5.8	145	33.64	841.0	1.50	2.25	56.25
12	25	5.8	145	33.64	841.0	0	0	0
13	25	5.8	145	33.64	841.0	1.50	2.25	56.25
Σ	413	$\bar{Y}=2.33$	961.8	—	4015	—	—	663

$$I_{XX} = I_{X'-X'} - \Sigma K \cdot \bar{Y}^2 = 4015 - 413 \cdot \overline{2.33}^2 = 1772$$

$$I_{YY} = 663$$

$$I_P = I_{XX} + I_{YY} = 1772 + 663 = 2435$$

$$P_{X_M} = \frac{M \bar{Y} K}{I_P} \qquad P_{Y_M} = \frac{M \bar{X} K}{I_P}$$

FOR BOLTS 1 & 3 – $\frac{3}{8}$ DIA.

$$P_{X_M} = \frac{(99000)(2.33)(36)}{2435} = 3410\#$$

$$P_{Y_M} = \frac{(99000)(1.43)(36)}{2435} = 2100\#$$

$$P_{BOLT} = 3410 \leftrightarrow 2100 = 4000\#$$

$$P_{ALLOW} = 11{,}900\# \text{ (REF 1)} \qquad M.S. = \frac{11500}{4000} - 1 = \underline{\underline{1.88}}$$

FOR BOLTS 11 & 13 $\frac{5}{16}$ DIA.

$$P_{X_M} = \frac{(99000)(3.47)(25)}{2435} = 3530\#$$

$$P_{Y_M} = \frac{(99000)(1.50)(25)}{2435} = 1530\#$$

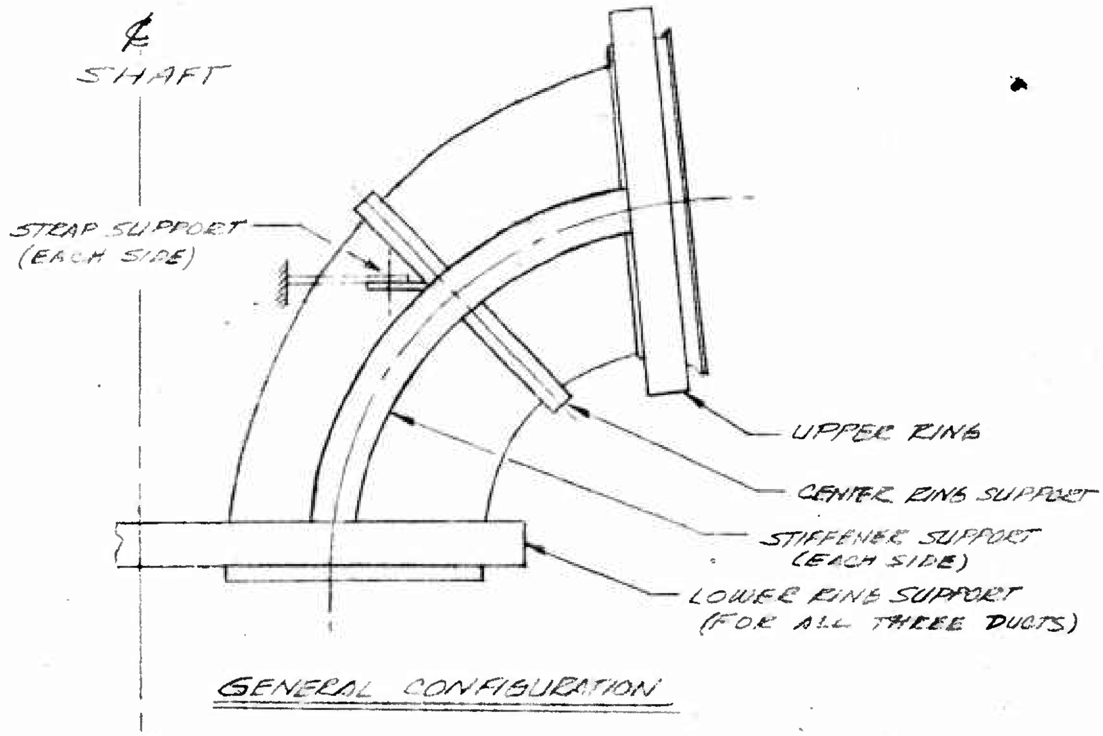
$$P_{BOLT} = 3530 \leftrightarrow 1530 = 3850\#$$

$$P_{ALLOW} = 7300\# \text{ (REF 1)} \qquad M.S. = \frac{7300}{3850} - 1 = \underline{\underline{.90}}$$

5.3.3 HUB DUCTS ANALYSIS

THE HUB DUCTS ARE COMPRISED OF THREE UPPER (ROTATING) SECTIONS AND OF TWO LOWER (STATIONARY) SECTIONS WITH DUCT CONTINUITY CARRIED THRU A SEAL RING. THE UPPER SECTIONS ARE SUPPORTED BY THE SEAL RING AND THE LEGS OF THE 285-0515 SPOKE. THE LOWER SECTIONS ARE SUPPORTED BY THE ROTOR SYSTEM MOUNTING STRUCTURE ATOP THE WHIRL TOWER TEST STAND.

5.3.3.1 285-0519 DUCT ASSY - UPPER, ROTATING



GENERAL CONFIGURATION

THE DUCTS ARE SUPPORTED AT 3 POINTS BY THE LEGS OF THE 285-0515 SPOKE. THE STRAP SUPPORTS HOLD THE WEIGHT OF THE DUCTS IN THE NON-OPERATING CONDITION.

OPERATING CONDITIONS —

1. STARTING CONDITION - DUCT PRESSURES ONLY

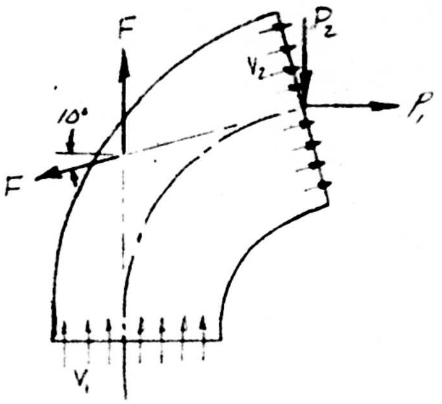
2. RUNNING CONDITION - DUCT PRESSURE + CENT. FORCE.

3. POWER OFF, ROTATING CONDITION.

DUCT ASSY - UPPER, ROTATING (CONT'D)

DESIGN CRITERIA - (REF SECTION 1)

DUCT PRESSURE - 26.9 PSIG LIMIT (P)
OPERATING TEMPERATURE - 1117°F (T)
GAS MASS FLOW - 25.0 #/(SEC) ($\dot{w}$)
SPEED OF GAS FLOW - M = .35



P_1 & P_2 ARE FORCES EXERTED BY THE INBOARD PORTION OF THE BLADE DUCT AND ARE MADE UP OF PRESSURE AND CENTRIFUGAL FORCE COMPONENTS.

FORCES DENOTED F ARE THOSE DUE TO THE GAS MASS FLOW

$V_1 = V_2$

WEIGHTED FATIGUE CONDITION

$P_1 = (728 \pm 4)_{C.F.} + (583 \pm 10)_{I.P.}$ LIMIT

$P_2 = (52 \pm 25)_{C.F.} + (197 \pm 95)_{I.P.}$ LIMIT

(REF SECTION 1)

2½G MANEUVER CONDITION

$P_1 = (723 \pm 11)_{C.F.} + (598 \pm 21)_{I.P.}$ LIMIT

$P_2 = (98 \pm 46)_{C.F.} + (266 \pm 175)_{I.P.}$ LIMIT

(REF SECTION 1)

OVER REV CONDITION

$P_1 = (1214 \pm 0)_{C.F.} + (569 \pm 0)_{I.P.}$ LIMIT (REF SECTION 1)

NOTE: SUBSCRIPTS DENOTE CENTRIFUGAL FORCE (C.F.) AND INTERNAL PRESSURE (I.P.)

DUCT ASSY - UPPER, ROTATING (CONT'D)

GAS MASS FLOW FORCES —

$$F = \frac{\dot{W} \Delta V}{32.2}$$

WHERE: $\dot{W} = 25.0$ #/SEC (REF SECTION 1)

$\Delta V = .35 V_e - V_o$

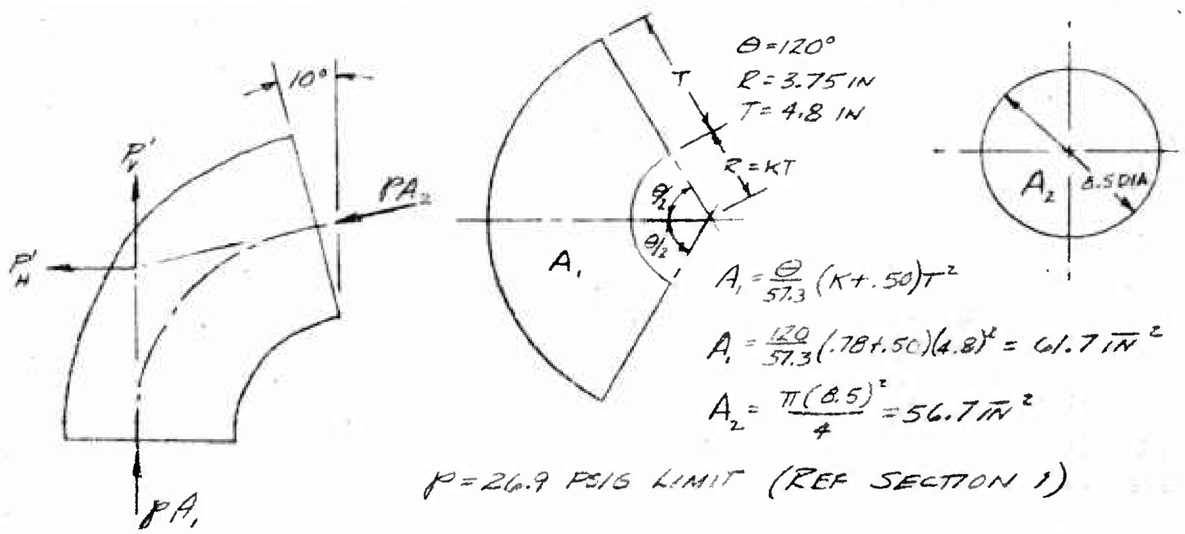
$V_e = 49\sqrt{T_{ABS}} = 49\sqrt{1174+460} = 1950$ FPS

$V_{GAS} = .35 V_e = .35(1950) = 682$ FPS

$F = \frac{(25.0)(682)}{32.2} = 530$# LIMIT [X1.5 = 795 # ULT]

THE FORCES ACTING THRU THE POINT SHOWN IN THE SKETCH ABOVE:

DUCT INTERNAL PRESSURE FORCES - EXTERNAL PICTURE —



θ = 120°
R = 3.75 IN
T = 4.8 IN

$A_1 = \frac{\theta}{57.3}(K+.50)T^2$

$A_1 = \frac{120}{57.3}(.78+.50)(4.8)^2 = 61.7\ IN^2$

$A_2 = \frac{\pi(8.5)^2}{4} = 56.7\ IN^2$

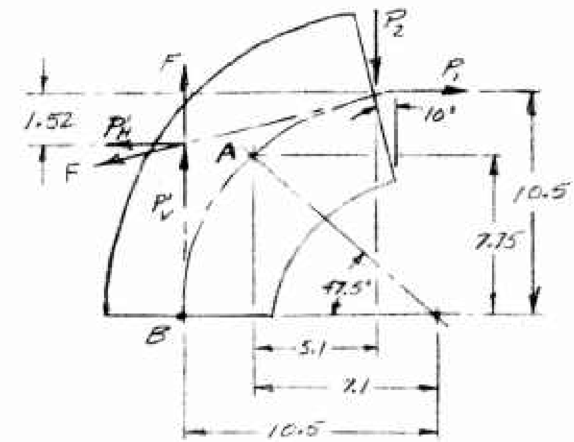
$P = 26.9$ PSIG LIMIT (REF SECTION 1)

$P'_V = (26.9)(61.7) - (26.9)(56.7)(\sin 10°) = 1400$ # LIMIT

$P'_H = (26.9)(56.7)(\cos 10°) = 1500$ # LIMIT

DUCT ASSY - UPPER ROTATING (CONT'D)

LOADING GEOMETRY -



POINT A REPRESENTS THE INTERSECTION OF THE STIFFENER AND CENTER RING SUPPORTS.

DUCT INTERNAL PRESSURE FORCES - INTERNAL PICTURE

THE INTERNAL PRESSURES OF THE DUCT WILL TEND TO STRAIGHTEN OUT THE DUCT CAUSING BENDING IN THE DUCT. THE STRUCTURE BELOW CENTER RING SUPPORT IS A WELL SUPPORTED, FAIRLY STIFF STRUCTURE AND IT IS REASONABLE TO CONSIDER THAT ANY MOMENT TENDING TO STRAIGHTEN OUT THE DUCT WILL BE RESISTED AS A COUPLE BETWEEN POINTS A & B. TO DETERMINE THIS BENDING MOMENT IT IS FIRST NECESSARY TO FIND THE INTERNAL LOADING OF THE DUCT.

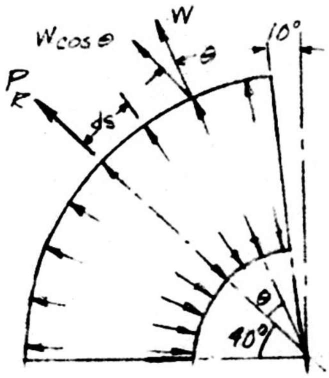
TO FACILITATE THE ANALYSIS, SEVERAL SIMPLIFYING GENERALIZATIONS ARE MADE TO THE GEOMETRY OF THE DUCT.

1. CONSIDER THE DUCT AS A QUARTER SECTION OF A TORUS.

2. A MEAN SECTION, ELLIPTICAL IN SHAPE IS ASSUMED

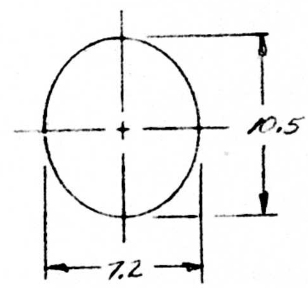
DUCT ASSY - UPPER, ROTATING (CONT'D)

BENDING DUE TO INTERNAL PRESSURE —



$R_1 = 6.4$ IN

$R_2 = 13.6$ IN



AVERAGE CROSS SECTION ASSUMED

FOR THE AVERAGE CROSS-SECTION -

$$A_{AVG} = \frac{61.7 + 56.7}{2} = 59.2 \text{ IN}^2$$

$$A_{ELLIPSE} = \pi a b \quad \text{WHERE } b = 3.6 \text{ IN}$$

$$a = \frac{59.2}{\pi(3.6)} = 5.25 \text{ IN}$$

UNIT LOADING —

USING A UNIT 1 INCH WIDE STRIP

$$W_{STRIP} = 10.5(26.9) = 282\# \text{ LIMIT}$$

REFERRING TO THE SKETCH ABOVE, LEFT:

$$ds = R\,d\theta$$

$$P_R = 2 \times \sum_{0}^{40^\circ} W \cos\theta$$

$$P_R = 2\int_0^{40^\circ} R\,ds\,W\cos\theta = 2WR\int_0^{40^\circ} \cos\theta\,d\theta$$

$$= 2WR\left[\sin\theta\right]_0^{40^\circ} = 1.286\,WR$$

$$P_R = 1.286(282)(13.6 - 6.4) = 2610\# \text{ LIMIT}$$

- CONT'D

DUCT ASSY – UPPER, ROTATING (CONT'D)

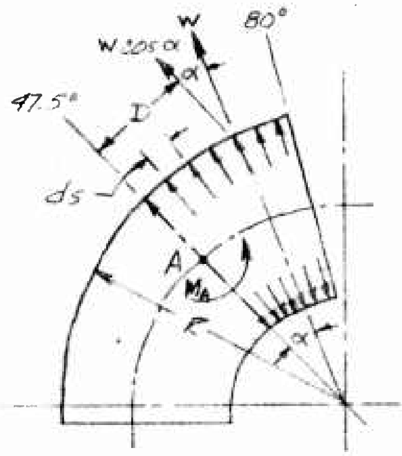
BENDING DUE TO INTERNAL PRESSURE – (CONT'D)

THESE LOADS CLOSELY APPROXIMATE THE LOADS DETERMINED EXTERNALLY:

$$P_{H_{EXT}} = 1500 + 530(\cos 10^\circ) = 2022\# \text{ LIMIT}$$

$$P_{V_{EXT}} = 1400 + 530(1 - \sin 10^\circ) = 1638\# \text{ LIMIT}$$

RESULTANT = 2022 +→ 1638 = 2600# LIMIT



$W = 282\ \#/\text{IN LIMIT}$

$D = R \sin\alpha$

$ds = R\,d\alpha$

$$M = (W\cos\alpha)(D) = (W\cos\alpha)(R\sin\alpha)$$

$$dM = (W\cos\alpha)(R\sin\alpha)(R\,d\alpha)$$

$$M = \int_0^{32.5^\circ} W\cos\alpha\, R^2 \sin\alpha\, d\alpha$$

$$= WR^2 \int_0^{32.5^\circ} \cos\alpha \sin\alpha\, d\alpha$$

$$= WR^2 \left[\tfrac{1}{2}\sin^2\alpha\right]_0^{32.5^\circ} = .1443\,WR^2$$

$$M_A = (.1443)(282)(7.2^2) = 2110\text{''}\# \text{ LIMIT}$$

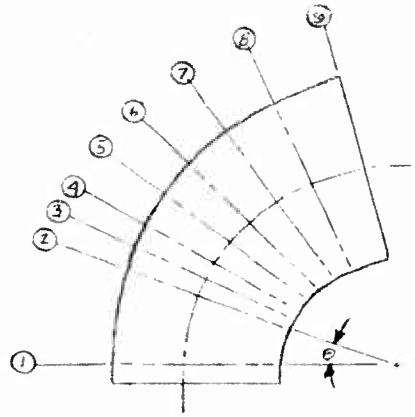
LOADS IN STIFFENER SUPPORTS –

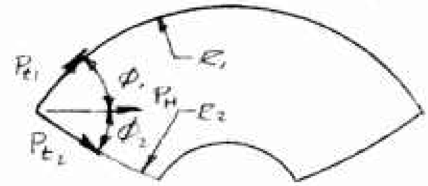
DUE TO THEIR CROSS-SECTIONAL SHAPE, THE INTERNAL PRESSURE ACTING ON THE DUCT "CORNERS" (i.e. THE INTERSECTION OF THE CURVED WALLS) WILL TEND TO SEPARATE THE WALL SEGMENTS AND IN SO DOING IMPOSE A LOADING ON THE DUCT STIFFENER SUPPORTS. THE "RADIAL" COMPONENTS OF THESE FORCES ARE NORMAL TO THE DUCT CENTER-PLANE AND AS SUCH ARE ALSO NORMAL TO THE FACE OF THE STIFFENER SUPPORTS ON EITHER SIDE OF THE DUCTS. THERE ARE ALSO, IN SOME CASES, "TANGENTIAL" FORCES, COPLANAR WITH, AND PERPENDICULAR TO THE "RADIAL" FORCES, BUT THESE ARE RELATIVELY SMALL AND ARE NEGLECTED IN THE ANALYSIS.

CONT'D –

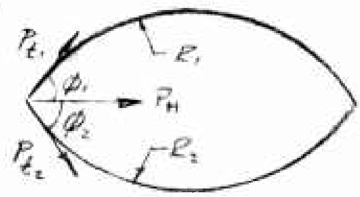
DUCT ASSY - UPPER, ROTATING (CONT'D)

LOADS IN STIFFENER SUPPORTS (CONT'D)





SECTIONS ①, ② & ③



SECTIONS ④ THRU ⑨

SECT	θ	R_1	R_2	P_{t_1}	P_{t_2}	ϕ_1	ϕ_2	P_V	P_H
①	0°	7.6	10.5	204	282	62.6	43.6	-13	299
②	13°	7.6	10.5	204	282	62.6	43.6	-13	299
③	26°	7.6	9.3	204	249	60.9	46.8	-3	269
④	32°	6.8	7.6	183	204	60.0	57.0	-13	203
⑤	40°	6.0	6.3	161	170	68.5	59.5	0	143
⑥	47.5°	5.2	5.2	140	140	75.5	74.5	0	73
⑦	57°	4.6	4.6	124	124	82.2	82.2	0	35
⑧	67°	4.3	4.3	116	116	88.7	88.7	0	6
⑨	80°	4.25	4.25	115	115	90.0	90.0	0	0

$P_t = pRW$

$P_V = P_{t_1} \sin\phi_1 - P_{t_2} \sin\phi_2$

$P_H = P_{t_1} \cos\phi_1 + P_{t_2} \cos\phi_2$

WHERE p = 26.9 PSI LIMIT (REF SECTION 1)
W = 1.0 IN WIDTH OF TUBE

CONT'D

HUGHES TOOL COMPANY – AIRCRAFT DIVISION

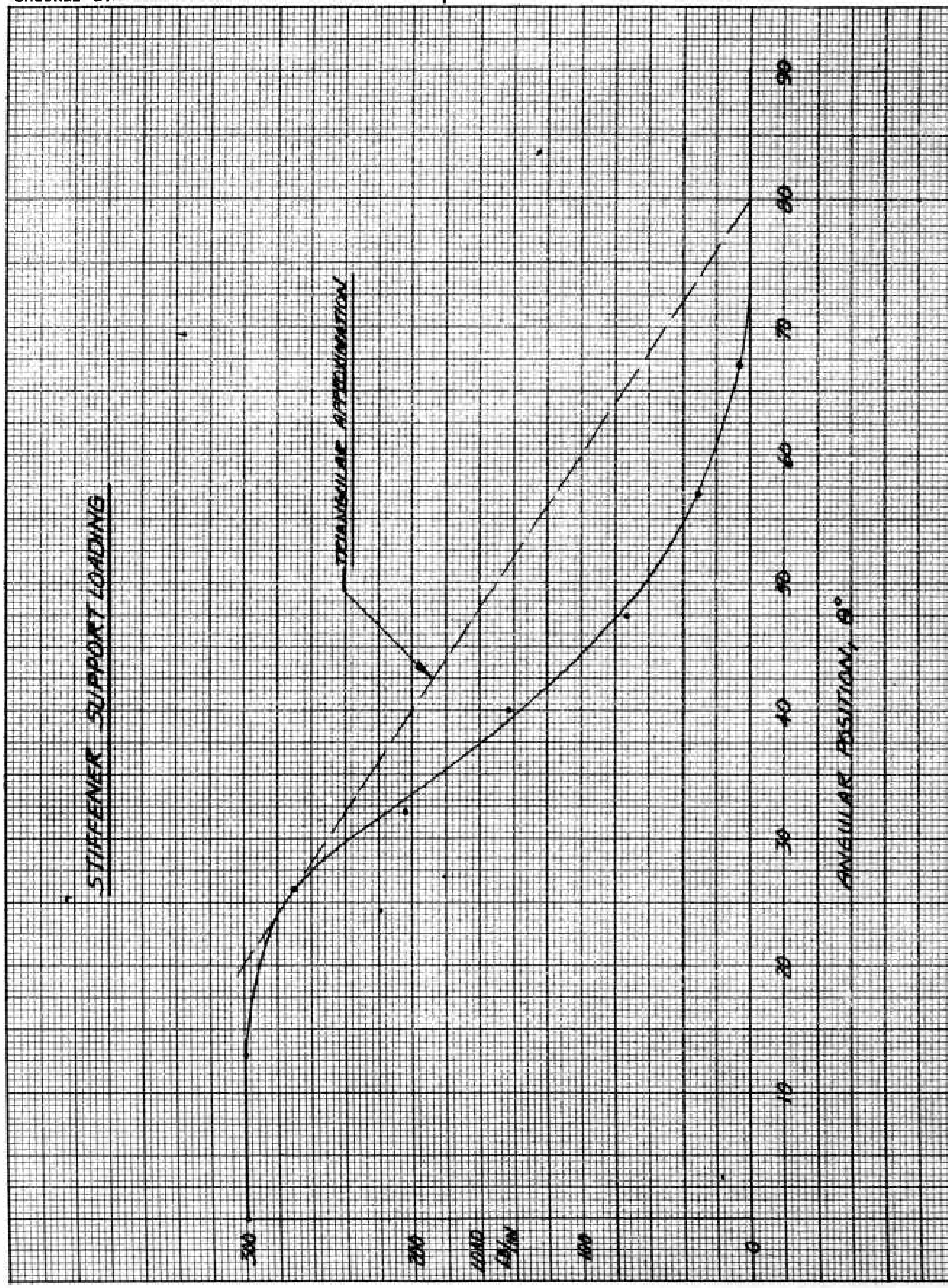
5.3.3.1.7

ANALYSIS Hot Cycle Rotor MODEL 285 REPORT NO. 285-13 PAGE —

PREPARED BY L. L. ERLE 8-11-60

CHECKED BY

HUB DUCTS



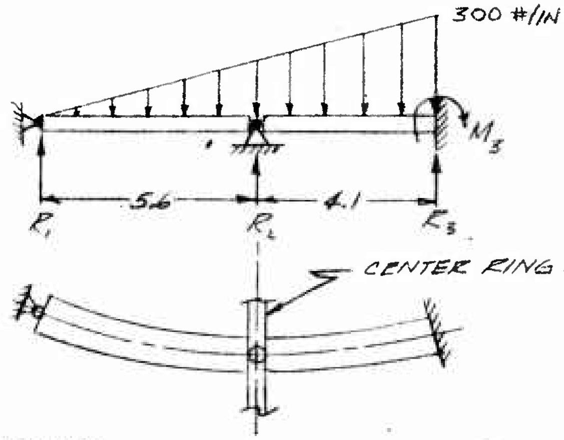
ALBANENE NO 195T

FORM NO. 9726

DUCT ASSY - UPPER, ROTATING (CONT'D)

LOADS IN STIFFENER SUPPORTS (CONT'D)

THE PLOT OF LOAD VS ANGULAR POSITION SHOWS THAT THE LOAD DISTRIBUTION ALONG THE STIFFENER IS BASICALLY TRIANGULAR AND FOR PURPOSES OF THIS ANALYSIS THE TRIANGULAR APPROXIMATION SHOWN WILL BE USED.



$w_2 = \frac{5.6(300)}{5.6+4.1} = 173$ #/IN

$W = \frac{173 \times 5.6}{2} = 485$ #

$e = .30$ IN

$T_e = (.30)(485) = 145.5$ "#

$R_1 = \frac{1}{3} \times 485 = 162$ #

$R_2 = \frac{2}{3} \times 485 = 323$ #

$w_3 = 300$ #/IN

$300 - 127 = 173$ #/IN

$W' = \frac{(127)(4.1)}{2} = 260$ #

$W'' = (173)(4.1) = 710$ #

$e' = .14$; $T_e' = (260)(.14) = 36.4$ "#

$e'' = .15$; $T_e'' = (710)(.15) = 106.4$ "#

$R_2 = (\frac{1}{3})(260) + (\frac{3}{8})(710) = 320$ #

$R_3 = (\frac{2}{3})(260) + (\frac{5}{8})(710) = 652$ #

$M_3 = (\frac{2}{15})(260)(4.1) + (\frac{1}{8})(710)(4.1) = 497$ "#

$Te_{TOTAL} = 145.5 + 36.4 + 106.4 = 288$ "# LIMIT

$R_1 = 162$ # LIMIT

$R_2 = 323$ # LIMIT

$R_3 = 652$ # LIMIT

$M_3 = 497$ "# LIMIT

CONT'D

DUCT ASSY - UPPER, ROTATING (CONT'D)

LOADS IN STIFFENER SUPPORTS (CONT'D)

REACTION R_1 IS IMPOSED ON THE UPPER RING.

REACTIONS R_2 & T_C ARE IMPOSED ON THE CENTER RING SUPPORT.

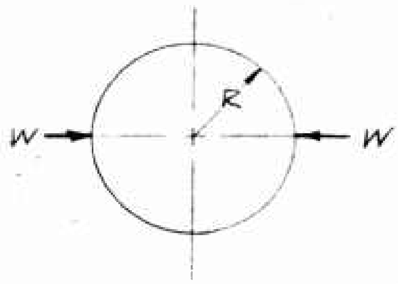
REACTIONS R_3 & M_3 ARE CARRIED INTO THE LOWER RING SUPPORT.

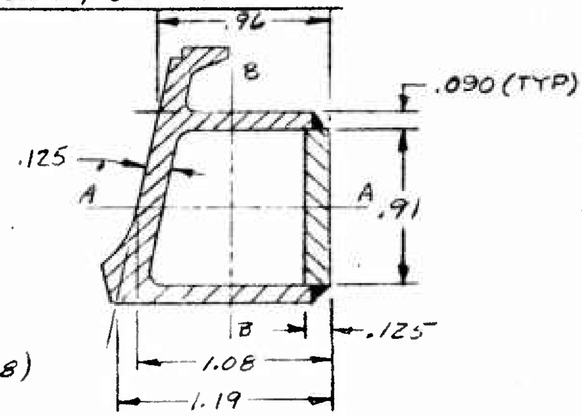
DUCT ASSY - UPPER, ROTATING (CONT'D)

5.3.3.2 —

RING ASSEMBLY - HOT CYCLE HUB DUCT, UPPER 285-0540

MAT'L - TYPE 347 CORR. RES. STEEL, OR TYPE 321





W = 162# LIMIT (REF PG 5.3.3.1.8)

R = 5.2 IN

CONSIDER THE CROSS-SECTION AS RECTANGULAR 1.08 X 1.09

$$A = (2)(1.08 \times .09) + (2)(.91 \times .125) = .422 \text{ IN}^2$$

$$I_{A-A} = \frac{1.08(1.09)^3 - (1.08-.25)(.91)^3}{12} = .064 \text{ IN}^4 \; ; \; I/c = \frac{.064}{.545} = .117 \text{ IN}^3$$

$$I_{B-B} = \frac{(1.09)(1.08)^3 - (.91)(1.08-.25)^3}{12} = .071 \text{ IN}^4 \; ; \; I/c = \frac{.071}{.54} = .132 \text{ IN}^3$$

FOR A RING LOADED AS SHOWN - (REF 2, TABLE VIII CASE 1)

$$defl. = -0.149 \frac{WR^3}{EI} = -0.149 \frac{(162)(5.2)^3}{(30 \times 10^6)(.071)} = -.0016 \text{ IN}$$

$$M_{MAX} = 0.3183\, WR = 0.3183(162)(5.2) = 268 \text{ "\# LIMIT}$$

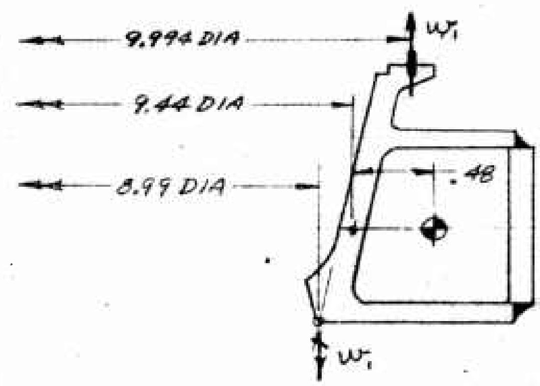
$$f_b = \frac{268}{.132} = 2040 \text{ PSI LIMIT}$$

$$F_{ty} = 18{,}000 \text{ PSI } (1200°F)$$ (REF 5, PG 62)

M.S. = HIGH +

DUCT ASSY - UPPER, ROTATING (CONT'D)

RING ASSY - HOT CYCLE HUB DUCT, UPPER 285-0540 (CONT'D)



w_1 IS AN EQUALLY DISTRIBUTED LOADING OVER THE CIRCUMFERENCE OF THE RING DUE TO LOAD P_1 (REF PG 5.3.3.1.1)

$$\text{CIRCUM.} = \pi D = \pi(9.994) = 31.40 \text{ IN}$$

$$P_1 = 1214 + 569 = 1783\# \text{ LIMIT (OVER-REV. COND.)}$$
$$P_2 = 723 + 598 = 1321\# \text{ LIMIT } (2\tfrac{1}{2} G \text{ MAN. COND})$$
(REF PG 5.3.3.1.1)

$$w_1 = \frac{1783}{31.40} = 56.8 \ \#/\text{IN LIMIT}$$

ASSUME THAT w_1 WILL BE CARRIED BY THE DUCT WALLS AND RE-DISTRIBUTE TO THE STIFFENER BY SHEAR CARRY-OVER.

REACTION TO w_1 LOADING IS IN THE FORM OF AN EQUALLY DISTRIBUTED LOADING AND AN EQUALLY DISTRIBUTED TORSIONAL MOMENT ABOUT THE CIRCUMFERENCE AT THE 8.99 DIA.
TORSIONAL MOMENT PER INCH IS AS FOLLOWS:

$$M_1 = w_1\left[\frac{9.44 - 8.99}{2} + .48\right]$$

$$= 56.8(.70) = 39.8 \ ''\#/\text{IN}$$

FROM ROARK, ARTICLE 62, EQUALLY DISTRIBUTED TORQUE ABOUT THE TUBE ℄ AXIS -

$$f_b = \frac{M \times R}{I/c} \quad \text{WHERE } I = I_{A-A}$$

CONT'D —

DUCT ASSY-UPPER, ROTATING (CONT'D)

RING ASSY - HOT CYCLE HUB DUCT, UPPER 285-0540 (CONT'D)

$R = 5.2\ IN$

$I/c = .117\ IN$

$$f_b = \frac{(39.8)(5.2)}{(.117)} = 1770\ PSI\ LIMIT$$

MAXIMUM STRESS OCCURS AT THE CORNERS OF THE SECTION

$$f_{b_{MAX}} = 2040 + 1770 = 3810\ PSI\ LIMIT$$

$F_{ty} = 18{,}000\ PSI$ (1200°F) (REF 5, PG 62)

M.S. = HIGH +

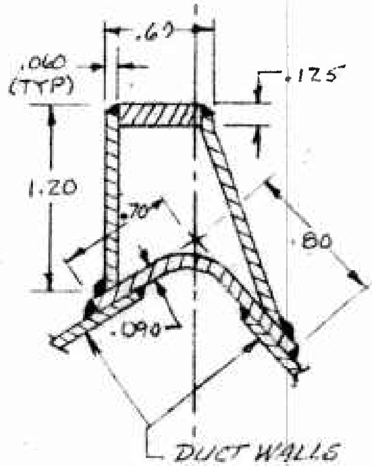
DUCT ASSY - UPPER, ROTATING (CONT'D)

5.3.3.3 STIFFENER SUPPORTS, REF DWGS 285-0519, -0541

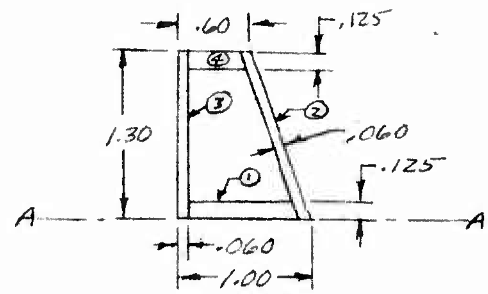
MAT'L - TYPE 347 CORR. RES. STEEL, OR TYPE 321

CHECK OF STIFFENER SECTION IS MADE AT ATTACHMENT TO LOWER DUCT STRUCTURE.

$M = 497''\#$ LIMIT
$P_s = 652\#$ LIMIT
} (REF PG 5.3.3.1.8)



THE STIFFENER SECTION AT THIS POINT IS SHOWN AT LEFT. DUE TO THE COMPLEXITY OF THE SECTION IT IS SIMPLIFIED TO THAT SHOWN BELOW.



ITEM	A	d	Ad	Ad^2	I_o
①	.110	.062	.0069	.0004	NEGLIG
②	.082	.650	.0533	.0346	.0110
③	.078	.650	.0507	.0330	.0110
④	.060	1.237	.0743	.0919	NEGLIG
Σ	.330		.1852	.1599	.0220

$\bar{d} = \frac{.1852}{.330} = .561$ IN

$I_{NA} = .0220 + .1599 - .561(.1852) = .078\ IN^4$; $I/c = \frac{.078}{.739} = .105\ IN^3$

$f_b = \frac{497}{.105} = 4730$ PSI LIMIT

$f_s = \frac{652}{.333} = 1960$ PSI LIMIT

$F_{ty} = 18,000$ PSI (1200°F) (REF 5, PG 62)

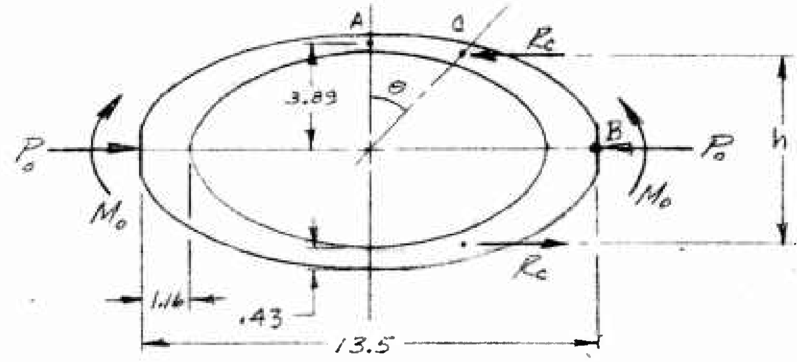
$F_{sy} = (.60)(18,000) = 10,800$ PSI

M.S. = HIGH +

DUCT ASSY - UPPER, ROTATING (CONT'D)

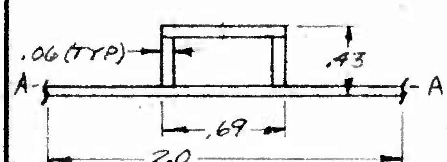
5.3.3.4 CENTER RING SUPPORT REF DWGS 285-0519, -0541

MAT'L - TYPE 347 CORR. RES. STEEL, OR TYPE 321



ASSUMPTION IS MADE THAT BENDING STRESSES IN THE RING ARE EQUAL IN SECTIONS AT A & B AND THAT AN INFLECTION POINT IS LOCATED AT C.

SECTION AT A —



$A = (2.0)(.06) + (2)(.31)(.06) + (.69)(.06) = .1986\ IN^2$

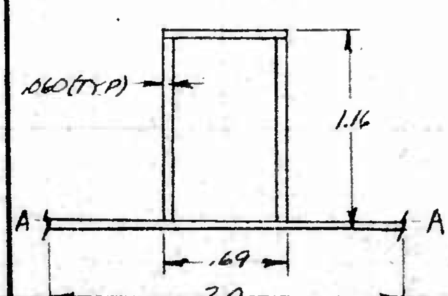
$A\bar{Y} = (.69)(.06)(.34) + (2)(.31)(.06)(\frac{.31}{2}) - (2.0)(.06)(.03) = .0163\ IN^3$

$\bar{Y} = \frac{.0163}{.1986} = .082\ IN$

$I_{A\text{-}A} = \frac{(.69)(.37)^3 - (.57)(.31)^3}{3} = .0060\ IN^4$

$I_{NA} = .0060 - .1986(.082)^2 = .0047\ IN^4$

SECTION AT B —



$A = (2.0)(.06) + (2)(1.04)(.06) + (.69)(.06) = .2862\ IN^2$

$A\bar{Y} = (.69)(.06)(1.07) + (2)(.06)(1.04)(\frac{1.04}{2}) - (2.0)(.06)(.03) = .1056\ IN^3$

$\bar{Y} = \frac{.1056}{.2862} = .369\ IN$

$I_{A\text{-}A} = \frac{(.69)(1.10)^3 - (.57)(1.04)^3}{3} = .0924\ IN^4$

$I_{NA} = .0924 - .2862(.369)^2 = .0534\ IN^4$

— CONT'D

DUCT ASSY - UPPER, ROTATING (CONT'D)

CENTER RING SUPPORT REF DWG 285-0519,-0541 (CONT'D)

CONSIDER A UNIT SOLUTION - $M_o = 1000''\#$, $P_o = 100\#$

STRESS AT B UNDER THE UNIT MOMENT -

$$f_b = \frac{My}{I} = \frac{(500)(1.10-.369)}{.0534} = 6845 \text{ PSI UNIT}$$

FOR AN EQUAL STRESS AT A -

$$M_A = \frac{f_b I}{y} = \frac{(6845)(.0047)}{(.37-.082)} = 112''\# \text{ UNIT}$$

LET $h_1 + h_2 = 3.89$

NOW $R_c h_1 = 500''\#$ AND $3.89 R_c - R_c h_2 = 500$

$R_c h_2 = 112''\#$ $\qquad R_c h_2 = 112$

$3.89 R_c - 0 = 612$

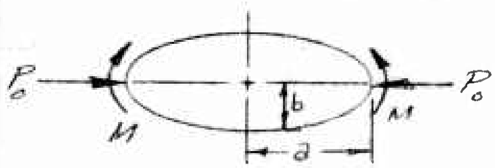
$R_c = 157\#$ UNIT

SO THAT -

$$h = \frac{1000}{157} = 6.37 \text{ IN}$$

$$\theta = 43.5°$$

FOR THE CASE OF P_o ALONE -



$M = K_1 P_o a$ (REF 2, ART 47)

WHERE K_1 IS A COEFFICIENT BASED ON RATIO a/b

FOR THIS RING - $a = \frac{1}{2}(13.5-1.16) = 6.17$

$b = 3.89$

$$a/b = \frac{6.17}{3.89} = 1.59; \quad K_1 = .22$$

$$M = (.22)(100)(6.17) = 136''\# \text{ UNIT}$$

— (CONT'D)

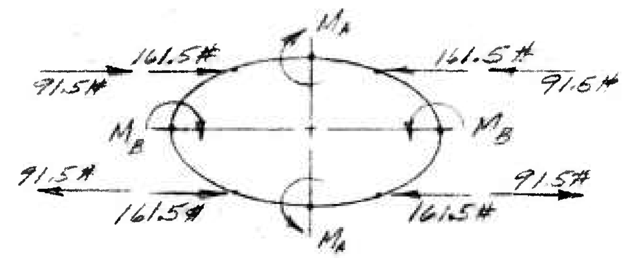
DUCT ASSY - UPPER, ROTATING (CONT'D)

CENTER RING SUPPORT - REF DWGS 285-0519, -0541 (CONT'D)

DESIGN LOADS - $M_o = 288$ "# LIMIT, $P_o = 323$ "# LIMIT } (REF PG 5.3.3.1.8)

$$M_B = 144 + \frac{323}{100}(136) = 583\text{"\# LIMIT}$$

$$M_A = \frac{583}{1000}(112) = 65.3\text{"\# LIMIT}$$



FROM $M = 583$"#, $R_c = \frac{583}{6.37} = 91.5$# LIMIT

$$P_A = 161.5 + 91.5 = 253\text{\# LIMIT}$$

$$f_{c_{MAX}} = \frac{(65.3)(.37-.082)}{.0047} + \frac{253}{.199} = 5270\text{ PSI LIMIT}$$

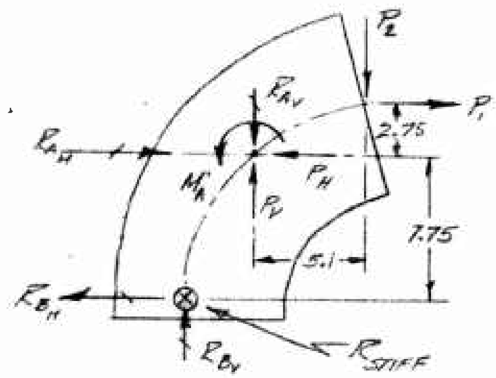
$F_{ty} = 18000$ PSI (1200°F), (REF 5, PG 62)

$$M.S. = \frac{18000}{5270} - 1 = \underline{2.42}$$

DUCT ASSY – UPPER, ROTATING (CONT'D)

5.3.3.5 LOWER SUPPORT RING REF DWGS 285-0505, -0541)

MAT'L – TYPE 347 CORR. RES. STEEL, OR TYPE 321



FOR THE OVER-REV CONDITION –

$P_1 = 1783$ # LIMIT
$P_2 = 0$ } (REF. PG. 5.3.3.1.1)

$P_H = 1500 + 530 = 2030$ # LIMIT
$P_V = 1400 + 530 = 1930$ # LIMIT } (REF PG 5.3.3.1.2)

$M_A = 2110$ "# LIMIT (REF PG 5.3.3.1.5)

$M_A' = M_A - P_1(2.75) - P_2(5.1)$
$= 2110 - 1783(2.75) - 0 = -2793$ "# LIMIT

$R_{BH} = \frac{M_A'}{7.75} = \frac{-2793}{7.75} = -360$ # LIMIT

$R_{AH} = -360 - 1783 + 2030 = -113$ # LIMIT

$R_{AV} = P_V = 1930$ # LIMIT

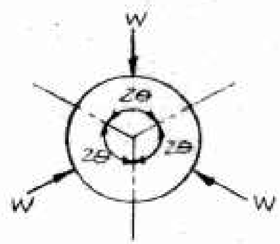
RING DEFLECTION –

THE LOWER SUPPORT RING FURNISHES THE MAJOR RESISTANCE TO RADIAL LOADS ON THE SEAL HOUSING (THE LOWER PORTION OF THE DUCT) ADVERSE DEFORMATIONS OF THE WALLS WILL ALLOW LEAKAGE IN THIS AREA.

– CONT'D –

DUCT ASSY - UPPER, ROTATING (CONT'D)

LOWER SUPPORT RING (REF DWGS 285-0505, -0541) (CONT'D)



REF 2 - CHAPTER 8
TABLE VIII, CASE 9

MAXIMUM RADIAL DISPLACEMENT (d_{MAX})

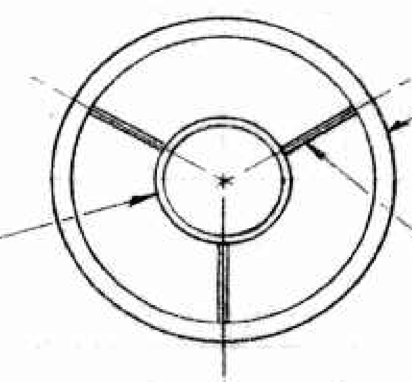
$$d_{MAX} = \frac{WR^3}{2EI}\left[\frac{1}{\sin^2\theta}\left(\frac{1}{2}\theta + \frac{1}{2}\sin\theta\cos\theta\right) - \frac{1}{\theta}\right]$$

WHERE $\theta = 60° = 1.047$ RADIANS

$$d_{MAX} = \frac{WR^3}{2EI}\left[\frac{1}{(.866)^2}\left(\frac{1}{2}\right)(1.047 + .866 \times .500) - \frac{1}{1.047}\right] = \frac{.032\,WR^3}{2EI},$$

AT THE POINT OF APPLICATION.

THE LOWER SUPPORT RING IS A PORTION OF THE SEAL HOUSING ASSEMBLY WHICH IS COMPRISED OF AN OUTER SEAL RING (LOWER SUPPORT RING) AND AN INNER SEAL RING AS SHOWN IN THE SKETCH BELOW.



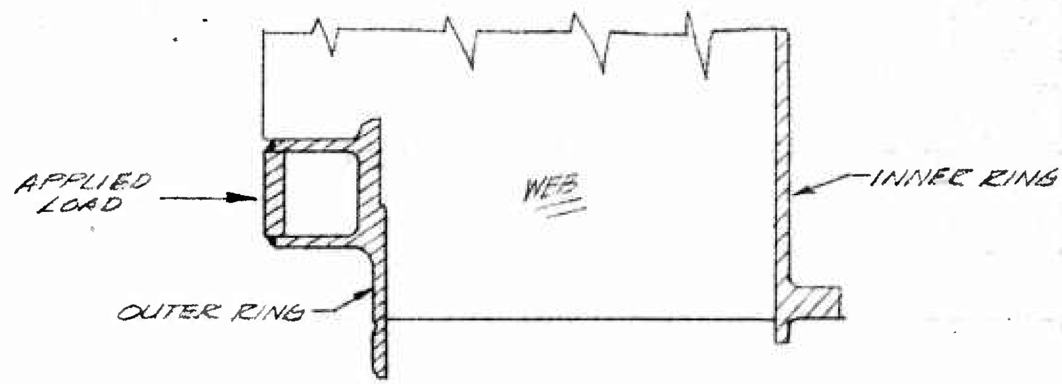
THE LOADS ARE IMPOSED ON THE OUTER RING IN THE SAME LOCATIONS AS THE RADIAL WEBS SO THAT LOADING OF THE OUTER RING ALSO LOADS THE INNER RING, THE LOADING IN EACH RING DEPENDING UPON ITS PORTION OF THE TOTAL STIFFNESS OF THE TWO RINGS WORKING TOGETHER.

- CONT'D -

HUB DUCTS

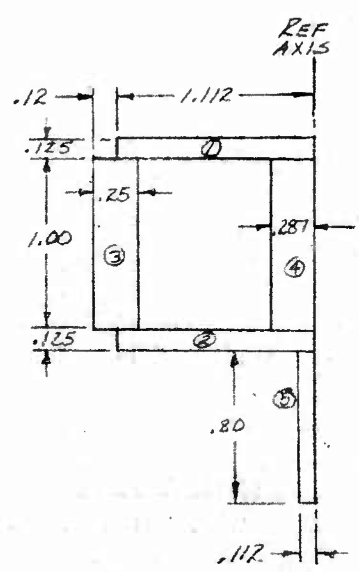
DUCT ASSY-UPPER, ROTATING (CONT'D)

LOWER SUPPORT RING (REF. DWGS 285-0505, -0541) (CONT'D)



FROM THE DEFLECTION EQUATION (PG 5.3.3.5.1) IT CAN BE BE SEEN THAT THE PARAMETER FOR DEFLECTION IS $\left(\frac{R^3}{EI}\right)$ AND THE RATIO OF THIS VALUE FOR EACH RING TO THE TOTAL FOR BOTH WILL DETERMINE THE PERCENTAGE OF THE IMPOSED LOAD CARRIED IN THAT RING.

OUTER RING —



ITEM	A	x	Ax	Ax²	I_o
①	.1390	.556	.0773	.0430	.0143
②	.1390	.556	.0773	.0430	.0143
③	.2500	1.112	.2780	.3091	.0013
④	.2870	.143	.0410	.0118	.0021
⑤	.0896	.056	.0050	.0003	.0001
Σ	.9046	—	.4786	.4072	.0321

$\bar{X} = \frac{.4786}{.9046} = .529\ IN$

$I_{NA} = .0321 + .4072 - (.529)(.4786) = .1861\ IN^4$

RADIUS R = 8.9 IN.

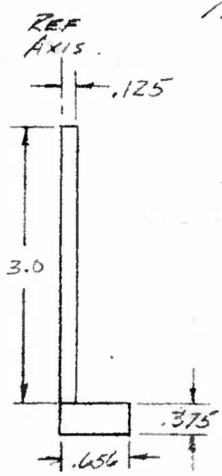
$\frac{R^3}{EI} = \frac{(8.9)^3}{(30\times10^6)(.1861)} = 12.62\times10^{-5}$

— CONT'D —

DUCT ASSY – UPPER, ROTATING (CONT'D)

LOWER SUPPORT RING (REF. DWGS. 285-0505, -0541) (CONT'D)

INNER RING –



$$A = (3.0)(.125) + (.375)(.656) = .621 \text{ IN}^2$$

$$\bar{y} = \frac{(3.0)(.125)(.0625) + (.375)(.656)(.328)}{.621} = .168 \text{ IN}$$

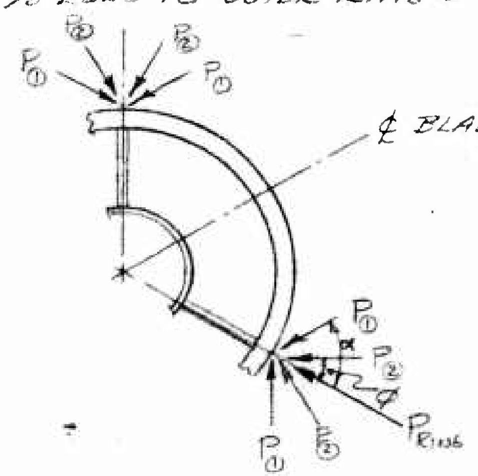
$$I_{R.A.} = \frac{(3.0)(.125)^3 + (.375)(.656)^3}{3} = .0373 \text{ IN}^4$$

$$I_{N.A.} = .0373 - (.621)(.168)^2 = .0198 \text{ IN}^4$$

RADIUS $R = 3.7$ IN

$$\frac{R^3}{EI} = \frac{(3.7)^3}{(30 \times 10^6)(.0198)} = 8.6 \times 10^{-5}$$

$$\% \text{ LOAD TO OUTER RING} = \frac{12.62}{12.62 + 8.6} = .59\%$$



$\alpha = 60°$

$\phi = 30°$

$P_{①} = R_{BH} = 360$ # LIMIT (REF PG 5.3.3.5.0)

$$P_{②} = 652 + \frac{497}{7.75} = 716 \text{ \# LIMIT}$$

(REF PG 5.3.3.1.8)

$$P_{RING} = (2)\left[716 \cos 30° + 360 \cos 60°\right] = 1600 \text{ \# LIMIT}$$

$$\text{RING DEFL., } d_{MAX} = \frac{.032 W R^3}{2EI} \quad \text{(REF PG 5.3.3.5.1)}$$

$$W = .59\, P_{RING}$$

$$d_{MAX} = (.016)(.59)(1600)(12.62 \times 10^{-5}) = .0019 \text{ IN}$$

– CONT'D –

DUCT ASSY - UPPER, ROTATING (CONT'D)

LOWER SUPPORT RING (REF DWGS 285-0505, -0541) (CONT'D)

RING BENDING -

$$M_{MAX} = \frac{1}{2} WR \left(\frac{1}{\sin\theta} - \frac{1}{\theta} \right)$$

(REF 2, CHAP 8, TABLE 8, CASE 9)

$$M_{MAX} = \left(\frac{1}{2}\right)(.59 \times 1600)(8.9)\left(\frac{1}{.866} - \frac{1}{1.047}\right)$$

$$M_{MAX} = 840 \text{ "\#}$$

$$f_b = \frac{(840)(.642)}{.1861} = 2900 \text{ PSI LIMIT}$$

$$F_{ty} = 18000 \text{ PSI } (1200°F) \text{ (REF 5, PG 62)}$$

M.S. = HIGH +

DUCT ASSY - UPPER, ROTATING (CONT'D)

DUCT SUPPORT STRAPS (REF. DWGS. 285-0588, -0541)(CONT'D)

ATTACH OF STRAP TO DUCT -

t_{DUCT} = .125 IN , .250 DIA BOLT
STRAP

MAT'L - TYPE 347 CORR. RES. STEEL H.T. 90 KSI

BOLT BEARING = 70,000 PSI (REF PG 5.3.3.6.0)

ASSUMING F_{BRY} AT ROOM TEMP = 150,000 PSI

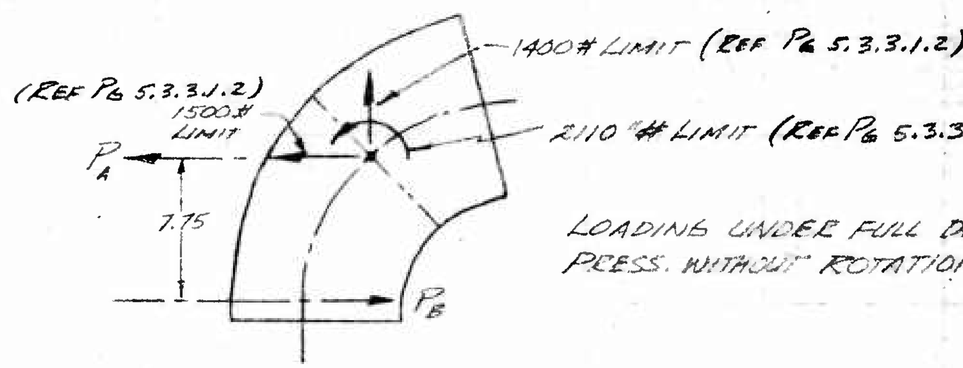
AT 1200° $F_{BRY} = \frac{43}{85} \times 150000 = 76,000$ PSI (REF 5, PG 62)

$$M.S. = \frac{76,000}{70,000} - 1 = .09$$

DUCT ASSY - UPPER, ROTATING (CONT'D)

5.3.3.6 DUCT SUPPORT STRAPS

REF DWGS 285-0588, -0541



LOADING UNDER FULL DUCT PRESS. WITHOUT ROTATION.

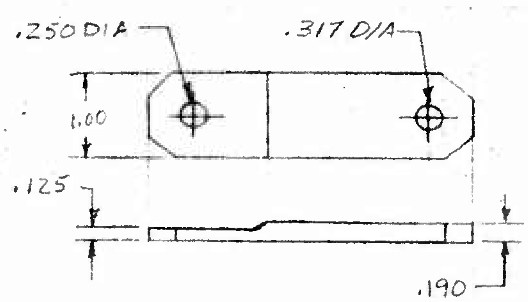
$$P_A = P_B = \frac{2110}{7.75} = 272\text{\# LIMIT}$$

$$R_{A_U} = (1500 + 272)(2) + 530(1.5) = 4340\text{\# ULT.}$$

THIS LOAD IS EQUALLY DIVIDED BETWEEN THE SUPPORT STRAPS ON EITHER SIDE OF THE DUCT.

$$P_{STRAP} = \frac{4340}{2} = 2170\text{\# ULT.}$$

LINK STRAP — MAT'L — 6AL-4V TITANIUM BAR STOCK



$$A_t = (1.00)(.125) = .125\ IN^2$$

$$P_C = 2170\text{\# ULT}$$

$$f_c = \frac{2170}{.125} = 17{,}400\ PSI\ ULT$$

$$A_{br} = .250 \times .125 = .031\ IN^2$$

$$f_{br} = \frac{2170}{.031} = 70{,}000\ PSI\ ULT$$

$$F_{BRU} = 196{,}000\ PSI \quad (REF\ 1)$$

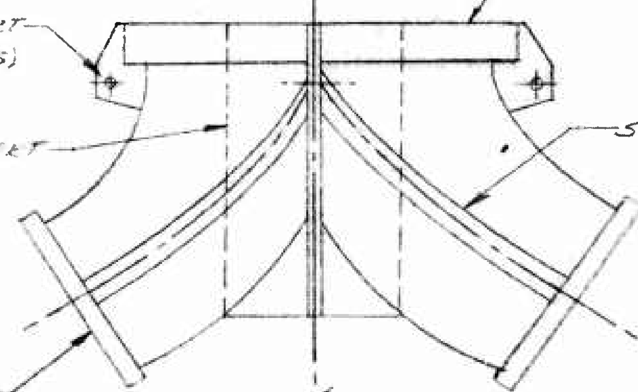
BOLT SHEAR — .250 DIA BOLT, 160-180 KSI H.T.

$$P_{ALLOW} = 4650\text{\#} \quad (REF.\ 1)$$

$$M.S. = \frac{4650}{2170} - 1 = \underline{1.14}$$

HUB DUCTS

5.3.3.7 285-0522 DUCT ASSY - LOWER, STATIONARY



GENERAL CONFIGURATION

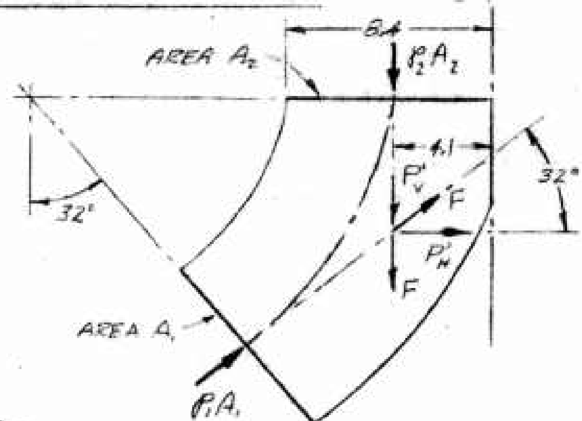
THE DUCTS ARE SUPPORTED AT 4 POINTS 90° APART ON THE CIRCUMFERENCE OF THE UPPER RING SUPPORT. THE 2 SUPPORTS LOCATED AT THE INTERSECTION OF THE STIFFENER SUPPORTS WILL CARRY THE MAJOR PORTION OF THE DUCT LOADS AND ANALYSIS WILL BE MADE ON THE ASSUMPTION THEY CARRY THE ENTIRE LOAD.

OPERATING CONDITIONS —

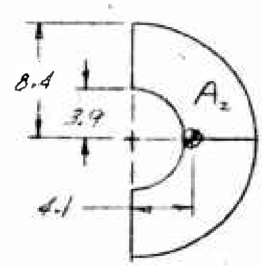
1. STARTING CONDITION - DUCT PRESSURE ONLY
2. RUNNING CONDITION - DUCT PRESSURE + CENT. FORCE.
3. POWER OFF, ROTATING CONDITION

DUCT ASSY - LOWER, STATIONARY (285-0522) (CONT'D)

EXTERNAL ANALYSIS OF FORCES



LOADS GEOMETRY

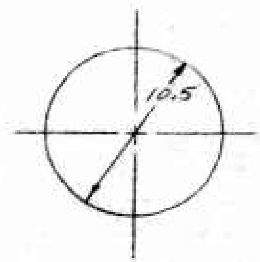


$A_2 = \frac{1}{2}\pi\left[(8.4)^2 - (3.9)^2\right]$

$A_2 = 86.9\ IN^2$

$A_1 = \frac{\pi(10.5)^2}{4}$

$A_1 = 86.6\ IN^2$



$P_1 = P_2 = 26.9$ PSIG (LIMIT)
OPERATING TEMP = 1117 °F
GAS MASS FLOW = 25.0 #/SEC
SPEED OF GAS FLOW, M = .35
(REF. DESIGN CRITERIA, SECT. 1)

$P_1A_1 = P_2A_2 = (26.9)(86.6) = 2330$ # LIMIT

$P_V' = P_2A_2 - P_1A_1 \sin 32° = 2330(1 - \sin 32°) = 1095$ # LIMIT

$P_H' = P_1A_1 \cos 32° = 2330 \cos 32° = 1976$ # LIMIT

F = 530# LIMIT (FROM CALCULATIONS ON UPPER DUCT PG 5.3.3.1.2)

TOTAL REACTION DUE TO FORCES

$P_V = P_V' + F(1 - \sin 32°) = 1095 + 530(1 - \sin 32°) = 1344$ # LIMIT

$P_H = P_H' + F \cos 32° = 1976 + 530 \cos 32° = 2425$ # LIMIT

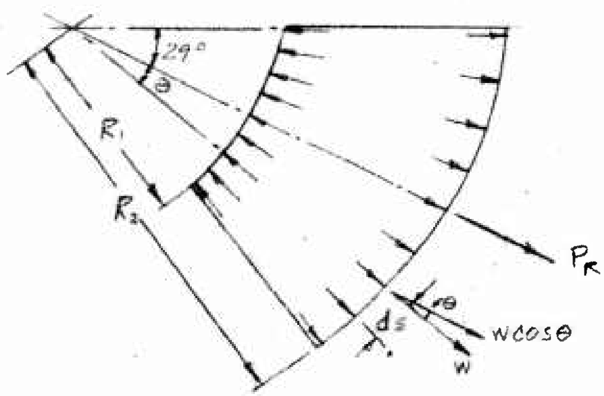
$P_R = (\overline{1344}^2 + \overline{2425}^2)^{1/2} = 2770$

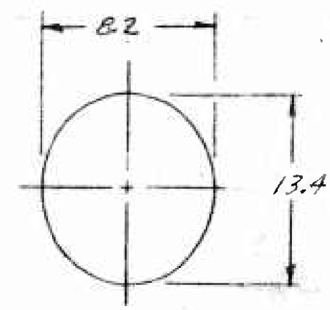
$\Theta_H = \tan^{-1}\left(\frac{1344}{2425}\right) = 29°$

DUCT ASSY - LOWER, STATIONARY (285-0522) (CONT'D)

INTERNAL ANALYSIS OF FORCES

THE INTERNAL PRESSURE ACTING ON THE DUCT WALLS WILL TEND TO STRAIGHTEN OUT THE DUCT AND THEREBY CAUSE BENDING IN THE DUCT. FROM THE GEOMETRY OF THE DUCT STRUCTURE IT CAN BE SEEN THAT WHAT AMOUNTS TO THE UPPER HALF OF THE DUCT IS SUPPORTED BETWEEN THE UPPER RING SUPPORT AND THE SUPPORT BRACES, THE LOWER HALF BEING ONLY PARTIALLY SUPPORTED. ON THIS BASIS, THE LOWER HALF WILL BE CONSIDERED AS UNSUPPORTED STRUCTURE.





AVERAGE CROSS-SECTION

$R_1 = 9.5 IN$

$R_2 = 9.5 + 8.2 = 17.7 IN$

TO FACILITATE ANALYSIS, THE FOLLOWING GENERALIZATIONS ARE MADE TO THE GEOMETRY OF THE DUCT:

1. CONSIDER THE DUCT AS A SECTION OF A TORUS
2. ASSUME A CONSTANT ELLIPTICAL CROSS-SECTION

UNIT LOADING -

USING A UNIT 1 INCH WIDE STRIP -

$W_{STRIP} = (13.4)(26.9) = 360$ # LIMIT

FOR THE FIGURE AT LEFT ABOVE:

$ds = R d\theta$

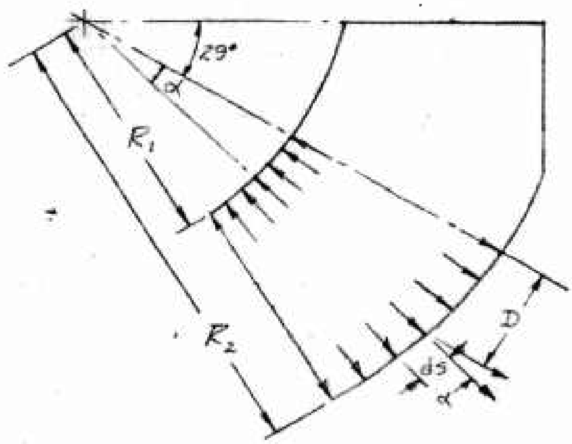
$$P_R = 2 \sum_{0}^{29°} W\cos\theta = 2\int_0^{29°} R d\theta \, W\cos\theta = 2WR\int_0^{29°} \cos\theta \, d\theta = 2WR\left[\sin\theta\right]_0^{29°}$$

AND: $P_R = (2)(360)(8.2)[.4848] = 2860$ # LIMIT

THIS COMPARES FAVORABLY TO $P_R = 2770$# LIMIT AS CALCULATED IN THE EXTERNAL ANALYSIS.

DUCT ASSY - LOWER, STATIONARY (285-0522) (CONT'D)

BENDING OF DUCT DUE TO INTERNAL PRESSURE -



$R_1 = 9.5$ IN
$R_2 = 17.7$ IN

$W = 360$ #/IN LIMIT
$D = R\sin\alpha$
$ds = R\,d\alpha$

$$M = (W\cos\alpha)(D) = (W\cos\alpha)(R\sin\alpha)$$
$$dM = (W\cos\alpha)(R\sin\alpha)(R\,d\alpha)$$

$$M = WR^2\int_0^{\alpha}\cos\alpha\sin\alpha\,d\alpha = WR^2\left[\tfrac{1}{2}\sin^2\alpha\right]_0^{14.5°} = .0314\,WR^2$$

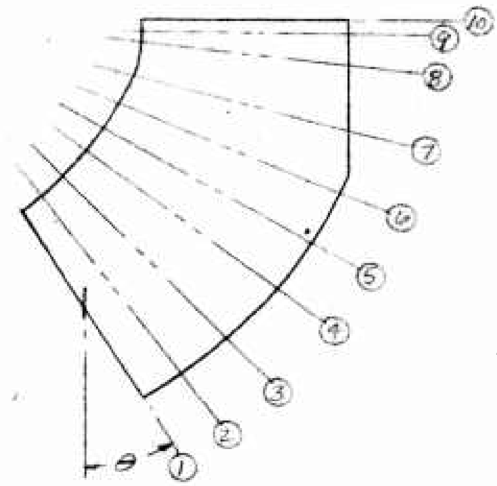
$$M = .0314(360)(8.2)^2 = 760\ ''\#\ \text{LIMIT}$$

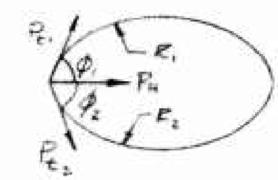
LOADS IN STIFFENER SUPPORTS

DUE TO THE CROSS-SECTIONAL SHAPE OF THE DUCT, THE INTERNAL PRESSURE ACTING ON THE DUCT WALLS WILL TEND TO PRY THEM APART AT THE DUCT "CORNERS" (I.E. THE INTERSECTION OF THE DUCT WALLS) AND IN SO DOING IMPOSE A LOADING ON THE STIFFENER SUPPORTS. THE "RADIAL" COMPONENTS OF THESE FORCES ARE PERPENDICULAR TO THE CENTER PLANE OF THE DUCT. THERE ARE ALSO "TANGENTIAL" FORCES, COPLANAR WITH, AND PERPENDICULAR TO THE "RADIAL" FORCES

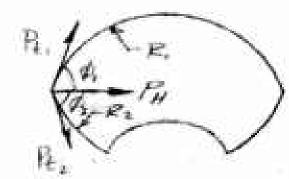
DUCT ASSY - LOWER, STATIONARY (285-0522) (CONT'D)

LOADS IN STIFFENER SUPPORTS (CONT'D)





SECTIONS ①, ② & ③



SECTIONS ④ THRU ⑩

SECT	θ	R_1	R_2	P_{t_1}	P_{t_2}	ϕ_1	ϕ_2	P_V	P_H
①	32°	5.2	5.2	140	140	90°	90°	0	0
②	38°	5.2	5.2	140	140	90°	90°	0	0
③	45°	5.5	5.5	148	148	89°	85°	.5	15
④	54°	5.9	5.9	159	159	89°	79°	3	33
⑤	61°	6.5	6.5	175	175	87°	71°	9	66
⑥	68°	7.1	7.1	191	191	86°	60°	25	109
⑦	76°	7.6	7.6	205	205	86°	51°	45	143
⑧	84°	8.0	8.0	165	165	87°	44°	65	166
⑨	90°	8.25	8.25	222	222	86°	40°	79	178
⑩	90°	6.4	6.4	226	226	90°	0°	—	—

$P_t = pRW$

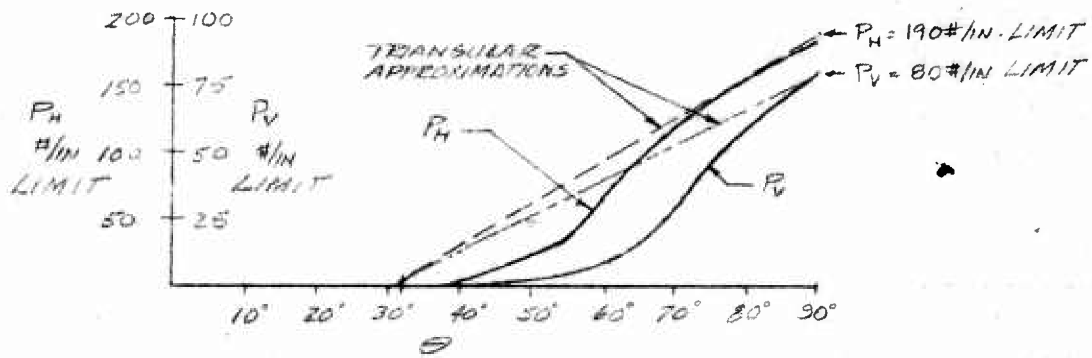
$P_V = P_{t_1} \sin\phi_1 - P_{t_2} \sin\phi_2$

$P_H = P_{t_1} \cos\phi_1 + P_{t_2} \cos\phi_2$

WHERE $p = 26.9$ PSIG LIMIT (REF SECTION 1)
$W = 1.0$ INCH WIDTH OF TUBE

DUCT ASSY - LOWER, STATIONARY (285-0522) (CONT'D)

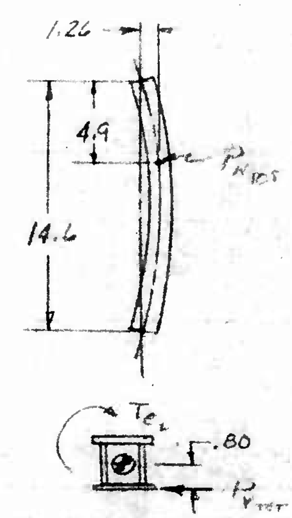
PLOTS OF ANGULAR POSITION VS LOAD SHOW THAT P_V AND P_H DISTRIBUTIONS ARE BASICALLY TRIANGULAR.



FOR PURPOSES OF THIS ANALYSIS THE LOADING USED WILL BE THE TRIANGULAR APPROXIMATIONS SHOWN, 32° TO 90°.

TORSION IN STIFFENER SUPPORTS –

DUE TO THE CURVATURE OF THE BEAM IN THE PLANE PARALLEL TO THE DUCT CENTER PLANE A TORSIONAL MOMENT IS INDUCED IN THE STIFFENER FROM THE LOADING P_H. THE SIDE LOADING, P_V, ALSO INDUCES A TORSIONAL MOMENT IN THE SAME DIRECTION DUE TO THE OFFSET OF THE STIFFENER AXIS AND THE POINTS OF APPLICATION OF THE LOADING



STIFFENER SECTION

FOR THE P_H DISTRIBUTION –

ASSUME THE TOTAL LOAD ACTING AT THE C.G. OF THE LOADING:

$$T_{e_1} = (95)(14.6)(1.26) = 1750 \text{ "\# LIMIT}$$

FOR THE P_V DISTRIBUTION –

ASSUME THE TOTAL LOAD ACTING AT ONE POINT ON THE BASE OF THE STIFFENER

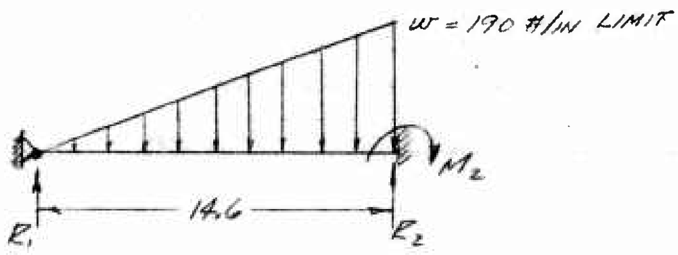
$$T_{e_2} = (40)(.8)(14.6) = 467 \text{ "\# LIMIT}$$

TORSION WILL BE RESISTED BY THE SUPPORT BRACES LOCATED APPROX. AT THE CENTER OF THE BEAM

HUB DUCTS

DUCT ASSY - LOWER, STATIONARY (285-0522) (CONT'D)

LOADS IN STIFFENER SUPPORTS (CONT'D) —



(REF. 2, TABLE III CASE 35)

$W = \frac{1}{2} wl = \frac{1}{2}(190)(14.6) = 1388\#$ LIMIT

$R_1 = \frac{1}{5} W = \frac{1}{5}(1388) = 278\#$ LIMIT

$R_2 = \frac{4}{5} W = \frac{4}{5}(1388) = 1110\#$ LIMIT

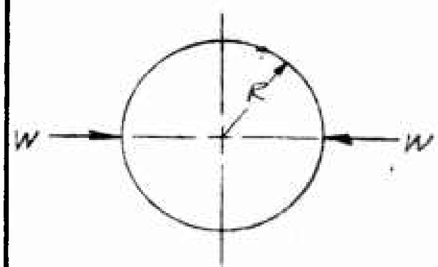
$M_2 = \frac{2}{15} Wl = \frac{2}{15}(1388)(14.6) = 2700''\#$ LIMIT

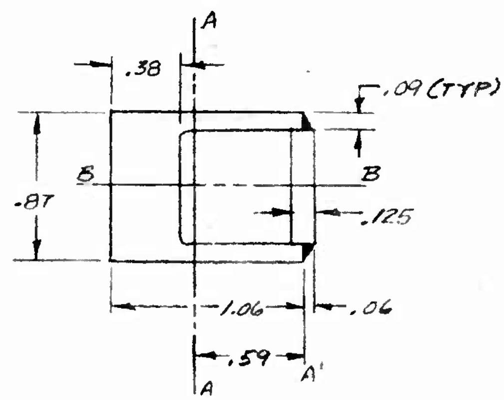
REACTION R_1 IS IMPOSED ON THE LOWER RING.
R_2 AND M_2 ARE CARRIED INTO THE UPPER RING SUPPORT.

DUCT ASSY - LOWER, STATIONARY (285-0522) (CONT'D)

5.3.3.8 285-0522-5 LOWER SEAL RING SUB-ASSY.

MAT'L - TYPE 347 CORR. RES. STEEL OR TYPE 321





W = 278 # LIMIT

R = 5.65 IN

SECTION PROPERTIES —

$$A = (.125)(.87-.18) + [(.87)(1.06) - (1.06-.38)(.87-.18)] = .539 \text{ IN}^2$$

$$I_{A'} = \frac{(.87)(1.06)^3 - (.69)(.68)^3}{3} = .274 \text{ IN}^4$$

$$I_{A\text{-}A} = .274 - (.539)(.59)^2 = .274 - .188 = .086 \text{ IN}^4 \; ; \; I/c = \frac{.086}{.65} = .132 \text{ IN}^3$$

$$I_{B\text{-}B} = \frac{(1.06)(.87)^3 - (.555)(.69)^3}{12} = \frac{.514}{12} = .043 \text{ IN}^4 \; ; \; I/c = \frac{.043}{.435} = .099 \text{ IN}^3$$

FOR A RING LOADED AS SHOWN. (REF 2, TABLE VIII, CASE 1)

$$defl. = -0.149 \frac{WR^3}{EI} = -0.149 \frac{(278)(5.65)^3}{(30 \times 10^6)(.086)} = -.0029 \text{ IN}$$

$$M_{MAX} = 0.3183\, WR = 0.3183(278)(5.65) = 500 \text{"\# LIMIT}$$

$$f_b = \frac{M}{I/c} = \frac{500}{.132} = 3790 \text{ PSI LIMIT}$$

$$F_{ty} = 18{,}000 \text{ PSI } (1200°F) \text{ (REF 5, PG 62)}$$

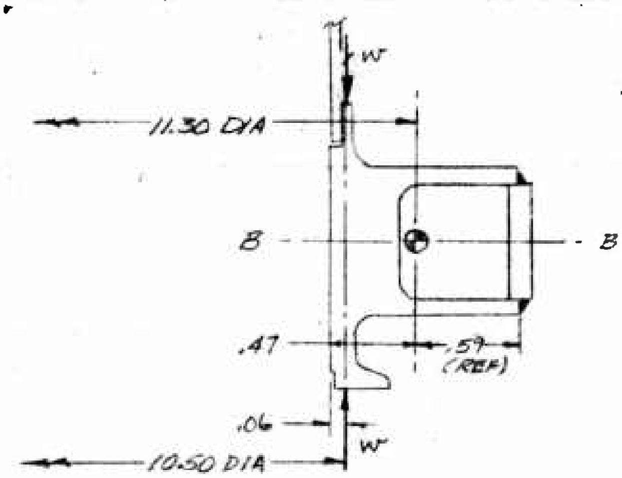
M.S. = HIGH +

CONT'D

HUB DUCTS

DUCT ASSY - LOWER, STATIONARY (285-0522) (CONT'D)

285-0522-5 LOWER SEAL RING SUB-ASSY (CONT'D)



W IS AN EQUALLY DISTRIBUTED LOADING OVER THE CIRCUMFERENCE OF THE RING DUE TO AN ARBITRARY LOAD P = 1000 #

$$W = \frac{P}{\pi D} = \frac{1000}{\pi(11.30)} = 28.2 \text{ \#/IN LIMIT}$$

ASSUME THAT W WILL BE CARRIED BY THE DUCT WALLS AND RE-DISTRIBUTE TO THE STIFFENER BY SHEAR TRANSFER.

REACTION TO W LOADING IS IN THE FORM OF AN EQUALLY DISTRIBUTED LOADING AND AN EQUALLY DISTRIBUTED TORSIONAL MOMENT ABOUT THE CIRCUMFERENCE AT THE 10.50 DIA.

TORSIONAL MOMENT PER INCH, $M_T = 28.2(.41) = 11.6$ "#/IN LIMIT

$$f_b = \frac{MR}{I/c} \quad \text{(ROARK, ART 62)} \quad (I = I_{B\text{-}B})$$

$$f_b = \frac{11.6(5.65)}{.099} = 662 \text{ PSI LIMIT}$$

MAXIMUM STRESS OCCURS AT CORNER OF SECTION -

$$f_{b_{MAX}} = 3790 + 662 = 4452 \text{ PSI LIMIT}$$

$$F_{ty} = 18{,}000 \text{ PSI } (1200°F) \quad \text{(REF. 5 PG 62)}$$

$$M.S. = \frac{18000}{4452} - 1 = \underline{3.04}$$

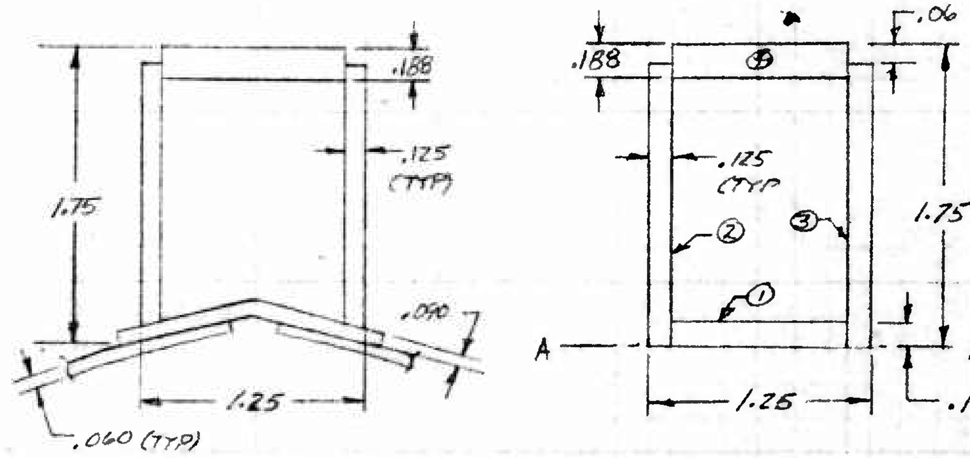
DUCT ASSY - LOWER, STATIONARY (285-0522) (CONT'D)

5.3.3.9 STIFFENER SUPPORTS, 285-0522-9, -11, -41

MAT'L - TYPE 347 CORR. RES. STEEL OR TYPE 321

CHECK OF STIFFENER SECTION IS MADE AT THE ATTACHMENT TO THE -19 STIFFENER AND DUCT WALL.

$M = 2700$ "# LIMIT
$P_S = 1110$ # LIMIT
(REF PAGE 5.3.3.7.6)



STIFFENER CROSS-SECTION AT POINT DISCUSSED APPROXIMATES THAT SHOWN AT LEFT ABOVE. SIMPLIFIED SECTION AT RIGHT.

ITEM	A	d	Ad	Ad^2	I_o
①	.1500	.075	.0113	.0008	.0003
②	.2113	.845	.1785	.1508	.0502
③	.2112	.845	.1785	.1508	.0502
④	.1880	1.656	.3113	.5155	.0006
Σ	.7605		.6796	.8139	.1013

$$\bar{d} = \frac{.6796}{.7605} = .894\ IN$$

$$I_{NA} = .1013 + .8139 - .894(.6796) = .3079\ IN^4 ; \quad I/c = \frac{.3079}{.894} = .344\ IN^3$$

$$f_b = \frac{2700}{.344} = 7850\ PSI\ LIMIT$$

$F_{ty} = 18{,}000$ PSI (1200°F) (REF 5, PG 62)

$$M.S. = \frac{18000}{7850} - 1 = \underline{1.29}$$

DUCT ASSY - LOWER, STATIONARY (285-0522) (CONT'D

5.3.3.10 STIFFENER SUPPORT BRACES, 285-0522-13, -25

MAT'L - TYPE 347 CORR. RES. STEEL OR TYPE 321

TORSION INDUCED IN STIFFENER SUPPORTS DUE TO CURVATURE IS RESISTED BY THE -13 AND -25 BRACES

$$T_c = T_{c_1} + T_{c_2} = 1750 + 467 = 2217 \text{ "\# LIMIT}$$

(REF PG 5.3.3.7.5)

LOAD TO BRACES:

$$P_{BRACES} = \frac{T_c}{h_{STIFF}} = \frac{2217}{1.75} = 1270 \text{ \# LIMIT}$$

COMPRESSIVE BUCKLING

$$\frac{F_{CR}}{\eta} = KE\left(\frac{t}{b}\right)^2$$

WHERE $\eta = 1$, $K = 3.62$

ACTUAL LENGTH OF LOADED EDGE, b, ≈ 1.5 IN. $t = .125$

$$f_c = \frac{1270}{(1.5)(.125)} = 6870 \text{ PSI LIMIT}$$

ASSUMING A RECTANGULAR PLATE WITH $b = 2.50$ IN —

$$F_{CR} = (3.62)(30 \times 10^6)\left(\frac{.125}{2.5}\right)^2 = 272{,}000 \text{ PSI}$$

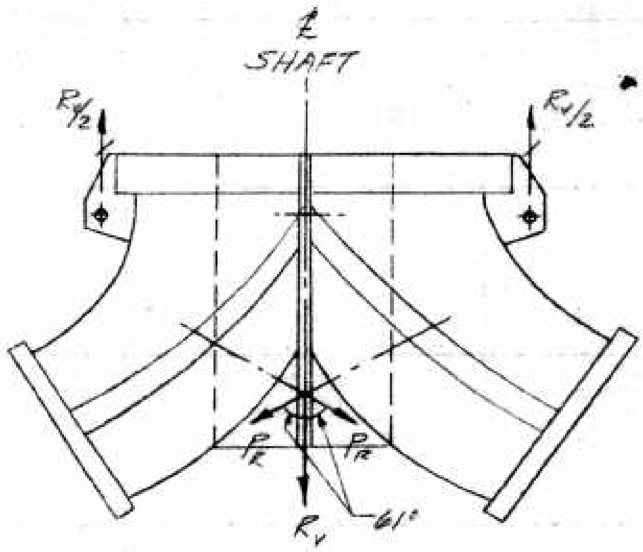
SINCE THIS PLATE IS THE DEEPER OF THE TWO, THE OTHER SUPPORT BRACE OK BY COMPARISON

$$F_{ty} = 18{,}000 \text{ PSI } (1200°F) \text{ (REF 5, PG 62)}$$

$$M.S. = \frac{18000}{6870} - 1 = \underline{\underline{1.62}}$$

DUCT ASSY - LOWER, STATIONARY (285-0522) (CONT'D)

5.3.3.11 DUCT SUPPORTS LOADING



THE LOWER DUCT ASSEMBLY IS SUPPORTED AT 4 POINTS 90° APART ON THE CIRCUMFERENCE OF THE DUCT.

P_R = 2860 # LIMIT (REF PG 5.3.3.7.2) PER DUCT

$R_V = 2(2860 \cos 61°) = 2780$ # LIMIT

$R_H = 0$

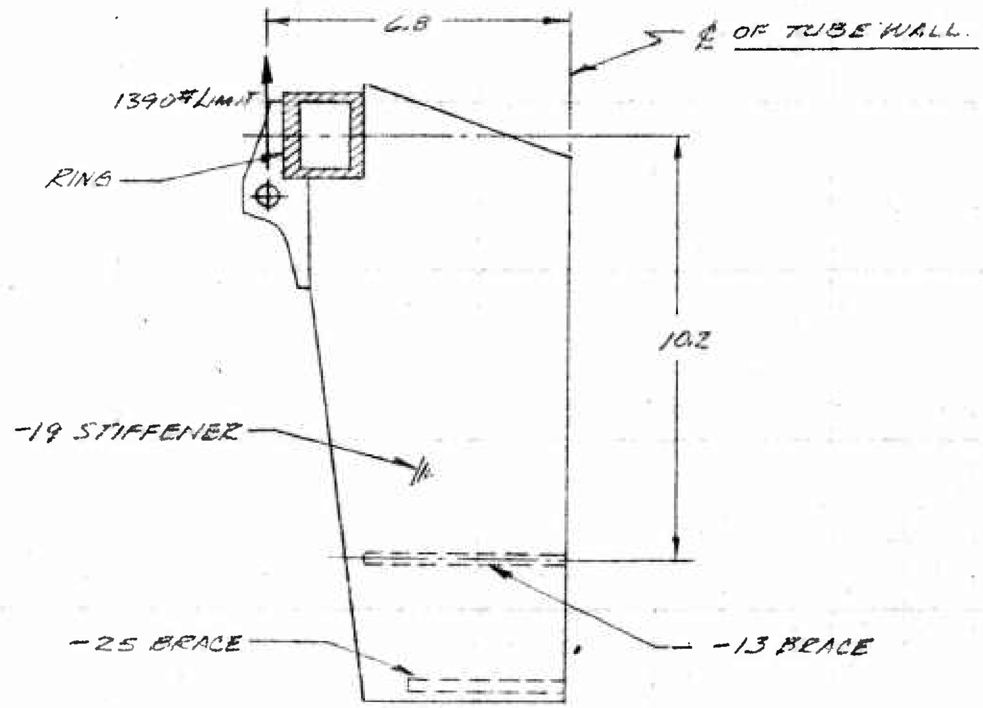
$P_{SUPPORT} = R_V/2 = \frac{2780}{2} = 1390$ # LIMIT

HUB DUCTS

DUCT ASST - LOWER, STATIONARY (285-0522) (CONT'D)

5.3.3.12 RING STIFFENER SUPPORTS, 285-0522-19, -29, -31

MAT'L - TYPE 347 CORR. RES. STEEL OR TYPE 321



THE REACTION, 1390# (REF PG 5.3.3.11.0) PRODUCES A MOMENT IN THE STIFFENER WHICH IS RESISTED AS A COUPLE BETWEEN THE RING AND THE BRACE.

$$P_{COUPLE} = \frac{1390\,(6.8)}{10.2} = 927\#\ \text{LIMIT}$$

RING STIFFENER OK BY INSPECTION.

THIS COUPLE LOAD IS APPLIED TO THE RING HORIZONTALLY AT TWO POINTS 180° APART.

DUE TO THE RADIAL LOADING, THE RING MUST BE THEN ANALYSED FOR RADIAL DEFLECTION THAT MAY POSSIBLY AFFECT THE RING SEALING ARRANGEMENT.

CONT'D -

HUGHES TOOL COMPANY-AIRCRAFT DIVISION

ANALYSIS: HOT CYCLE ROTOR MODEL: 285 REPORT NO. 285-13 PAGE: 5.3.3.12.1

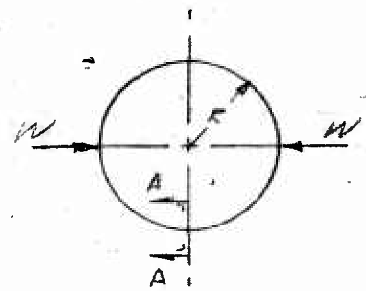
PREPARED BY: L.L. ERLE 8-3-60

CHECKED BY:

HUB DUCTS

DUCT ASST - LOWER, STATIONARY (285-0522) (CONT'D)

RING SUPPORT — REF -19, -29, -31 (CONT'D)



METHOD - ROARK, TABLE VIII, CASE 1

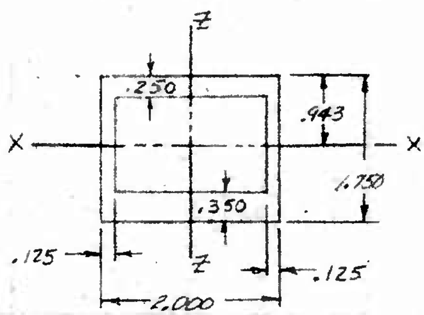
$$D' = -0.149 \frac{WR^3}{EI}$$

$W = 927\#$ LIMIT (REF PG 5.3.3.12.0)

$E = 30 \times 10^6$ PSI

$R = 9.25$ IN

$$I_{xx} = \frac{(2.0)(.943)^3 - (1.75)(.693)^3 + (2.0)(.807)^3 - (1.75)(.457)^3}{3} = .660 \text{ IN}^4$$



SECTION A-A

$$D' = -0.149 \frac{(927)(9.25)^3}{(30 \times 10^6)(.660)} = .0037 \text{ IN}$$

THIS VALUE IS CONSERVATIVE AS IT DOES NOT INCLUDE THE TUBE AS A RESISTING RING.

$$M_{MAX} = 0.3183\, WR$$

$$= 0.3183 (927)(9.25)$$

$$= 2735 \text{ "\# LIMIT}$$

$$I_{ZZ} = \frac{(1.75)(2.0)^3 - (1.15)(1.75)^3}{12} = .653 \text{ IN}^4$$

$$f_b = \frac{(2735)(1.0)}{.653} = 4190 \text{ PSI LIMIT.}$$

$F'_{ty} = 18{,}000$ PSI (1200°F) (REF 5, PG 62)

$$M.S. = \frac{18000}{4190} - 1 = \underline{3.30}$$

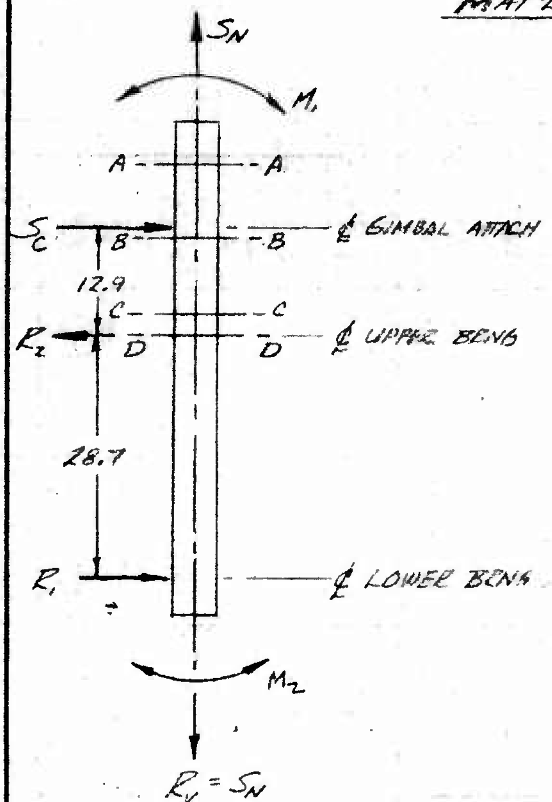
9704

5.3.4 MAIN ROTOR SHAFT

THIS ANALYSIS INCLUDES THOSE ITEMS DIRECTLY CONCERNED WITH THE MOUNTING OF THE MAIN ROTOR SHAFT AND INCLUDES THE SPOKE, UPPER AND LOWER BEARINGS, TRUNNION AND GIMBAL RING. REFERENCE IS DIRECTED TO DRAWING 285-0500 FOR A COMPLETE PICTURE.

5.3.4.1 285-0517 SHAFT

MAT'L - 4340 STL H.T. 160-180 KSI



LIMIT LOADS

COND	WEIGHTED FATIGUE	$2\frac{1}{2}$ G MANEUVER
M_1	42390 "#	52290 "#
M_2	39400 "#	48750 "#
S_N	22950 #	38250 #
S_C	±1610 #	±6740 #
R_1	±4620 #	±8880 #
R_2	±2330 #	±9770 #

(REF BASIC LOADS SECT 4)

SECTION A-A

$D_o = 5.301$

$D_i = 5.125$

$t = \frac{5.301 - 5.125}{2} = .088$

$A = \frac{3.14(5.301^2 - 5.125^2)}{4} = 1.39 \text{ IN}^2$

$I = \pi R^3 t = \pi (2.575)^3 (.088) = 4.75 \text{ IN}^4$

ASSUMING THAT THE RETAINING NUT IS COMPLETELY TIGHT, ONLY THE ULTIMATE BENDING CONDITION IS ANALYZED -

$2\frac{1}{2}$ G MAN. COND. - ULT

$$f_t = \frac{(52,290)(1.5)(2.65)}{4.75} + \frac{(38250)(1.5)}{1.39} = 85,200 \text{ PSI (ULT)}$$

$$M.S. = \frac{160,000}{85,200} - 1 = \underline{.88}$$

WEIGHTED FATIGUE COND -

NO FATIGUE CHECK IS MADE SINCE THE RETAINING NUT IS TORQUED TO PROVIDE 60,000 # PRELOAD IN THE SHAFT.

(NEXT PAGE)

285-0517 SHAFT CONT'D

FATIGUE ANALYSIS OF SECTION A-A ~ CONT'D

FOR THE WHIRL TOWER CONDITION, MAKE THE FOLLOWING ASSUMPTIONS:

$$M_1 = (.40)(42,390) = 17000 "\#$$

$$S_N = (1.25 \pm .1)(15,300)^* = 19,100 \pm 1530 "\#$$

$$f_t = \frac{\pm 17000(2.65)}{4.75} + \frac{19,100 \pm 1530}{1.39} = 13,700 \pm 10,600 \text{ PSI}$$

TORQUE REQ'D ~

$$R.L./_{"CIR} = \frac{P}{CIRCUM} + \frac{M}{A_{bx}} \qquad A_{bx} = \frac{\pi D^2}{4} = \frac{\pi}{4}(5.6)^2 = 24.5 \text{ IN}^2$$

$$R.L./_{"CIR} = \frac{19,100+1530}{\pi(5.6)} + \frac{17000}{24.5} = 1866 \#/\text{IN}$$

$$R.L. = \pi(5.6)(1866) = 32,800 \#$$

$$\text{TORQUE} = P \times \mu \times 2 \times R$$
$$= (32,800)(.15)(2)(2.7)$$
$$= 26,600 "\#$$

SEE PAGE 5.3.4.1.3

* REF BASIC LOADS DATA (SECT 4)

285-0517 SHAFT -(CONT'D)

SECTION B-B

THIS AREA IS NOTCHED DUE TO THE RELIEF PROVIDED FOR THE SPLINES

$f_t = \frac{22950}{3.056} = 7500$ PSI

AT THE SECTION, $D_o = 5.3725$; $D_i = 5.000$, AREA $= 3.056\ IN^2$

$I_{BB} = .0491\left[(5.3725)^4 - (5.0000)^4\right] = 10.22\ IN^4$

$f_b = \frac{42390(269)}{10.22} = \pm 11{,}160$ PSI M.S. $\frac{16,100}{11,160} - 1 = \underline{.45}$

$F_{tc} = \pm 35000$ PSI (REF FIG 2.8.1)

$K_t = 2.17$ (REF 4, FIG 42) $F_a = \frac{\pm 35000}{2.17} = \pm 16,100$

SECTION C-C

$D_o = 5.895$ IN $A = \pi \frac{(5.895^2 - 5.125^2)}{4} = 6.66\ IN^2$

$D_i = 5.125$ IN

$t = .385$ $I = \pi(2.755)^3(.385) = 25.43\ IN^4$

$M_{C-C} = 42390 + 1610(10.6) = 59500$ "#

$f_t = \frac{(59500)(2.948)}{25.43} = 6900$ PSI LIM

$F_{tc} = \pm 35000$ PSI (REF FIG 2.8.1)

$K_t = 2.39$ (REF 4, FIG 85) M.S. $= \frac{14.650}{6900} - 1 = \underline{1.12}$

$F_a = \frac{\pm 35000}{2.39} = \pm 14,650$ PSI

SECTION D-D

$D_o = 5.438$ $A = \pi \frac{(5.438^2 - 5.000^2)}{4} = 3.59\ IN^2$

$D_i = 5.000$

$t = .219$ $I = \pi(2.64^3)(.219) = 12.60\ IN^4$

$M_{D-D} = 42390 + 1610(12.9) = 63,200$ "#

$f_t = \frac{(63200)(2.719)}{12.60} = 13,600$ PSI

$F_a = 35,000$ PSI (REF FIG 2.8.1)

M.S. $= \frac{35,000}{13,600} - 1 = \underline{1.58}$

285-0517 SHAFT (CONT'D)

TORQUE REQ'D ON RETENTION NUT

REACTION LOAD PER INCH OF CIRCUMFERENCE -

$$R.L./_{''CIR} = \frac{P}{CIRCUM} + \frac{M}{A_{BR}}$$

$$A_{BR} = \frac{\pi D^2}{4} = \frac{\pi}{4}(5.6)^2 = 24.5 \text{ in}^2$$

$$R.L./_{''CIR} = \frac{22930}{\pi(5.6)} + \frac{42390}{24.5} = 3030 \ \#/IN$$

$$R.L. = \pi(5.6)(3030) = 53000 \#$$

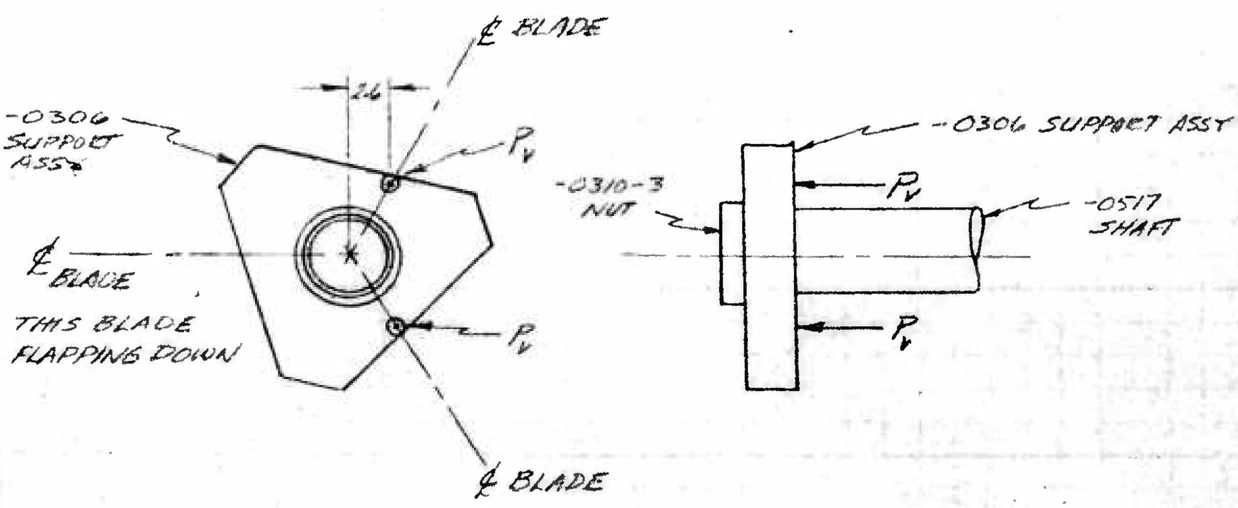
$$TORQUE = P \times \mu \times 2 \times R$$
$$= 53000 \times .15 \times 2 \times 2.7$$
$$= 43000 \ ''\#$$

ARBITRARILY $T = 50-55000 \ ''\#$

GROUND FLAPPING CONDITION

THE GROUND FLAPPING MOMENT BASED ON A 2.5 G LIMIT FACTOR IS 125,810 "# (REF. LOADS, SECTION 4) FOR THE 2° DROOP STOP A 2.0 G LIMIT FACTOR IS USED.

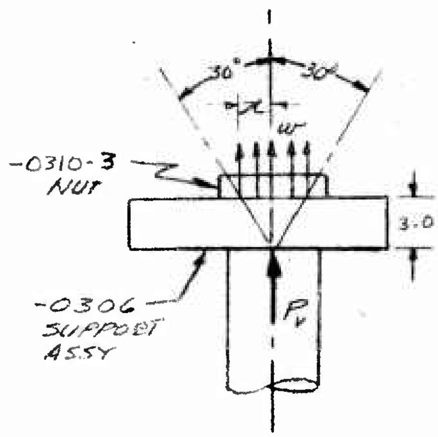
$$M_{GF} = \frac{2.0}{2.5}(125,810)(1.5) = 150,975 \ ''\# \ ULT$$



285-0517 SHAFT CONT'D

GROUND FLAPPING CONDITION - CONT'D

$$P_v = \frac{150975}{(2.6)(2)} = 29000\# \text{ ULT}$$



ASSUMPTION IS MADE THAT THE APPLIED LOAD WILL REDISTRIBUTE THRU THE SUPPORT IN THE MANNER SHOWN.

$x = 3.0 \tan 30° = 1.73$ IN

$2x = 3.46$ IN

UNDER THIS ASSUMPTION THE FORCE WILL BE APPLIED TO THE -0310-3 NUT AS AN EQUALLY DISTRIBUTED LOADING OVER 3.46 INCHES. THE NUT APPLIES THIS LOADING TO THE SHAFT.

IN THIS PORTION OF THE SHAFT THE WALL THICKNESS = .09 IN

TENSION STRESS IN THE SHAFT -

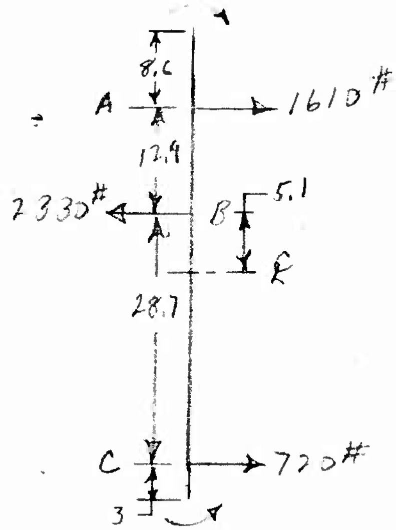
$$f_t = \frac{29000}{(3.46)(.09)} = 93{,}200 \text{ PSI ULT}$$

$F_t = 160{,}000$ PSI

$$M.S. = \frac{160000}{93200} - 1 = \underline{\underline{.72}}$$

285-0517 SHAFT - CONT'D

MAIN ROTOR SHAFT DEFLECTIONS



$R_2 = \frac{1610 \times 41.6}{28.7} = 2330^{\#}$

$I \cong \pi R^3 t = \pi \times \overline{2.64}^3 \times .16$

$= 9.3^{in^4}$

$E = 3 \times 10^7$

$\theta_A = \frac{1}{6} \frac{W}{EI} \left(b\ell - \frac{b^3}{\ell} \right) = \frac{1}{6} \times \frac{2330}{3 \times 10^7 \times 9.3} \left(28.7 \times 41.6 - \frac{\overline{28.7}^3}{41.6} \right)$

$= .00087$ RAD.

$\Delta\theta \, (A \text{ TO } B) = \int_A^B \frac{M \, d\ell}{EI} = \frac{1610 \times 6.45 \times 12.9}{3 \times 10^7 \times 9.3}$

$= -.00048$ RAD.

ROTATION AT B $= .00039$ RAD.

ROTATION DUE TO CONTROLS MOMENT:

$\Delta\theta = \frac{ML}{EI} = \frac{40000 \times 5.1}{3 \times 10^7 \times 9.3} = .00073$ RAD.

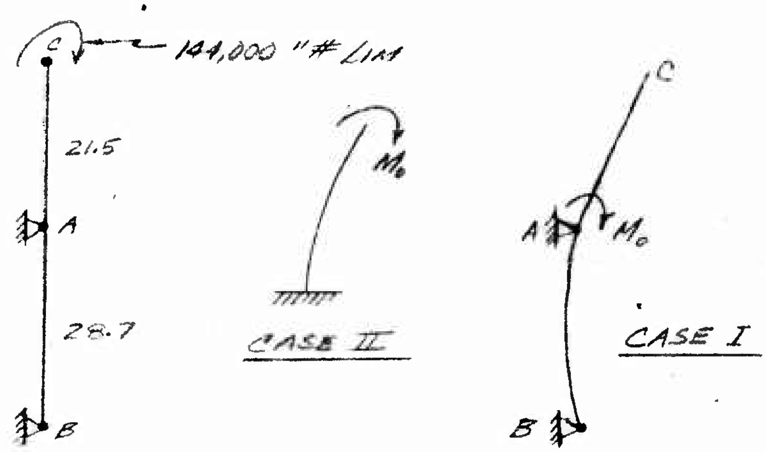
TOTAL ROTATION (WEIGHTED FATIGUE):

$= \underline{.00112}$ RAD

TOTAL ROTATION ($2\frac{1}{2}$G MANEUVER):

$= \underline{.00254}$ RAD

285-0517 SHAFT CONT'D



$I = 12.62 \text{ IN}^4$
$E = 29 \times 10^6 \text{ PSI}$

$P.E. = \frac{1}{2} M\theta$

CASE I

$$\theta_A = -\frac{1}{3}\frac{M_o l}{EI} = -\frac{1}{3}\frac{(144{,}000)(28.7)}{(29{,}000{,}000)(12.62)} = .00378 \text{ RAD}$$

CASE II

$$\theta_C = -\frac{M_o l}{EI} = \frac{(144{,}000)(21.5)}{(29{,}000{,}000)(12.62)} = .00845 \text{ RAD}$$

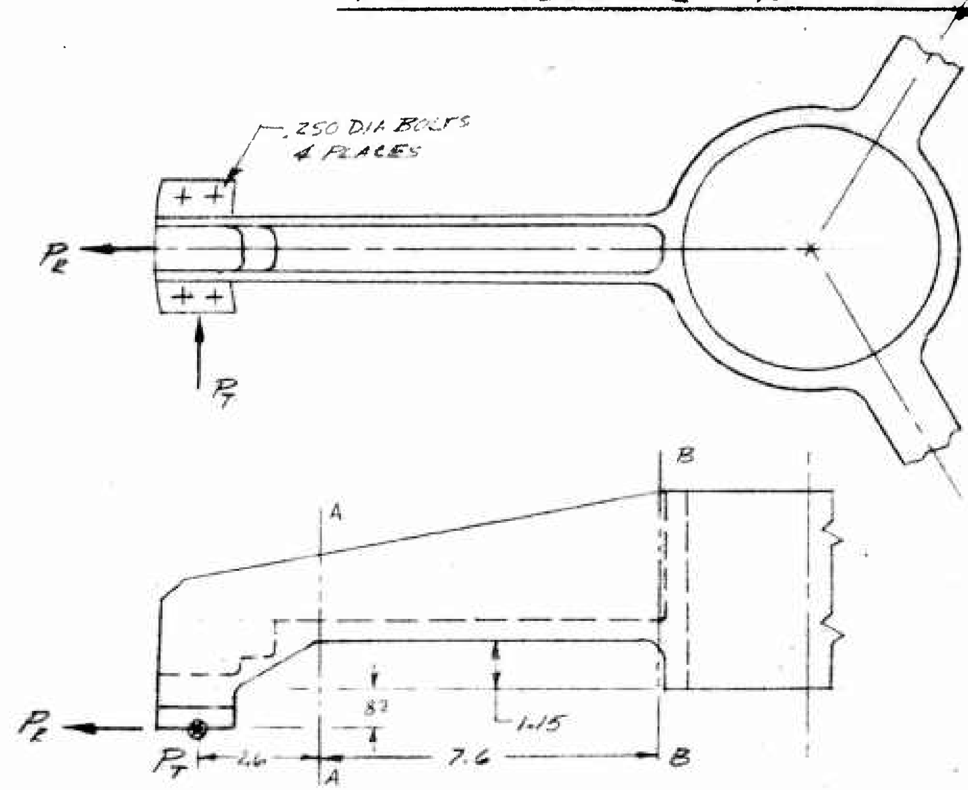
$$\theta_{TOTAL} @ C = .00845 + .00378 = .0122 \text{ RAD}$$

$$P.E. = \frac{1}{2} M\theta = \frac{1}{2}(144000)(.0122) = 880 \text{ "\#}$$

MAIN ROTOR SHAFT

5.3.4.2 285-0515 SPOKE

MAT'L – 4340 STL H.T. 160-180 KSI



2½G MANEUVER CONDITION --

$P_R = \pm 9770$ # LIM (REF PG 5.3.4.1.0)

$P_T = \frac{1}{3} \times (.10)(9770) = 326$ # LIM

WEIGHTED FATIGUE CONDITION -

$P_R = 0 \rightarrow 2330$ (REF PG 5.3.4.1.0)

$P_T = 0$

285-0515 SPOKE (CONT'D)

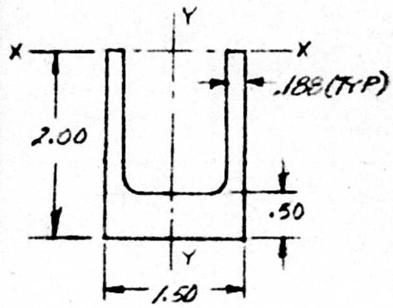
PIN SHEAR -

$2\frac{1}{2}$ G MAN. COND.

$$P_{BOLT} = \frac{1.5(326)}{4} \longleftrightarrow \frac{1.5(9770)}{4} = 3667\# \text{ ULT}$$

$$P_{ALLOW} = 4650\# \quad \text{(REF 1)}$$

$$M.S. = \frac{4650}{3667} - 1 = \underline{.27}$$



SECTION A-A

WEIGHTED FATIGUE COND.

IN THIS CONDITION, SECTION IS SUBJECTED TO COMBINED TENSION AND BENDING

$$A_{SECT} = 1.50(.50 + .376) = 1.314 \text{ IN}^2$$

$$N.A._x = \frac{(2.0)(1.5)(1.0) - (1.5)(1.124)(.75)}{1.314} = 1.324 \text{ IN}$$

$$I_{xx} = \frac{(1.50)(2.00)^3 - (1.124)(1.5)^3}{3} = 2.735 \text{ IN}^4$$

$$I_{NA} = 2.735 - (1.314)(1.324)^2 = .432 \text{ IN}^4$$

$$M_{W.F} = (2330)(.82 + 1.15 + .68) = 6174 \text{ "\# LIM}$$

$$f_t = \frac{6174(.676)}{.432} + \frac{2330}{1.314} = 9631 + 1773 = 11{,}404 \text{ PSI LIM}$$

$$f_t = 0 \longrightarrow 11{,}404 \text{ PSI LIM}$$

$$F_a = 35{,}000 \text{ PSI (REF SECT 2, FIG 2.8.1)} \qquad M.S. = \frac{35{,}000}{11{,}404} - 1 = \underline{\underline{2.06}}$$

$2\frac{1}{2}$ G MANEUVER CONDITION. -

IN THIS CONDITION, THE SECTION IS SUBJECTED TO COMBINED TENSION AND BENDING FROM LOAD P_R AS WELL AS ADDITIONAL BENDING FROM LOAD P_T

MOMENT DUE TO P_R - $M_{P_R} = 9770(.82 + 1.15 + .68)(1.5) = 38{,}840$ "# ULT

STRESS DUE TO P_R - $f_c = \frac{38{,}840(1.324)}{.432} + \frac{9770(1.5)}{1.314} = 130{,}180$ PSI ULT

MOMENT DUE TO P_T - $M_{P_T} = 326(2.6)(1.5) = 1271$ "# ULT

$$I_{YY} = \frac{2.00(1.50)^3 - 1.50(1.12)^3}{12} = .387 \text{ IN}^4$$

STRESS DUE TO P_T $f_c = \frac{1271(.75)}{.387} = 2470$ PSI ULT

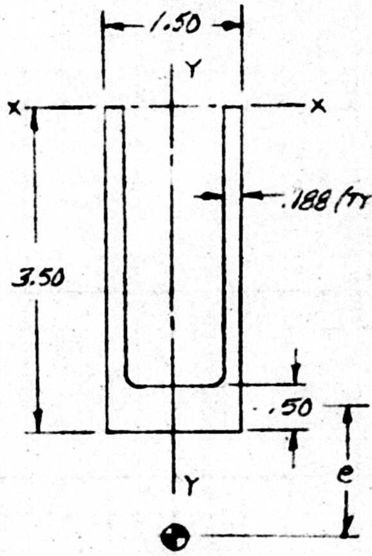
-CONT'D-

285-0515 SPOKE (CONT'D)

SECTION A-A - 2½ G MANEUVER COND. - CONT'D -

TOTAL STRESS $f_{t_{(TOTAL)}} = 130{,}180 + 2470 = 132{,}650$ PSI ULT

$$M.S. = \frac{160{,}000}{132{,}650} - 1 = \underline{.21}$$



SECTION B-B

2½ G MANEUVER CONDITION - SECT B-B

$$A_{SECT} = (1.50)(3.50) - (3.00)(1.124) = 1.878\ IN^2$$

$$(NA)_x = \frac{(1.5)(3.5)(1.75) - (3.0)(1.124)(1.5)}{1.878} = 2.20\ IN$$

$$I_{XX} = \frac{(1.50)(3.5)^3 - (1.124)(3.0)^3}{3} = 11.322\ IN^4$$

$$I_{NA} = 11.322 - 1.878(2.2)^2 = 2.233\ IN^4$$

$$I_{YY} = \frac{(3.50)(1.5)^3 - (3.0)(1.124)^3}{12} = .628\ IN^4$$

$$M_{P_R} = 9770(.82 + 1.15 + 1.3)(1.5) = 47{,}920\ \text{"\# ULT}$$

$$M_{P_T} = 326(1.5)(10.2) = 4990\ \text{"\# ULT}$$

$$f_c = \frac{(47{,}920)(2.2)}{2.233} + \frac{(9770)(1.5)}{1.878} + \frac{(4990)(.75)}{.628} = 60{,}960\ \text{PSI ULT}$$

ADDED TO THIS IS THE STRESS DUE TO TORSION -

THE ELASTIC AXIS FOR SECTIONS A-A & B-B

$$e_{A\text{-}A} = \frac{3(2.0)}{6 + \frac{(.50)(1.50)}{(.188)(2.0)}} = .75\ ;\quad e_{B\text{-}B} = \frac{3(3.50)}{6 + \frac{(.50)(1.50)}{(.188)(3.50)}} = 1.47\ ;\quad e_{AVG} = \frac{1.47 + .75}{2} = 1.11$$

THE LOAD P_T IS APPLIED AT 1.97 INCHES FROM FACE OF FITTING

$$T = (326)(1.5)(1.97 - 1.11) = 420\ \text{"\# ULT}$$

DIVIDING THIS MOMENT INTO A COUPLE ACTING AS LOADS IN THE FLANGES OF THE FITTING AT SECTION A-A -

$$\frac{420}{1.33} = 315\#\ \text{IN EACH FLANGE (ULT)}$$

- CONT'D -

285-0515 SPOKE (CONT'D)

SECTION B-B 2½ G MANEUVER COND. -CONT'D-

THIS LOAD PRODUCES A MOMENT IN THE FLANGE AT SECTION B-B

$$M_T = 315(10.2) = 3213 \text{ "\# ULT}$$

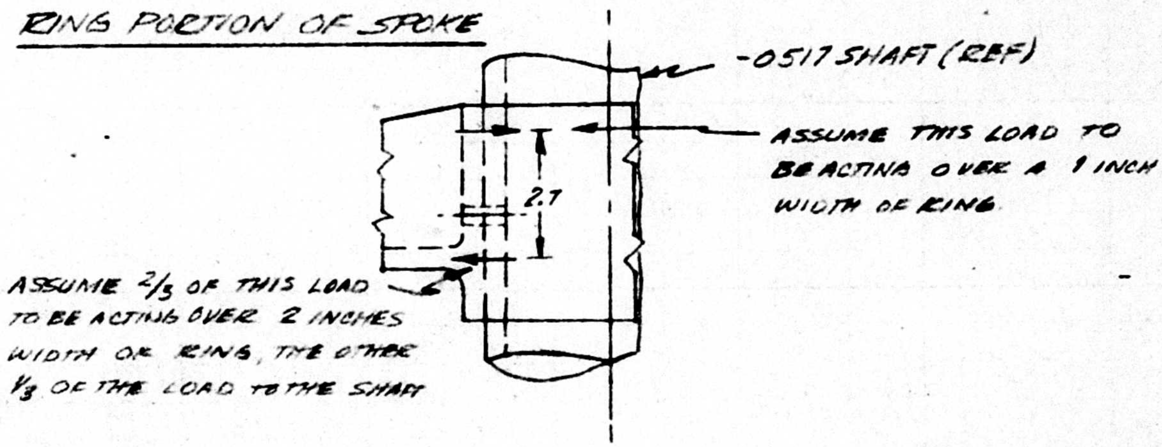
$$I_{FLANGE} = \frac{.188(3.5)^3}{12} = .672 \text{ IN}^4$$

$$f_b = \frac{3213(1.75)}{.672} = 8370 \text{ PSI ULT}$$

$$f_{c\,TOTAL} = 60960 + 8370 = 69{,}330 \text{ PSI ULT}$$

$$M.S. = \frac{160{,}000}{69330} - 1 = \underline{\underline{1.31}}$$

RING PORTION OF SPOKE



THE MOMENT DUE TO THE APPLIED LOAD, P_R, IS REDUCED TO A COUPLE ACTING AS SHOWN ABOVE, PRODUCING COMPRESSION IN THE UPPER PORTION OF THE RING AND TENSION IN THE LOWER.

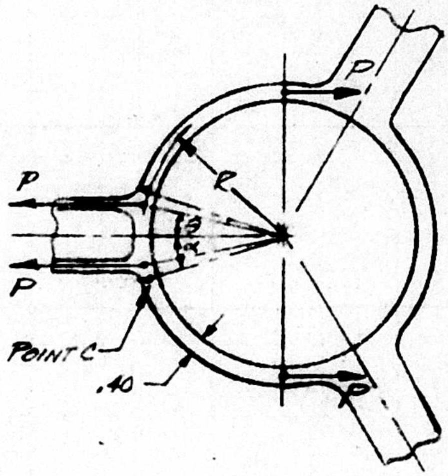
$$M = (9770)(1.5)(.82+1.15+.25+1.35) = 52{,}320 \text{ "\# ULT}$$

$$P_{COUPLE} = \frac{52{,}320}{2.7} = 19{,}380 \text{ \# ULT}$$

285-0515 SPOKE (CONT'D)

RING PORTION OF SPOKE - CONT'D.

THE LOWER PORTION OF THE RING IS ANALYZED USING THE ANALOGY SHOWN AT RIGHT (REF 2, TABLE VIII, CASE 6)



MOMENT & BENDING STRESSES AT POINT C ARE DETERMINED

$P = \frac{2}{3} \times \frac{19380}{2} = 6460$ # ULT

$R = 3.15$ IN ; $\theta = 12°$; $\alpha = 20°$

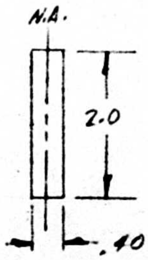
FROM REF 2, ABOVE —

$$M = PR\left[0.3183(\cos\alpha \cos^2\theta - \sin\theta \times \theta - \cos\theta) + \sin\alpha - \frac{1}{2}\right]$$

$$= (6460)(3.15)\left[0.3183(.9397 \times .9567 - .2079 \times .2094 - .9781) + .3420 - .5000\right]$$

$$= (6460)(3.15)\left[-.0390 + .3420 - .5000\right]$$

$$= 4010 \text{ "\#}$$



SECTION AT POINT C

$$I_{SECT} = \frac{(2.0)(.40)^3}{12} = .0107 \text{ IN}^4$$

$$f_b = \frac{Mc}{I} = \frac{4010\,(.20)}{.0107} = 74{,}950 \text{ PSI ULT}$$

$$M.S. = \frac{160{,}000}{74950} - 1 = \underline{1.14}$$

5.3.4.3 UPPER BEARING (#22)

DWGS 285-0553
-0552
-0546

SINCE THE UPPER BEARING CLOSELY APPROXIMATES A 'KAYDON' ROLLER BEARING - KR-232 - EXCEPT FOR ROLLER LENGTH, THE BEARING CAPACITY IS OBTAINED BY RATIO OF THE ROLLER LENGTHS.

$$\text{STATIC CAPACITY} = \frac{.50}{.593} \times 98000^{*}$$

$$= 82{,}500 \text{ LBS}$$

$$\text{CAPACITY (100 RPM)} = \frac{.50}{.593} \times 25000^{*}$$

(H-1382-B TORRINGTON)
(C=47300# @ 100RPM)
(& 600 B-10HRS)

$$= 21{,}000 \text{ LBS} \quad (600\ B\text{-}10 \text{ HRS})$$

AT 243 R.P.M THE CAPACITY IS:

$$C = \left(\frac{100}{243}\right)^{1/3} \times 21000 \times .70^{\ddagger}$$

$$= \underline{11{,}000 \text{ LBS}} \quad (600\ B\text{-}10 \text{ HRS})$$

CUBIC MEAN LOAD

$F = 2{,}340$ LBS (CRUISE COND. 98%).

$F = 9{,}760$ LBS. (MANEUVER, 2%)

$$F_m = \sqrt[3]{.02 \times \overline{13{,}670}^3 + .98 \times (6600)^3}$$

$$= 3{,}140 \text{ LBS}$$

$$\text{LIFE} = \left(\frac{11{,}000}{3{,}140}\right)^3 \times 600 = \underline{4{,}020\ B\text{-}10 \text{ HRS}}$$

* REF 12

‡ ROTATING OUTER RACE FACTOR, REF 15, PG 87

UPPER BEARING (CONT.)

THE UPPER RADIAL ROLLER BEARING OUTER RACE MOVES AXIALLY UPWARD WHEN THE MAIN ROTOR SHAFT IS SUBJECTED TO THERMAL EXPANSION. THIS EXPANSION AMOUNTS TO:

$$\delta = 6.6 \times 10^{-6} \times 28 \times 200°F$$

$$= .037 \text{ INCHES}$$

PROVISION IS MADE TO ACCOMODATE MORE THAN TWICE THIS AMOUNT.

MAIN ROTOR SHAFT

5.3.4.4 LOWER BEARINGS (#21)

TIMKEN 74550 BRNG. CONE RPM = 243
74850 " CUP K = 1.04

BRR = 14,600 LBS

BTR = 14,100 LBS

S.F. = 1.24

FATIGUE CONDITION

T = 35,810 LBS
R = 4,620 LBS } REF. DWG. 285-0333 BRG #21

$R_E = .53R + KT = .53 \times 4{,}620 + 1.04 \times 35{,}810$

$= 39{,}650^{\#}$

$L.F. = \frac{BRR \times S.F.}{R_E}$

$= \frac{14600 \times 1.24}{39{,}650}$

$= .458$

$LIFE = .458^{10/3} \times 3000$

= 220 B-10 HOURS

5.3.4.5 LOWER BEARING (REF. #20 ON DWG. 285-0333)

TIMKEN BRG. - REF 7, Pg 200
CUP LL428310
CONE LL 428349

BASIC RATING @ 500 R.P.M.

RADIAL (BRR)	4,300#
THRUST (BTR)	3,080#

K = 1.39

S.F. @ 243 R.P.M. = 1.24
S.F. @ 120 R.P.M. = 1.54

WEIGHTED FATIGUE

THRUST = 5,000# @ 120 R.P.M. (98%)

2½ G MANEUVER

THRUST = 7,750# @ 243 R.P.M. (2%)

CUBE MEAN THRUST LOAD

$$F_m = \sqrt[3]{.02(7{,}750)^3 + .98(5{,}000)^3} = 5{,}080^{\#}$$

$$L.F. = \frac{BTR \times S.F.}{T} = \frac{3{,}080 \times 1.54}{5{,}080} = .935$$

LIFE (LB-10) = 2,400 HRS. (REF. FIG. 43)

5.3.4.6 285-0527 TRUNNION

MAT'L – 4340 STL H.T. 140-160 KSI

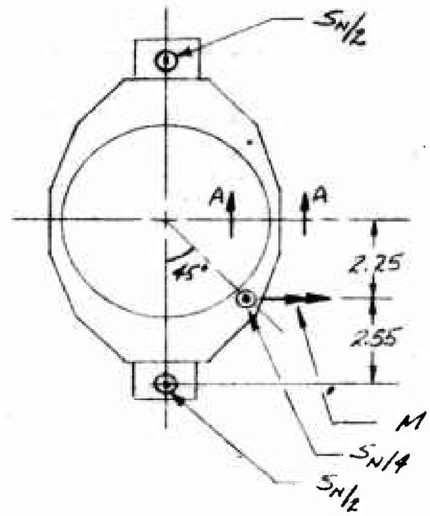
VERTICAL LOADS

FROM BASIC LOADS –

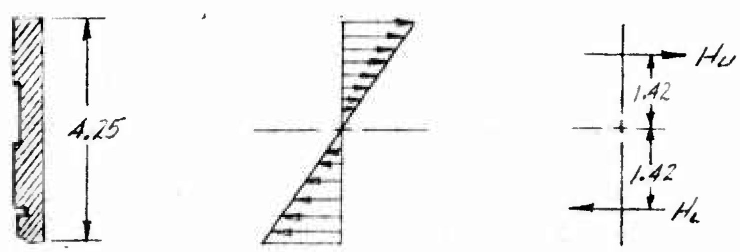
FOR 2½ G MAN. COND
$S_N = 38250\#$ ULT

FOR WT. FATIGUE COND
$S_N = 22950\#$ LIM

(REF SECTION 4)



HALF OF LOAD $S_N/2$ IS TRANSFERRED TO AN ASSUMED REACTION POINT AS SHOWN. THE RESULTING MOMENT MAY BE RESOLVED INTO A COUPLE SO THAT ONLY THE UPPER HALF OF THE "RING" NEED BE ANALYZED FOR MAXIMUM STRESSES.

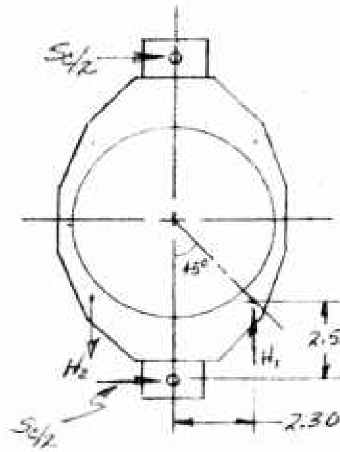


SECTION A-A STRESS DISTRIB MOMENT COUPLE

$$H_U = H_L = \frac{(S_N/4)(2.55)}{2.84} = .224\,S_N$$

285-0527 TRUNNION - CONT'D

SIDE LOADS



$$H_1 = H_2 = \frac{(S_c/2)(2.55)}{4.60} = .277\,S_c$$

FROM BASIC LOADS

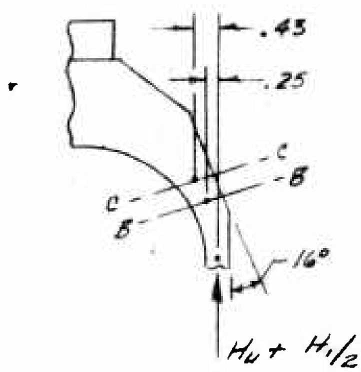
FOR 2½ G MAN. COND.

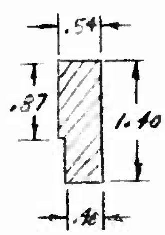
$S_c = 6740$ # ULT

FOR WT. FATIGUE COND.

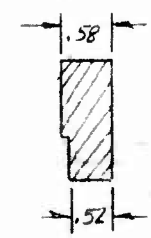
$S_c = \pm 1610$ # LIM

(REF SECTION 4)





SECTION B-B



SECTION C-C

SECTION B-B

$$I_{(PART.\,SECT)} = \frac{(1.40)(.51)^3}{12} = .0155\ in^4 \; ; \quad I_{(TOTAL\ SECT)} = \frac{4.25(.51)^3}{12} = .0471\ in^4$$

FOR 2½ G MANEUVER COND

① $M_{BB} = H_u \times .25 = (.224)(38250)(.25)(1.5) = 3130$ "# ULT

② $M_{BB} = H_1 \times .25 = (.277)(6740)(.25)(1.5) = 700$ "# ULT

$$f_b = \frac{(3130)(.255)}{.0155} + \frac{(700)(.255)}{.0471} = 55{,}300\ PSI\ (ULT)$$

FURTHER CALCULATIONS UNNECESSARY - SEE SECT. C-C ANALYSIS

285-0527 TRUNNION (CONT'D)

SECTION C-C

$$I_{(PART\ SECT)} = \frac{(1.40)(.55)^3}{12} = .0194\ IN^4 \ ;\ A_{(PART\ SECT)} = (1.40)(.55) = .77\ IN^2$$

$$I_{(TOTAL\ SECT)} = \frac{(4.25)(.55)^3}{12} = .0589\ IN^4 \ ;\ A_{(TOTAL\ SECT)} = (4.25)(.55) = 2.34\ IN^2$$

$$① M_{cc} = H_u \times .43 = (.224)(38250)(.43)(1.5) = 5510\ \text{"\#}\ (ULT)$$

$$② M_{cc} = H_1 \times .43 = (.277)(6740)(.43)(1.5) = 1200\ \text{"\#}\ (ULT)$$

$$f_b = \frac{(5510)(.275)}{.0194} + \frac{(1200)(.275)}{.0589} = 83{,}600\ PSI\ (ULT)$$

$$f_c = (1.5)\left[\frac{H_u \cos 16^\circ}{.77} + \frac{H_1 \cos 16^\circ}{2.34}\right] = (1.5)\left[\frac{(.224)(38250)\cos 16^\circ}{.77} + \frac{(.277)(6740)\cos 16^\circ}{2.34}\right] = 17{,}200\ PSI\ ULT$$

$$f_{c_{TOTAL}} = 83600 + 17{,}200 = 100{,}800\ PSI\ (ULT)$$

STRESS MAY BE CONSERVATIVELY REDUCED BY 20% TO ACCOUNT FOR COMPRESSION CARRIED BY THE ROTOR SHAFT

$$f_c = (.80)(100{,}800)\quad 80{,}640\ PSI\ ULT$$

$$M.S. = \frac{140{,}000}{80640} - 1 = \underline{.74}$$

WEIGHTED FATIGUE CONDITION

$$① M_{cc} = (.224)(22950)(.43) = 2210\ \text{"\#}$$

$$② M_{cc} = (.277)(1610)(.43) = 192\ \text{"\#}$$

$$f_b = \frac{(2210)(.275)}{.0194} + \frac{(192)(.275)}{.0589} = 31{,}300 \pm 896\ PSI\ LIM$$

$$f_t = \frac{H_u \cos 16^\circ}{.77} \pm \frac{H_1 \cos 16^\circ}{2.34} = \frac{(.224)(22950)\cos 16^\circ}{.77} \pm \frac{(.277)(1610)\cos 16^\circ}{2.34}$$

$$f_t = 6415 \pm 555\ PSI\ LIM$$

$$f_{t\,(TOTAL)} = 37{,}720 \pm 1450\ PSI\ LIMIT$$

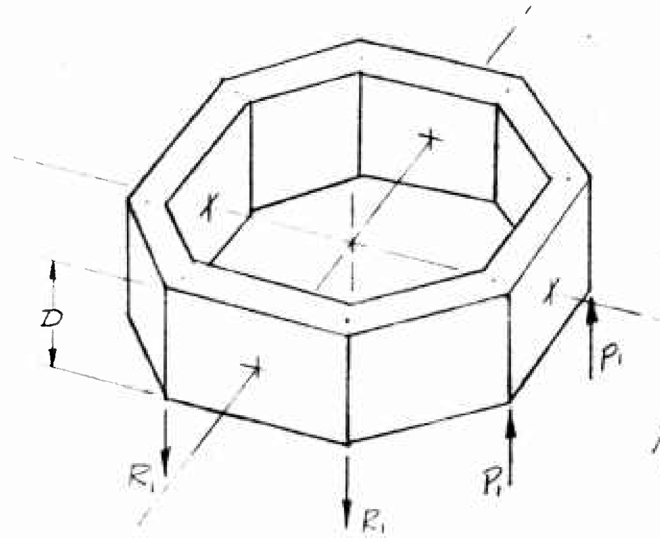
$$M.S. = \underline{HIGH +}$$

$$F_a = 30{,}000\ PSI$$

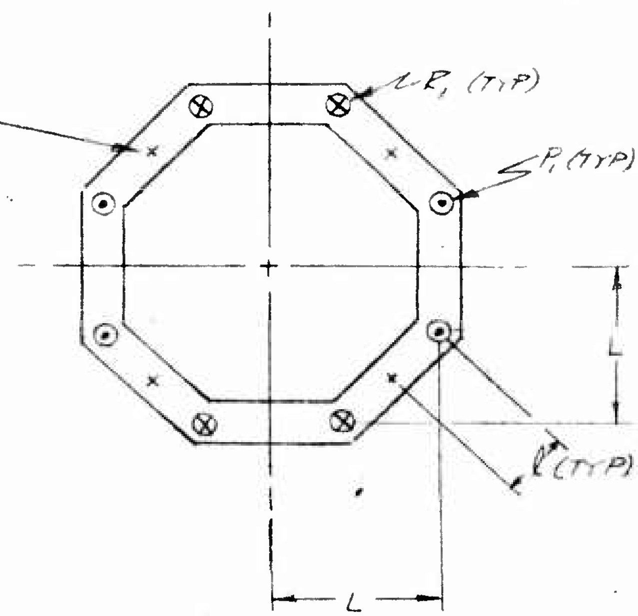
(REF, SECT 2.8, FIG 2.8.1)

5.3.4.7 285-0528 GIMBAL RING

MAT'L - 4340 STL H.T. 140-160 KSI



$$P_1 = R_1 = \frac{P}{4}$$



ℓ = 1.80 IN

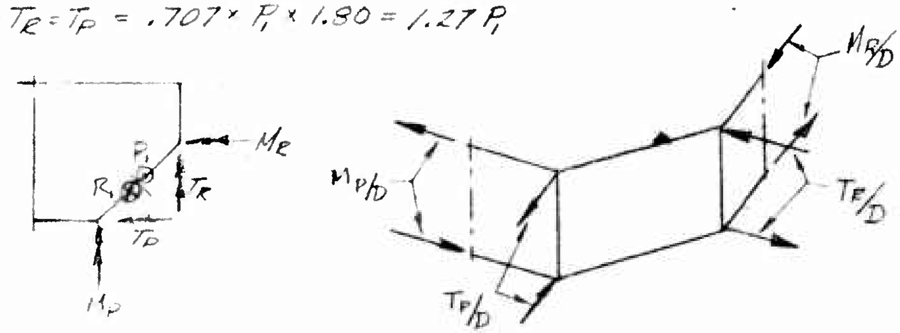
L = 4.86 IN

D ≅ 4.50 IN

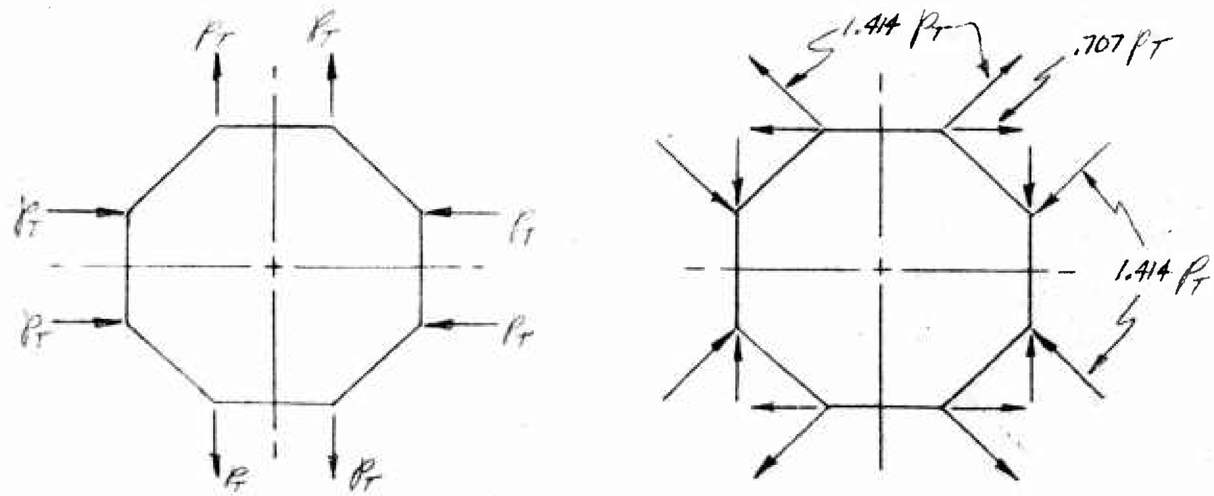
285-0528 GIMBAL RING (CONT'D)

SINCE THE RING WILL NOT RESIST TORSION IN ANY "PANEL" THE APPLIED TORSIONAL MOMENTS WILL BE RESISTED AS BENDING IN THE SECTIONS AT RIGHT ANGLES TO THE SECTIONS OF APPLICATION.

$M_R = M_P = T_R = T_P = .707 \times P_1 \times 1.80 = 1.27\, P_1$



TREATING THE PART AS TWO SEPARATE "UPPER" AND "LOWER" RINGS THE MOMENTS ARE RESOLVED INTO COUPLES AS SHOWN. THE "UPPER" RING THEN HAS THE LOADS SHOWN LEFT BELOW



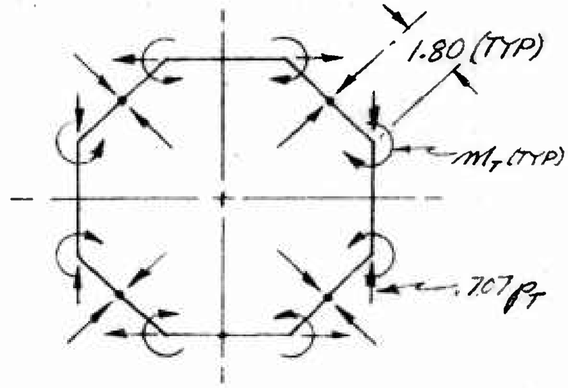
$T_R/D = T_P/D$; LET $T_P/D = P_T$

THE LOADS ARE THEN RESOLVED INTO THE COMPONENTS AS SHOWN AT RIGHT ABOVE. THESE FORCES ARE NOW TRANSFERRED TO ASSUMED POINTS OF INFLECTION TAKEN AT THE CENTER OF THE OBLIQUE SECTIONS

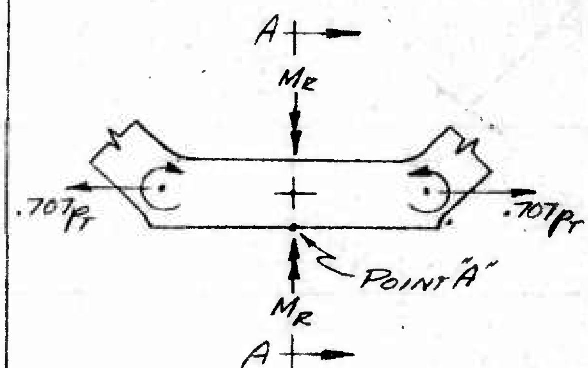
(CONT'D)

285-0528 GIMBAL RING (CONT'D)

AND RESULT IN THE COMBINED AXIAL & MOMENT FORCES AS INDICATED AT LEFT BELOW.

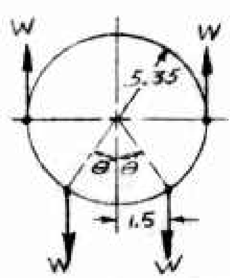


$m_T = (1.80)(1.414\,P_T)$



ISOLATING A SECTION OF THE RING AS SHOWN ABOVE IT IS APPARENT THAT MAXIMUM STRESS WILL OCCUR AT POINT "A" ON THE OUTER SURFACE OF THE RING.

THE RING IS ALSO SUBJECTED TO A CYCLIC SIDE LOAD WHICH WILL PRODUCE ADDITIONAL STRESSES AT POINT "A" WHEN COMBINED WITH THE VERTICAL LOADS. USING A RING ANALOGY AND REFERRING TO REF. 2, TABLE VIII THE METHOD OF ANALYSIS IS AS FOLLOWS:



$\sin\theta = \frac{1.5}{5.35} = .2804$; $\theta = 16.3° = .284$ RAD

$m_o = WR\left[0.3183(\cos\phi\cos\theta^2 - \sin\theta\cdot\theta - \cos\theta) + \sin\theta - \frac{1}{2}\right]$

$= WR[0.3183(1.0\times .9212 - .2804\times .284 - .9598) + .2804 - .5000]$

$= WR[-.2572]$

$= -1.376\,W$

$t_o = W(0.3183\cos\phi\cos\theta^2)$

$= W(0.3183\times 1.0\times .9212)$

$= .2932\,W$

POSITIVE CONVENTION

285-0528 GIMBAL PINS (CONT'D)

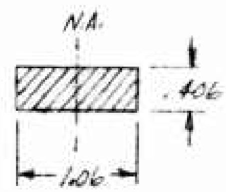
THE TOTAL STRESS AT POINT "A" IS AS FOLLOWS:

$$f_t = \frac{.707 P_T}{A} + \frac{M_K/D}{A} + \frac{M_T}{(I/c)} + \frac{t_0}{A} + \frac{M_0}{2(I/c)}$$

$$P_T = \frac{T_P}{D} = \frac{1.27 P_1}{4.50} = .282 P_1$$

$$\frac{M_K}{D} = \frac{T_P}{D} = .282 P_1$$

$$M_T = (1.80)(1.414 P_T) = .718 P_1$$



SECTION A-A

$$A = 1.06 \times .406 = .430 \text{ IN}^2$$

$$I = \frac{(.406)(1.06)^3}{12} = .0401 \text{ IN}^4$$

$$I/c = \frac{.080}{.53} = .0755 \text{ IN}^3$$

$$f_t = \frac{(.707)(.282 P_1)}{.430} + \frac{.282 P_1}{.430} + \frac{.718 P_1}{.0755} + \frac{.2932 W}{.430} + \frac{1.376 W}{.151}$$

$$f_t = 10.64 P_1 + 9.11 W$$

2½G MANEUVER CONDITION

$P = 38{,}840\#$ (LIMIT)

$P_1 = P_1 = \frac{38840}{4} = 9710\#$ (LIMIT)

$4W = 3675\#$ LIMIT

$$f_t = [10.64(9710) + 9.11(920)]1.5 = 167{,}550 \text{ PSI ULT}$$

$F_a = F_t + (K-1)\delta$ $\quad K = 1.5$; $\delta = 150$ KSI (REF 13)

$= 160 + (1.5-1)150$

$= 235$ KSI

$$M.S. \ \frac{235000}{167550} - 1 = .40$$

285-0528 GIMBAL RING (CONT'D)

WEIGHTED FATIGUE CONDITION

$P = 22,950\#$ (REF BASIC LOADS, SECTION 4)

$R_1 = P_1 = \frac{22950}{4} = 5740\#$ LIMIT

$4W = \pm 1050\#$ LIMIT

$f_t = (10.64)(5740) \pm (9.11)\left(\frac{1050}{4}\right)$

$= 61,100 \pm 2390$ PSI LIMIT

$F_{tc} = \pm 25000$ PSI (REF FIG 2.8.1)

M.S. = HIGH +

5.3.4.8 GIMBAL BEARINGS (REF #24 ON DWG 285-0333)

SKF 21309 SPHERICAL ROLLER BEARING (REF 8, PAGE 88)

BASIC DYNAMIC LOAD RATING C = 16,300#

WEIGHTED FATIGUE CONDITION

RADIAL LOAD = ▲25,400# x .5 = 12,700#
THRUST LOAD* = 1,050# } (REF SECT 4)

*ALL THRUST TAKEN BY ONE BEARING

▲ LOAD IS CONSERVATIVE BASED ON LATER DATA

EQUIVALENT R.P.M. = $\frac{2 \times 240 \text{ R.P.M.} \times 12°}{360°}$ = 16 R.P.M.

EQUIVALENT LOAD (P) = $VF_r + YF_a$ = 1.4(12,700) + 3.1 (1,050) = 21,060#

$\frac{C}{P} = \frac{16,300}{21,060} = .775$

B-10 LIFE = $500 \left(\frac{C}{P}\right)^3$ = 232 HRS.

GIMBAL BEARINGS - SKF 21309 (REF #23 ON DWG 285-0333)

THESE BEARINGS HAVE THE SAME LOADS AS THE ABOVE #24 BEARINGS EXCEPT THAT THE ROTATION FACTOR (V) IS EQUAL TO 1 SINCE THE INNER RING ROTATES

$P = F_r + YF_a$ = 12,700 + 3.1 (1,050) = 15,960#

$C/P = \frac{16,300}{15,960}$ = 1.02

B-10 LIFE = 530 HRS

STATIC CAPACITY - 2 1/2 G MAN. (REF 8, PG. 14)

$P_{ao} = F_{ro} + Y_o F_{ao}$ = $\frac{42,800}{2}$ + 1.5(3685) = 26,900#

GROUND FLAPPING

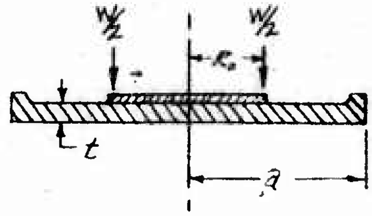
P_{ao} = 1.5(9,700) = 14,500#

STATIC CAPACITY (C_o) = 16,300#

5.3.4.9 285-0530-3 RETAINER ASSY

MAT'L - 4130 STL BAR H.T. 70-90 KSI

REF ALSO 285-0514 FOR INSTL.



R_o = .90 IN

a = 2.00 IN

t = .25 IN

FROM "ROARK" - MAX STRESS AT CENTER OF PLATE

$$f_{t_{MAX}} = -\frac{3W}{2\pi m t^2}\left[\frac{1}{2}(m-1)+(m+1)\ln\frac{a}{R_o}-(m-1)\frac{R_o^2}{2a^2}\right]$$

WHERE $m = \frac{1}{\text{POISSONS RATIO}} = \frac{1}{.3}$

$$f_{t_{MAX}} = \frac{-3W}{2\pi(3.33)(.25)^2}\left[\frac{1}{2}(3.33-1)+(3.33+1)\ln\frac{2.00}{.90}-(3.33-1)\frac{.90^2}{2\times 2.0^2}\right]$$

$= -10.025W$ (COMPRESSION)

2½ G MANEUVER CONDITION

W = 3675 LIM (REF PG 5.3.4.7.3)

$f_{t_{MAX}} = (10.025)(3675)(1.5) = 55{,}300$ PSI

$M.S. = \frac{70{,}000}{55{,}300} - 1 = \underline{.26}$

WEIGHTED FATIGUE CONDITION

W = 0 → 1610

$f_t = (10.025)\left(\frac{1610}{2}\right) = \pm 8100$ PSI

M.S. = HIGH +

5.4 CONTROLS ANALYSIS

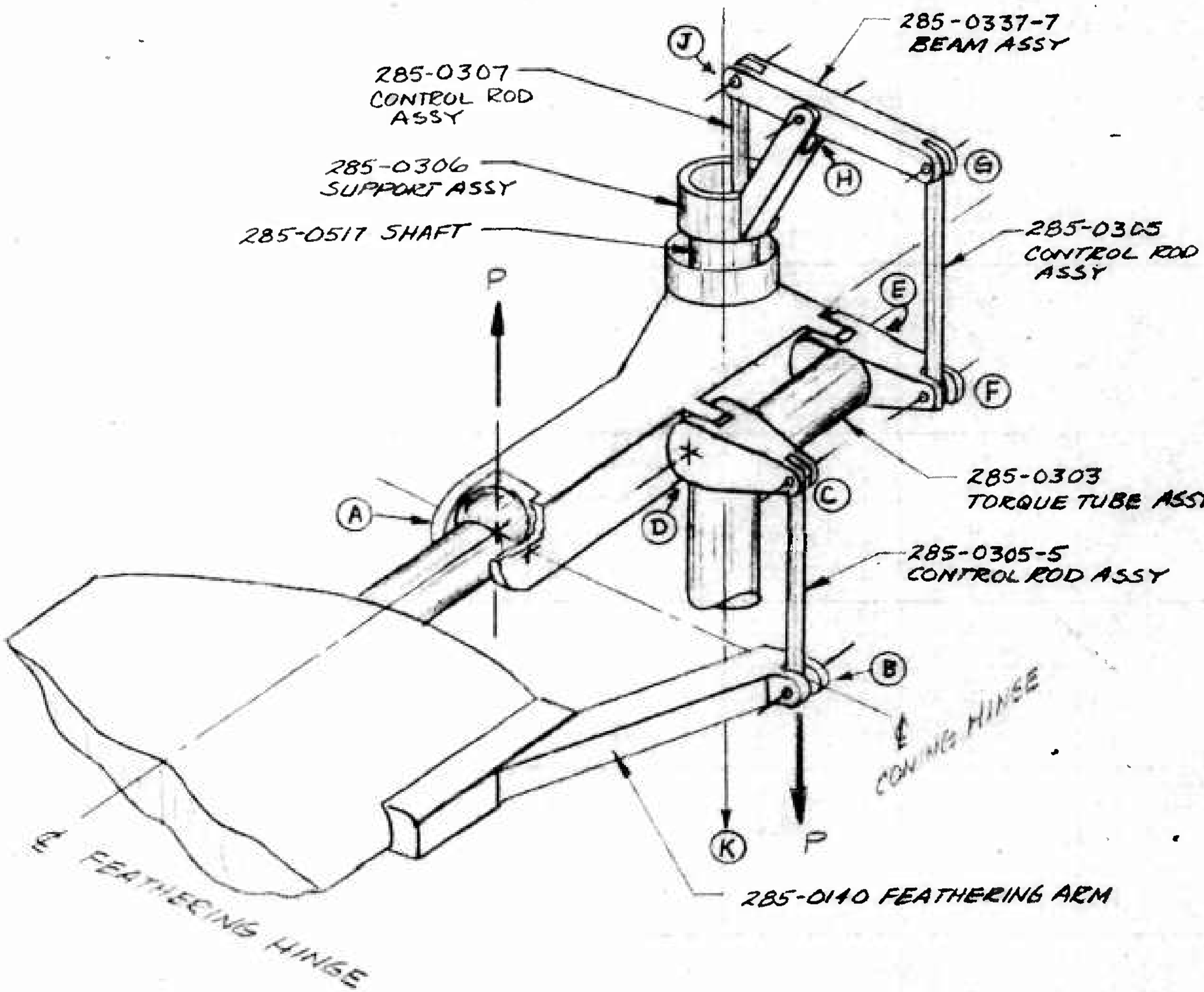
5.4.1 INTRODUCTION

THE CONTROL SYSTEM IS DIVIDED INTO UPPER AND LOWER HUB CONTROLS GROUPINGS AS SHOWN IN THE SCHEMATIC SKETCHES ON PAGES 5.4.1.1 AND 5.4.1.2 DETAIL PARTS OF THE SYSTEM ARE ALSO IDENTIFIED.

DETAIL LOADS ANALYSIS IS COVERED IN SECTION 5.4.2

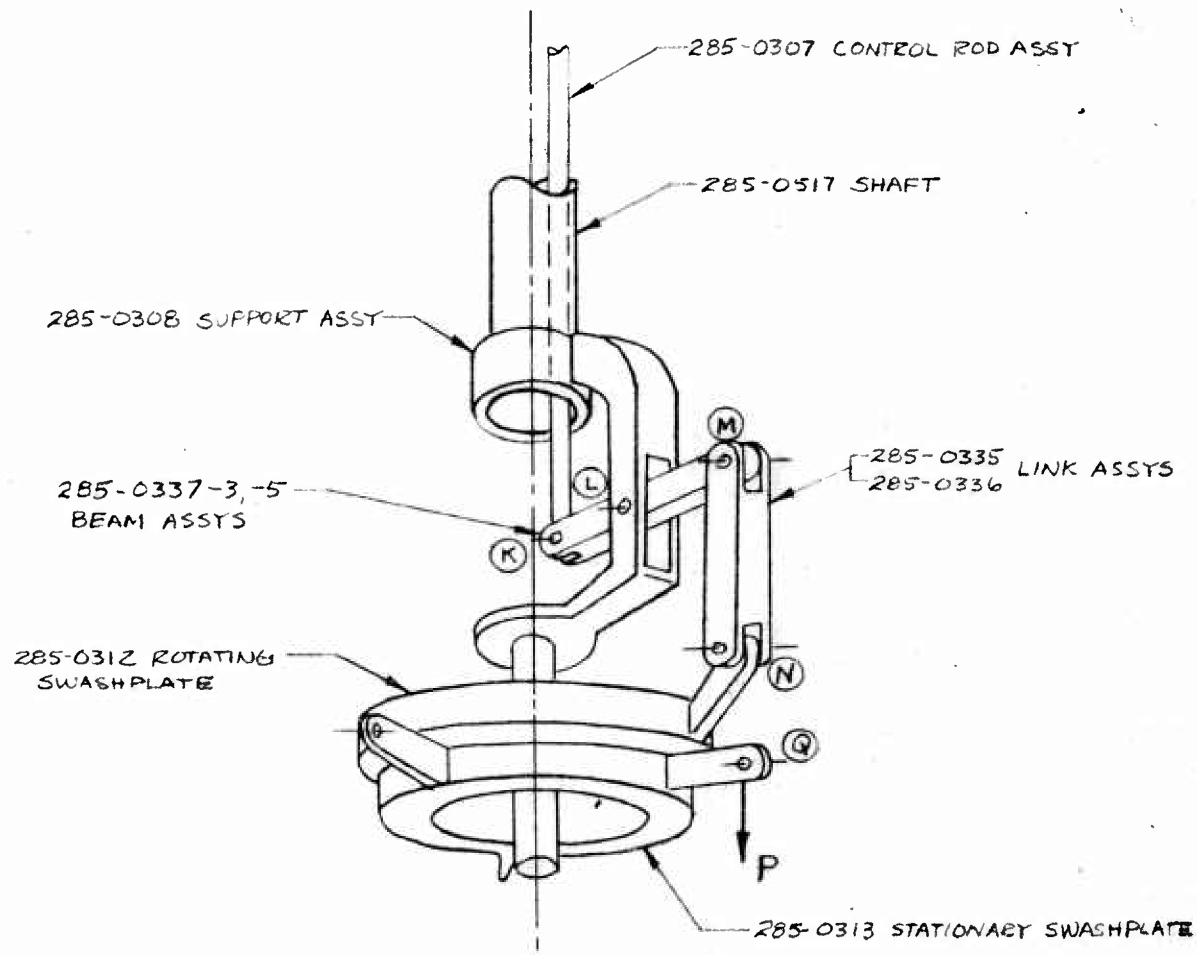
REFER TO DRAWING 285-0300 FOR CONTROLS INSTALLATION.

5.4.1.1 UPPER HUB CONTROLS SCHEMATIC



NOTE: CIRCLED LETTERS FOR IDENTIFICATION IN LOADS ANALYSIS.

5.4.1.2 LOWER HUB CONTROLS SCHEMATIC



NOTE: CIRCLED LETTERS FOR IDENTIFICATION IN LOADS ANALYSIS

5.4.2 DETAIL LOADS ANALYSIS

5.4.2.1 ROTOR BLADE POSITION VS CYCLIC PITCH ANGLE

CYCLIC PITCH ANGLE - 2½G MAN. COND.

$$\theta = \theta_{1_S} \sin\psi + \theta_{2_S} \cos\psi$$ (REF. BASIC LOADS, SECTION 1)

$$\theta_{1_S} = -3.8^\circ$$

$$\theta_{2_S} = +1.7^\circ$$

$$\theta = -3.8 \sin\psi + 1.7 \cos\psi$$

FIND MAX θ.

LET $\frac{d\theta}{d\psi} = 0$

$$\frac{d\theta}{d\psi} = -3.8 \cos\psi - 1.7 \sin\psi = 0$$

$$3.8 \cos\psi = -1.7 \sin\psi$$

$$\tan\psi = -2.23$$

$$\psi_{MAX.} = 114^\circ \text{ OR } 294^\circ$$

FIND MIN θ.

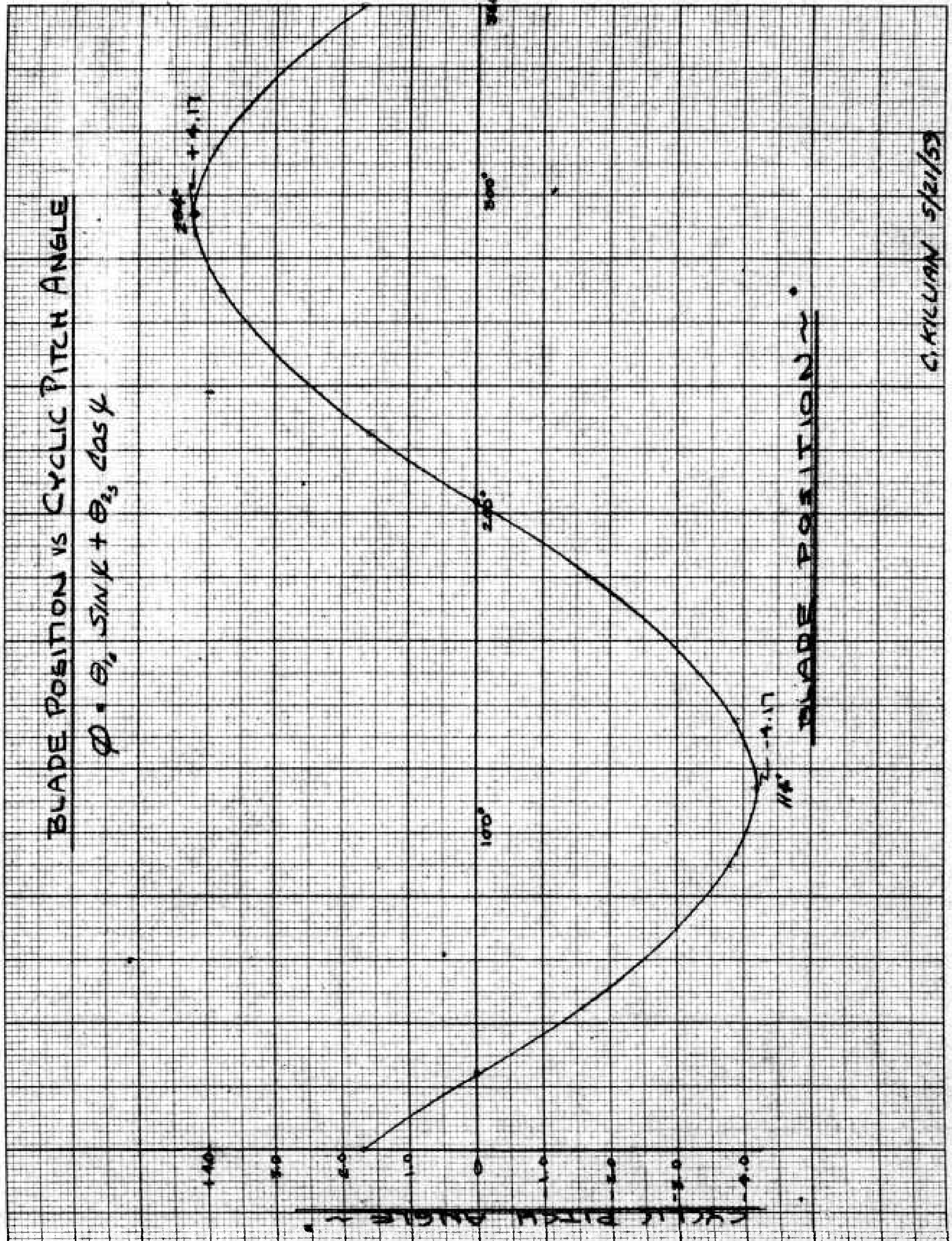
LET $\frac{d^2\theta}{d\psi^2} = 0$

$$\frac{d^2\theta}{d\psi^2} = 3.8 \sin\psi - 1.7 \cos\psi = 0$$

$$3.8 \sin\psi = 1.7 \cos\psi$$

$$\tan\psi = .447$$

$$\psi = 24^\circ \text{ OR } 204^\circ$$


BLADE POSITION VS CYCLIC PITCH ANGLE
θ = θ11 SIN ψ + θ23 COS ψ
C. KILLIAN 5/21/59
BLADE POSITION ~
CYCLIC PITCH ANGLE ~ °
+4.0
3.0
2.0
1.0
0
-1.0
-2.0
-3.0
-4.0
100°
200°
300°
360°
294°
+4.17
114°
-4.17

CONTROLS ANALYSIS

5.4.2.2 UPPER CONTROLS

TABLE 5.4.2.2-1 UPPER CONTROL LOADS FOR 2½ G MANEUVER COND. (LIMIT)

(NOTE: SMALL CASE LETTERS USED FOR DIMENSIONS)

BLADE	① MOMENT "#	② INERTIA FACTOR	③ ①×② "#	ab IN.	BC #	cd IN.	DE "#	ef IN.	FG #	gh IN.	hj IN.	JK #**
0°	20,170 ±32,300	1.25	25,213 ±40,375	15.25	1653 ±2648	7.45	12320 ±19,728	8.48	1453 ±2326	9.58	5.60	2185 ±3500
0+120°	↕	↕	↕	15.50	1627 ±2604	7.95	12,930 ±20,700	8.40	1642 ±2629	9.10	5.55	2220 ±3556
0-120°	↕	↕	↕	15.22	1656 ±2653	7.38	12,220 ±19,580	8.50	1440 ±2300	9.65	5.56	2205 ±3522
294°	↕	↕	↕	15.15	1664 ±2665	6.85	11,398 ±18,255	8.25	1380 ±2150	9.75	5.50	2149 ±3349
294° +120°	↕	↕	↕	15.43	1634 ±2617	7.70	12,580 ±20,150	8.48	1480 ±2,380	9.35	5.50	2213 ±3560
294° -120°	20,170 ±32,300	1.25	25,213 ±40,375	15.43	1634 ±2617	7.70	12,580 ±20,150	8.48	1480 ±2,380	9.35	5.50	2213 ±3560

$\psi_{MAX} = 294°$ PITCH ANGLE = 7.6° + 4.17° = 11.77°

$120 + \psi_{MAX} = 54°$ PITCH ANGLE = 7.6° − 2.2° = 5.4°

$\psi_{MAX} - 120° = 174°$ PITCH ANGLE = 7.6 − 2.1 = 5.4°

** LOADS ON JK CALCULATED BY USING INERTIA FACTOR = 1.10

5.4.2.2 UPPER CONTROLS (CONT'D)

TABLE 5.4.2.2-2 UPPER CONTROL LOADS FOR THE WEIGHTED FATIGUE COND.

BLADE	① MOMENT "#	② INERTIA FACTOR	③ ①×② "#	ab IN.	BC #	cd IN.	DE "#	ef IN.	FG #	gh IN.	hj IN.	JK #
ALL POSITIONS	13,100 ±27,720	1.00	13,100 ±27,720	16.0	819 ±1732	8.50	6,962 ±14,720	8.50	874 ±1848	2.77	6.58	1212 ±2563

NOTE: SMALL CASE LETTERS USED FOR DIMENSIONS

5.4.2.3 LOWER CONTROLS

TABLE 5.4.2.3-1 LOWER CONTROL LOADS FOR THE WEIGHTED FATIGUE COND.

BLADE	MOMENT	INERTIA FACTOR	KL "	LM "	MN #	P #
ALL POSITIONS	13,100 ±27,720	1.0	5.10	4.40	1,400 ±2970	4,370*

TABLE 5.4.2.3-2 LOWER CONTROL LOADS FOR 2½ G MANUEVER-RECOVERY (LIMIT)

BLADE	① MOMENT	② INERTIA FACTOR	①×② "#	KL "	LM "	MN "	P #
ALL POSITIONS	20,170 ±32,300	1.10	22,187 ±35,530	5.10	4.40	2,580 ±4125	6705

5.4.2.4 BALANCED SYSTEM LOADS 2½ G MANEUVER COND.

TABLE 5.4.2.4-1 CONTROL LIMIT LOADS FOR 2½ G MANUEVER - BALANCED SYSTEM

SUPPLEMENT TO BASIC LOADS DATA

BLADE	MOMENT	ab IN.	BC #	cd IN.	DE #	ef IN.	FG #	gh IN.	hJ IN.	JK #	kl IN.	lm IN.	MN #	P(LOWER) #
	20,170 ±32,300	15.15	1,330 ±2,130	-	-	-	1,330 ±2130	9.77	6.58	1,980 ±3,160	5.10	4.40	2,300 ±3,680	5,980

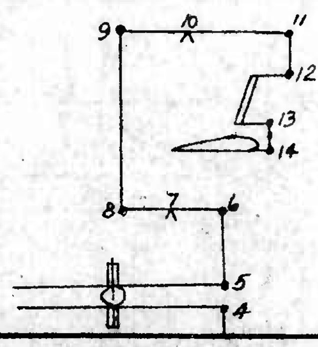
(R_3) REACTION AT H = FG + JK = 3,310 ± 5,290 #

(R_4) REACTION AT L = JK + MN = 4,280 ± 6,840 #

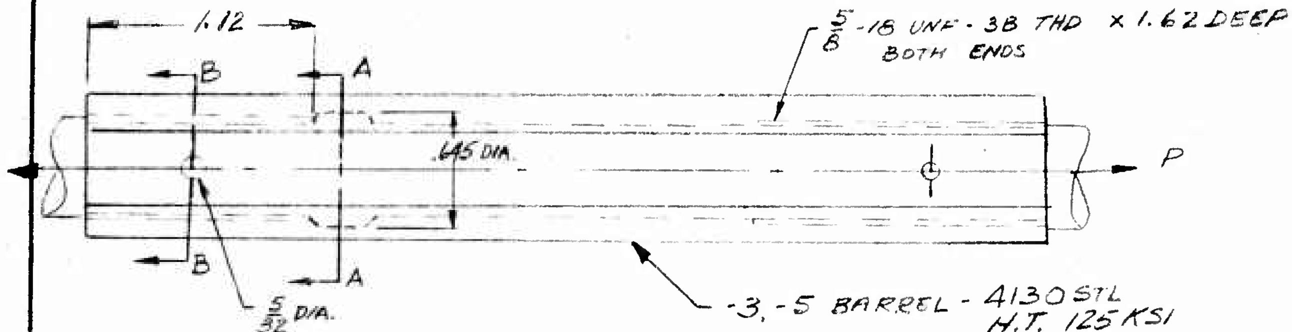
5.4.2.5 CONTROL SYSTEM BEARINGS

TABLE 5.4.2.5-1 LOADS ON CONTROL SYSTEM BEARINGS

BRG. No.	BEARING	LETTER CODE	2 X CRUISE (WEIGHTED FATIGUE) RADIAL TRAVEL	MISALIGN.	RADIAL ± LOAD	THRUST ± LOAD	2 1/2 G MANUEVER (LIMIT LOADS) RADIAL TRAVEL	MISALIGN.	RADIAL LOAD (LB)	THRUST LOAD (LB)
4	MR 10R	Q	±5°	±2°	4,370 STEADY	153 STEADY	±5°	±5°	6700 STEADY	585 STEADY
5	SPECIAL A-8 ±15° MISALIGN.	N	±5°	±2°	1,400 ±2,970	49 ±103	±6°	±5°	2,580 ±4125	225 ±360
6	MR 10R	M	±9°	0	1,400 ±2,970	–	±10°	0°	2,580 ±4125	225 ±360
8	A-44788	K	±8°	0	1212 ±2,563	–	±10°	0°	2,220 ±3556	–
9	A-44788	J	±6°	0	1,212 ±2,563	–	±8°	0°	2,220 ±3556	–
11	MR 8R	G	±6°	0	819 ±1732	–	±8°	+9° / -6°	1539 ±2464	240 ±380
12	MR8R	F	±7°	0	819 ±1732	–	±10°	0°	1539 ±2464	–
13	MR8R	C	±7°	0	819 ±1732	–	±22°	0° TO +3°	1664 ±2665	87 ±140
14	SPECIAL MRB ±15° MISALIGN.	B	±4°	0	819 ±1732	–	±10°	0° TO +14°	1664 ±2665	402 ±646

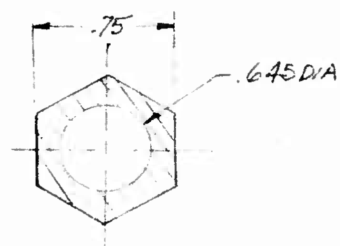


5.4.3.1 285-0305 CONTROL ROD ASSY.



REF. MEMBER BC

SECTION A-A



$$A_{AA} = \frac{\pi}{4}(O.D.^2 - .645^2)$$

$$= .785(.75^2 - .645^2) = .785(.146) = .115 \text{ IN}^2$$

FATIGUE ANALYSIS - WEIGHTED FATIGUE LOAD

$P = 819 \pm 1732$ # REF TABLE 5.4.2.2-2

$$\text{FATIGUE STRESS} = P/A = \frac{819 \pm 1732}{.115 \text{ IN}^2} = 7,130 \pm 15,050 \text{ PSI}$$

FROM STRESS CONCENTRATION DESIGN FACTORS - REF 4 ; $K_T = 3.8$

FROM REF. 1, TABLE 2.3.1 (2), NOTCH FREE ENDURANCE LIMIT = ±74,000 PSI

$F_{tc} = \pm 35000$ PSI (REF FIG 2.8.1)

$$F_a = \frac{\pm 35000}{3.8} = \pm 9200 \text{ PSI}$$

$$M.S. = \frac{9200}{15,050} - 1 = \underline{-.39}$$

WHIRL TOWER CONDITION

REF STRUCTURAL CRITERIA, SECTION 1:

CYCLIC COMPONENT = 40% OF FLIGHT VALUES = ±15,050 x .4 = 6,030 PSI

$$M.S. = \frac{9200}{6030} - 1 = \underline{+.52}$$

2 1/2 G MANUEVER COND. 285-0305 CONTROL ROD ASST CONT'D

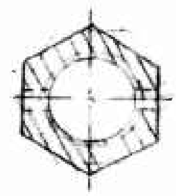
LOAD REF. TABLE 5.4.2.2-1, BC = 1664 ± 2665# = 4329# MAX. (LIM.)

$4329 \times 1.5 = 6{,}500^{\#}$ (ULT.)

$$\frac{P}{A_{AA}} = \frac{6500^{\#}}{.115\,IN^2} = 56{,}500\ PSI$$

$$M.S. = \frac{125}{56.5} - 1 = +1.22$$

SECTION BB - (THROUGH RIVET HOLE)



$$A_{BB} = \frac{\pi}{4}(O.D.^2 - MINOR\ DIA.^2) - dia_{RIVET} \times 2t$$

$$= \frac{\pi}{4}(.75^2 - .625^2) - 5/32\,(O.D. - MAJ.\ DIA.)$$

$$= .135\,IN^2 - .019\,IN^2 = .116\,IN^2$$

SINCE YET CROSS SECTIONAL AREA AND K_T ARE THE SAME AS FOR SECT. AA, STATIC & FATIGUE STRESS ARE THE SAME AS FOR SECT. A-A

THREAD SHEAR CHECK

MINOR DIA (d) = .553"

$\ell = 1.62 - .52 = 1.12$

$$SHEAR\ AREA = \frac{\pi d \ell}{3} = \frac{\pi}{3}\,.553 \times 1.12 = .63\,IN^2$$

$$\frac{P_{ULT}}{A_S} = \frac{6{,}500^{\#}}{.63\,IN^2} = 10{,}300\ PSI$$

F_{Su} = 82,000 PSI (REF 1)

COMPRESSION BUCKLING CHECK

$$\ell = 10.13 \quad \rho = \sqrt{\frac{D^2 + (D-2t)^2}{4}} = .25 \quad \frac{\ell}{\rho} = 40.6$$

F_c = 86,000 PSI (REF 1)

COMPRESSION BUCKLING CHECK (CONT'D.) 285-0305 CONTROL ROD ASSY CONT'D

COMPRESSION LOAD FOR 2 1/2 G MANUEVER COND. = 1664 − 2665 = −1,001# (LIM.)

1,001# × 1.5 = 1500# (ULT.)

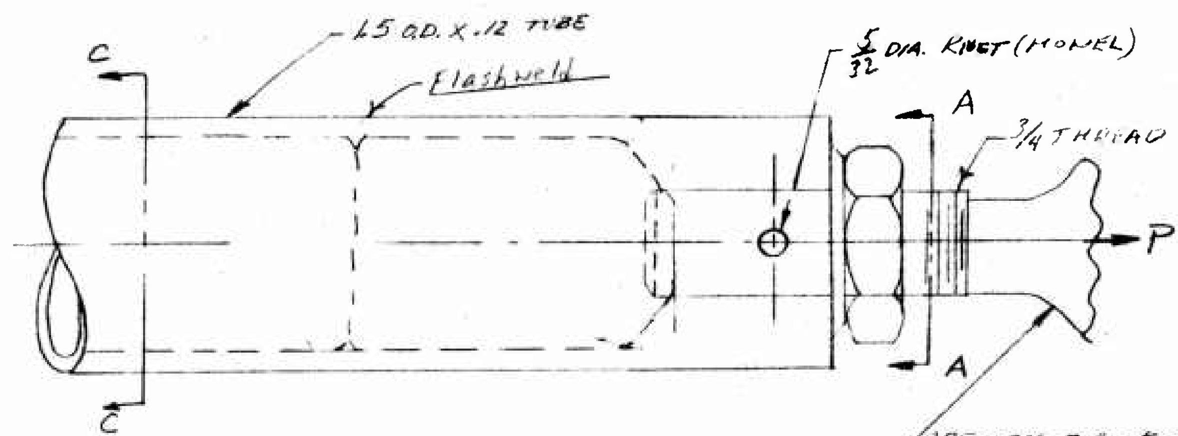
MIN. SECTION IS AT SEC. B-B A_{BB} = .115 IN.²

$f_c = \frac{1500^{\#}}{.115\ IN^2} = 13,000$ PSI M.S. = HIGH +

$D/t = \frac{.75}{.05} = 15$ ∴ LOCAL STABILITY O.K.
(REF 1, FIG 2.4.1.1.1)

5.4.3.2 285-0307 Control Rod Assy (Center)

(Ref Member JK) Mat'l - 4130 Stl, H.T. 125 KSI



Sec. A-A Weighted Fatigue Cond.

$P = 1212 \pm 2563$ (Ref Table 5.4.2.2-2)

Area at Root = .3513 □"

$$f_A = \frac{1212 \pm 2563}{.3513} = 3460 \pm 7300 \text{ PSI}$$

$F_{tc} = \pm 35000$ PSI (Ref Fig 2.8.1)

$K_t = 3.8$ (Ref 4)

$$F_a = \frac{\pm 35000}{3.8} = \pm 9200 \text{ PSI} \qquad M.S. \ \frac{9200}{7300} - 1 = .26$$

Notch Free Endurance Limit = 74,000 PSI
(Ref 1, Table 2.3.1(a))

SEC. CC - 2 1/2 G MANUEVER COND. 285-0307 CONT'D

COMPRESSION LOAD = 2,220 ± 3556 = 5776 # (LIM) = 8690 # (ULT.)
(REF TABLE 5.4.2.2-1)

SEC. PROPS.

$A = .52\text{-}IN^2$ $\rho = .50\text{-}IN.$ $I = .125$ $D/t = 12.5$ $\frac{L}{\rho} = \frac{66.4}{.50} = 132$

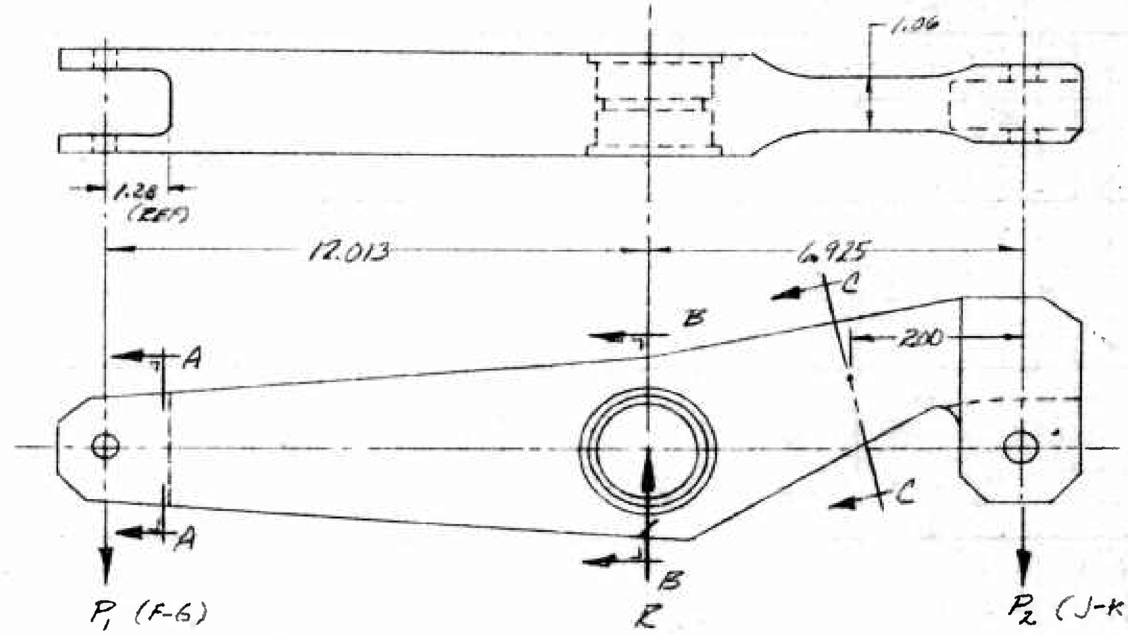
for $\frac{L}{\rho} = 132$, $F_c = 16{,}500$ PSI (REF 1, FIG 2.4.2.3 (c))

$f_c = \frac{8690}{.52} = 16{,}700$ PSI

$M.S. = \frac{16500}{16700} - 1 = \underline{\underline{0}}$

5.4.3.3 285-0337-7, BEAM ASSY, UPPER

MAT'L - 4140 STL, H.T. 129-142 KSI



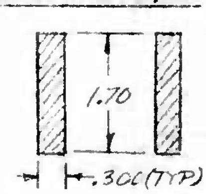
P_1 = 874 ± 1848# (WEIGHTED FATIGUE COND)
= 1642 ± 2629# ($2\frac{1}{2}$ g MAN. COND. LIM.)

P_2 = 1212 ± 2563# (WEIGHTED FATIGUE COND)
= 2220 ± 3556# ($2\frac{1}{2}$ g MAN. COND. LIM.)

(REF TABLES 5.4.2.2-1 & 5.4.2.2-2)

R = 2086 ± 4411# (WEIGHTED FATIGUE COND)
= 3862 ± 6185# ($2\frac{1}{2}$ g MAN. COND. LIM.)

SECTION A-A



WEIGHTED FATIGUE COND

$P = 874 \pm 1848$ (LIM)

$M_{A-A} = (874 \pm 1848)(1.28) = 1120 \pm 2365$ "# (LIM)

$I = \frac{(.60)(1.70)^3}{12} = .246$

$f_b = (1120 \pm 2365)\left(\frac{.85}{.246}\right) = 3870 \pm 8170$ PSI (LIM)

$F_{te} \cong 35,000$ (REF SECT 2.8, FIG 2.8.1)

$2\frac{1}{2}$ G MANEUVER COND. O.K. BY COMPARISON CONT'D

ANALYSIS: HOT CYCLE ROTOR MODEL: 285 REPORT NO. 285-13 PAGE —

PREPARED BY: L. L. EARLE 4-6-60

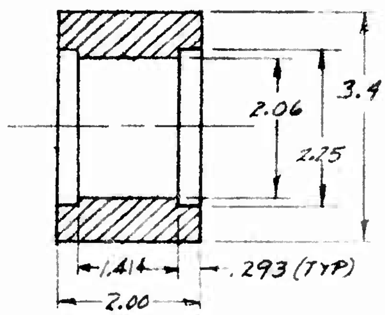
CHECKED BY: L KAYSING 4/27/60

CONTROLS ANALYSIS

285-0337-7 BEAM ASSY, UPPER (CONT'D)

SECTION B-B

WEIGHTED FATIGUE COND. $P_z = 1212 \pm 2563$ #



SIMPLIFIED SECTION

$$I = \frac{(2.00)(3.4)^3 - (2)(.293)(2.25)^3 - (1.414)(2.06)^3}{12}$$

$$I = 4.964 \text{ IN}^4$$

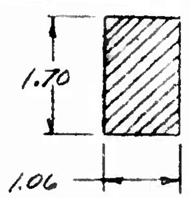
$$M_{BB} = (1212 \pm 2563)(6.925) = 8400 \pm 17{,}750 \text{ "\#} \text{ (LIM)}$$

$$f_b = \frac{(8400 \pm 17750)(1.7)}{4.964} = 2870 \pm 6070 \text{ PSI (LIM)}$$

$F_{tc} \cong 35{,}000$ PSI (REF SECT 2.8, FIG 2.8.1)

2½ G MANEUVER COND OK BY COMPARISON

SECTION C-C



WEIGHTED FATIGUE CONDITION

$$M_{C-C} = (1212 \pm 2563)(2.00) = 2424 \pm 5126 \text{ "\# (LIM)}$$

$$I_{SECT} = \frac{(1.06)(1.70)^3}{12} = .434 \text{ IN}^4$$

$$f_b = \frac{(2424 \pm 5126)(.85)}{.434} = 4750 \pm 10050 \text{ PSI (LIM)}$$

$F_{tc} \cong 35{,}000$ PSI (REF FIG 2.8.1) $M.S. = \frac{35000}{10050} - 1 = \underline{2.48}$

2½ G MANEUVER COND. OK BY COMPARISON

HUGHES TOOL COMPANY-AIRCRAFT DIVISION

ANALYSIS: HOT CYCLE ROTOR MODEL: 285 REPORT NO. 285-13

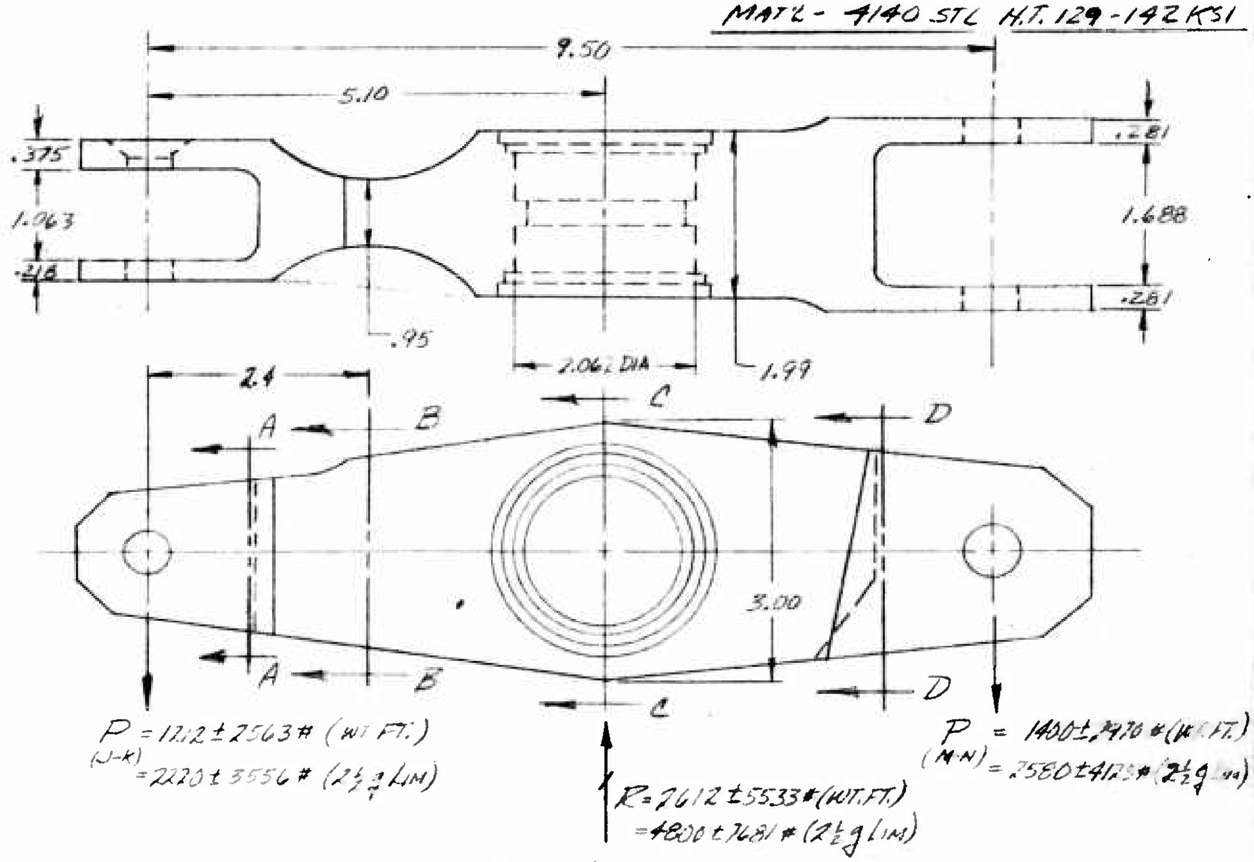
PREPARED BY: L.L. ERLE 3-1-60

CHECKED BY:

CONTROLS ANALYSIS

5.4.3.4 285-0337-3, BEAM ASSY, LOWER

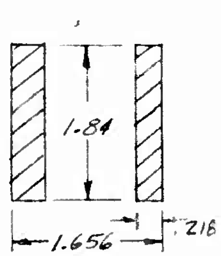
MAT'L - 4140 STL H.T. 129-142 KSI



LOADS REF TABLES 5.4.2.2-1 & 5.4.2.2-2

SECTION A-A

WEIGHTED FATIGUE COND $P = 1212 \pm 2563\#$ (LIM)



$$M_{A-A} = (1.25)(1212 \pm 2563) = 1515 \pm 3204 \text{ "\# (LIM)}$$

$$f_b = \frac{6M}{bh^2} = \frac{(6)(1515)(3204)}{(2)(.218)(1.84)^2} = 6150 \pm 13000 \text{ PSI (LIM)}$$

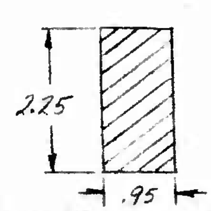
$F_{te} \cong 35000$ PSI (REF SECT 2.8, FIG 2.8.1)

$$M.S. = \frac{35000}{13000} - 1 = \underline{1.70}$$

2½ g MAN COND OK BY COMPARISON

SECTION B-B

WEIGHTED FATIGUE COND



$$M_{B-B} = 2.4(1212 \pm 2563) = 2909 \pm 6151 \text{ "\# (LIM)}$$

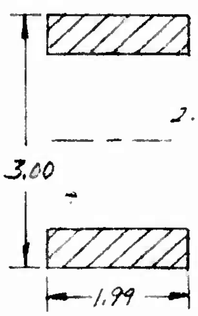
$$f_b = \frac{6M}{bh^2} = \frac{(6)(2909 \pm 6151)}{(.95)(2.25)} = 3630 \pm 7670 \text{ PSI (LIM)}$$

$F_{te} \cong 35{,}000$ PSI (REF FIG 2.8.1)

2½ G MANEUVER COND OK BY COMPARISON

285-0337-3 BEAM ASSY - LOWER (CONT'D)

SECTION C-C



WEIGHTED FATIGUE COND.

$M_{C-C} = (5.1)(1212 \pm 2563) = 6181 \pm 13071$ "#

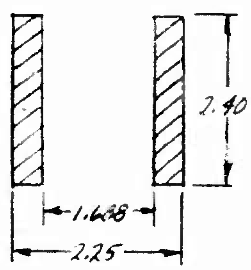
$I_{CC} = \dfrac{(1.99)(\overline{3.00}^3 - \overline{2.062}^3)}{12} = 3.02\ IN^4$

$f_b = (6181 \pm 13071)\left(\dfrac{1.50}{3.02}\right) = 3070 \pm 6490$ PSI

$F_{tc} = 35000$ PSI (REF FIG 2.8.1)

2½ G MANEUVER COND. O.K. BY COMPARISON

SECTION D-D



WEIGHTED FATIGUE COND. $P = 1400 \pm 2970$ #

$M_{D-D} = (1.375)(1400 \pm 2970) = 1925 \pm 4084$ "#

$I_{D-D} = \dfrac{(2.40)^3(2.250 - 1.688)}{12} = .647\ IN^4$

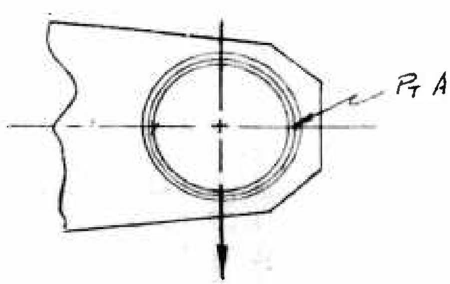
$f_b = (1925 \pm 4084)\left(\dfrac{1.20}{.647}\right) = 3570 \pm 7576$ PSI

$F_{tc} = 35,000$ PSI (REF FIG 2.8.1)

2½ G MANEUVER COND. O.K. BY COMPARISON

285-0337-5 BEAM ASSY - LOWER

ALL ANALYSES AS DONE FOR -3 BEAM ASSY ARE APPLICABLE EXCEPT SECTION D-D WHICH IS REPLACED BY FOLLOWING ANALYSIS -



ASSUMING A LUG LOADED AXIALLY RATHER THAN TRANSVERSELY, THE HIGHEST STRESS WILL BE ENCOUNTERED AT POINT ON THE INNER SURFACE.

ACCORDING TO REF. 9.:

$$P_{tru} = K_{tru} A_{br} F_{tu}$$

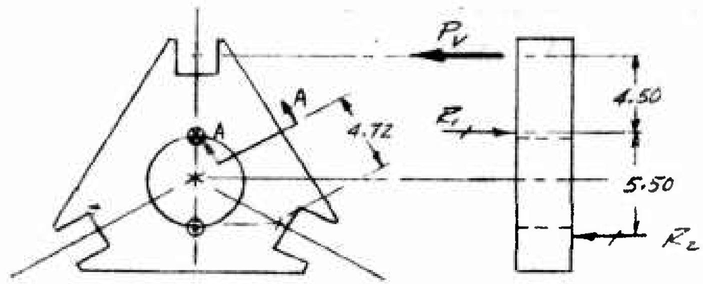
$P_{(M-N)} = 1400 \pm 2970$ # (WT. FT.)

$= 2580 \pm 4125$ # (2½ g LIM)

FROM THIS METHOD A HIGH MARGIN OF SAFETY IS INDICATED.

5.4.3.5 285-0306 SUPPORT ASSY 'MAT'L - AS NOTED

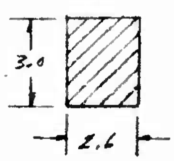
-5 BASE MAT'L 2014-T6 ALUM FORGING



THE LOAD P_V IS RESISTED BY A COUPLE AS SHOWN, THE COUPLE, IN TURN, PRODUCING BENDING IN THE STRUCTURE

P_V = 2086 ± 4411 # LIM (WEIGHTED FAT. COND)
= 3862 ± 6185 # LIM (2½ G MAN. COND)
(REF 285-0337-7 ANALYSIS PAGE 5.4.3.3.0)

BENDING AT SECTION A-A -



$I = \frac{(2.6)(3.0)^3}{12} = 5.85 \text{ IN}^4$

WEIGHTED FATIGUE COND.

$R_1 = R_2 = \frac{(2086 \pm 4411)(4.5)}{5.5} = 1710 \pm 3610 \# \text{ LIM}$

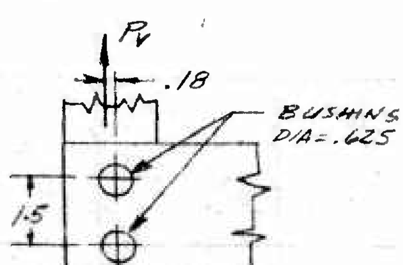
$\frac{1}{2}M = \frac{1}{2}[(1710 \pm 3610)(4.72)] = 4040 \pm 8520 \text{ "\# LIM}$

$f_b = \frac{(4040 \pm 8520)(1.5)}{5.85} = 1040 \pm 2190 \text{ PSI LIM}$

F_{tc} = 8000 PSI (REF 1, TABLE 3.3.1 (b))

2½ G MANEUVER CONDITION OK BY COMPARISON

THE -7 POST IS ATTACHED TO THE -5 BASE BY TWO .500 DIA BOLTS. THE SMALL ECCENTRICITY NOTED PRODUCES A SMALL SIDE LOAD ON THE BOLTS WHICH IS ADDED VECTORIALLY TO THE DIRECT LOAD P_V.



$A_{br} = (2)(.625)(.615) = .768 \text{ IN}^2$

285-0306 SUPPORT ASSY (CONT'D)

-5 BASE (CONT'D)

BUSHINGS BEARING IN BASE

WEIGHTED FATIGUE COND.

$P_{V_{MAX}} = 2086 + 4411 = 6497$ # LIM

$P_{BOLTS} = 0$ TO $3250 \longleftrightarrow \frac{6497(.18)}{1.5} = 0$ TO 3340

$f_{br} = 0$ TO $\frac{3340}{.768} = 0$ TO 4350 PSI LIM

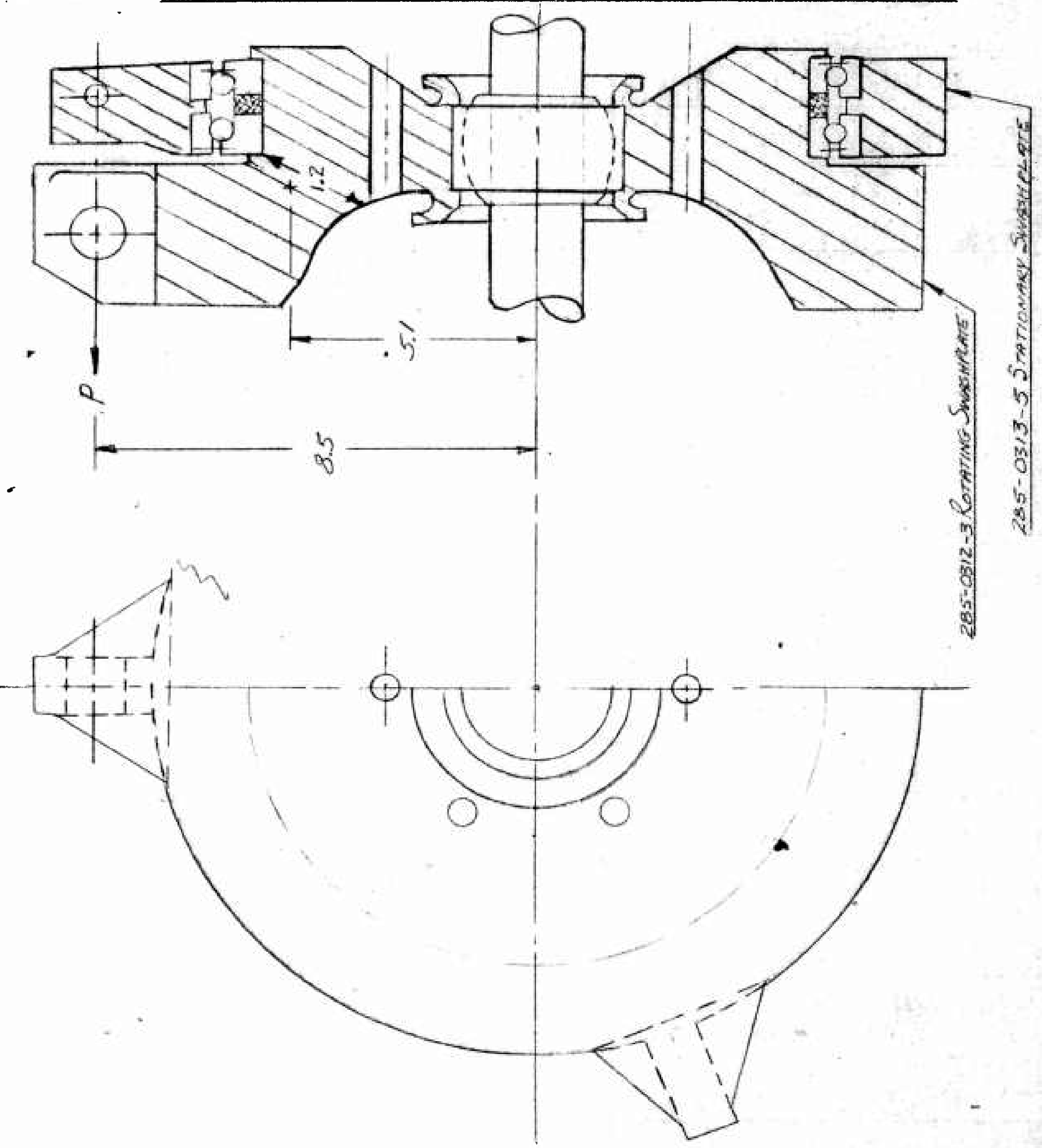
-7 POST MAT'L - 2024-T4 ALUM BAR

BUSHINGS BEARING IN LUGS

$A_{br} = (1.06)(.615) = .651 \text{ in}^2$

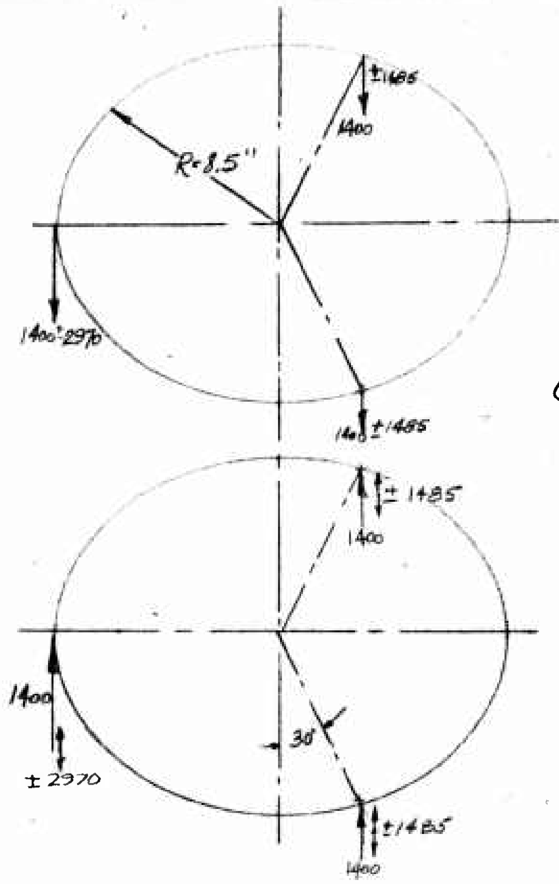
$f_{br} = 0 \rightarrow \frac{3340}{.651} \quad 0 \rightarrow 5130$ PSI LIM

5.4.3.6 UPPER (ROTATING) & LOWER (STATIONARY) SWASHPLATES



LOADS ON UPPER (ROTATING) & LOWER (STATIONARY) SWASHPLATES (CONT'D)

285-0312-3, 285-0313-5



(REF LOADS - TABLE 5.4.2.3-1)

THE CYCLIC LIFT ROD LOADS SHOWN VARY SINUSOIDALLY AND PRODUCE A TOTAL MOMENT ON THE SWASH PLATE EQUAL TO:

$$M_{TOTAL} = (1.5)(R)(P_{LR})$$

WHERE: (1.5) IS A FACTOR WHICH ACCOUNTS FOR THE SINUSOIDAL VARIATION OF THE LOAD ACTING ON 3 BLADES

- (R) IS THE DISTANCE OF THE LIFT RODS FROM THE ℄ OF ROTATION
- (P_{LR}) IS CYCLIC LOAD

$$M_{TOTAL} = (1.5)(8.5)(\pm 2{,}970) = \pm 37{,}800 \text{ "\# (LIM)}$$

UPPER & LOWER SWASHPLATES (CONT'D)

THE STEADY COMPONENT OF LOAD IN THE LIFT RODS PRODUCES NO MOMENT IN THE SWASHPLATES. THE TOTAL STEADY LOAD ON THE SWASHPLATE IS EQUAL TO P_{LR} (STEADY) × 3. THEREFORE, THE TOTAL THRUST ON THE Y176PW1 FAFNIR BEARING (REF 285-0300) (2×CRUISE) = 3 × 1400# = 4200#

TO OBTAIN A STEADY THRUST OF 4200# WITH A STEADY MOMENT OF 37800"# IN THE LOWER SWASHPLATE THE FOLLOWING LOWER SWASHPLATE CONTROL ROD LOADS ARE OBTAINED:

1) $P_1 + P_2 + P_3 = 4200$, $P_2 = P_3$

2) $9P_1 - 9P_2 = 37800$

3) $4.5P_1 + 9P_2 = 18900$ (Modifying Eq 1)

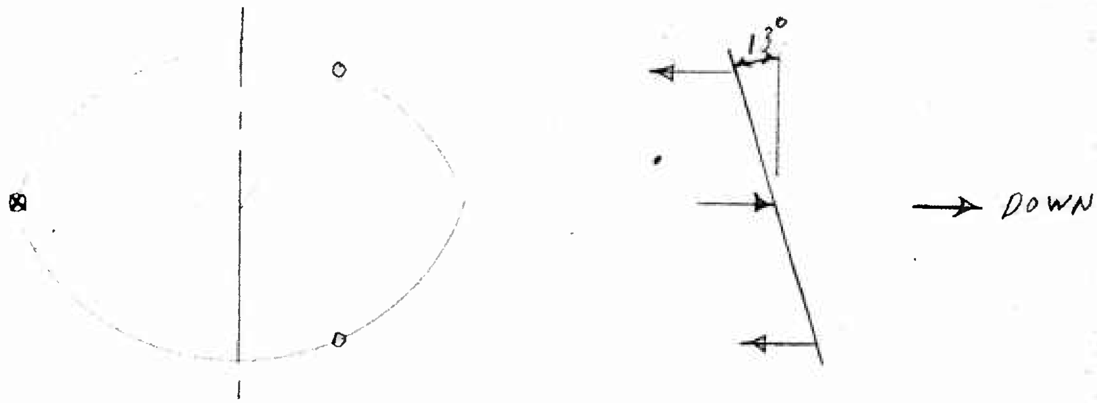
4) $13.5P_1 = 56700$

$\therefore P_1 = 4200$, $P_2 = P_3 = 0$

UPPER & LOWER SWASHPLATES (CONT'D)

WEIGHTED FATIGUE COND.

SWASHPLATE INDUCED SIDE LOADS



$$R = \frac{\text{CYCLIC AIR LOAD TORQUE}}{\text{TOTAL CYCL. TORQUE}} = \frac{9920}{27720} \quad \text{(REF SECTION 1)}$$

$= .358$

STEADY TORQUE RESULTING FROM 90° OUT-OF-PHASE AIRLOAD TORQUE & TILTED SWASHPLATE:

$T = .358 \times 37{,}800 \times \tan 13°$

$= 3.120$ ''#

THIS TORQUE PRODUCES A STEADY DRAG (OR FWD.) FORCE ON THE DRIVE LINK AND A ROTATING FORCE ON THE SWASHPLATE CENTERING SHAFT (WHICH ROTATES AT THE SAME SPEED).

$P = \frac{3120}{8.5} = \underline{367}$ #

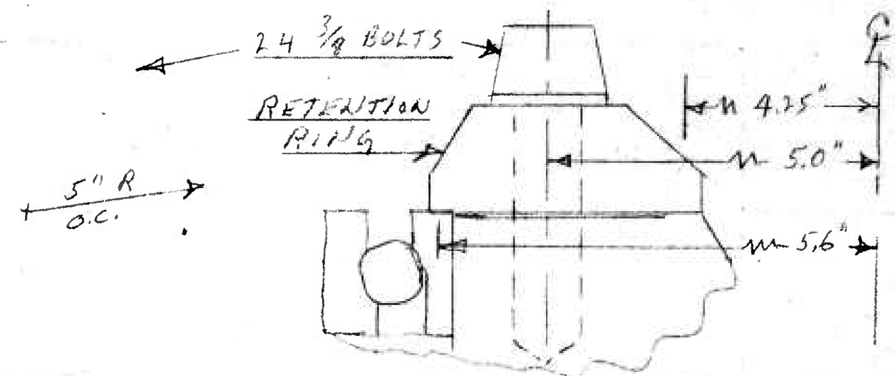
THE REACTIONS TO THIS STEADY TORQUE AT THE STATIONARY SWASH PLATE ARE:

$\dot{P} = \frac{3120}{13.25} = 235$ #

P (DUE TO FRICTION TORQUE) $\cong \frac{1330}{13.25} = 100$ #

ROTATING SWASHPLATE (CONT'D) DWG 285-0312

SWASH PLATE BEARING RETENTION



FATIGUE COND.

THRUST = 4200#, M = 37800"# (Pg 5.4.3.6.2)

$$P_{MAX}/IN = \frac{4200}{2\pi \times 5} + \frac{37800}{\pi \times 5^2}$$

$$= 134 + 482 = 616^{\#}$$

$$P_{MAX}/BOLT = \frac{2\pi \times 5}{24} \times 616 \times \frac{5.6 - 4.25}{5.0 - 4.25}$$

$$= \underline{1450^{\#}}$$

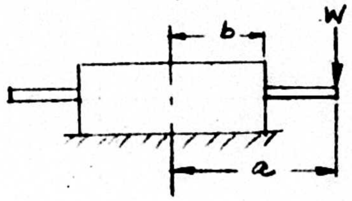
ESTIMATED PRELOAD IN BOLT (TORQUE = 350 TO 400"#) IS:

$$PRELOAD = \frac{350}{390} \times 90000 \times .08 = 6450^{\#}$$

THEREFORE THE BOLT WILL UNDERGO VIRTUALLY NO FATIGUE STRESS.

THE RETENTION RING IS OK BY INSPECTION

285-0312 Rotating Swashplate - Matl 2014-T6 Al Forg.



W = 1400 ± 2970 # (Ref. Load MN-Table 5.4.2.3-1)

a = 8.5", b = 5.1" a/b = 1.67

β = 4.57 t = 2.5"

(Ref 2, Table X, Case 63)

$$f_{max\,(\text{at inner edge})} = \beta \frac{W}{t^2} = \frac{4.57 \times 1400 \pm 2970}{(2.5)^2}$$

$$= 1070 \pm 2180 \text{ PSI}$$

F_s = 9000 PSI (Ref 1, Table 3.3.1(b))

$$M.S. = \frac{9000}{2180} - 1 = \underline{\underline{3.12}}$$

FATIGUE TENSION AT LUG

BEARING AREA (ONE SIDE) = .56 X .81

= .453 □"

$$f_{br} = \frac{0 \text{ TO } 4370}{2 \times .453} = 0 \text{ TO } 4810 \text{ PSI}$$

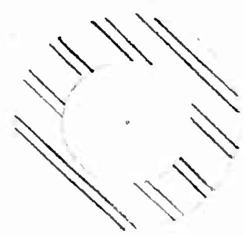
$$Z^{-1} = \frac{6}{1.4 \times 2.8^2} = .546$$

$$M = \pm 1.4 \times 2970 = 4150$$

$$f_{b-a} = \frac{\pm 4150 \times .546}{2} = \pm 1130 \text{ PSI}$$

UPPER & LOWER SWASHPLATES - CONT'D

SPINDLE & SUPPORT ASSEM., 285-0327



$I = .049(1.25^4 - .75^4)$

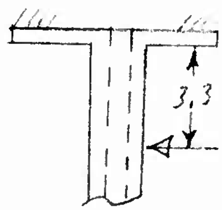
$= .104 \text{ in}^4$

$y = .625 \text{ in}$

FATIGUE BENDING FROM SWASHPLATE LOADS

SPINDLE - 285-0311-3

MAT'L - 3310 STL MIN H.T. 139,000 PSI



$M = \pm 335 \times 3.3$

$= 1110^{\text{in}\#}$ LIMIT

$f_{b-a} = 1110 \times \frac{.625}{.104} = \pm 6670$ PSI LIMIT

$F_{tc} = 35{,}000$ PSI (REF SECT 2.8, FIG 2.8.1)

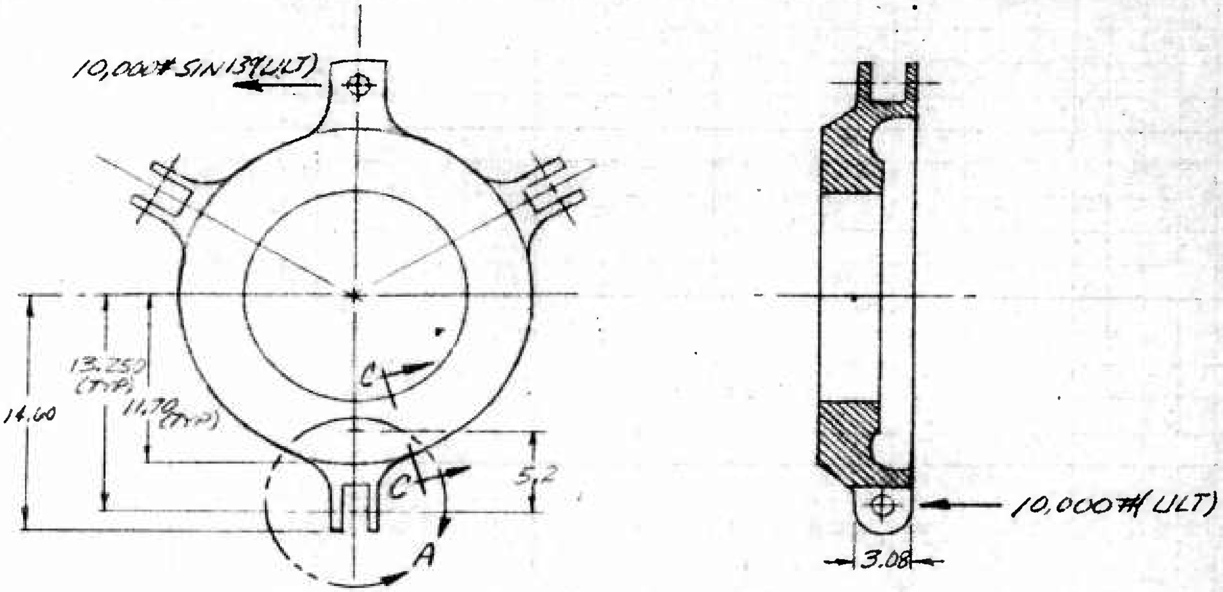
$K_t \leqq 1.2$ (REF 4, FIG 66)

$F_a = \frac{35000}{1.2} = 29{,}200$ PSI

$M.S. = \frac{29200}{6670} - 1 = \underline{\underline{3.37}}$

CONTROLS ANALYSIS

285-0313 STATIONARY SWASHPLATE MAT'L 2014-T6



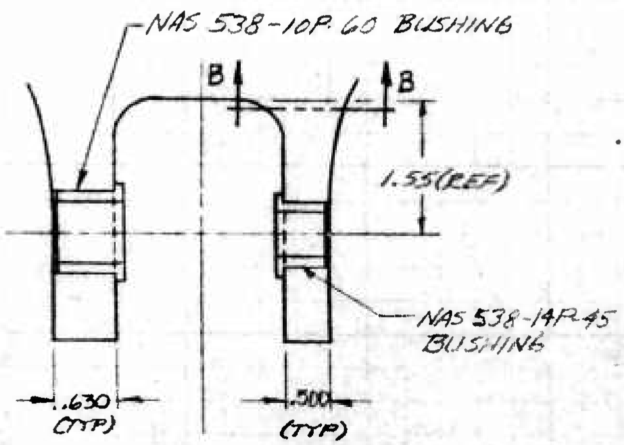
AN ARBITRARY LOAD OF 10,000# ULT BASED ON MAXIMUM CYLINDER OUTPUT IS USED.

NO CYCLIC LOADS ARE INVOLVED.

LUGS ANALYSIS

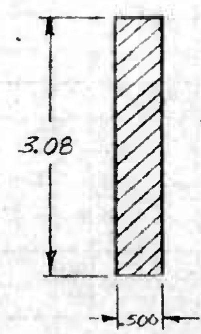
THE LUG SUBJECTED TO THE 10,000 SIN 13° # LOAD IS OK BY INSPECTION

SHEAR-OUT OF ALL LUGS OK BY INSPECTION.



VIEW A

(TYP 3 PLACES)



SECTION B-B

$A = 3.08 \times .500 = 1.54 \text{ IN}^2$

$I = \frac{(.500)(3.08)^3}{12} = 1.217 \text{ IN}^4$

285-0313 STATIONARY SWASHPLATE (CONT'D)

BEARING OF BUSHINGS -

$A_{br} = 1.061 \times .45 = .477 \text{ IN}^2$ - THINNER LUG

$A_{br} = .811 \times .60 = .487 \text{ IN}^2$ - THICKER LUG

$f_{br} = \dfrac{5000}{.477} = 10,500$ PSI (ULT)

M.S. = HIGH +

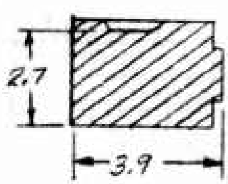
BENDING IN THINNER LUG -

$M_{B\text{-}B} = \frac{1}{2}(10,000)(1.55) = 7750$ "# (ULT)

$f_b = \dfrac{(7750)(1.54)}{1.217} = 9810$ PSI (ULT)

M.S. = HIGH +

RING ANALYSIS



$T_{ULT} = \frac{1}{2}(10,000)(5.2) = 26,000$ "#

FROM REF 2, TABLE IX CASE 4

$f_{MAX} = \dfrac{T(3a + 1.8b)}{8a^2b^2}$ $a = \dfrac{3.9}{2} = 1.95$

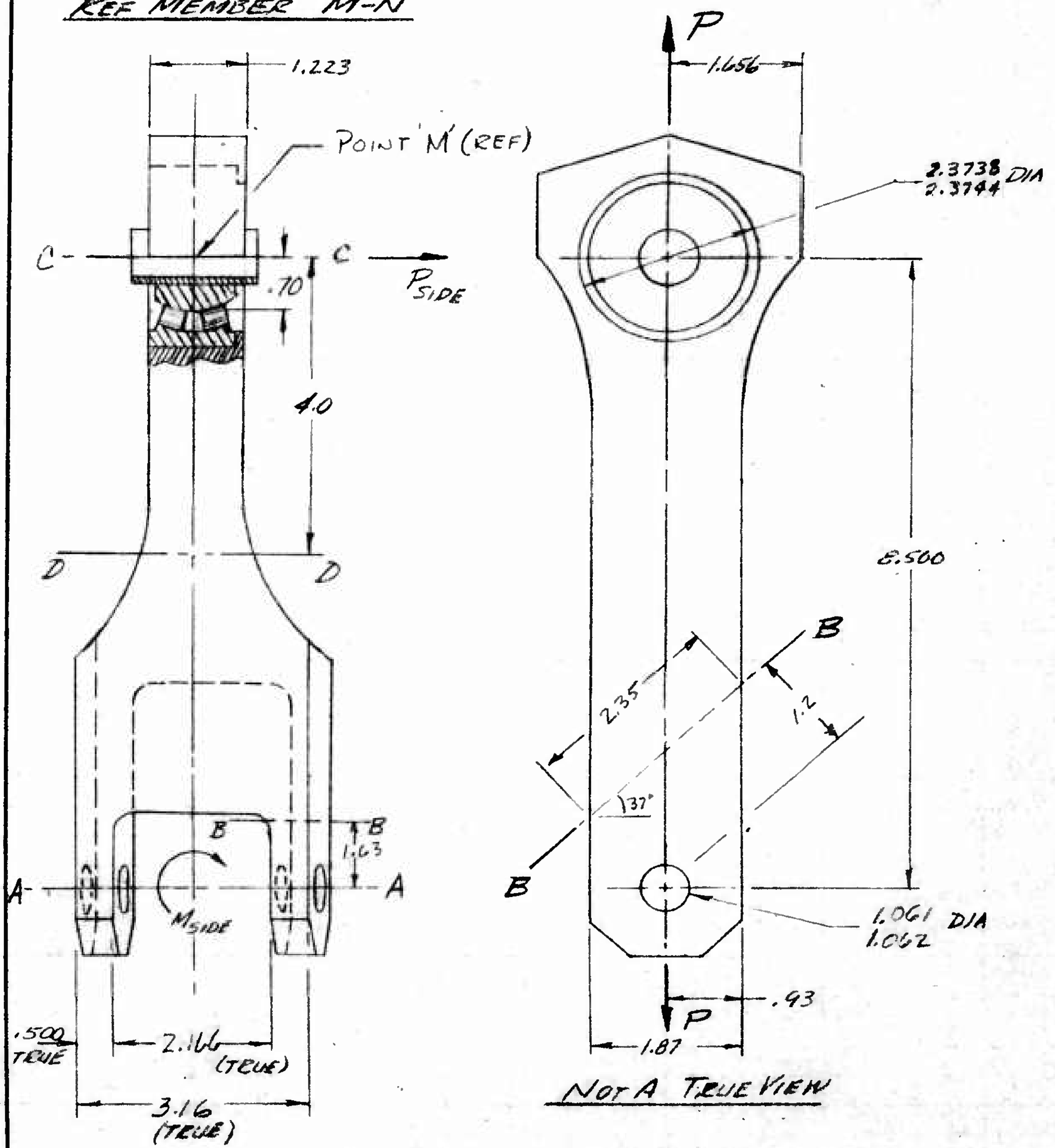
$b = \dfrac{2.7}{2} = 1.35$

$$f_{MAX} = \frac{(26000)(3 \times 1.95 + 1.8 \times 1.35)}{(8)(1.95)^2(1.35)^2} = 3900 \text{ PSI (ULT)}$$

M.S. = HIGH +

5.4.3.7 285-0335 DRIVE LINK ASSY, ROTATING SWASHPLATE
MAT'L - 4140 STL H.T. 140-160 KSI

REF MEMBER M-N



P = 1400 ± 2970# (WT. FATIGUE) (REF TABLE 5.4.2.3-1)

P = 2580 ± 4125# ($2\frac{1}{2}$ G LIMIT) (REF TABLE 5.4.2.3-2)

285-0335 DRIVE LINK ASSY (CONT'D)

ROTATING SWASHPLATE LOADS VARY SINUSOIDALLY AND PRODUCE A MOMENT –

$$M = (1.5)(R)(P)$$

WHERE 1.5 IS A FACTOR TO ACCOUNT FOR THE SINUSOIDAL VARIATION OF THE LOAD ACTING ON 3 BLADES

FOR THE 2½ G MANEUVER CONDITION

$$M = (1.5)(8.5)(2580 \pm 4125)$$

$$= 31,600 \pm 52,600 \text{ "\# (LIM)}$$

$$= 47,400 \pm 79000 \text{ "\# (ULT)}$$

SWASH PLATE TILT WILL PRODUCE A TORSIONAL MOMENT –

SWASHPLATE TILT = 13°

$$M_{SIDE} = (47400 \pm 79000) \sin 13°$$

$$= 10,800 \pm 17,800 \text{ "\# (ULT)}$$

THIS MOMENT WILL PRODUCE A SIDELOAD ON THE DRIVE LINK ASSY

$$P_{SIDE} = \frac{10,800 \pm 17,800}{8.5}$$

$$= 1270 \pm 2100 \text{ \# (ULT)} \text{ –}$$

– ACTING AT THE BEARING END OF THE ASSY.

REACTIONS AT SECTION A-A. –

$$P_{SIDE_{MAX}} = 1270 + 2100 = 3370 \text{\# ULT}$$

$$M_{SIDE\ MAX} = 10,800 + 17800 = 28,600 \text{ "\# ULT}$$

$$P_{MAX} = 2580 + 4125 = 6705 \text{\# ULT}$$

$$P_{MAX} \text{(ON LUG)} = \frac{6705}{2} + \frac{28600}{2.5} = 3350 + 11,450 = 14,800 \text{\# ULT}$$

.625 DIA NAS BOLT: $P_{ALLOW} = 23,000$ PSI (REF 1)

$$M.S. = \frac{23000}{14800} - 1 = .55$$

285-0335 DRIVE LINK ASSY - CONT'D

AT SECTION A-A - CONT'D

LUG BRG - $A_{br} = (.625)(.500) = .3125 \text{ IN}^2$

$f_{br} = \frac{14800}{.3125} = 47{,}400 \text{ PSI (ULT)}$ OK BY INSP.

LUG SHEAR-OUT - $A_{S.O.} = (2)(.65)(.50) = .65 \text{ IN}^2$

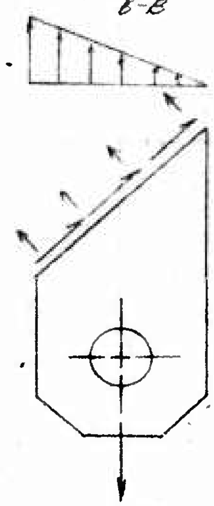
$f_{S.O.} = \frac{14800}{.65} = 22{,}800 \text{ PSI (ULT)}$ OK BY INSP

SECTION B-B

ASSUME SIDE LOAD TAKEN BY ONE SIDE -

COMBINED BENDING & TENSION -

$M_{B-B} = 3370\,(1.2) = 4050''\#$



ASSUME DISTRIBUTION FOR BENDING

$f_b = \frac{4050\,(6)(2)}{(2.35)\,(.50)^2} = 82{,}700 \text{ PSI}$

$f_t = \frac{14800 \cos 37^\circ}{(2.35)(.50)} = 10{,}000 \text{ PSI}$

$f_{t_{TOT}} = 92{,}700 \text{ PSI}$

$F_{tu} = 140{,}000 \text{ PSI}$

$M.S. = \frac{140{,}000}{92{,}700} - 1 = .51$

285-0335 DRIVE LINK ASSY - CONT'D

SECTION C-C

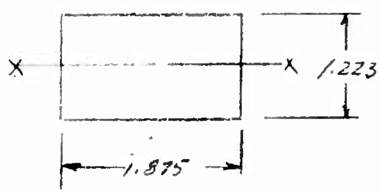
SHEAR-OUT - $A_{S.O.} = 2(.44)(1.223) = .108\ IN^2$

$$f_{S.O} = \frac{6705(1.5)}{.108} = 93{,}000\ PSI$$

$F_{SU} = 95{,}000\ PSI$ (REF 1)

$$M.S = \frac{95000}{93000} - 1 = \underline{.02}$$

SECTION D-D



$M_{XX} = 3370(4.0) = 13{,}500$ "# ULT

$P_{AXIAL} = 6705 \times 1.5 = 10050$ # ULT

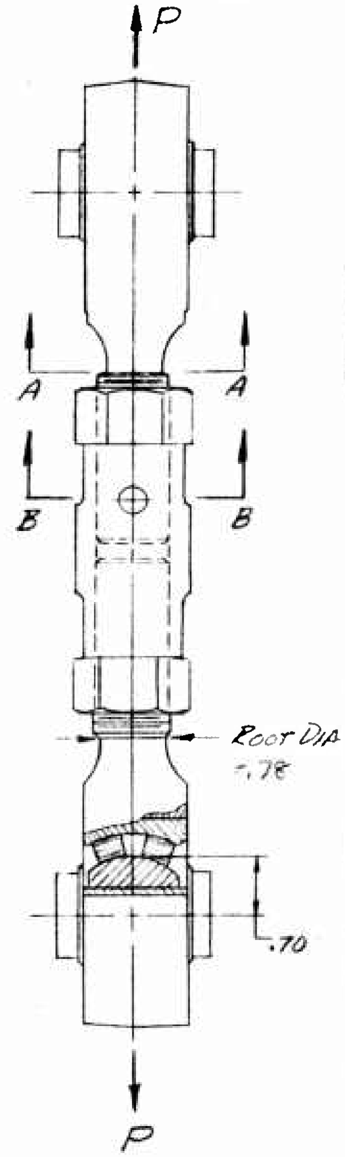
$$f_{t_{MAX}} = \frac{6(13500)}{(1.875)(1.223)^2} + \frac{10050}{(1.875)(1.223)}$$

$= 33{,}200\ PSI$

OK BY INSP

5.4.3.8 285-0336 LINK ASSY, ROTATING SWASHPLATE

MATL - AS NOTED — REF. MEMBER M-N



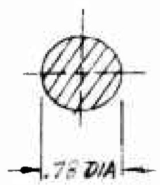
$P = 1400 \pm 2970\#$ (WT FATIGUE)
(REF TABLE 5.4.2.3-1)

$\mu_{BEARING} = .04$

$P_{FRICT} = \mu P = (.04)(1400 \pm 2970) = 56 \pm 119\#$

$M_{FRICT} = (.70)(56 \pm 119)\ 39 \pm 83$ IN#

SECTION A-A



AREA = .480 IN^2 — MAT'L STEEL 4130 H.T. 140-160 KSI

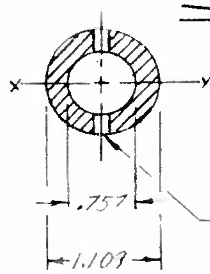
$I = \frac{\pi (.78)^4}{64} = .0183\ IN^4$

$f_b = \frac{(39 \pm 83)(.39)}{.0183}\ 831 \pm 1768$ PSI

$f_t = \frac{1400 \pm 2970}{.480} = 2917 \pm 6187$ PSI

$f_{t\ TOTAL} = 3748 \pm 7955$ PSI

SECTION B-B



AREA = .463 IN^2 — MAT'L 4130 STEEL H.T. 140-160 KSI

$I_{xx} = .0514\ IN^4$

$f_b = \frac{(39 \pm 83)(.555)}{.0514} = 421 \pm 896$ PSI

$f_t = \frac{1400 \pm 2970}{.463}\ 3024 \pm 6415$ PSI

$f_{t\ TOTAL} = 3445 \pm 7311$ PSI

$F_{te} = \pm 35{,}000$ PSI FOR $K_t = 2.0$ (REF SECT 2.8, FIG 2.8.1)

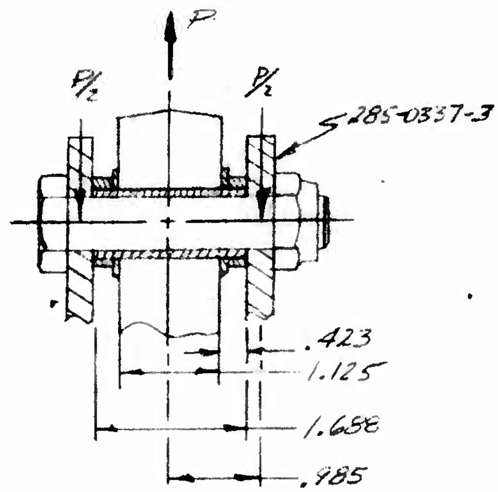
$K_t = 3.8$ (REF 4)

$F_a = \frac{35000}{3.8} = 9200$ PSI

MIN. M.S. $= \frac{9200}{7955} - 1 = .16$

285-0335, 285-0336 LINK ASSYS – ROTATING SWASHPLATE (CONT'D)

BOLT ANALYSIS



BOLT DIA – .625D, H.T. 160–180 KSI

BOLT SHEAR

ULTIMATE COND – (1.5 x 2½ g MAN)

$P = (1.5)(2580 + 4125) = 10{,}000\#$

$f_s = \dfrac{10{,}000}{(2)(.3068)} = 16{,}300$ PSI (ULT)

M.S. = HIGH +

WEIGHTED FATIGUE COND – $P = 1400 \pm 2970\#$

$f_s = \dfrac{2185}{(2).3068} = 3560$ PSI

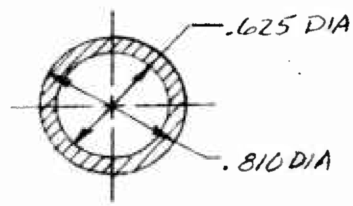
M.S. = HIGH +

BOLT BENDING –

CRITICAL IN WEIGHTED FATIGUE COND

$P = 1400 \pm 2970\#$

USING BOLT – BEARING COMBINATION ANALYSIS –



BEARING SLEEVE

$A_{(SLEEVE)} = \dfrac{\pi}{4}(.810^2 - .625^2) = .2085\ IN^2$

$I_{(SLEEVE)} = \dfrac{\pi}{64}(.810^4 - .625^4) = .0136\ IN^4$

$\bar{y}_{(SLEEVE)} = .405$ IN

BENDING STRESS TO PRODUCE GAPPING BETWEEN BEARING SLEEVE AND FITTING –

$f_{B_{SLEEVE}} = \dfrac{M\bar{y}}{I} = \dfrac{[(2185)(.19)](.405)}{(.0136)} = 9100$ PSI

REQ'D PRE-LOAD TENSILE LOAD IN BOLT –

$f_{t(BOLT)} = f_{c(SLEEVE)}$

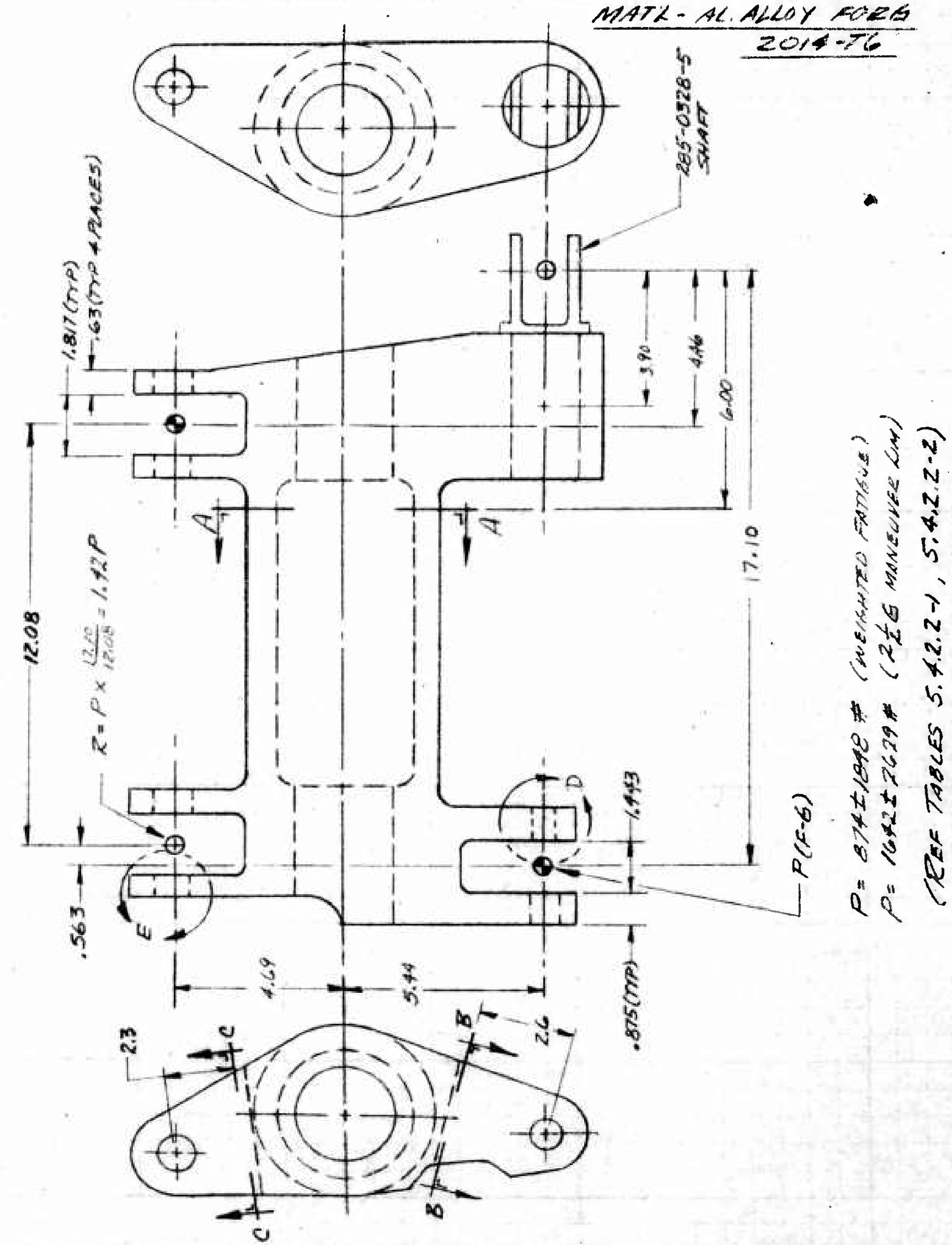
$P_{t(BOLT)} = f_{t(BOLT)} \times A_{SLEEVE} = 9100(.2085) = 1900\#$

FOR DESIGN PURPOSES USE $P_{t(BOLT)} = 3000\#$

DESIGN TORQUE REQ'D = 500 – 600 IN-#

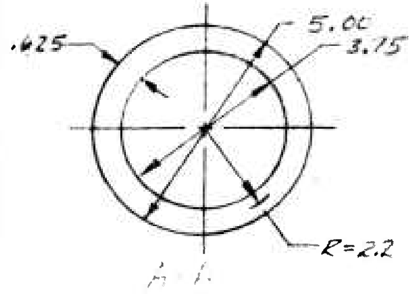
5.4.3.9 285-0303 TORQUE TUBE ASSY

MATL - AL. ALLOY FORG 2014-T6



HUGHES TOOL COMPANY-AIRCRAFT DIVISION

285-0303 TORQUE TUBE ASSY (CONT'D)



$I = .0491\left[D^4 - (D-2t)^4\right] = .049\left[625 - 198\right] = 21\ \text{IN}^4$

$A = \pi\left[t(D-t)\right] = \pi\left[.625(4.37)\right] = 8.6\ \text{IN}^2$

$Q = 2R^2t = 2(2.2)^2(.625) = 6.05\ \text{IN}^3$

$$f_s = \frac{VQ}{Ib} + \frac{Tc}{2I} = \frac{(.42P)(6.05)}{(21)(2 \times .625)} + \frac{(T)(2.5)}{(2)(21)} = .097P + .06T$$

WEIGHTED FATIGUE CONDITION –

$P = 874 \pm 1848$

$T = \left[5.44(874 \pm 1848)\right] + \left[(4.64)(1.42)(874 \pm 1848)\right]$

$= \left[4754 \pm 10053\right] + \left[5821 \pm 12308\right]$

$= 10{,}575 \pm 22{,}361$ "# LIMIT

$f_s = .097(874 \pm 1848) + .06(10575 \pm 22361)$

$f_s = 720 \pm 1521$ PSI LIMIT

f_s' (MAX SHEAR STRESS) $= \sqrt{(f_s)^2 + \left(\frac{f_b}{2}\right)^2}$

$M_{A\text{-}A} = (10.54)(1.42P) - 11.10P = 3.87P = 3.87(874 \pm 1848)$

$M_{A\text{-}A} = 3382 \pm 7152$ "# LIMIT

$$f_b = \frac{Mc}{I} = \frac{(3382 \pm 7152)(2.5)}{21} = 402 \pm 851 \text{ PSI LIMIT}$$

$$f_s' = \sqrt{(720 \pm 1521)^2 + \left(\frac{402 \pm 851}{2}\right)^2}$$

$f_s' = 750 \pm 1580$ PSI LIMIT

$F_{tc} = 18000$ PSI (REF 1, TABLE 3.3.1(a))

$$F_{sa} = .60\left(\frac{\pm 18000}{3}\right)\left(1 - \frac{750}{40000}\right) = \pm 3600 \text{ PSI LIMIT}$$

$$M.S. = \frac{}{1580} - 1 = \underline{1.28}$$

285-0303 TORQUE TUBE ASSY (CONT'D)

MAXIMUM PRINCIPAL STRESS

$$f_p = \frac{1}{2} f_b + f_s$$

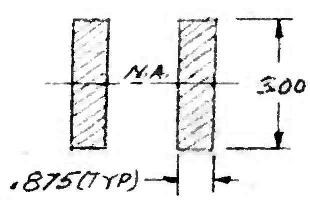
$$= \frac{1}{2}(402 \pm 851) + (720 \pm 1521)$$

$$= 921 \pm 1946 \text{ PSI LIMIT}$$

$$F_a = \left(\frac{\pm 18000}{3}\right)\left(1 - \frac{921}{65000}\right) = \pm 5920 \text{ PSI}$$

USE $F_a = \pm 4000$ PSI $M.S. = \frac{4000}{1946} - 1 = \underline{1.06}$

SECTION B-B



$$I = (2)\frac{.875(3)^3}{12} = 3.94 \text{ IN}^4$$

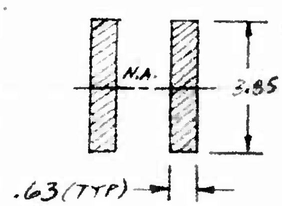
$$f_b = \frac{Mc}{I} = \frac{(874 \pm 1848)(2.6)(1.5)}{3.94}$$

$$f_b = 865 \pm 1830 \text{ PSI LIMIT}$$

$$F_a = \left(\frac{\pm 18000}{3}\right)\left(1 - \frac{865}{65000}\right) = \pm 5922 \text{ PSI}$$

USE $F_a = \pm 4000$ PSI $M.S. = \frac{4000}{1830} - 1 = \underline{1.18}$

SECTION C-C



$$I = (2)\frac{(.63)(3.85)^3}{12} = 6.02 \text{ IN}^4$$

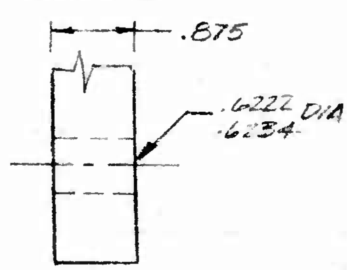
$$f_b = \frac{Mc}{I} = \frac{(1.42)(874 \pm 1848)(1.93)}{6.02}$$

$$f_b = 398 \pm 841 \text{ PSI LIMIT}$$

$F_a = \pm 4000$ PSI $M.S. = \frac{4000}{841} - 1 = \underline{3.75}$

BEARING ON LUGS –

VIEW D



LOAD ON LUG IS ONE-HALF OF THE APPLIED LOAD P.

$$f_{br} = \frac{(.5)(P)}{A_{br}} = \frac{(.5)(874 \pm 1848)}{(.622)(.875)}$$

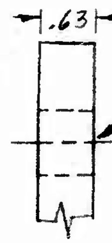
$$f_{br} = 803 \pm 1698 \text{ PSI LIMIT}$$

USE $F_a = \pm 9000$ PSI $M.S. = \underline{HIGH +}$

(REF 1, TABLE 3.3.1(b))

285-0303 TORQUE TUBE ASSY (CONT'D)

VIEW E -



LOAD ON LUG IS ONE-HALF OF APPLIED LOAD = (.50)(1.42P)

$$f_{br} = \frac{(.50)(1.42)(874 \pm 1848)}{(.81)(.63)}$$

$f_{br} = 1217 \pm 2572$ PSI LIMIT

USE F_a = 9000 PSI (REF 1, TABLE 3.3.1 (b))

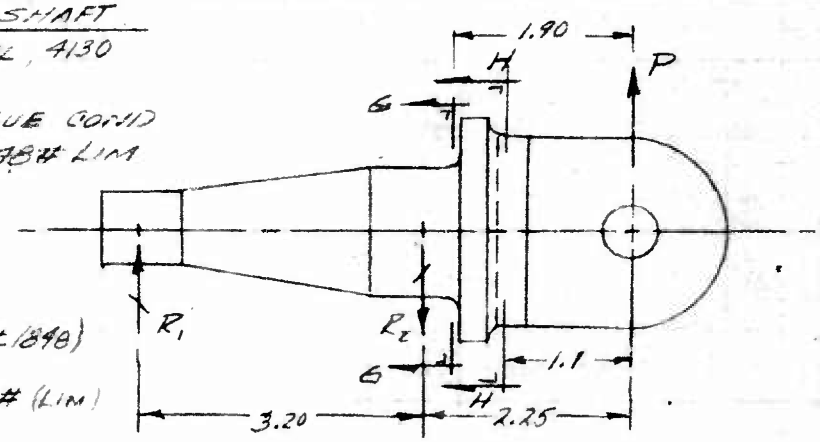
$$M.S. = \frac{9000}{2572} - 1 = \underline{2.50}$$

285-0328-3 SHAFT

MAT'L - STEEL, 4130

WEIGHTED FATIGUE COND

$P = 874 \pm 1848$# LIM



$3.20 R_1 = 2.25 P$

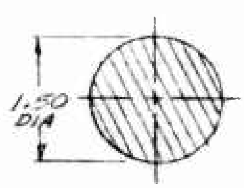
$$R_1 = \frac{2.25}{3.20}(874 \pm 1848)$$

$R_1 = 614 \pm 1300$# (LIM)

$R_2 = P + R_1 = (874 \pm 1848) + (614 \pm 1300)$

$R_2 = 1488 \pm 3148$# (LIM)

SECTION G-G



$$I = \frac{\pi D^4}{64} = .248\ IN^4$$

$M_{G-G} = 1.90(874 \pm 1848) = 1660 \pm 3510$ "# (LIM)

$$f_b = \frac{Mc}{I} = \frac{(1660 \pm 3510)(.75)}{.248} = 5020 \pm 10{,}615 \text{ PSI (LIM)}$$

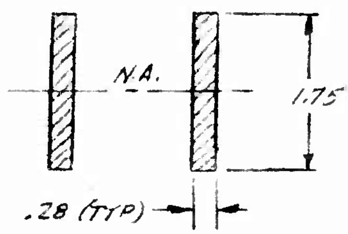
USE $F_a = \pm 35000$ PSI (REF SECT 2.8, FIG 2.8.1)

$$M.S. = \frac{35000}{10{,}615} - 1 = \underline{2.30}$$

285-0303 TORQUE TUBE ASSY (CONT'D)

285-0328-3 SHAFT (CONT'D)

SECTION H-H



$$I = \frac{(2)(1.75)^3(.28)}{12} = .250\ in^4$$

$$M_{H-H} = (1.1)(874 \pm 1848) = 960 \pm 2030\ ''\#\ (LIM)$$

$$f_b = \frac{Mc}{I} = \frac{(960 \pm 2030)(.875)}{.250}$$

$$f_b = 3820 \pm 8080\ PSI\ (LIM)$$

$F_{tc} = \pm 35000$ PSI (REF SECT 2.8, FIG 2.8.1)

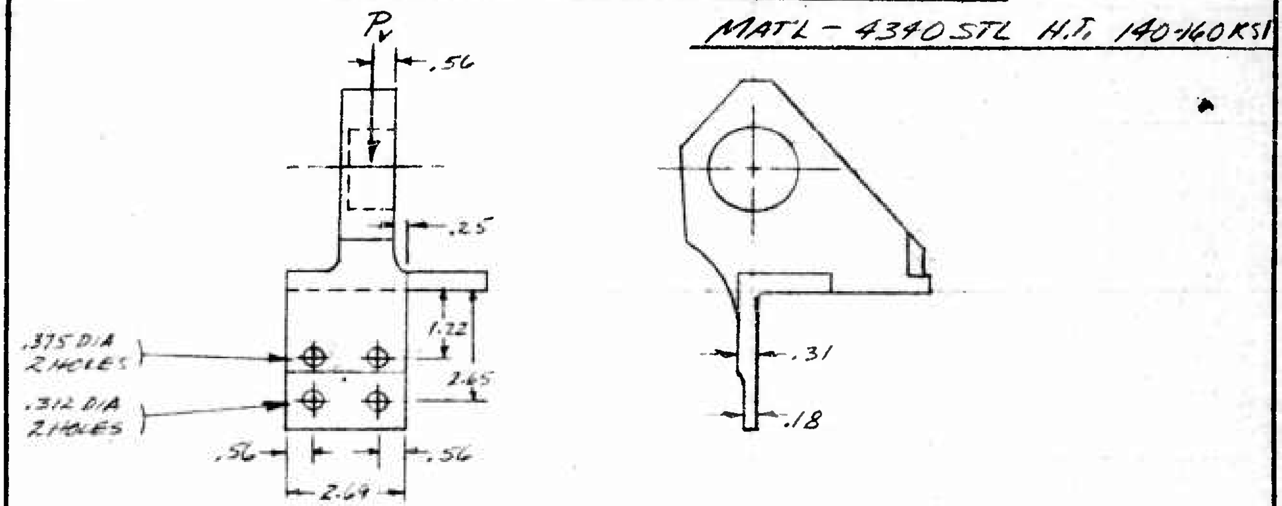
$K_t \doteq 1.35$ (REF 4 FIG 60)

$$F_a = \frac{\pm 35000}{1.35} = \pm 26000\ PSI$$

$$M.S. = \frac{26000}{8080} - 1 = \underline{\underline{2.22}}$$

5.4.3.10 285-0330 CONTROL FITTING ASSY

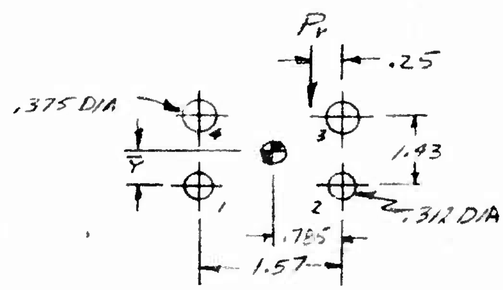
MAT'L - 4340 STL H.T. 140-160 KSI



P_v = 874 ± 1646 # LIM (WEIGHTED FATIGUE COND)

= 1642 ± 2629 # LIM (2 ½ G MANEUVER COND)

CONSIDER THAT ENTIRE LOAD IS CARRIED BY 4 BOLT PATTERN



$$\bar{Y} = \frac{(36)(2)(1.43)}{(36)(2)+(25)(2)} = .844 \text{ IN}$$

BOLT	K	Y	Y^2	KY^2	X	X^2	KX^2
1	25	.844	.712	17.80	.785	.616	15.40
2	25	.844	.712	17.80	.785	.616	15.40
3	36	.586	.343	21.10	.785	.616	22.17
4	36	.586	.343	21.10	.785	.616	22.17
Σ	122			77.80			75.14

I_p = 77.80 + 75.14 = 153

- CONT'D -

285-0330 CONTROL FITTING ASSY (CONT'D)

$$P_{X_M} = \frac{M \bar{y} K}{I_P} \qquad P_{Y_M} = \frac{M \bar{x} K}{I_P}$$

FOR BOLTS 1 & 2

WEIGHTED FATIGUE COND. —

DIRECT LOAD TO BOLTS

$$P_{D.L.} = \frac{25}{122}(P_V) = \frac{25}{122}(874 \pm 1848) = 179 \pm 379\#\ (LIM)$$

MOMENT LOADS

$$M = P_V(.785 - .25) = 874 \pm 1848(.535) = 468 \pm 989\ ''\#\ (LIM)$$

$$P_{X_M} = \frac{(468 \pm 989)(.844)(25)}{153} = 65 \pm 136\#\ (LIM)$$

$$P_{Y_M} = \frac{(468 \pm 989)(.785)(25)}{153} = 60 \pm 127\#\ (LIM)$$

$$P_{BOLT} = (179 \pm 379) + (60 \pm 127) + \longrightarrow (65 \pm 136)$$

$$= 248 \pm 524\ \#\ (LIM)$$

$$A_{be} = (.312)(.125) = .039\ IN^2$$

$$f_{be} = \frac{248 \pm 524}{.039} = 0 \longrightarrow 19{,}800\ PSI\ (LIM) \quad \text{OR } 9900 \pm 9900\ PSI$$

USE $F_{te} = 34{,}500$ PSI FOR $K_t = 2.6$ (REF SECT 2.8, FIG 2.8.1)

$K_{tb} = 1.26$ (REF 4, FIG 83)

$$F_a = \frac{34500}{1.26} = 27{,}400\ PSI$$

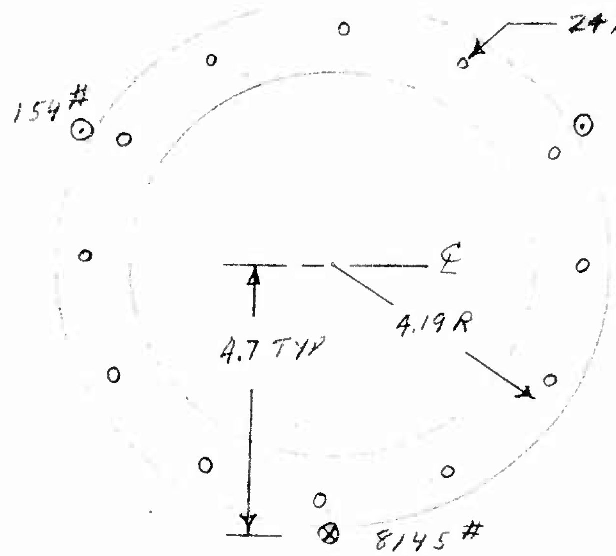
$$M.S. = \frac{27400}{9900} - 1 = \underline{\underline{1.77}}$$

5.4.3.11

LOWER CONTROLS SUPPORT ASSY.

DWG. 285-0308

REF DWG 285-0327



AREA BOLT ⊙

$= \pi \times 4.19^2$

$= 55\ IN^2$

FROM TABLES 5.4.2.2-2 & 5.4.2.3-1

$P = JK + MN = 1212 \pm 2563 + 1400 \pm 2970$

$= 2612 \pm 5533$ LBS

$P_1 = 8145\#,\ P_2 = P_3 = -154\#$

THRUST = 8145 − 2×154 = 7837#

MOMENT = 8145 × 4.7 + 154 × 2 × 4.7 sin 30°

= 38920 "#

$MAX.\ LOAD/BOLT = \frac{7837}{24} + \frac{38920}{55} \times \frac{\pi \times 8.38}{24}$

= 2203#

MIN. LOAD/BOLT = 0

THESE BOLTS HAVE AN ULTIMATE STRENGTH OF 8700# TENSION AND WILL BE TORQUED TO 200-225"# TO GIVE THEM A PRELOAD > 4000# WHICH WILL VIRTUALLY ELIMINATE FATIGUE.

LOWER CONTROLS SUPPORT ASSY. (CONT.)
DWG 285-0308

2½G MANEUVER COND. (LIMIT)

FROM TABLES 5.4.2.2-1 & 5.4.2.3-2 -

$P = JK + MN = 2220 \pm 3556 + 2580 \pm 4125$

$= 4800 \pm 7681$ LBS

$P_1 = 12481$, $P_2 = P_3 = 960$

THRUST $= 12481 + 2 \times 960 = 14400$ LBS

MOMENT $= 12481 \times 4.7 - 2 \times 960 \times 4.7 \sin 30°$

$= 54000$ IN LBS

MAX. LOAD/BOLT $= \frac{14400}{12} + \frac{54000}{35} \times \frac{\pi \times 8.38}{12}$ (REF. PREV. PG.)

$= 3350$ LBS (LIMIT)

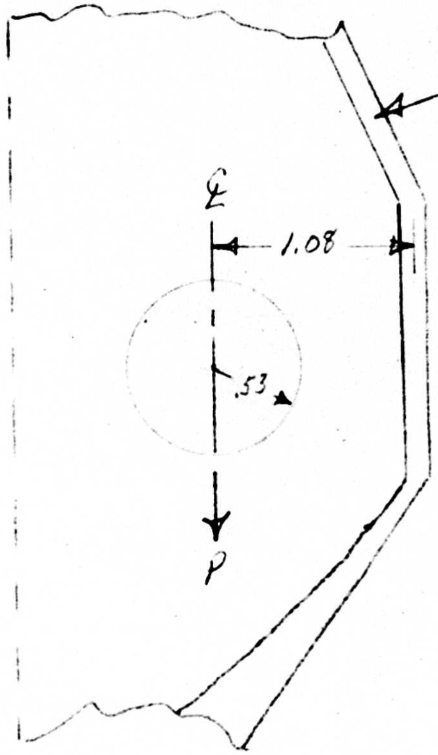
$\therefore P_{ALLOW} = 8200\#$ (REF ANC-5 TABLE 2.6111(b))

(ULT.) $M.S. = \frac{8200}{1.5 \times 3350} - 1 = .63$

LOWER CONTROLS SUPPORT ASSY.

DWG 285-0308

4130 STL. HT 140,000



$$\frac{2r}{D} = \frac{2 \times .53}{2 \times 1.08} = .492$$

$K_b = 2.5$ (REF. 10, VOL II, FIG. 6.13, PG 192)

$$P = \tfrac{1}{2}^{*}(0 + 8145)$$

$$= 2036 \pm 2036\ \#$$

$$f_{br} = \frac{2036 \pm 2036}{.106 \times .30} = 6400 \pm 6400 \text{ PSI}$$

$$f_t = K_b \times f_{br} = 2.5(6400 \pm 6400)$$

$$= 16,000 \pm 16,000 \text{ PSI}$$

$F_{te} = \pm 34000$ PSI (REF FIG. 2.8.1)

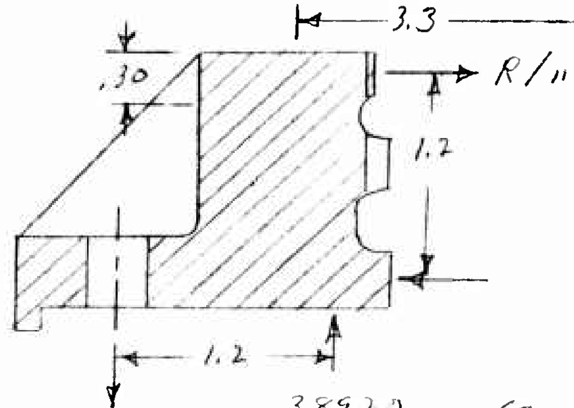
$$M.S. = \frac{34000}{16000} - 1 = \underline{\underline{1.12}}$$

* 2 LUGS

COLLAR ASSEMBLY LOWER SUPPORT

DWG. 285-0318

WEIGHTED FATIGUE COND.



MAT'L - 4340 STL
H.T. 140-160 KSI

$$P/in = \frac{38970}{55} \quad \text{(REF PG 5.4.3.11.0)}$$

$$= 707 \ \#/in$$

$$R/in = \frac{4.19}{3.3} \times 707 = 910 \ \#/in$$

THIS OUTWARD LOAD (0 TO 910 #/in) PRODUCES AN ALTERNATING HOOP TENSION IN THE UPPER (.30" THICK) PORTION OF THE COLLAR.

$$f_t = \frac{0 \text{ TO } 910 \times 3.3}{.30 \times .95}$$

$$= 5260 \pm 5260 \text{ PSI}$$

$F_{tt} = \pm 35{,}000$ PSI (REF SECT 2.8, FIG 2.8.1)

$K_t = 1.52$ (REF 4, FIG 60)

$$F_a = \frac{35000}{1.52} = \pm 23000 \text{ PSI}$$

M.S. = HIGH +

SPLINE OK BY INSPECTION

UNCLASSIFIED

UNCLASSIFIED