

QcX  
Avro  
CF105  
R7-0558-8



# TECHNICAL REPORT



A. V. ROE CANADA LIMITED  
MALTON - ONTARIO

ANALYZED

**TECHNICAL DEPARTMENT (Aircraft)**

AIRCRAFT: C-105

REPORT NO. 7-0558-8

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NO. OF SHEETS 77.

TITLE:

~~CONFIDENTIAL~~

Classification cancelled / Changed to UNCLASS  
By authority of AVRS  
Date 30 Sept 96  
Signature DBully  
Unit / Rank / Appointment AVRSS

## DEFLECTION FORMULAS

FORMER - SPAR - STRUT ASSEMBLY.



PREPARED BY *V. J. Masi*

DATE 5-17-55

CHECKED BY \_\_\_\_\_

DATE \_\_\_\_\_

SUPERVISED BY

DATE MAY 55

APPROVED BY \_\_\_\_\_

DATE \_\_\_\_\_

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SHEET NO. Introduction

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V. J. Masi

6-10-55

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Introduction:

On page 29 the result for  $\delta_i$  was first obtained in error; i.e., the coefficient of  $T_1$  was smaller than the coefficient of  $T_2$ . In searching for the truth a time came when we felt that the error might be due to the method of reducing the strain energy.

We proved that the method was correct and discovered that the error was arithmetic. We include the proof because it is worth something and ought to appear somewhere; if only to preclude the possibility of its being sought again.

m





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**TECHNICAL DEPARTMENT (Aircraft)**

C-105

Derivation  
of Formulas for  
 $d_1; d_2; d_3; \& d_4$

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1

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Mass

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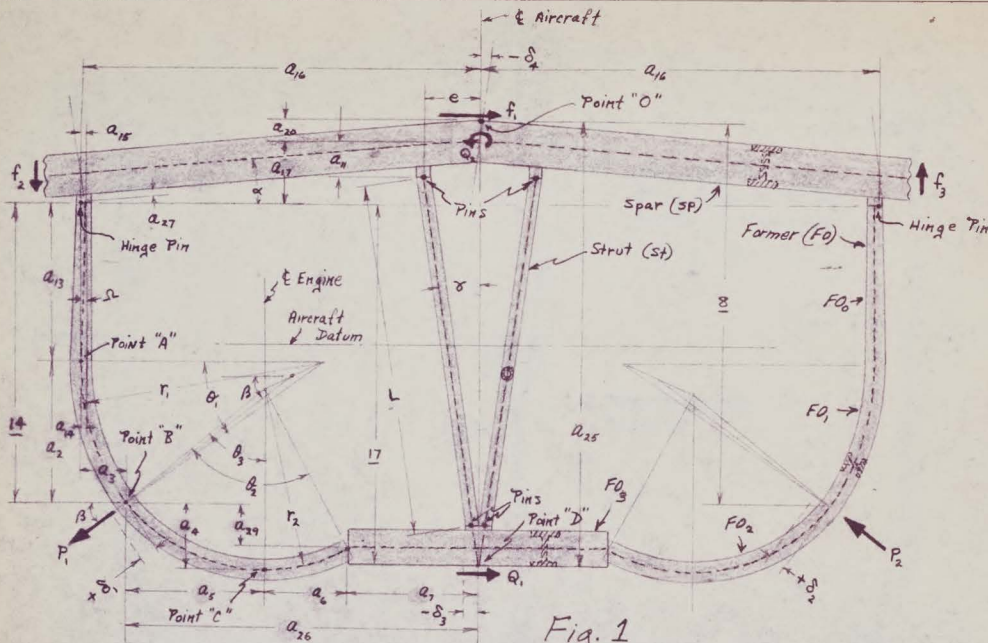
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Fig. 1

Note: Forces are positive in the directions shown;  $P_1$  &  $P_2$  are produced by the longerons;  $Q_1$  is produced by shear webs;  $Q_2$  is produced by the fin end/or adjacent structure;  $f_1, f_2, f_3$  are functions of the  $P$ 's and  $Q$ 's by statics. Second degree curves are approximated by radii  $r_1$  &  $r_2$  through control points A, B, & C. An underlined number is the name of a constant; e.g.,  $\underline{1} = C_1 = 19.09189$ , etc.



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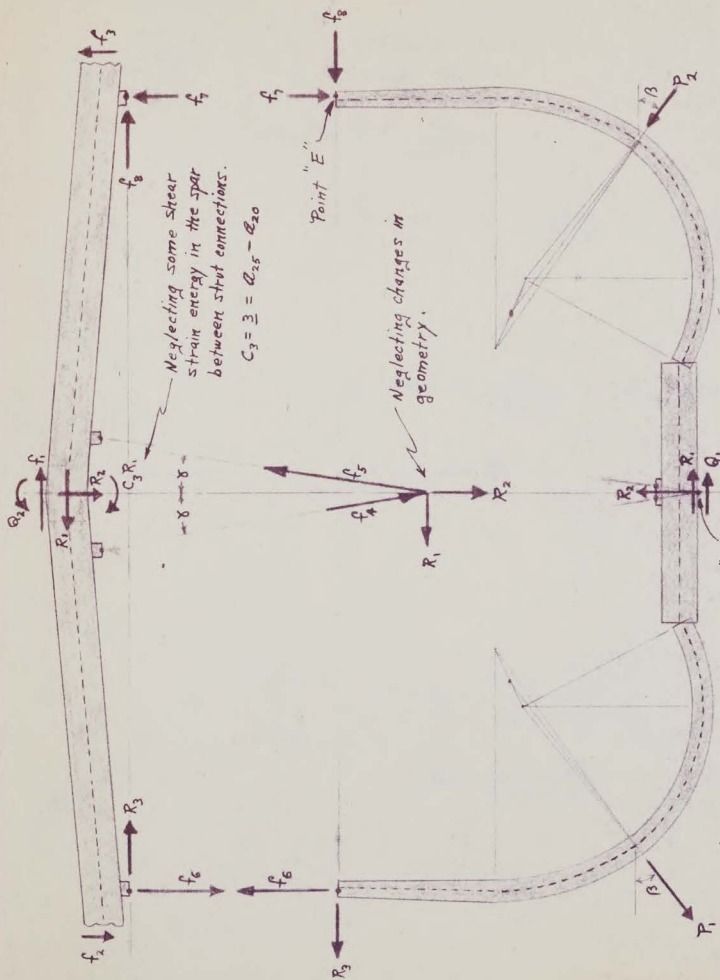
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Forces  $f_1 \dots f_8$  by statics:

P's & Q's are applied loads; R's are redundants.

Referring to fig. 1,

$$F_u = 0 = f_1 + Q_1 - P_1 \cos \beta - P_2 \cos \beta$$

$$F_v = 0 = f_3 - f_2 - P_1 \sin \beta + P_2 \sin \beta$$

$$M_o = 0 = Q_{16} f_2 + Q_2 + Q_{16} f_3 + Q_{25} Q_1 - 8 P_2 \cos \beta - 8 P_1 \cos \beta + Q_{26} P_2 \sin \beta + Q_{26} P_1 \sin \beta$$

$$\underline{8} = \cos \beta \quad ; \quad \underline{7} = \sin \beta$$

$$f_1 = \underline{6} P_1 + \underline{6} P_2 - Q_1$$

$$f_2 - f_3 = -\underline{7} P_1 + \underline{7} P_2$$

$$f_2 + f_3 = \frac{68}{a_{16}} P_1 + \frac{68}{a_{16}} P_2 - \frac{7 Q_{26}}{a_{16}} P_1 - \frac{7 Q_{26}}{a_{16}} P_2 - \frac{Q_{25}}{a_{16}} Q_1 - \frac{1}{a_{16}} Q_2$$

$$f_2 = \frac{1}{2 a_{16}} \left[ P_1 (\underline{68} - 7 Q_{26} - 7 Q_{16}) + P_2 (\underline{68} - 7 Q_{26} + 7 Q_{16}) - Q_{25} Q_1 - Q_2 \right]$$

$$f_3 = \frac{1}{2 a_{16}} \left[ P_1 (\underline{68} - 7 Q_{26} + 7 Q_{16}) + P_2 (\underline{68} - 7 Q_{26} - 7 Q_{16}) - Q_{25} Q_1 - Q_2 \right]$$

$$\underline{8} = Q_{20} + Q_{17} + Q_2 + Q_{13} \quad ; \quad \underline{7} = Q_3 - Q_{14} + Q_{15} \quad ; \quad Q_{26} = Q_{16} - \underline{9}$$

$$\underline{10} = \frac{68 - (Q_{16} - \underline{9}) \underline{7} - 7 Q_{16}}{2 a_{16}} = \frac{68 + 7 \underline{9}}{2 a_{16}} - \underline{7} = \underline{11} - \underline{7}$$

$$\underline{11} = \frac{68 - (Q_{16} - \underline{9}) \underline{7} + 7 Q_{16}}{2 a_{16}} = \frac{68 + 7 \underline{9}}{2 a_{16}}$$

$$\underline{12} = \frac{Q_{25}}{2 a_{16}} \quad ; \quad \underline{13} = \frac{1}{2 a_{16}} \quad ; \quad \underline{14} = Q_2 + Q_{13} \quad ; \quad \underline{15} = Q_{26} + Q_{16}$$

$$f_1 = \underline{6} P_1 + \underline{6} P_2 - Q_1$$

$$f_2 = \underline{10} P_1 + \underline{11} P_2 - \underline{12} Q_1 - \underline{13} Q_2$$

$$f_3 = \underline{11} P_1 + \underline{10} P_2 - \underline{12} Q_1 - \underline{13} Q_2$$

Referring to fig. 2,  $\underline{4} = \frac{1}{2 \cos \theta} \quad ; \quad \underline{5} = \frac{1}{2 \sin \theta} \quad ; \quad f_5 - f_4 = \frac{R_2}{\cos \theta}$

$$f_5 + f_4 = \frac{R_1}{\sin \theta}$$

$$\left. \begin{aligned} f_4 &= \underline{5} R_1 - \underline{4} R_2 \\ f_5 &= \underline{5} R_1 + \underline{4} R_2 \end{aligned} \right\}$$





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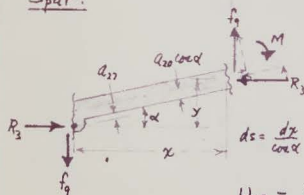
Strain Energy Function: "U" $M = \text{Bending moment} ; N = \text{Axial force} ; V = \text{Shear force.}$ 

$$U = \int \frac{M^2}{2EI} ds + \int \frac{N^2}{2AE} ds + \int \frac{\alpha V^2}{2AG} ds ; \alpha = \frac{V_{max}}{V_{ave.}}$$

Struts:

$$M=0 ; V=0 ; N=f_4, f_5$$

$$\begin{aligned} U_{ST} &= \left[ \frac{L}{2A_{ST}E_{ST}} \right] (f_4^2 + f_5^2) \\ &= 25 \left[ (\underline{5}R_1 - \underline{4}R_2)^2 + (\underline{5}R_1 + \underline{4}R_2)^2 \right] \\ &= (2 \underline{25} \underline{5}^2) R_1^2 + (2 \underline{25} \underline{4}^2) R_2^2 \\ &= \underline{26} R_1^2 + \underline{27} R_2^2 \end{aligned}$$

Spar:

$$\underline{28} = \tan \alpha ; \underline{29} = \sin \alpha ; \underline{30} = \cos \alpha$$

$$y = \left( \frac{d_{27}}{\underline{30}} + \frac{d_{30}}{\underline{30}} \right) + \underline{28} x = \underline{31} + \underline{28} x$$

$$U_{sp} = U_{SP,L,H} + U_{SP,R,H}$$

Note: Symmetry is such that substitution of  $f_8$  and  $f_{10}$  for  $R_3$  and  $f_9$  respectively in  $U_{SP,L,H}$  yields  $U_{SP,R,H}$ .

$$M = R_3 y + f_9 x = \underline{31} R_3 + \underline{28} R_3 x + f_9 x = \underline{31} R_3 + (\underline{f}_9 + \underline{28} R_3) x$$

$$N = \underline{30} R_3 + \underline{29} f_9$$

$$V = \underline{29} R_3 + \underline{30} f_9$$

$$U_{SP,L,H} = \int_0^{d_{16}} \left( \frac{1}{2 \underline{30} E_{SP} I_{SP}} \right) \left( \underline{31}^2 R_3^2 + 2 \underline{31} R_3 (\underline{f}_9 + \underline{28} R_3) x + (\underline{f}_9 + \underline{28} R_3)^2 x^2 \right) dx + \left( \frac{d_{16}}{2 \underline{30} A_{SP} E_{SP}} \right) N^2 + \left( \frac{d_{16}}{2 \underline{30} A_{SP} G_{SP}} \right) V^2$$





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$$U_{SP_{L.H.}} = \left( 32 \overset{35}{31^2} a_{13} R_3^2 + (32 \overset{36}{31} a_{13}) R_3 (f_9 + 28 R_3) + \left[ \frac{32 \overset{38}{31}}{3} \right] (f_9 + 28 R_3)^2 + 33 (10 R_3 - 29 f_9)^2 + 34 (29 R_3 + 30 f_9)^2 \right. \\ = 35 R_3^2 + 36 R_3 f_9 + (32 \overset{37}{29}) R_3^2 + 38 f_9^2 + (2 \overset{39}{38} 28) R_3 f_9 + (38 \overset{39}{28}) R_3^2 + (33 \overset{40}{30}) R_3^2 - (2 \overset{41}{33} 30 29) R_3 f_9 \\ \left. + (33 \overset{42}{29}) f_9^2 + (34 \overset{43}{29}) R_3^2 + (2 \overset{44}{34} 29 30) R_3 f_9 + (34 \overset{45}{30}) f_9^2 \right.$$

$$46 = 35 + 37 + 38 + 40 + 43$$

$$47 = 36 + 399 - 41 + 44$$

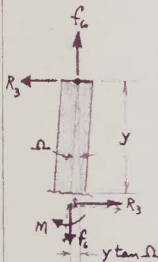
$$48 = 38 + 42 + 45$$

$$U_{SP} = 46 R_3^2 + 47 R_3 f_9 + 48 f_9^2 + 46 f_9^2 + 47 f_9 f_{90} + 48 f_{90}^2$$

Former:

$$U_{FO} = U_{FO_{L.H.}} + U_{FO_{R.H.}}$$

Note: When  $U_{FO_{L.H.}}$  is obtained as a function of  $R_3$ ;  $f_6$ ; and  $P$ ; symmetry allows  $U_{FO_{R.H.}}$  to be written by substitution of  $f_2$ ;  $f_1$ ; &  $R_2$ ; respectively.



Assume the pin is at the centroid of the section and that section properties do not vary along the length  $a_{13}$ .

$$\alpha = \tan^{-1} \frac{a_{46} - a_{15}}{a_{13}} = \tan^{-1} 55; \quad 56 = \sin \alpha; \quad 57 = \cos \alpha$$

$$N = f_6 57 - R_3 56$$

$$V = R_3 57 + f_6 56$$

$$M = R_3 y + f_6 y \tan \alpha = (R_3 + 55 f_6) y; \quad ds = \frac{dy}{\cos \alpha}$$

$$U_{FO_{L.H.}} = \int_0^{a_{13}} \left( \frac{(R_3 + 55 f_6)^2 y^2 dy}{2 E_{FO} I_{FO} 57} + \frac{(57 f_6 - 56 R_3) a_{13}}{2 A_{FO} E_{FO} 57} + \frac{\alpha a_{13} (57 R_3 + 56 f_6) a_{13}}{2 A_{FO} G_{FO} 57} \right)$$

$$= \left( \frac{a_{13}^3}{6 E_{FO} I_{FO} 57} \right) (R_3^2 + 2 \overset{82}{55} R_3 f_6 + 55^2 f_6^2) + \left( \frac{a_{13}}{2 A_{FO} E_{FO} 57} \right) (57^2 f_6^2 - 2 \overset{83}{57} 56 R_3 f_6 + 56^2 R_3^2)$$

$$+ \left( \frac{a_{13} \alpha a_{13}}{2 A_{FO} G_{FO} 57} \right) (57^2 R_3^2 + 2 \overset{84}{57} 56 R_3 f_6 + 56^2 f_6^2)$$

$$= R_3^2 (82 + 83 \overset{85}{56^2} + 84 \overset{85}{57}) + R_3 f_6 (2 \overset{86}{55} 82 - 2 \overset{86}{57} 83 + 2 \overset{86}{56} 57 \overset{86}{84}) + f_6^2 (32 \overset{87}{55^2} + 83 \overset{87}{57} + 84 \overset{87}{56})$$



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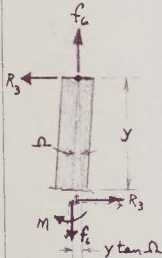
$$\begin{aligned}
 U_{SP, L.H.} &= (32 \overset{55}{31} a_{13}^2) R_3^2 + (32 \overset{36}{21} a_{13}^2) R_3 (f_9 + 28 R_3) + \left[ \frac{32 \overset{38}{44}}{3} \right] f_9^2 + 28 R_3^3 + 33 (10 R_3 - 27 f_9^2) + 34 (29 R_3 + 30 f_9^2) \\
 &= 35 R_3^2 + 36 R_3 f_9 + (34 \overset{37}{28}) R_3^2 + 38 f_9^2 + (2 \overset{29}{38} \overset{28}{28}) R_3 f_9 + (38 \overset{39}{28}) R_3^2 + (33 \overset{40}{28}) R_3^2 - (23 \overset{41}{30} \overset{40}{28}) R_3 f_9 \\
 &\quad + (33 \overset{42}{29}) f_9^2 + (34 \overset{43}{29}) R_3^2 + (2 \overset{44}{34} \overset{44}{29} \overset{44}{30}) R_3 f_9 + (34 \overset{45}{30}) f_9^2 \\
 46 &= 35 + 37 + 39 + 40 + 43 \\
 47 &= 36 + 299 - 41 + 44 \\
 48 &= 38 + 42 + 45
 \end{aligned}$$

$$U_{SP} = 46 R_3^2 + 47 R_3 f_9 + 48 f_9^2 + 46 R_3^2 + 47 f_9^2 + 48 f_9^2$$

Former:

$$U_{FO} = U_{FO, L.H.} + U_{FO, R.H.}$$

Note: When  $U_{FO, L.H.}$  is obtained as a function of  $R_3$ ;  $f_6$ ; and  $P$ ; symmetry allows  $U_{FO, R.H.}$  to be written by substitution of  $f_8$ ;  $f_7$ ;  $2 R_2$ ; respectively.



Assume the pin is at the centroid of the section and that section properties do not vary along the length  $a_{13}$ .

$$\Omega = \tan^{-1} \frac{44 - 416}{a_{13}} = \tan^{-1} 55; \quad 56 = \sin \Omega; \quad 57 = \cos \Omega$$

$$N = f_6 57 - R_3 56$$

$$V = R_3 57 + f_6 56$$

$$M = R_3 y + f_6 y \tan \Omega = (R_3 + 55 f_6) y; \quad ds = \frac{dy}{\cos \Omega}$$

$$\begin{aligned}
 U_{FO, L.H.O} &= \int_0^{a_{13}} \frac{(R_3 + 55 f_6)^2 y^2 dy}{2 E_{FO} I_{FO} 57} + \frac{(57 f_6 - 56 R_3) a_{13}}{2 A_{FO} E_{FO} 57} + \frac{\alpha_{FO} (57 R_3 + 56 f_6) a_{13}}{2 A_{FO} G_{FO} 57} \\
 &= \left( \frac{a_{13}^2}{6 E_{FO} I_{FO} 57} \right) (R_3^2 + 255 R_3 f_6 + 55^2 f_6^2) + \left( \frac{a_{13}}{2 A_{FO} E_{FO} 57} \right) (57^2 f_6^2 - 257 56 R_3 f_6 + 56^2 R_3^2) \\
 &\quad + \left( \frac{a_{13} \alpha_{FO}}{2 A_{FO} G_{FO} 57} \right) (57^2 R_3^2 + 257 56 R_3 f_6 + 56^2 f_6^2) \\
 &= R_3^2 (22 + 83 \overset{55}{56} + 84 \overset{57}{57}) + R_3 f_6 (2 \overset{58}{55} 82 - 256 \overset{57}{57} 83 + 2 \overset{56}{56} 57 84) + f_6^2 (22 \overset{59}{55} + 83 \overset{57}{57} + 24 \overset{56}{56})
 \end{aligned}$$



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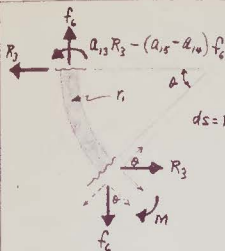
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$$N = R_3 \sin \theta + f_6 \cos \theta$$

$$V = R_3 \cos \theta - f_6 \sin \theta$$

$$M = Q_3 R_3 - (Q_5 - Q_4) f_6 + R_3 r_1 \sin \theta - f_6 r_1 (1 - \cos \theta) \\ = u + R_3 r_1 \sin \theta + f_6 r_1 \cos \theta$$

$$u = Q_3 R_3 - (r_1 + Q_5 - Q_4) f_6$$

$$U_{FOLH_1} = \int_0^{\theta_1} \left\{ \left( \frac{r_1^2}{2E_{F0} I_{F0}} \right) \left( u^2 + R_3^2 r_1^2 \sin^2 \theta + f_6^2 r_1^2 \cos^2 \theta + 2u R_3 r_1 \sin \theta + 2u f_6 r_1 \cos \theta + R_3 r_1 f_6 \sin 2\theta \right) \right. \\ \left. + \left( \frac{r_1^3}{2A_{F0} E_{F0}} \right) \left( R_3^2 \sin^2 \theta + f_6^2 \cos^2 \theta + R_3 f_6 \sin 2\theta \right) + \left( \frac{d_{F0} r_1}{2A_{F0} S_{F0}} \right) \left( f_6^2 \sin^2 \theta + R_3^2 \cos^2 \theta - R_3 f_6 \sin 2\theta \right) \right\} d\theta$$

$$90 = \int_0^{\theta_1} \sin^2 \theta d\theta = \left[ \frac{\theta}{2} - \frac{\sin 2\theta}{4} \right]_0^{\theta_1} = \frac{1}{2} \left( \theta_1 - \frac{\sin 2\theta_1}{2} \right)$$

$$91 = \int_0^{\theta_1} \cos^2 \theta d\theta = \left[ \frac{\theta}{2} + \frac{\sin 2\theta}{4} \right]_0^{\theta_1} = \frac{1}{2} \left( \theta_1 + \frac{\sin 2\theta_1}{2} \right)$$

$$92 = \int_0^{\theta_1} \sin \theta d\theta = \left[ -\cos \theta \right]_0^{\theta_1} = 1 - \cos \theta_1$$

$$93 = \int_0^{\theta_1} \cos \theta d\theta = \left[ \sin \theta \right]_0^{\theta_1} = \sin \theta_1$$

$$94 = \int_0^{\theta_1} \sin 2\theta d\theta = \left[ -\frac{1}{2} \cos 2\theta \right]_0^{\theta_1} = \frac{1}{2} (1 - \cos 2\theta_1)$$

$$U_{FOLH_1} = 87 (\theta_1 u^2 + 90 r_1^2 R_3^2 + 91 r_1^2 f_6^2 + 2 \cdot 92 r_1 R_3 u + 2 \cdot 93 r_1 f_6 u + 94 r_1^2 R_3 f_6) \\ + 88 (90 R_3^2 + 91 f_6^2 + 94 R_3 f_6) + 89 (90 f_6^2 + 91 R_3^2 - 94 R_3 f_6)$$

$$= \left( \frac{87}{2} \theta_1^2 \right) R_3^2 - \left( \frac{2 \cdot 87}{2} \theta_1 \right) Q_3 f_6 + \left( \frac{87}{2} \theta_1^2 \right) f_6^2 + \left( \frac{87}{2} \theta_1 \right) r_1^2 R_3^2 + \left( \frac{87}{2} \theta_1 \right) r_1^2 f_6^2 \\ + \left( \frac{2 \cdot 87}{2} \theta_1 \right) r_1 Q_3 R_3 - \left( \frac{2 \cdot 87}{2} \theta_1 \right) r_1 Q_3 f_6 + \left( \frac{2 \cdot 87}{2} \theta_1 \right) r_1 Q_3 R_3 f_6 - \left( \frac{2 \cdot 87}{2} \theta_1 \right) r_1 Q_3 f_6^2 + \left( \frac{87}{2} \theta_1^2 \right) R_3^2 f_6 \\ + \left( \frac{87}{2} \theta_1^2 \right) R_3^2 + \left( \frac{87}{2} \theta_1^2 \right) f_6^2 + \left( \frac{87}{2} \theta_1 \right) R_3 f_6 + \left( \frac{87}{2} \theta_1 \right) f_6^2 + \left( \frac{87}{2} \theta_1 \right) R_3^2 - \left( \frac{87}{2} \theta_1 \right) R_3 f_6$$



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$$U_{F0, H_1} = R_3^2 \left( \frac{95}{95} + \frac{98}{98} + \frac{100}{100} + \frac{105}{105} + \frac{107}{107} \right) + R_3^2 \left( \frac{112}{-96 - 101 + 102 + 104 + 107 - 110} \right) \\ + R_3^2 \left( \frac{113}{97 + 99 - 103 + 106 + 108} \right)$$

$$M_0 = R_3^2 (a_{13} + a_{14}) - R_3^2 (a_{15} - a_{14} + a_{13}) \quad \underline{6} = \cos \beta ; \quad \underline{7} = \sin \beta ; \quad \underline{114} = \cos \beta_3 ; \quad \underline{115} = \sin \beta_3$$



$$N_0 = (R_3 - R_1 \sin \beta) \sin \beta_3 + (R_3 + R_1 \cos \beta) \cos \beta_3 \\ V_0 = (R_3 - R_1 \sin \beta) \cos \beta_3 - (R_3 + R_1 \cos \beta) \sin \beta_3$$

$$N_0 = \underline{115} (R_3 - R_1) + \underline{114} (R_3 + R_1) \\ V_0 = \underline{114} (R_3 - R_1) - \underline{115} (R_3 + R_1)$$

$$N_0 = \underline{115} \mu + \underline{114} N$$

$$V_0 = \underline{114} \mu - \underline{115} N$$

$$N = N_0 \cos \theta - V_0 \sin \theta$$

$$V = N_0 \sin \theta + V_0 \cos \theta$$

$$M = M_0 - V_0 r_2 \sin \theta - N_0 r_2 (1 - \cos \theta) = (M_0 - N_0 r_2) - V_0 r_2 \sin \theta + N_0 r_2 \cos \theta$$

$$U_{F0, H_2} = \int_0^{\beta_2} \left\{ \left( \frac{R_3^2}{2 E_{F0} I_{F02}} \right) \left[ -w^2 + V_0^2 r_2^2 \sin^2 \theta + N_0^2 r_2^2 \cos^2 \theta - 2 w V_0 r_2 \sin \theta + 2 w N_0 r_2 \cos \theta - V_0 N_0 r_2^2 \sin 2 \theta \right] \right. \\ \left. + \left( \frac{r_2}{2 A_{F02} E_{F0}} \right) \left[ V_0^2 \sin^2 \theta + N_0^2 \cos^2 \theta - N_0 V_0 \sin 2 \theta \right] \right. \\ \left. + \left( \frac{r_2^3}{2 A_{F02} I_{F02}} \right) \left[ N_0^2 \sin^2 \theta + V_0^2 \cos^2 \theta + N_0 V_0 \sin 2 \theta \right] \right\} d\theta$$

$$\underline{119} = \int_0^{\beta_2} \sin^2 \theta d\theta = \frac{1}{2} \left( \beta_2 - \frac{\sin 2 \beta_2}{2} \right)$$

$$\underline{120} = \int_0^{\beta_2} \cos^2 \theta d\theta = \frac{1}{2} \left( \beta_2 + \frac{\sin 2 \beta_2}{2} \right)$$

$$\underline{121} = \int_0^{\beta_2} \sin \theta d\theta = 1 - \cos \beta_2$$

$$\underline{122} = \int_0^{\beta_2} \cos \theta d\theta = \sin \beta_2$$

$$\underline{123} = \int_0^{\beta_2} \sin 2 \theta d\theta = \frac{1}{2} (1 - \cos 2 \beta_2)$$





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$$\begin{aligned}
 U_{F0, L_2} &= \frac{116}{117} (44^2 \delta_2 + 119 V_0^2 f_2^2 + 120 N_0^2 f_2^2 - 2 \cdot 121 V_0 f_2 4N - 2 \cdot 122 N_0 f_2 4N - 123 V_0 N_0 f_2^2) \\
 &\quad + \frac{117}{118} (119 V_0^2 + 120 N_0^2 - 123 N_0 V_0) + \frac{118}{119} (119 N_0^2 + 120 V_0^2 + 123 N_0 V_0) . \\
 &= \frac{124}{116} M_0^2 - \frac{125}{(2 \cdot 116 \delta_2 f_2)} M_0 N_0 + \frac{126}{(116 \delta_2 f_2^2)} N_0^2 + \frac{127}{(116 \cdot 119 f_2^2)} V_0^2 + \frac{128}{(116 \cdot 120 f_2^2)} N_0^2 - \frac{129}{(2 \cdot 116 \cdot 121 f_2)} M_0 V_0 \\
 &\quad + (2 \cdot \frac{130}{116 \cdot 121 f_2^2}) N_0 V_0 + (2 \cdot \frac{131}{116 \cdot 122 f_2}) M_0 N_0 - \frac{132}{(2 \cdot 116 \cdot 122 f_2^2)} N_0^2 - \frac{133}{(116 \cdot 123 f_2^2)} N_0 V_0 + \frac{134}{(117 \cdot 119)} V_0^2 \\
 &\quad + \frac{135}{(117 \cdot 120)} N_0^2 - \frac{136}{(117 \cdot 123)} N_0 V_0 + \frac{137}{(118 \cdot 119)} N_0^2 + \frac{138}{(118 \cdot 120)} V_0^2 + \frac{139}{(118 \cdot 123)} N_0 V_0 . \\
 &= M_0^2 (124) + N_0^2 (\frac{126}{128} - \frac{132}{132} + \frac{135}{135} + \frac{137}{137}) + V_0^2 (\frac{127}{127} + \frac{134}{134} + \frac{138}{138}) + M_0 N_0 (-\frac{125}{125} + \frac{131}{131}) \\
 &\quad + M_0 V_0 (-\frac{129}{129}) + N_0 V_0 (\frac{130}{130} - \frac{133}{133} - \frac{136}{136} + \frac{139}{139}) . \\
 &= 124 (14^2 \pi_3^2 + 9^2 f_6^2 - 2 \cdot 9 \cdot 14 \pi_3 f_6^2) + 140 (115^2 u^2 + 114^2 v^2 + 2 \cdot 114 \cdot 115 u v) \\
 &\quad + 141 (114^2 u^2 + 115^2 v^2 - 2 \cdot 114 \cdot 115 u v) + 142 (14 \cdot 115 \pi_3 u + 14 \cdot 114 \pi_3 v - 9 \cdot 115 f_6 u - 9 \cdot 114 f_6 v) \\
 &\quad - 129 (14 \cdot 114 \pi_3 u - 14 \cdot 115 \pi_3 v - 9 \cdot 114 f_6 u + 9 \cdot 115 f_6 v) + 143 (114 \cdot 115 u^2 + [114^2 - 115^2] u v - 114 \cdot 115 v^2) . \\
 &= (124 \cdot 14^2) \pi_3^2 + (\frac{145}{124 \cdot 9^2}) f_6^2 - (\frac{146}{2 \cdot 124 \cdot 9 \cdot 14}) \pi_3 f_6^2 + (\frac{4^2}{f_6^2 \cdot 2 \cdot 2 f_6^2 \pi_3^2 + 2^2 \pi_3^2}) \times \frac{147}{140 \cdot 115^2 + 141 \cdot 114^2 + 143 \cdot 114 \cdot 115} \\
 &\quad + (\pi_3^2 + 2 \cdot \frac{148}{140 \cdot 114^2} + \frac{151}{141 \cdot 115^2} - \frac{153}{143 \cdot 114 \cdot 115}) \\
 &\quad + (\pi_3 f_6^2 + \frac{154}{140 \cdot 114^2} - \frac{156}{141 \cdot 115^2} + \frac{157}{143 \cdot 114 \cdot 115}) \\
 &\quad + (\pi_3 f_6^2 + \frac{159}{142 \cdot 114 \cdot 115} - \frac{160}{143 \cdot 114 \cdot 115} + \frac{161}{144 \cdot 115^2}) \\
 &\quad + (\pi_3 f_6^2 + \frac{162}{142 \cdot 114 \cdot 115} - \frac{163}{143 \cdot 114 \cdot 115} + \frac{164}{144 \cdot 115^2}) \\
 &\quad + (f_6^2 - 2 \cdot \frac{165}{142 \cdot 9 \cdot 115} + \frac{166}{143 \cdot 9 \cdot 114}) + (\pi_3 f_6^2 + \frac{167}{142 \cdot 9 \cdot 114} - \frac{168}{143 \cdot 9 \cdot 115}) . \\
 &= \pi_3^2 (\frac{171}{144 + 154 + 164}) + f_6^2 (\frac{172}{145 + 150 + 167}) + \pi_3^2 (2^2 \cdot \frac{173}{150} + \frac{174}{154} - \frac{175}{158}) \\
 &\quad + \pi_3 f_6^2 (-\frac{174}{146} + \frac{175}{158} + \frac{161}{161} + \frac{170}{170}) + \pi_3 \pi_3 (\frac{175}{2 \cdot 154} - \frac{176}{158} - \frac{177}{161} + \frac{178}{164}) \\
 &\quad + f_6^2 (-2 \cdot \frac{179}{150} + \frac{176}{158} - \frac{177}{167} + \frac{178}{170}) .
 \end{aligned}$$











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$$\underline{UP_1} = \delta_1 = \underline{UP_1^2 P_1} + \underline{UPR_1 R_1} + \underline{UPQ_1 Q_1} + \underline{UP_1 Q_2 Q_2} + \underline{UPR_1 R_1} + \underline{UPR_2 R_2} + \underline{UPR_3 R_3}$$

$$\underline{UP_2} = \delta_2 = \underline{UP_2^2 P_1} + \underline{UP_2^2 R_2} + \underline{UP_2 Q_1 Q_1} + \underline{UP_2 Q_2 Q_2} + \underline{UPR_2 R_1} + \underline{UPR_2 R_2} + \underline{UPR_2 R_3}$$

$$\underline{UP_3} = \delta_3 = \underline{UP_3^2 P_1} + \underline{UP_3^2 R_2} + \underline{UP_3 Q_1 Q_1} + \underline{UP_3 Q_2 Q_2} + \underline{UPQ_3 R_1} + \underline{UPQ_3 R_2} + \underline{UPQ_3 R_3}$$

$$\underline{UP_4} = \delta_4 = \underline{UP_4^2 P_1} + \underline{UP_4^2 R_2} + \underline{UP_4 Q_1 Q_1} + \underline{UP_4^2 Q_2} + \underline{UPQ_4 R_1} + \underline{UPQ_4 R_2} + \underline{UPQ_4 R_3}$$

$$\underline{UR_1} = 0 = \underline{UR_1^2 P_1} + \underline{UR_1^2 R_2} + \underline{UR_1 Q_1 Q_1} + \underline{UR_1 Q_2 Q_2} + \underline{UR_1^2 R_1} + \underline{UR_1^2 R_2} + \underline{UR_1 R_3 R_3}$$

$$\underline{UR_2} = 0 = \underline{UR_2^2 P_1} + \underline{UR_2^2 R_2} + \underline{UR_2 Q_1 Q_1} + \underline{UR_2 Q_2 Q_2} + \underline{UR_2^2 R_1} + \underline{UR_2^2 R_2} + \underline{UR_2 R_3 R_3}$$

$$\underline{UR_3} = 0 = \underline{UR_3^2 P_1} + \underline{UR_3^2 R_2} + \underline{UR_3 Q_1 Q_1} + \underline{UR_3 Q_2 Q_2} + \underline{UR_3 R_1 R_1} + \underline{UR_3 R_2 R_2} + \underline{UR_3^2 R_3}$$

$$\underline{UPX} = 301 \underline{PX} + 212 \underline{R_3 X} + 214 \underline{f_6 X} + 18 \underline{305 f_6 X} + 18 \underline{214 P_1 X} + 18 \underline{213 R_3 X} + 24 \underline{305 f_7 X} + 24 \underline{214 P_1 X} \\ + 24 \underline{213 f_6 X} - 6 \underline{304 f_8 X} - 6 \underline{212 P_1 X} - 6 \underline{213 P_1 X} - 6 \underline{47 f_6 X} + 44 \underline{306 f_9 X} + 44 \underline{47 P_1 X} + 52 \underline{306 f_9 X} + 52 \underline{47 f_6 X}$$

$$\underline{UPX} = 301 \underline{P_1 X} + 214 \underline{f_6 X} + 212 \underline{f_6 X} + 19 \underline{305 f_6 X} + 19 \underline{214 P_1 X} + 19 \underline{213 R_3 X} + 23 \underline{305 f_7 X} + 23 \underline{214 P_1 X} + 23 \underline{213 f_6 X} \\ - 6 \underline{304 f_8 X} - 6 \underline{212 P_1 X} - 6 \underline{213 f_7 X} - 6 \underline{47 f_6 X} + 50 \underline{306 f_9 X} + 50 \underline{47 R_3 X} + 53 \underline{306 f_9 X} + 53 \underline{47 f_6 X}$$

$$\underline{UPX} = 20 \underline{305 f_6 X} + 20 \underline{214 P_1 X} + 20 \underline{213 R_3 X} + 20 \underline{305 f_7 X} + 20 \underline{214 P_1 X} + 20 \underline{213 f_6 X} + 304 \underline{f_6 X} + 212 \underline{P_1 X} \\ + 213 \underline{f_7 X} + 47 \underline{f_6 X} + 51 \underline{306 f_9 X} + 51 \underline{47 R_3 X} + 51 \underline{306 f_9 X} + 51 \underline{47 f_6 X}$$

$$\underline{UPX} = -13 \underline{306 f_9 X} - 13 \underline{47 R_3 X} - 13 \underline{306 f_9 X} - 13 \underline{47 f_6 X}$$

$$\underline{UPX} = 302 \underline{R_1 X} + 20 \underline{305 f_6 X} + 20 \underline{214 P_1 X} + 20 \underline{213 R_3 X} + 20 \underline{305 f_7 X} + 20 \underline{214 P_1 X} + 20 \underline{213 f_6 X} + 304 \underline{f_6 X} + 212 \underline{P_1 X} \\ + 213 \underline{f_7 X} + 47 \underline{f_6 X} + 20 \underline{306 f_9 X} + 20 \underline{47 R_3 X} + 20 \underline{306 f_9 X} + 20 \underline{47 f_6 X}$$

$$\underline{UPX} = 303 \underline{R_3 X} - 5 \underline{305 f_6 X} - 5 \underline{214 P_1 X} - 5 \underline{213 R_3 X} + 5 \underline{305 f_7 X} + 5 \underline{214 P_1 X} + 5 \underline{213 f_6 X} - 5 \underline{306 f_9 X} \\ - 5 \underline{47 R_3 X} + 5 \underline{306 f_9 X} + 5 \underline{47 f_6 X}$$

$$\underline{UPX} = 304 \underline{R_3 X} + 212 \underline{P_1 X} + 213 \underline{f_6 X} + 47 \underline{f_6 X} - 304 \underline{f_6 X} - 212 \underline{P_1 X} - 213 \underline{f_6 X} - 47 \underline{f_6 X}$$

$$\underline{UP^2} = 301 + 18 \underline{214} + 18^2 \underline{305} + 18 \underline{214} + 24^2 \underline{305} - 6 \underline{24 213} + 6^2 \underline{304} - 6 \underline{24 213} - 6 \underline{47 52} + 49^2 \underline{306} \\ + 52^2 \underline{306} - 6 \underline{47 52} \\ = 301 + 2 \underline{18 214} + 205 (18^2 + 24^2) - 2 \underline{6 24 213} + 6^2 \underline{304} - 2 \underline{6 47 52} + 306 (49^2 + 52^2)$$

$$\underline{UPR} = 19 \underline{214} + 18 \underline{19 305} + 23 \underline{24 305} + 24 \underline{214} - 6 \underline{24 213} + 6^2 \underline{304} - 6 \underline{212} - 6 \underline{27 213} - 6 \underline{47 52} + 49 \underline{50 306} \\ + 52 \underline{53 306} - 6 \underline{47 52} \\ = 214 (19 + 24) + 305 (18 \underline{19} + 23 \underline{24}) - 6 \underline{213 (23 + 24)} + 6^2 \underline{304} - 6 \underline{212} - 6 \underline{47 (52 + 53)} + 306 (49 \underline{50} + 52 \underline{53})$$



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$$\begin{aligned} UP_{Q_1} &= 20 \ 214 + 18 \ 20 \ 305 + 20 \ 24 \ 305 + 24 \ 213 - 6 \ 304 - 6 \ 20 \ 213 - 6 \ 47 \ 51 + 49 \ 51 \ 306 + 51 \ 52 \ 306 + 47 \ 52 \\ &= 20 \ 214 + 20 \ 305 (18+24) + 213 (24-6 \ 20) - 6 \ 304 - 47 (6 \ 51-52) + 306 \ 51 (49+52). \end{aligned}$$

$$\begin{aligned} UP_{Q_2} &= 6 \ 13 \ 47 - 13 \ 49 \ 306 - 13 \ 52 \ 306 \\ &= 6 \ 13 \ 47 - 13 \ 306 (49+52) \end{aligned}$$

$$\begin{aligned} UP_{R_1} &= 20 \ 214 + 18 \ 20 \ 305 + 20 \ 24 \ 305 + 24 \ 213 - 6 \ 304 - 6 \ 20 \ 213 - 6 \ 20 \ 47 + 20 \ 49 \ 306 + 20 \ 52 \ 306 + 47 \ 52 \\ &= 20 \ 214 + 20 \ 305 (18+24) + 213 (24-6 \ 20) - 6 \ 304 - 47 (6 \ 20-52) + 20 \ 306 (49+52). \end{aligned}$$

$$\begin{aligned} UP_{R_2} &= -5 \ 214 - 5 \ 18 \ 305 + 5 \ 24 \ 305 - 5 \ 6 \ 213 - 5 \ 6 \ 47 - 5 \ 49 \ 306 + 5 \ 52 \ 306 \\ &= -5 \ 214 - 5 \ 305 (18-24) - 5 \ 6 \ 213 - 5 \ 6 \ 47 - 5 \ 306 (49-52). \end{aligned}$$

$$\begin{aligned} UP_{R_3} &= 212 + 18 \ 213 - 24 \ 213 + 6 \ 304 + 47 \ 49 - 47 \ 52 \\ &= 212 + 213 (18-24) + 6 \ 304 + 47 (49-52). \end{aligned}$$

$$\begin{aligned} UP^2 &= 301 + 23 \ 214 - 6 \ 212 + 19^2 \ 305 + 23^2 \ 305 + 23 \ 214 - 6 \ 23 \ 213 + 6^2 \ 304 - 6 \ 212 - 6 \ 23 \ 213 \\ &\quad - 6 \ 47 \ 53 + 50^2 \ 306 + 53^2 \ 306 - 6 \ 47 \ 53 \\ &= 301 + 2 \ 23 \ 214 - 2 \ 6 \ 212 + 305 (19^2+23^2) - 2 \ 6 \ 23 \ 213 + 6^2 \ 304 - 2 \ 6 \ 47 \ 53 + 306 (50^2+53^2). \end{aligned}$$

$$\begin{aligned} UP_{Q_1} &= 20 \ 214 + 212 + 19 \ 20 \ 305 + 20 \ 23 \ 305 + 23 \ 213 - 6 \ 304 - 6 \ 20 \ 213 - 6 \ 47 \ 51 + 50 \ 51 \ 306 \\ &\quad + 51 \ 52 \ 306 + 47 \ 53 \\ &= 20 \ 214 + 212 + 20 \ 305 (19+23) + 213 (23-6 \ 20) - 6 \ 304 - 47 (6 \ 51-53) + 51 \ 306 (50+53). \end{aligned}$$

$$\begin{aligned} UP_{Q_2} &= 6 \ 13 \ 47 - 13 \ 50 \ 306 - 13 \ 52 \ 306 \\ &= 6 \ 13 \ 47 - 13 \ 306 (50+52). \end{aligned}$$

$$\begin{aligned} UP_{R_1} &= 20 \ 214 + 212 + 19 \ 20 \ 305 + 20 \ 23 \ 305 + 23 \ 213 - 6 \ 304 - 6 \ 20 \ 213 - 6 \ 20 \ 47 + 20 \ 50 \ 306 \\ &\quad + 20 \ 53 \ 306 + 47 \ 53. \end{aligned}$$

$$\begin{aligned} UP_{R_2} &= -5 \ 214 - 5 \ 19 \ 305 + 5 \ 23 \ 305 - 5 \ 6 \ 213 - 5 \ 6 \ 47 - 5 \ 50 \ 306 + 5 \ 53 \ 306 \\ &= -5 \ 214 - 5 \ 305 (19-23) - 5 \ 6 \ 213 - 5 \ 6 \ 47 - 5 \ 306 (50-53). \end{aligned}$$

$$\begin{aligned} UP_{R_3} &= -212 + 19 \ 213 + 23 \ 213 + 6 \ 304 + 47 \ 50 - 47 \ 53 \\ &= -212 + 213 (19+23) + 6 \ 304 + 47 (50-53). \end{aligned}$$



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$$\begin{aligned} UQ_1^2 &= 20^2 \underline{305} + 20^2 \underline{305} + 20 \underline{213} + \underline{304} + 20 \underline{213} + 47 \underline{51} + 51^2 \underline{306} + 51^2 \underline{306} + 47 \underline{51} \\ &= 2 \underline{20^2 305} + 2 \underline{20 213} + \underline{304} + 2 \underline{47 51} + 2 \underline{51^2 306} . \end{aligned}$$

$$UQ_1 Q_2 = -13 \underline{47} - 13 \underline{51 306} - 13 \underline{51 306} = -13 \underline{47} - 2 \underline{13 51 306} .$$

$$UQ_1 R_1 = 2 \underline{20^2 305} + 2 \underline{20 213} + \underline{304} + 47 (\underline{20} + \underline{51}) + 2 \underline{20 51 306} .$$

$$UQ_1 R_2 = .5 \underline{213} + .5 \underline{47} .$$

$$UQ_1 R_3 = -\underline{304}$$

$$UQ_2^2 = 2 \underline{13^2 306} .$$

$$UQ_2 R_1 = -2 \underline{13 20 306} - \underline{13 47} .$$

$$UQ_2 R_2 = 0 .$$

$$UQ_2 R_3 = 0 .$$

$$UR_1^2 = \underline{302} + 2 \underline{20^2 305} + 2 \underline{20 213} + \underline{304} + 2 \underline{20 47} + 2 \underline{20^2 306} .$$

$$UR_1 R_2 = .5 \underline{213} + .5 \underline{47} .$$

$$UR_1 R_3 = -\underline{304}$$

$$UR_2^2 = \underline{303} + .5 \underline{305} + .5 \underline{306} .$$

$$UR_2 R_3 = -\underline{213} - \underline{47}$$

$$UR_3^2 = 2 \underline{304} .$$



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Sample Calculation

Using the geometry as shown on sheet no. of the check analysis,

$$c = 8.00000 ; d = 3.20000 ; a = 27.00000 ; L = 54.5894$$

$$a_2 = .707107 \times 27 = 19.09189$$

$$a_{16} = 54.00000$$

$$a_3 = .292893 \times 27 = 7.90811$$

$$a_{17} = 3.20000$$

$$a_4 = 7.90811$$

$$a_{20} = 3.20000$$

$$a_5 = 19.09189$$

$$a_{25} = 60.40000$$

$$a_6 = 0$$

$$a_{26} = 46.09189$$

$$a_7 = 27.00000$$

$$a_{27} = 0$$

$$a_{11} = 3.20000$$

$$a_{29} = 7.90811$$

$$a_{13} = 27.00000$$

$$a_{14} = 0$$

$$a_{15} = 0$$

For another geometry these numbers would be measurements. Although a measurement might be 16.85", it must be carried as 16.85000" in order to insure accuracy when we obtain numbers consisting of few digits by subtraction of two numbers consisting of many digits.

$$\theta_1 = 180 - 2 \sin^{-1} \frac{a_2}{\sqrt{a_2^2 + a_3^2}} = 45^\circ$$

$$r_1 = \frac{a_2}{\sin \theta_1} = 27.00000$$

$$\theta_3 = 180 - 2 \sin^{-1} \frac{a_5}{\sqrt{a_5^2 + a_7^2}} = 45^\circ$$

$$r_2 = \frac{a_5}{\sin \theta_3} = 27.00000$$

$$\theta_2 = \theta_3 + \sin^{-1} \frac{a_6}{r_2}$$

$$\beta = \tan^{-1} \frac{r_2 + a_2 - a_4}{r_1 + a_5 - a_3}$$

$$A_{ST} = .20000 \text{ in}^2 ; E_{ST} = 2.90000 \times 10^3 \text{ p.s.i.}$$

$$A_{SP} = .471100 ; E_{SP} = 1.00000 \times 10^3 ; G_{SP} = .40000 \times 10^3 ; I_{SP} = 33.72000 \text{ in}^4 ; A_{SP} = 4.14600$$

$$A_{FO} = 1.21040 ; E_{FO} = 1.00000 \times 10^3 ; G_{FO} = .40000 \times 10^3 ; I_{FO} = 1.73820 ; A_{FO} = 5.93100$$





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$$3 = a_{25} - a_{20} = 60.4 - 3.2 = 57.20000$$

$$4 = \frac{1}{2 a_{18}} = \frac{54.5894}{108} = .505457$$

$$5 = \frac{1}{2 a_{18}} = \frac{54.5894}{16} = 3.411838$$

$$6 = \cos \beta = .707107$$

$$7 = \sin \beta = .707107$$

$$8 = a_{20} + a_{17} + a_2 + a_{13} = 3.2 + 3.2 + 19.09189 + 27 = 52.49189$$

$$9 = a_3 - a_{14} + a_{15} = 7.90811 - 0 + 0 = 7.90811$$

$$10 = 11 - 7 = .395456 - .707107 = -.311651$$

$$11 = \frac{6.8 + 7.9}{2 a_{16}} = \frac{.707107(52.49189 + 7.90811)}{108} = .395456$$

$$12 = \frac{a_{25}}{2 a_{16}} = \frac{60.4}{108} = .559259$$

$$13 = \frac{1}{2 a_{16}} = \frac{1}{108} = .00925925$$

$$14 = a_2 + a_{13} = 19.09189 + 27 = 46.09189$$

$$15 = 2 a_{16} - 9 = 108 - 7.90811 = 100.09189$$

$$16 = 9 = 7.90811$$

$$17 = a_{25} - a_{20} - a_{17} = 60.4 - 3.2 - 3.2 = 54.00000$$

$$18 = \frac{7.15 - 6.14}{2 a_{16}} = \frac{.707107(100.09189 - 46.09189)}{108} = .353553$$

$$19 = -\frac{6.14 + 7.16}{2 a_{16}} = -\frac{.707107(46.09189 + 7.90811)}{108} = -.353553$$

$$20 = \frac{17}{2 a_{16}} = \frac{54}{108} = .50000$$

$$21 = 11 = .395456$$

$$22 = 10 = -.311651$$

$$23 = 19 + 7 = -.353553 + .707107 = .353553$$

$$24 = 18 - 7 = .353553 - .707107 = -.353553$$

$$25 = \frac{L}{2 A_{ST} E_{ST}} = \frac{54.5894}{2 \times 2 \times 2.9 \times 10^7} = 47.05982 \times 10^{-7}$$

$$10^{-7} = g$$

$$26 = 2 \cdot 25 \cdot 5^2 = 2 \times 47.05982 g \cdot 3.411838^2 = 1095.613 g$$

$$27 = 2 \cdot 25 \cdot A^2 = 2 \times 47.05982 g \cdot .505457^2 = 24.04632 g$$



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$$28 = \tan \alpha = 0$$

$$29 = \sin \alpha = 0$$

$$30 = \cos \alpha = 1.00000$$

$$31 = \frac{a_{32}}{30} + a_{30} = 0 + 3.2 = 3.20000$$

$$32 = \frac{1}{230 E_{sp} I_{sp}} = \frac{1}{2 \times 1 \times 10^7 \times 33.72} = .014828 \text{ g}$$

$$33 = \frac{a_{16}}{230 A_{sp} E_{sp}} = \frac{54}{2 \times 1 \times 4.471 \times 10^7} = 6.03890 \text{ g}$$

$$34 = \frac{a_{16} \alpha_{sp}}{230 A_{sp} G_{sp}} = \frac{54 \times 4.146}{2 \times 1 \times 4.471 \times 4 \times 10^7} = 62.5932 \text{ g}$$

$$35 = 32 \cdot 31^2 \cdot a_{16} = .014828 \text{ g} \cdot 3.2^2 \times 54 = 8.19929 \text{ g}$$

$$36 = 32 \cdot 31 \cdot a_{16}^2 = .014828 \text{ g} \cdot 3.2 \times 54^2 = 138.363 \text{ g}$$

$$37 = 32 \cdot 31 \cdot a_{16}^2 \cdot 28 = 0$$

$$38 = \frac{32}{3} \cdot \frac{a_{16}}{28} = .014828 \times 54^2 \times 18 = 778.292 \text{ g}$$

$$39 = 38 \cdot 28^2 = 0$$

$$40 = 33 \cdot 30^2 = 6.03890 \text{ g}$$

$$299 = 2 \cdot 38 \cdot 28 = 0$$

$$41 = 2 \cdot 33 \cdot 30 \cdot 29 = 0$$

$$42 = 33 \cdot 29^2 = 0$$

$$43 = 34 \cdot 29^2 = 0$$

$$44 = 2 \cdot 34 \cdot 29 \cdot 30 = 0$$

$$45 = 34 \cdot 30^2 = 62.5932 \text{ g}$$

$$46 = 35 + 37 + 39 + 40 + 43 = \text{g} (8.19929 + 0 + 0 + 6.03890 + 0) = 14.2382 \text{ g}$$

$$47 = 36 + 299 - 41 + 44 = \text{g} (138.363 + 0 - 0 + 0) = 138.363 \text{ g}$$

$$48 = 38 + 42 + 45 = \text{g} (778.292 + 0 + 62.5932) = 840.885 \text{ g}$$

$$49 = 10 + 18 = -.311651 + .353553 = .041902$$

$$50 = 11 + 19 = .395456 - .353553 = .041903$$

$$51 = 20 - 12 = .500000 - .559159 = -.059259$$

$$52 = 21 + 24 = .395456 - .353553 = .041903$$

$$53 = 22 + 23 = -.311651 + .353553 = .041902$$

$$55 = \tan \Omega = \frac{a_{14} - a_{15}}{a_{13}} = 0 ; \quad \Omega = 0$$

$$56 = \sin \Omega = 0$$

$$57 = \cos \Omega = 1.00000$$



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$$\underline{82} = \frac{a_3^3}{6 E_{F0} I_{F0} \underline{57}} = \frac{27^3}{6 \times 10^3 \times 1.7382 \times 1} = 1887.3 \text{ g}$$

$$\underline{83} = \frac{a_2}{2 A_{F0} E_{F0} \underline{57}} = \frac{27}{2 \times 1.2104 \times 10^3 \times 1} = 11.1533 \text{ g}$$

$$\underline{84} = \frac{a_3 \Delta F_{02}}{2 A_{F0} G_{F0} \underline{57}} = \frac{27 \times 5.931}{2 \times 1.2104 \times 10^3 \times 4 \times 10^3} = 165.376 \text{ g}$$

$$\underline{85} = \underline{82} + \underline{83} \underline{56}^2 + \underline{84} \underline{57}^2 = \text{g} (1887.3 + 0 + 165.376) = 2052.68 \text{ g}$$

$$\underline{86} = 2 \underline{55} \underline{82} + 2 \underline{56} \underline{57} (\underline{84} - \underline{83}) = 0$$

$$\underline{59} = \underline{82} \underline{56}^2 + \underline{83} \underline{57}^2 + \underline{84} \underline{56}^2 = \text{g} (0 + 11.1533 \times 1 + 0) = 11.1533 \text{ g}$$

$$\underline{86} = r_1 + a_{15} - a_{14} = 27 + 0 - 0 = 27.0000$$

$$\underline{87} = \frac{r_1}{2 E_{F0} I_{F0}} = \frac{27}{2 \times 10^3 \times 1.7382} = 7.76665 \text{ g}$$

$$\underline{88} = \frac{r_1}{2 A_{F0} E_{F0}} = 11.1533 \text{ g}$$

$$\underline{89} = \frac{r_1 \Delta F_{01}}{2 A_{F0} G_{F0}} = 165.376 \text{ g}$$

$$\underline{90} = .5 (\theta_1 - .5 \sin 2\theta_1) = .5 (.7854 - .5) = .14270$$

$$\underline{91} = .5 (\theta_1 + .5 \sin 2\theta_1) = .64270$$

$$\underline{92} = 1 - \cos \theta_1 = 1 - .707107 = .292893$$

$$\underline{93} = \sin \theta_1 = .707107$$

$$\underline{94} = .5 (1 - \cos 2\theta_1) = .5 (1 - 0) = .50000$$

$$\underline{95} = \underline{87} \theta_1 \underline{91}^2 = 7.76665 \text{ g} \cdot .7854 \times 27^2 = 4446.85 \text{ g}$$

$$\underline{96} = 2 \underline{87} \theta_1 \underline{91} \underline{86} = 2 \times 4446.85 = 8893.70 \text{ g}$$

$$\underline{97} = \underline{87} \theta_1 \underline{86}^2 = 4446.85 \text{ g}$$

$$\underline{98} = \underline{87} \underline{90} r_1^2 = 7.76665 \text{ g} \cdot .1427 \times 27^2 = 807.949 \text{ g}$$

$$\underline{99} = \underline{87} \underline{91} r_1^2 = 7.76665 \text{ g} \cdot .6427 \times 27^2 = 3638.893 \text{ g}$$

$$\underline{100} = 2 \underline{87} \underline{92} r_1 \underline{91} = 2 \times 7.76665 \text{ g} \cdot .292893 \times 27^2 = 3316.655 \text{ g}$$

$$\underline{101} = 2 \underline{87} \underline{92} r_1 \underline{86} = 3316.655 \text{ g}$$

$$\underline{102} = 2 \underline{87} \underline{93} r_1 \underline{91} = 2 \times 7.76665 \text{ g} \cdot .707107 \times 27^2 = 8007.121 \text{ g}$$

$$\underline{103} = 2 \underline{87} \underline{93} r_1 \underline{86} = 8007.121 \text{ g}$$

$$\underline{104} = \underline{87} \underline{94} r_1^2 = 7.76665 \text{ g} \cdot .5 \times 27^2 = 2830.944 \text{ g}$$

$$\underline{105} = \underline{88} \underline{90} = 11.1533 \text{ g} \cdot .1427 = 1.59158 \text{ g}$$

$$\underline{106} = \underline{88} \underline{91} = 11.1533 \text{ g} \cdot .6427 = 7.16823 \text{ g}$$

$$\underline{107} = \underline{88} \underline{94} = 11.1533 \text{ g} \cdot .50000 = 5.57665 \text{ g}$$



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$$108 = 89 \ 90 = 165.376 \ g \cdot 1427 = 23.5892 \ g$$

$$109 = 89 \ 91 = 165.376 \ g \cdot 6427 = 106.2872 \ g$$

$$110 = 89 \ 94 = 165.376 \ g \cdot 5000 = 82.6880 \ g$$

$$111 = 95 + 98 + 100 + 105 + 109 = g(4446.85 + 807.95 + 3316.66 + 1.59 + 106.29) = 8679.34 \ g$$

$$112 = -96 - 101 + 102 + 104 + 107 - 110 = g(-8893.70 - 3316.66 + 8007.12 + 2820.94 + 5.58 - 82.69) = -1449.41 \ g$$

$$113 = 97 + 99 - 103 + 105 + 108 = g(4446.85 + 3638.89 - 8007.12 + 7.17 + 23.60) = 109.39 \ g$$

$$114 = \cos \theta_3 = .707107$$

$$115 = \sin \theta_3 = .707107$$

$$116 = \frac{r_2}{2 E_{F0} I_{F02}} = 7.76665 \ g$$

$$117 = \frac{r_2}{2 A_{F02} E_{F0}} = 11.1533 \ g$$

$$118 = \frac{r_2 d_{F02}}{2 A_{F02} G_{F0}} = 165.376 \ g$$

$$119 = .5(\theta_2 - .5 \sin 2\theta_2) = .1427$$

$$120 = .5(\theta_2 + .5 \sin 2\theta_2) = .6427$$

$$121 = 1 - \cos \theta_2 = .292893$$

$$122 = \sin \theta_2 = .707107$$

$$123 = .5(1 - \cos 2\theta_2) = .50000$$

$$124 = 116 \ \theta_2 = 7.76665 \ g \cdot 7854 = 6.09993 \ g$$

$$125 = 2 \ 116 \ \theta_2 \ r_2 = 2 \times 6.09993 \times 27 = 329.396 \ g$$

$$126 = 116 \ \theta_2 \ r_2^2 = 4446.85 \ g$$

$$127 = 116 \ 119 \ r_2^2 = 807.949 \ g$$

$$128 = 116 \ 120 \ r_2^2 = 3638.893 \ g$$

$$129 = 2 \ 116 \ 121 \ r_2 = 122.839 \ g$$

$$130 = 2 \ 116 \ 121 \ r_2^2 = 3316.655 \ g$$

$$131 = 2 \ 116 \ 122 \ r_2 = 296.560 \ g$$

$$132 = 2 \ 116 \ 122 \ r_2^2 = 8007.121 \ g$$

$$133 = 116 \ 123 \ r_2^2 = 2820.944 \ g$$

$$134 = 117 \ 119 = 1.5958 \ g$$

$$135 = 117 \ 120 = 7.16823 \ g$$

$$136 = 117 \ 123 = 5.57665 \ g$$

$$137 = 118 \ 119 = 23.5792 \ g$$

$$138 = 118 \ 120 = 106.2872 \ g$$

$$139 = 118 \ 123 = 82.6880 \ g$$





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$$140 = 126 + 128 - 132 + 135 + 137 = g(4446.85 + 2638.89 - 8007.12 + 7.17 + 23.60) = 109.39 g$$

$$141 = 127 + 134 + 138 = g(807.95 + 1.59 + 106.29) = 915.83 g$$

$$142 = -125 + 131 = g(-329.40 + 296.56) = -32.84 g$$

$$143 = 130 - 123 - 136 + 129 = g(3316.66 - 2830.94 - 5558 + 82.69) = 562.83 g$$

$$144 = 124 14^2 = 6.09993 g 46.09189^2 = 12,959.06 g$$

$$145 = 124 9^2 = 6.09993 g 7.90811^2 = 381.48 g$$

$$146 = 2 124 9 14 = 2 \times 6.09993 g 7.90811 \times 46.09189 = 4446.85 g$$

$$147 = 140 115^2 = 109.39 g 5000 = 54.695 g$$

$$148 = 141 114^2 = 915.83 g 5000 = 457.915 g$$

$$149 = 143 114 115 = 562.83 g 5000 = 281.415 g$$

$$150 = 147 + 148 + 149 = 794.025 g$$

$$151 = 140 114^2 = 54.695 g$$

$$152 = 141 115^2 = 457.915 g$$

$$153 = 143 114 115 = 281.415 g$$

$$154 = 151 + 152 - 153 = 231.195 g$$

$$155 = 2 140 114 115 = 109.39 g$$

$$156 = 2 141 114 115 = 915.83 g$$

$$157 = 143 (114^2 - 115^2) = 0$$

$$158 = 155 - 156 + 157 = -806.44 g$$

$$159 = 142 14 115 = -32.84 g 46.09189 \times 7.90707 = -1070.312 g$$

$$160 = 129 14 114 = 122.839 g 46.09189 \times 7.907107 = 4083.56 g$$

$$161 = 159 - 160 = -5073.878 g$$

$$162 = 142 14 114 = -1070.312 g$$

$$163 = 129 14 115 = 4083.56 g$$

$$164 = 162 + 163 = 2933.242 g$$

$$165 = 142 9 115 = -32.84 g 7.90811 \times 7.907107 = -183.637 g$$

$$166 = 129 9 114 = 122.839 g 7.90811 \times 7.907107 = 686.901 g$$

$$167 = -165 + 166 = 870.538 g$$

$$168 = 142 9 114 = -183.637 g$$

$$169 = 129 9 115 = 686.901 g$$

$$170 = -168 - 169 = -503.264 g$$

$$171 = 144 + 154 + 164 = g(12,959.06 + 231.195 + 2933.242) = 16,123.497 g$$

$$172 = 145 + 150 + 167 = g(381.48 + 794.025 + 370.538) = 2046.043 g$$

$$173 = 2^2 150 + 6^2 154 - 6^2 158 = -5 g(794.025 + 231.195 + 806.44) = 915.83 g$$

$$174 = -144 + 158 + 161 + 170 = g(-4446.84 - 806.44 - 5073.878 - 503.264) = -10,830.422 g$$

$$175 = 2 6 154 - 2(158 + 161) + 6 168 = 707107 g(462.39 + 806.44 + 5073.878 + 2930.242) = 6559,089 g$$

$$176 = -7(2 150 + 167) + 6(158 + 170) = -707107(-1838.05 - 870.538 - 806.44 - 503.264) = -2664.586 g$$



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$$177 = Q_{16} - Q_7 = 54 - 27 = 27$$

$$178 = 14 + Q_{29} = 46.09189 + 7.90811 = 54$$

$$179 = Q_5 + Q_6 = 19.09189 + 0 = 19.09189$$

$$180 = 6 Q_{24} + 7 179 = .707107 (7.90811 + 19.09189) = 19.09189$$

$$181 = \frac{1}{2 E_{F0} I_{F0_3}} = .287654 g$$

$$182 = \frac{Q_7}{2 A_{F0_3} E_{F0}} = 11.1533 g$$

$$183 = \frac{Q_7 \times F_{0_2}}{2 A_{F0_3} G_{F0}} = 165.376 g$$

$$184 = 181 Q_7 = 7.76665 g$$

$$185 = 184 Q_7 = 209.700$$

$$186 = 185 \frac{Q_7}{g} + 183 = 1887.300 + 165.376 = 2052.676 g$$

$$187 = 184 178^2 = 7.76665 g 54^2 = 22,647.551 g$$

$$188 = 184 180^2 = 2830.94 g$$

$$189 = 184 177^2 = 5661.888 g$$

$$190 = 2 184 178 180 = 2 \times 7.76665 g 54 \times 19.09189 = 16,014.24 g$$

$$191 = 2 184 178 177 = 2 \times 7.76665 g 54 \times 27 = 22,647.55 g$$

$$192 = 2 184 180 177 = 2 \times 7.76665 g 19.09189 \times 27 = 8007.12 g$$

$$193 = 185 178 = 209.7 g 54 = 11,323.800 g$$

$$194 = 185 180 = 209.7 g 19.09189 = 4003.56 g$$

$$195 = 185 177 = 209.7 g 27 = 5661.9 g$$

$$196 = 185 7 178 = 209.7 g .707107 \times 54 = 8007.12 g$$

$$197 = 185 7 180 = 209.7 g .707107 \times 19.09189 = 2830.95 g$$

$$198 = 185 7 177 = 209.7 g .707107 \times 27 = 4003.56 g$$

$$199 = 2 186 7 = 1.414214 \times 2052.676 = 2902.923 g$$

$$200 = 186 7^2 = 1026.338 g$$

$$201 = 2 182 6 = 15.7732 g$$

$$202 = 182 6^2 = 5.5767 g$$

$$203 = 187 + 182 = g (22,647.55 + 11.15) = 22,658.70 g$$

$$204 = 188 + 197 + 200 + 202 = g (2830.94 + 2830.94 + 1026.34 + 5.58) = 6693.80 g$$

$$205 = 189 + 195 + 186 = g (5661.89 + 5661.89 + 2052.68) = 13,376.46 g$$

$$206 = 190 + 196 + 201 = g (16,014.24 + 8007.12 + 15.77) = 24,037.13 g$$

$$207 = -191 - 193 = g (-22,647.55 - 11,323.80) = -33,971.35 g$$

$$208 = -192 - 194 - 198 - 199 = g (-8007.12 - 4003.56 - 4003.56 - 2902.92) = -18,917.16 g$$

$$209 = 85 + 111 + 171 + 203 = g (2052.68 + 8679.34 + 16,123.497 + 22,658.70) = 49,514.217 g$$



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$$\begin{aligned}
 210 &= 173 + 204 = q(915.83 + 6673.80) = 7609.63 \text{ q} \\
 211 &= 59 + 113 + 172 + 205 = q(11.15 + 107.39 + 2046.043 + 13,376.46) = 15,543.043 \\
 212 &= 175 + 206 = q(4559.09 + 24,037.13) = 30,596.22 \text{ q} \\
 213 &= 58 + 112 + 178 + 207 = q(-1449.41 - 10,830.422 - 33,971.35) = -46,251.182 \\
 214 &= 176 + 209 = -2664.59 \text{ q} - 18,917.16 \text{ q} = -21,581.75 \text{ q} \\
 300 &= 209 + 46 = 49,528.455 \text{ q} \\
 301 &= 2 \ 210 = 15,219.26 \text{ q} \\
 302 &= 2 \ 26 = 2,191.226 \text{ q} \\
 303 &= 2 \ 27 = 48.09264 \text{ q} \\
 304 &= 2 \ 300 = 99,056.91 \text{ q} \\
 305 &= 2 \ 211 = 31,086.086 \text{ q} \\
 306 &= 2 \ 48 = 1681.770 \text{ q}
 \end{aligned}$$

$$\begin{aligned}
 UP_1 &= + 301 = &= 15,219.260 \\
 &+ 2 \ 18 \ 214 = 2 \times .353553(-21,581.75) &= -15,260.606 \\
 &+ 305(18^2 + 24^2) = 31,086.086(.125 + .125) &= 7,771.522 \\
 &- 2 \ 6 \ 213 = -2 \times .707107(-353553)(-46,251.182) &= -23,125.591 \\
 &+ 6^2 \ 304 = .5 \times 99,056.91 &= 49,528.455 \\
 &- 2 \ 6 \ 47 \ 52 = -1.414214 \times 138.363 \times .0419025 &= -8.199 \\
 &+ 306(49^2 + 52^2) = 1681.770 \times 2(.0419025)^2 &= 5.906 \\
 &&= 34,130.747 \text{ q}
 \end{aligned}$$

$$\begin{aligned}
 UPP_2 &= + 214(19 + 24) = -21,581.75(-2)(.353553) &= 15,260.606 \\
 &+ 305(1819 + 2324) = 31,086.086(-.125 - .125) &= -7,771.522 \\
 &- 6 \ 213(23 + 24) = -7,071.07(-46,251.182) &= 0.0 \\
 &+ 6^2 \ 304 = &= 49,528.455 \\
 &- 6 \ 212 = -7,071.07 \times 30,596.22 &= -21,634.801 \\
 &- 6 \ 47(52 + 53) = -2 \ 6 \ 47 \ 52 &= -8.199 \\
 &+ 306(49 \ 50 + 52 \ 53) = 306(49^2 + 52^2) &= 5.906 \\
 &&= 35,380.445 \text{ q}
 \end{aligned}$$

$$\begin{aligned}
 UPQ_1 &= + 20 \ 214 = .5(-21,581.75) &= -10,790.875 \\
 &+ 20 \ 305(18 + 24) = .5(31,086.086)(0) &= 0.0 \\
 &+ 213(24 - 6 \ 20) = (-46,251.182)(-.707107) &= 32,704.535 \\
 &- 6 \ 304 = -.707107 \times 99,056.91 &= -70,043.834 \\
 &- 47(6 \ 51 - 52) = -138.363[-.707107(-.059259) - .0419025] &= 11.596 \\
 &+ 306 \ 51(49 + 52) = 1681.770(-.059259)(2)(.0419025) &= -8.352 \\
 &&= -48,135.930
 \end{aligned}$$



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Note: We wish to  
compare  
 $\frac{\partial U_0}{\partial R_i}$  with  $\frac{\partial U}{\partial Q_i}$ .

Considering only the  
strain energy of the  
former (Infinitely stiff  
spar and struts)

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Referring to page 12,  $u_6 = 0$   $\therefore \frac{300}{209} = \frac{209}{209} = 49,514.217 \text{ g}$

Also  $0 = \frac{26}{26}, \frac{27}{27}, \frac{48}{48}, \frac{47}{47}, \frac{302}{302}, \frac{303}{303}, \frac{306}{306}$   $304 = 99,028.834 \text{ g}$

$$UP_1^2 = 34,120.747 \text{ g} - 5.906 \text{ g} + 8.199 - 49,528.455 \text{ g} + 49,514.217 \text{ g} = 34,118.602 \text{ g}$$

$$UP_1^2 = 35,380.445 - 5.906 + 8.199 - 49,528.455 + 49,514.217 = 35,368.500 \text{ g}$$

$$UP_1^9 = -48,126.930 + 8.352 - 11.596 + 70,043.834 - 70,023.699 = -48,110.05 \text{ g}$$

$$UP_1 Q_2 = 0$$

$$UP_1 R_1 = -48,102.825 - 70.47 + 43.12 + 70,043.834 - 70,023.699 = -48,110.05 \text{ g}$$

$$UP_1 R_2 = 16,103.62 + 48.919 = 16,152.54 \text{ g}$$

$$UP_1 R_3 = 67,935.519 - 70,043.834 + 70,023.699 = 67,915.39 \text{ g}$$

$$UP_2^2 = 37,112.326 - 5.906 + 8.199 - 49,528.455 + 49,514.217 = 37,100.38 \text{ g}$$

$$UP_2^9 = -50,235.245 + 8.352 - 11.596 + 70,043.834 - 70,023.699 = -50,218.37 \text{ g}$$

$$UP_2 Q_2 = 0$$

$$UP_2 R_1 = -50,211.14 - 70.47 + 43.12 + 70,043.83 - 70,023.70 = -50,218.26 \text{ g}$$

$$UP_2 R_2 = 16,503.029 + 48.919 = 16,551.95 \text{ g}$$

$$UP_2 R_3 = 72,152.15 - 70,043.83 + 70,023.70 = 72,132.02 \text{ g}$$

$$UQ_1^2 = 68,744.18 - 11.81 + 16.40 - 99,056.91 + 99,028.43 = 68,720.29 \text{ g}$$

$$UQ_1 Q_2 = 0$$

$$UQ_1 R_1 = 68,710.09 + 99.66 - 60.98 - 99,056.91 + 99,028.43 = 68,720.29 \text{ g}$$

$$UQ_1 R_2 = -23,056.411 - 69.18 = -23,125.59 \text{ g}$$





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$$\begin{aligned}
 UPQ_2 &= +6 \underline{13} \underline{42} &= .707107(.00925925)(138.363) &= .9059014 \\
 &- \underline{13} \underline{306} (\underline{49} + \underline{52}) &= -.00925925(1681.770)(.083805) &= \underline{-1.3250052} \\
 &&&= \underline{-.399104 g}
 \end{aligned}$$

$$\begin{aligned}
 UPR_1 &= \underline{20} \underline{214} &= &= -10,790.875 \\
 &+ \underline{20} \underline{305} (\underline{18} + \underline{24}) &= &= 0.0 \\
 &+ \underline{213} (\underline{24} - \underline{6} \underline{30}) &= &= 32,704.535 \\
 &- \underline{6} \underline{304} &= &= -70,043.834 \\
 &- \underline{47} (\underline{6} \underline{20} - \underline{52}) &= -138.263(.353553 - .0419025) &= -43.121 \\
 &+ \underline{20} \underline{306} (\underline{49} + \underline{52}) &= .5(1681.770)(.083805) &= \underline{70.420} \\
 &&&= \underline{-48,102.825 g}
 \end{aligned}$$

$$\begin{aligned}
 UPR_2 &= -.5 \underline{214} &= &= 10,790.875 \\
 &- .5 \underline{305} (\underline{18} - \underline{24}) &= -.5(31,086.086)(.707107) &= -10,990.579 \\
 &- .5 \underline{6} \underline{213} &= -.353553(-44,251.182) &= 16,352.244 \\
 &- .5 \underline{6} \underline{42} &= -.353553(138.363) &= -48.919 \\
 &- .5 \underline{306} (\underline{49} - \underline{52}) &= &= \underline{0.0} \\
 &&&= \underline{16,103.621 g}
 \end{aligned}$$

$$\begin{aligned}
 UPR_3 &= + \underline{212} &= &= 30,596.22 \\
 &+ \underline{213} (\underline{18} - \underline{24}) &= -46,251.182(.707107) &= -32,704.535 \\
 &+ \underline{6} \underline{304} &= &= 70,043.834 \\
 &+ \underline{47} (\underline{49} - \underline{52}) &= &= \underline{0.0} \\
 &&&= \underline{67,935.519 g}
 \end{aligned}$$

$$\begin{aligned}
 UP_2^2 &= + \underline{301} &= &= 15,219.26 \\
 &+ \underline{2} \underline{33} \underline{214} &= .707107 \underline{214} &= -15,260.606 \\
 &- \underline{2} \underline{6} \underline{212} &= -1.414214 \underline{212} &= -43,269.603 \\
 &+ \underline{305} (\underline{19}^2 + \underline{23}^2) &= &= 7,771.522 \\
 &- \underline{2} \underline{6} \underline{23} \underline{213} &= -.5 \underline{213} &= 23,125.591 \\
 &+ \underline{6}^2 \underline{308} &= .5 \underline{304} &= 49,528.455 \\
 &- \underline{2} \underline{6} \underline{47} \underline{53} &= &= -8.199 \\
 &+ \underline{306} (\underline{50}^2 + \underline{53}^2) &= &= \underline{5.906} \\
 &&&= \underline{37,112.326 g}
 \end{aligned}$$



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$$U_1 R_3 = -99,028.43 \text{ g}$$

$$0 = U_2^2; U_2 R_1; U_2 R_2; U_2 R_3$$

$$U_1 R_1^2 = 71,519.25 - 840.89 - 138.36 - 99,056.91 + 99,028.43 - 2,191.33 = 68,720.29 \text{ g}$$

$$U_1 R_1 R_2 = -23,125.59 \text{ g}$$

$$U_1 R_1 R_3 = -99,028.43 \text{ g}$$

$$U_1 R_3^2 = 16,432.02 - 840.89 = 15,591.13 \text{ g}$$

$$U_1 R_2 R_3 = 46,251.18 \text{ g}$$

$$U_1 R_3^2 = 198,056.27 \text{ g}$$

$$0 = U_1 + .006832029 R_1 - .002312559 R_2 - .009902843 R_3$$

$$0 = U_2 - .002312559 R_1 + .001559113 R_2 + .004625118 R_3$$

$$0 = U_3 - .009902843 R_1 + .004625118 R_2 + .019805687 R_3$$

$$0 = 144.8740 U_1 + R_1 - .3350297 R_2 - 1.434664 R_3$$

$$0 = 432.4213 U_2 - R_1 + .6741937 R_2 + 2.000000 R_3$$

$$0 = -100.9811 U_3 + R_1 - .4670495 R_2 - 2.000000 R_3$$

$$.2071442 R_2 = -432.4213 U_2 + 100.9811 U_3$$

$$R_2 = \underline{-2087.538 U_2 + 487.4918 U_3}$$

$$.565336 R_3 + .339164 R_2 = -144.8740 U_1 - 432.4213 U_2$$

$$.565336 R_3 = -144.8740 U_1 - 432.4213 U_2 + 708.0177 U_2 - 165.3397 U_3$$

$$= -144.8740 U_1 + 275.5964 U_2 - 165.3397 U_3$$

$$R_3 = \underline{-256.2617 U_1 + 487.4912 U_2 - 292.4626 U_3}$$

$$R_1 = 100.9811 U_3 - 974.9836 U_2 + 227.6828 U_3 - 512.5234 U_1 + 974.9824 U_2$$

$$= -584.9852 U_3$$

$$= \underline{-512.5234 U_1 - 256.2613 U_3}$$



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$$\begin{aligned}
 \frac{\partial U_0}{\partial R_2} = \delta_{3V} &= u_2 - .002312559 R_1 + .001559113 R_2 + .004625118 R_3 \\
 &= .001610362 P_1 + .001650303 P_2 - .002305641 Q_1 \\
 &\quad - .001486448 P_1 - .001486448 P_2 + .001975085 Q_1 - .0000017722 Q_2 \\
 &\quad - .000079616 P_1 + .000079624 P_2 \\
 &\quad - .000044582 P_1 - .000025291 P_2 + .000337472 Q_1 + .000017722 Q_2 \\
 &= -.00000284 P_1 - .000009492 P_2 - .000060661 Q_1 \\
 &\quad \text{(Cannot be correct).}
 \end{aligned}$$

$$\begin{aligned}
 \frac{\partial U_{F0}}{\partial R_1} = \delta_3 &= u_1 + .006832029 R_1 - .002312559 R_2 - .009902843 R_3 \\
 &= -.004811005 P_1 - .00502836 P_2 + .006832029 Q_1 \\
 &\quad + .004391437 P_1 + .004391437 P_2 - .005835024 Q_1 + .0000052357 Q_2 \\
 &\quad + .000118091 P_1 - .000118102 P_2 \\
 &\quad + .0000954535 P_1 + .000541676 P_2 - .000722561 Q_1 - .00000379453 Q_2 \\
 &= -.00020602 P_1 - .00020686 P_2 + .00027444 Q_1 + .0000014412 Q_2
 \end{aligned}$$

Note: We obtained  $\delta_3$  previously from  $\frac{\partial U}{\partial Q_1} = \delta_3$ , which was

$$\delta_3 = -.00020869 P_1 - .00020869 P_2 + .00027750 Q_1 + .0000014958 Q_2$$

The different results are attributed to the approximation we made in writing the spar energy. The deflection  $\delta_{3V}$  is extremely small, and cannot be computed in the manner shown above.







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$$UR_1 R_2 = .5 \underline{213} + .5 \underline{47} = -23,125.591_f + 69.18_g = -23,056.411_g$$

$$UR_1 R_3 = -\underline{304} = -99,056.91_g$$

$$UR_2^2 = \underline{303} + .5 \underline{305} + .5 \underline{306} = 48.093 + 15,543.043 + 840.885 = 16,432.021_g$$

$$UR_2 R_3 = -\underline{213} - \underline{47} = 46,251.182 - 138.363 = 46,112.819_g$$

$$UR_3^2 = 2 \underline{304} = 198,113.820_g$$

Referring to the set of equations at the top of sheet No. , using the last 3 equations, let  $u_i$  represent the first 4 terms in  $UR_i = 0$ ;  $u_2$  in  $UR_2 = 0$ ;  $u_3$  in  $UR_3 = 0$ .

$$\left. \begin{aligned} 0 &= u_1 + .0071519245 R_1 - .002305641 R_2 - .009905691 R_3 \\ 0 &= u_2 - .002305641 R_1 + .0016432021 R_2 + .0046112819 R_3 \\ 0 &= u_3 - .009905691 R_1 + .0046112819 R_2 + .0198113820 R_3 \end{aligned} \right\}$$

$$\left. \begin{aligned} 0 &= 139.8225 u_1 + R_1 - .3223805 R_2 - 1.385038 R_3 \\ 0 &= 433.7188 u_2 - R_1 + .7126876 R_2 + 2.000000 R_3 \\ 0 &= -100.9520 u_3 + R_1 - .4655181 R_2 - 2.000000 R_3 \end{aligned} \right\}$$

$$\left. \begin{aligned} -139.8225 u_1 - 433.7188 u_2 &= .3803071 R_2 + .614962 R_3 \\ 100.9520 u_3 - 433.7188 u_2 &= .2471695 R_2 + \end{aligned} \right\}$$

$$R_2 = \underline{408.4322 u_3 - 1754.7423 u_1}$$

$$.614962 R_3 = -139.8225 u_1 - 433.7188 u_2 - 159.4140 u_3 + 684.8884 u_2$$

$$R_3 = \underline{-227.3676 u_1 + 408.4309 u_2 - 259.2257 u_3}$$

$$R_1 = 100.9520 u_3 + .4655181 (408.4322 u_3 - 1754.7423 u_1) + 2 R_3$$

$$= 100.9520 u_3$$

$$+ 190.1326 u_3 - 816.8643 u_2$$

$$- 518.4514 u_3 + 816.8618 u_2 - 454.7352 u_1$$

$$= \underline{-454.7352 u_1 - .0025 u_2 - 227.3668 u_3}$$



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$$R_1 = 2.187404 P_1 + 2.283277 P_2 - 3.106300 Q_1 + .000766351 Q_2 \\ - .000004 P_1 - .000004 P_2 + .000006 Q_1 \\ - 1.544628 P_1 - 1.640500 P_2 + 2.252225 Q_1$$

$$= .642772 P_1 + .642773 P_2 - .854069 Q_1 + .000766351 Q_2$$

$$R_2 = 2.774705 P_1 + 2.944926 P_2 - 4.045803 Q_1 \\ - 2.825770 P_1 - 2.895856 P_2 + 4.045806 Q_1$$

$$= -.051065 P_1 + .051070 P_2$$

$$R_3 = 1.093702 P_1 + 1.141639 P_2 - 1.553150 Q_1 + .000383176 Q_2 \\ + .657722 P_1 + .674035 P_2 - .941695 Q_1 \\ - 1.761063 P_1 - 1.870369 P_2 + 2.567810 Q_1$$

$$= -.009639 P_1 - .054695 P_2 + .072965 Q_1 + .000383176 Q_2$$

Substituting for  $R$ 's, the first 4 equations on sheet No 14 become;

$$\delta_1 = .0034130747 P_1 + .0035380445 P_2 - .004812693 Q_1 - .000000039910 Q_2 \\ - .003091915 P_1 - .003091920 P_2 + .004108313 Q_1 - .000003686365 Q_2 \\ - .0000882233 P_1 + .000082241 P_2 \\ - .000065483 P_1 - .000371573 P_2 + .0004495692 Q_1 + .00000260313 Q_2$$

$$= -.00017344 P_1 + .00015679 P_2 - .00020869 Q_1 - .0000011232 Q_2$$

$$\delta_2 = .0035380445 P_1 + .0037112326 P_2 - .0050235245 Q_1 - .00000003991 Q_2 \\ - .003227431 P_1 - .003227436 P_2 + .004288378 Q_1 - .00000384794 Q_2 \\ - .000084273 P_1 + .000084281 P_2 \\ - .000069547 P_1 - .000394636 P_2 + .00052646 Q_1 + .00000276470 Q_2$$

$$= -.00015679 P_1 + .00017344 P_2 - .00020869 Q_1 - .0000011232 Q_2$$

When  $P_2 = P_1 = P$ , &  $Q = Q_1 = Q_2$ ; then  $\delta_1 = \delta_2 = .00033023 P$  (3028. #/IN.)  
 $P_2 = -P_1 = -P$ , &  $Q = Q_1 = Q_2$ ; then  $\delta_1 = -\delta_2 = .00001665 P$  (66,700. #/IN.)



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$$\begin{aligned}\delta_3 = & -.0048126930 P_1 - .0050235245 P_2 + .0068344184 Q_1 + .0000005644 Q_2 \\ & + .0042907814 P_1 + .004390788 P_2 - .0058341531 Q_1 + .000005234951 Q_2 \\ & + .000117738 P_1 - .0001177491 P_2 \\ & + .000095481 P_1 + .000541792 P_2 - .000722769 Q_1 - .000003795623 Q_2\end{aligned}$$

$$= -.00020869 P_1 - .00020869 P_2 + .00027750 Q_1 + .0000014958 Q_2$$

$$\begin{aligned}\delta_4 = & -.00000039910 P_1 - .00000039910 P_2 + .00000056441 Q_1 + .00000028836 Q_2 \\ & -.0000108324 P_1 - .0000108325 P_2 + .00000143934 Q_1 - .00000001292 Q_2\end{aligned}$$

$$= -.0000011232 P_1 - .0000011232 P_2 + .0000014958 Q_1 + .00000027544 Q_2$$

Note: If  $P_1 = P_2$  &  $\delta_3 = 0$  ; &  $Q_2 = 0$ ,

$$Q_1 = \frac{2 \times .00020869}{.00027750} P = 1.50407 P$$

$$\text{Then } \delta_1 = .00033023 P - .00020869 \times 1.50407 P = .00001635 P$$

This checks with  $\delta_1$  when  $P_1 = -P_2$  and  $Q_1 = 0$ , &  $Q_2 = 0$ .

(Difference is due to strut deflection when  $P_1 = -P_2$ ).

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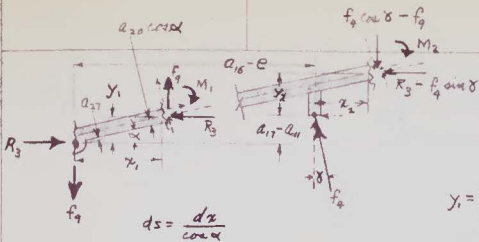
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$$28 = \tan \alpha$$

$$29 = \sin \alpha$$

$$30 = \cos \alpha$$

$$Y_1 = \left[ \frac{a_{27} + 30 a_{20}}{30} \right] + 28 X_1 = 31 + 28 X_1$$

$$Q_{17} - Q_{11} + Y_2 = 31 + 28 (a_{16} - e + X_2)$$

$$Y_2 = \left[ 31 + \frac{61}{28} (a_{16} - e) \right] + 28 X_2 - (Q_{17} - Q_{11})$$

Alternate Spar Energy Function:

$$N_1 = 30 R_3 - 29 f_9$$

$$V_1 = 29 R_3 + 30 f_9$$

$$M_1 = R_3 X_1 + f_9 X_1 = 31 R_3 + 28 R_3 X_1 + f_9 X_1 = 31 R_3 + (f_9 + 28 R_3) X_1$$

$$\begin{aligned} U_{s, H_1} &= \int_0^{a_{16}-e} \left( \frac{1}{2 E_{sp} I_{sp}} \right) M_1^2 dx + \left( \frac{60}{230 E_{sp}} \right) N^2 + \left( \frac{60 V_{sp}}{230 A_{sp}} \right) V^2 \\ &= \int_0^{60} \left[ 31^2 R_3^2 + 2 \cdot 31 R_3 (f_9 + 28 R_3) X_1 + (f_9 + 28 R_3)^2 X_1^2 \right] dx + 62 N^2 + 63 V^2 \\ &= \left( 32 \cdot 31^2 \cdot 60 \right) R_3^2 + \left( 32 \cdot 31 \cdot 60 \right) R_3 (f_9 + 28 R_3) + \left( \frac{32 \cdot 60^3}{3} \right) (f_9 + 28 R_3)^2 + 62 N^2 + 63 V^2 \\ &= 64 R_3^2 + 65 R_3 f_9 + 65 \cdot 28^2 R_3^2 + 66 f_9^2 + 2 \cdot 28 \cdot 66 R_3 f_9 + (44 \cdot 28^2) R_3^2 + (62 \cdot 30^2) R_3^2 - (2 \cdot 29 \cdot 30 \cdot 62) R_3 f_9 \\ &\quad + (62 \cdot 29^2) f_9^2 + (63 \cdot 29^2) R_3^2 + (2 \cdot 29 \cdot 30 \cdot 63) R_3 f_9 + (63 \cdot 30^2) f_9^2 \\ &= R_3^2 (64 + 67 + 69 + 70 + 73) + R_3 f_9 (65 + 68 \cdot 21 + 74) + f_9^2 (66 + 72 + 25) \end{aligned}$$

$$N_2 = (f_9 \cos \alpha - f_9) \sin \alpha + (R_3 - f_9 \sin \alpha) \cos \alpha$$

$$307 = \sin \alpha ; 308 = \cos \alpha$$

$$V_2 = (f_9 \cos \alpha - f_9) \cos \alpha - (R_3 - f_9 \sin \alpha) \sin \alpha$$

$$M_2 = R_3 (e_1 + 28 X_2) + f_9 (a_{16} - e + X_2) - f_9 \cos \alpha X_2 - f_9 \sin \alpha (e_1 + 28 X_2 - (a_{17} - a_{11}))$$

$$N_2 = (308 f_9 - f_9) 29 + (R_3 - 307 f_9) 30 = 29 U + 30 W$$

$$V_2 = (308 f_9 - f_9) 30 - (R_3 - 307 f_9) 29 = 30 U - 29 W$$

$$\begin{aligned} M_2 &= X_2 \left[ 28 R_3 + f_9 - f_9 308 - f_9 207 \cdot 28 \right] + e_1 (R_3 - 307 f_9) + (a_{16} - e) (f_9) + (a_{17} - a_{11}) 307 f_9 \\ &= (28 W - U) X_2 + \left[ e_1 W + f_9 (a_{16} - e) + 307 f_9 (a_{17} - a_{11}) \right] \end{aligned}$$



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$$\begin{aligned}
 U_{SP_{LH_2}} &= \int_0^e 32 \left[ \left( \frac{28}{60} N - u \right)^2 X_2^2 + 2u \left( \frac{28}{60} N - u \right) X_2 + u^2 \right] dX_2 + \left[ \frac{310}{60} \frac{64}{60} N^2 + \left[ \frac{311}{60} \frac{63}{60} \right] N^2 \right] V^2 \\
 &= \left( \frac{32}{3} \frac{64}{3} \right) \left( 28^2 N^2 - 2 \frac{28}{60} u N + u^2 \right) + \left( \frac{312}{3} \frac{64}{3} \right) u N - \left( \frac{314}{3} \frac{64}{3} \right) u u + \left( \frac{315}{3} \frac{64}{3} \right) u^2 \\
 &\quad + \frac{316}{30} \frac{29^2}{3} u^2 + 2 \frac{317}{30} \frac{29}{30} \frac{30}{30} u N + \frac{318}{30} \frac{30^2}{30} N^2 + \frac{319}{30} \frac{30^2}{30} u^2 - 2 \frac{311}{30} \frac{29}{30} \frac{30}{30} u N + \frac{321}{30} \frac{29^2}{30} N^2 \\
 &= \frac{322}{30} \frac{28^2}{30} N^2 - 2 \frac{312}{30} \frac{28}{30} u N + \frac{312}{30} u^2 + \frac{313}{30} u N - \frac{314}{30} u u + \frac{315}{30} u^2 + \frac{316}{30} u^2 \\
 &\quad + \frac{317}{30} u N + \frac{318}{30} N^2 + \frac{319}{30} u^2 - \frac{320}{30} u N + \frac{321}{30} N^2 \\
 &= N^2 \left( \frac{322}{30} + \frac{318}{30} + \frac{321}{30} \right) + u^2 \left( \frac{312}{30} + \frac{316}{30} + \frac{319}{30} \right) + u N^2 \left( \frac{315}{30} \right) + u N \left( -\frac{323}{30} + \frac{317}{30} - \frac{320}{30} \right) \\
 &\quad + N u \left( \frac{313}{30} \right) + u u \left( -\frac{314}{30} \right) \\
 &= \frac{324}{30} N^2 + \frac{325}{30} u^2 + \frac{326}{30} u N + \frac{315}{30} \frac{61}{30} N^2 + \frac{315}{30} \frac{60}{30} f_9^2 + \frac{315}{30} \frac{307}{30} \frac{307}{30} f_4^2 \\
 &\quad + 2 \frac{315}{30} \frac{61}{30} \frac{60}{30} f_9 N + 2 \frac{315}{30} \frac{61}{30} \frac{307}{30} \frac{307}{30} f_4 N + 2 \frac{315}{30} \frac{60}{30} \frac{307}{30} \frac{307}{30} f_4 f_9 + \frac{313}{30} \frac{61}{30} N^2 \\
 &\quad + \frac{313}{30} \frac{60}{30} f_9 N + \frac{313}{30} \frac{307}{30} \frac{307}{30} f_4 N - \frac{314}{30} \frac{61}{30} u N - \frac{314}{30} \frac{60}{30} f_4 u - \frac{314}{30} \frac{307}{30} \frac{307}{30} f_4 u \\
 &= N^2 \left( \frac{324}{30} + \frac{327}{30} + \frac{333}{30} \right) + u^2 \left( \frac{325}{30} \right) + u N \left( \frac{326}{30} - \frac{336}{30} \right) + f_9^2 \left( \frac{325}{30} \right) + f_4^2 \left( \frac{325}{30} \right) \\
 &\quad + f_4 f_9 \left( \frac{332}{30} \right) + f_9 N \left( \frac{330}{30} + \frac{334}{30} \right) + f_4 N \left( \frac{331}{30} + \frac{335}{30} \right) + f_9 u \left( -\frac{337}{30} \right) + f_4 u \left( -\frac{338}{30} \right) \\
 &= \frac{339}{30} \left( R_3^2 - 2 \frac{307}{30} R_3 f_4 + \frac{307^2}{30} f_4^2 \right) + \frac{325}{30} \left( \frac{308^2}{30} f_4^2 - 2 \frac{308}{30} f_4 f_9 + f_9^2 \right) \\
 &\quad + \frac{340}{30} \left( \frac{308}{30} R_3 f_4 - \frac{307}{30} \frac{308}{30} f_4^2 - R_3 f_9 + \frac{307}{30} f_4 f_9 \right) + \frac{328}{30} f_9^2 + \frac{329}{30} f_4^2 + \frac{332}{30} f_4 f_9 \\
 &\quad + \frac{341}{30} R_3 f_9 - \frac{341}{30} \frac{307}{30} f_4 f_9 + \frac{342}{30} R_3 f_4 - \frac{342}{30} \frac{307}{30} f_4^2 - \frac{337}{30} \frac{308}{30} f_4 f_9 + \frac{337}{30} f_9^2 - \frac{338}{30} \frac{308}{30} f_4^2 + \frac{336}{30} f_4 f_9 \\
 &= R_3^2 \left( \frac{339}{30} \right) + R_3 f_4 \left( -\frac{342}{30} \frac{307}{30} \frac{339}{30} + \frac{340}{30} \frac{308}{30} + \frac{342}{30} \right) + f_4^2 \left( \frac{329}{30} \frac{307^2}{30} + \frac{325}{30} \frac{308^2}{30} \right) \\
 &\quad - \frac{307}{30} \frac{308}{30} \frac{340}{30} + \frac{329}{30} - \frac{342}{30} \frac{307}{30} - \frac{338}{30} \frac{308}{30} \left( -\frac{308}{30} \frac{325}{30} + \frac{307}{30} \frac{340}{30} + \frac{332}{30} \right) \\
 &\quad - \frac{341}{30} \frac{307}{30} - \frac{337}{30} \frac{308}{30} + \frac{338}{30} \left( \frac{325}{30} + \frac{328}{30} + \frac{337}{30} \right) + R_3 f_9 \left( -\frac{340}{30} + \frac{341}{30} \right) \\
 U_{SP_{LH}} &= R_3^2 \left( \frac{359}{30} \right) + R_3 f_9 \left( \frac{360}{30} \right) + f_9^2 \left( \frac{361}{30} \right) + R_3 f_4 \left( \frac{345}{30} \right) + f_4^2 \left( \frac{351}{30} \right) + f_4 f_9 \left( \frac{350}{30} \right) \\
 U_{SP} &= \frac{359}{30} R_3^2 + \frac{359}{30} f_9^2 + \frac{360}{30} R_3 f_9 + \frac{360}{30} f_4^2 + \frac{361}{30} f_9^2 + \frac{361}{30} f_4^2 + \frac{345}{30} R_3 f_4 + \frac{345}{30} f_4 f_9 + \frac{351}{30} f_4^2 + \frac{351}{30} f_9^2 \\
 &\quad + \frac{356}{30} f_4 f_9 + \frac{356}{30} f_4 f_9
 \end{aligned}$$





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$$\begin{aligned}
 \frac{\partial U}{\partial P_i} &= \frac{11}{\partial P_1} P_1 + \frac{21}{\partial P_2} P_2 + \dots + \frac{211}{\partial P_n} P_n; + \frac{11}{\partial R_1} R_1 + \frac{12}{\partial R_2} R_2 + \dots + \frac{1m}{\partial R_m} R_m; \leftarrow \text{This} = \delta_i \\
 &+ \frac{\partial R_1}{\partial P_i} \left( \frac{11}{\partial P_1} P_1 + \frac{21}{\partial P_2} P_2 + \dots + \frac{211}{\partial P_n} P_n; + \frac{211}{\partial R_1} R_1 + \frac{12}{\partial R_2} R_2 + \dots + \frac{1m}{\partial R_m} R_m \right); \leftarrow \text{This} = \frac{\partial R_1}{\partial P_i} \left[ \frac{\partial U}{\partial R_1} \right] \\
 &+ \frac{\partial R_2}{\partial P_i} \left( \frac{12}{\partial P_1} P_1 + \frac{22}{\partial P_2} P_2 + \dots + \frac{212}{\partial P_n} P_n; + \frac{12}{\partial R_1} R_1 + \frac{222}{\partial R_2} R_2 + \dots + \frac{2m}{\partial R_m} R_m \right); \leftarrow \text{This} = \frac{\partial R_2}{\partial P_i} \left[ \frac{\partial U}{\partial R_2} \right] \\
 &\vdots \\
 &+ \frac{\partial R_m}{\partial P_i} \left( \frac{1m}{\partial P_1} P_1 + \frac{2m}{\partial P_2} P_2 + \dots + \frac{21m}{\partial P_n} P_n; + \frac{1m}{\partial R_1} R_1 + \frac{2m}{\partial R_2} R_2 + \dots + \frac{2mm}{\partial R_m} R_m \right); \leftarrow \text{This} = \frac{\partial R_m}{\partial P_i} \left[ \frac{\partial U}{\partial R_m} \right]
 \end{aligned}$$

Inasmuch as the deflection of one redundant member depends upon the deflections of other redundant members, the corresponding forces are dependent. When we consider  $\frac{\partial U}{\partial R_i}$  we ought to consider  $\frac{\partial R_i}{\partial P_i}$ . Following the pattern of  $\frac{\partial U}{\partial P_i}$ ,

$$0 = \frac{\partial U}{\partial R_i} = \frac{\partial R_1}{\partial R_i} \left[ \frac{\partial U}{\partial R_1} \right]_0 + \frac{\partial R_2}{\partial R_i} \left[ \frac{\partial U}{\partial R_2} \right]_0 + \dots + \frac{\partial R_m}{\partial R_i} \left[ \frac{\partial U}{\partial R_m} \right]_0$$

Now, if we multiply this expression by  $\frac{\partial R_i}{\partial P_i}$ , we have

$$0 = \frac{\partial U}{\partial P_i} - \left[ \frac{\partial U}{\partial P_i} \right]_0, \text{ which was to be proved.}$$

To see that every term in  $\frac{\partial U}{\partial R_i}$  is zero, consider

$$\begin{aligned}
 0 = \frac{\partial U}{\partial R_1} &= \left[ \frac{\partial U}{\partial R_1} \right]_0 + \frac{\partial R_2}{\partial R_1} \left[ \frac{\partial U}{\partial R_2} \right]_0 + \frac{\partial R_3}{\partial R_1} \left[ \frac{\partial U}{\partial R_3} \right]_0 \\
 0 = \frac{\partial U}{\partial R_2} &= \frac{\partial R_1}{\partial R_2} \left[ \frac{\partial U}{\partial R_1} \right]_0 + \left[ \frac{\partial U}{\partial R_2} \right]_0 + \frac{\partial R_3}{\partial R_2} \left[ \frac{\partial U}{\partial R_3} \right]_0 \\
 0 = \frac{\partial U}{\partial R_3} &= \frac{\partial R_1}{\partial R_3} \left[ \frac{\partial U}{\partial R_1} \right]_0 + \frac{\partial R_2}{\partial R_3} \left[ \frac{\partial U}{\partial R_2} \right]_0 + \left[ \frac{\partial U}{\partial R_3} \right]_0
 \end{aligned}
 \quad \left. \begin{aligned} & \\ & \\ & \end{aligned} \right\} \begin{aligned} 0 &= x + ay + bz \\ 0 &= \frac{1}{2}x + y + cz \\ 0 &= \frac{1}{8}x + \frac{1}{2}y + z \end{aligned}$$

$$0 = x = y = z$$

Nevertheless, one final doubt remains: If the coefficients of  $P_i$  in  $\frac{\partial U}{\partial P_i}$  and  $\frac{\partial U}{\partial R_i}$  are not the same as the coefficients of  $P_i$  in  $\left[ \frac{\partial U}{\partial P_i} \right]_0$  and  $\left[ \frac{\partial U}{\partial R_i} \right]_0$ , it may be that  $\left[ \frac{\partial R_i}{\partial P_i} \right]_0 \neq \frac{\partial R_i}{\partial P_i}$ .



The coefficient of  $P_i$  in  $\frac{\partial U}{\partial P_i}$  is  $\left\{ j_1 + j_1 \frac{\partial R_1}{\partial P_i} + j_2 \frac{\partial R_2}{\partial P_i} + \dots + j_m \frac{\partial R_m}{\partial P_i} \right\}$ ; and in  $\left[ \frac{\partial U}{\partial P_i} \right]_0$  it is  $\{ j_1 \}$ .

The coefficient of  $P_j$  in  $\frac{\partial U}{\partial R_i}$  is  $\left\{ j_1 + j_2 \frac{\partial R_1}{\partial R_i} + j_3 \frac{\partial R_2}{\partial R_i} + \dots + j_m \frac{\partial R_m}{\partial R_i} \right\}$ ; and in  $\left[ \frac{\partial U}{\partial R_i} \right]_0$  it is  $\{ j_1 \}$ .

Now subtracting the respective coefficients, we see that the differences cannot both be zero. If the first difference is zero, then

$$0 = j_1 \frac{\partial R_1}{\partial P_i} + j_2 \frac{\partial R_2}{\partial P_i} + \dots + j_m \frac{\partial R_m}{\partial P_i}; \text{ but if the second difference is zero,}$$

$$0 = j_2 \frac{\partial R_2}{\partial R_i} + \dots + j_m \frac{\partial R_m}{\partial R_i}. \text{ Therefore, the (m+1)th order matrix}$$

obtained by reduction of the strain energy function by the simplified method cannot be identical (Coefficient for Coefficient) to the matrix one ought to obtain by the long method. Moreover, we may conclude that none of the coefficients can correspond between matrices because

$$\frac{\partial^2 U}{\partial R_i \partial R_j} = \frac{\partial^2 U}{\partial R_j \partial R_i}; \text{ i.e., in each matrix there are complementary}$$

coefficients which must both correspond if one corresponds.

$$\begin{aligned} \frac{\partial U}{\partial P_i} &= P_1 \left\{ j_1 + j_1 \frac{\partial R_1}{\partial P_i} + j_2 \frac{\partial R_2}{\partial P_i} + \dots + j_m \frac{\partial R_m}{\partial P_i} \right\} \\ &+ P_2 \left\{ j_1 + j_1 \frac{\partial R_1}{\partial P_i} + j_2 \frac{\partial R_2}{\partial P_i} + \dots + j_m \frac{\partial R_m}{\partial P_i} \right\} \\ &\vdots \\ &+ P_n \left\{ j_1 + j_1 \alpha_1 + j_2 \alpha_2 + \dots + j_m \alpha_m \right\} \\ &+ R_1 \left\{ j_1 + j_1 \alpha_1 + j_2 \alpha_2 + \dots + j_m \alpha_m \right\} \\ &+ R_2 \left\{ j_1 + j_1 \alpha_1 + j_2 \alpha_2 + \dots + j_m \alpha_m \right\} \\ &\vdots \\ &+ R_m \left\{ j_1 + j_1 \alpha_1 + j_2 \alpha_2 + \dots + j_m \alpha_m \right\}. \end{aligned} \quad \alpha_j = \frac{\partial R_j}{\partial P_i}$$

Zero.

On the other hand, if the co-factor of every  $R_j$  above is zero, it may be seen that the two methods are absolutely identical. The general expression for the cofactors is  $\frac{\partial^2 U}{\partial P_i}$  of  $\left[ \frac{\partial U}{\partial R_j} \right]_0$ ; which certainly is zero.

$$0 = \left[ \frac{\partial^2 U}{\partial R_j \partial P_i} \right]_0 + \left[ \frac{\partial^2 U}{\partial R_i \partial R_j} \right]_0 \frac{\partial R_j}{\partial P_i} + \left[ \frac{\partial^2 U}{\partial R_i \partial R_j} \right]_0 \frac{\partial R_j}{\partial P_i} + \dots + \left[ \frac{\partial^2 U}{\partial R_m \partial R_j} \right]_0 \frac{\partial R_m}{\partial P_i}.$$







AVRO AIRCRAFT LIMITED

## TECHNICAL DEPARTMENT (Aircraft)

REPORT NO. 7-0558-8

SHEET NO. C2

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4-13-55

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Strut Energy:

$$U_{ST} = 2 \frac{f_4^2 L}{2 R_{ST} E_{ST}} = \frac{R_1^2 L^3}{4 E^3 R_{ST} E_{ST}} = \frac{1}{4} R_1^2$$

$$\frac{1}{4} = \frac{L^3}{4 E^3 R_{ST} E_{ST}}$$

Spar Energy:

$$U_{SP} = 2 \int_0^{2a} \left\{ \frac{M^2}{2 E_{SP} I_{SP}} + \frac{N^2}{2 A_{SP} E_{SP}} + \frac{\alpha_{SP} V^2}{2 A_{SP} G_{SP}} \right\} dx$$

$$M = f_9 x + d f_8 ; \quad N = f_8 ; \quad V = f_9$$

$$U_{SP} = 2 \int_0^{2a} \left\{ \frac{f_9^2 x^2 + 2 d f_8 f_9 x + d^2 f_8^2}{2 E_{SP} I_{SP}} + \frac{f_8^2}{2 A_{SP} E_{SP}} + \frac{\alpha_{SP} f_9^2}{2 A_{SP} G_{SP}} \right\} dx$$

$$= \frac{1}{E_{SP} I_{SP}} \left( \frac{3 a^3 f_9^2}{3} + 4 a d f_8 f_9 + 2 a d^2 f_8^2 \right) + \frac{2 a}{A_{SP} E_{SP}} f_8^2 + \frac{2 a \alpha_{SP}}{A_{SP} G_{SP}} f_9^2$$

$$\underline{2} = \frac{2 a}{E_{SP} I_{SP}} ; \quad \underline{3} = \frac{2 a}{A_{SP} E_{SP}} ; \quad \underline{4} = \frac{2 a \alpha_{SP}}{A_{SP} G_{SP}}$$

$$U_{SP} = \underline{2} \frac{4 a^3 f_9^2}{3} + \underline{2} 2 a d f_8 f_9 + \underline{2} d^2 f_8^2 + \underline{3} f_8^2 + \underline{4} f_9^2$$

$$\underline{5} = \underline{2} \frac{4 a^3}{3} + \underline{4} ; \quad \underline{6} = \underline{2} d^2 + \underline{3} ; \quad \underline{7} = \underline{2} 2 a d$$

$$U_{SP} = \underline{6} f_8^2 + \underline{7} f_8 f_9 + \underline{5} f_9^2$$

Former Energy:U<sub>F0AB</sub>

$$V = f_8 ; \quad N = f_6 ; \quad M = f_8 x$$

$$U_{F0AB} = \int_0^a \left\{ \frac{f_8^2 x^3}{6 E_{F0} I_{F0}} + \frac{f_6^2 a}{2 A_{F0} E_{F0}} + \frac{\alpha_{F0} f_8^2 a}{2 A_{F0} G_{F0}} \right\} dx$$

$$\underline{8} = \frac{a^3}{6 E_{F0} I_{F0}} ; \quad \underline{9} = \frac{a}{2 A_{F0} E_{F0}} ; \quad \underline{10} = \frac{\alpha_{F0} a}{2 A_{F0} G_{F0}} ; \quad \underline{11} = \underline{8} + \underline{10}$$

$$U_{F0AB} = \underline{9} f_6^2 + \underline{11} f_8^2$$





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## TECHNICAL DEPARTMENT (Aircraft)

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 $U_{F0AB_2}$ 

$$N = f_8 \sin \theta + f_6 \cos \theta$$

$$V = f_6 \sin \theta - f_8 \cos \theta$$

$$M = af_8 + f_8 a \sin \theta - f_6 a (1 - \cos \theta) = a (f_8 - f_6 + f_8 \sin \theta + f_6 \cos \theta)$$

$$f_8 - f_6 = -\frac{f_1}{2}$$

$$ds = a d\theta$$

$$U_{F0AB_2} = \int_0^{\frac{\pi}{2}} \left\{ 3 \left( \frac{f_1^2}{4} + f_8^2 \sin^2 \theta + f_6^2 \cos^2 \theta - f_8 f_6 \sin \theta - f_6 f_8 \cos \theta + f_8 f_6 \sin 2\theta \right) \right. \\ \left. + 9 (f_8^2 \sin^2 \theta + f_6^2 \cos^2 \theta + f_8 f_6 \sin 2\theta) + 10 (f_8^2 \sin^2 \theta + f_6^2 \cos^2 \theta - f_8 f_6 \sin 2\theta) \right\} d\theta$$

$$12 = \int_0^{\frac{\pi}{2}} \sin^2 \theta d\theta = \left[ \frac{\theta}{2} - \frac{\sin 2\theta}{4} \right]_0^{\frac{\pi}{2}} = .14270$$

$$13 = \int_0^{\frac{\pi}{2}} \cos^2 \theta d\theta = \left[ \frac{\theta}{2} + \frac{\sin 2\theta}{4} \right]_0^{\frac{\pi}{2}} = .64270$$

$$14 = \int_0^{\frac{\pi}{2}} \sin \theta d\theta = [-\cos \theta]_0^{\frac{\pi}{2}} = .292893$$

$$15 = \int_0^{\frac{\pi}{2}} \cos \theta d\theta = [\sin \theta]_0^{\frac{\pi}{2}} = .707107$$

$$16 = \int_0^{\frac{\pi}{2}} \sin 2\theta d\theta = \left[ -\frac{1}{2} \cos 2\theta \right]_0^{\frac{\pi}{2}} = .50000$$

$$U_{F0AB_2} = \overbrace{.75 \times .7854 \times 8 f_1^2}^{17} + 3 \cdot 8 \cdot 12 f_8^2 + 3 \cdot 8 \cdot 13 f_6^2 - 3 \cdot 8 \cdot 14 f_8 f_6 - 3 \cdot 8 \cdot 15 f_6 f_8 + 3 \cdot 8 \cdot 16 f_8 f_6 \\ + 9 \cdot 12 f_8^2 + 9 \cdot 13 f_6^2 + 9 \cdot 16 f_8 f_6 + 10 \cdot 12 f_8^2 + 10 \cdot 13 f_6^2 - 10 \cdot 16 f_8 f_6$$

$$29 = 19 + 24 + 26$$

$$32 = 9 + 29$$

$$30 = 18 + 23 + 27$$

$$33 = 11 + 30$$

$$31 = 22 + 25 - 28$$

$$U_{F0AB_2} = 17 f_1^2 + 29 f_8^2 + 30 f_6^2 - 21 f_8 f_6 - 20 f_6 f_8 + 31 f_8 f_6$$

$$U_{F0AB} = 17 f_1^2 + 32 f_6^2 + 33 f_8^2 - 21 f_8 f_6 - 20 f_6 f_8 + 31 f_8 f_6$$

Inasmuch as  $f_2 = f_1 = \frac{R_1}{2}$ ;  $R_2 = f_6 = \frac{R_1 - f_1}{2}$ ; and  $\eta = \eta_2$ ; the strain energy of the right half equals the energy of the left half. Therefore  $U_{F0} = 4 U_{F0AB}$ .

$$34 = 6 + 4.33$$

$$U = 1 R_1^2 + 4 [17 f_1^2 + 42 f_6^2 + 33 f_8^2 + 5 f_9^2 - 4 \cdot 21 f_8 f_6 - 4 \cdot 20 f_6 f_8 + 4 \cdot 31 f_8 f_6 + 7 f_8 f_9]$$





AVRO AIRCRAFT LIMITED

# TECHNICAL DEPARTMENT (Aircraft)

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For substitution in  $\frac{\partial^2 U}{\partial x \partial y}$ ,

$$\frac{\partial R_1}{\partial R_1} = 1$$

$$\frac{\partial R_1}{\partial R_2} = 0$$

$$\frac{\partial R_1}{\partial R_2} = 0$$

$$\frac{\partial f_1}{\partial R_1} = 0$$

$$\frac{\partial f_1}{\partial R_2} = \frac{1}{\sqrt{2}}$$

$$\frac{\partial f_1}{\partial R_2} = \frac{1}{\sqrt{2}}$$

$$\frac{\partial f_2}{\partial R_1} = \frac{1}{2}$$

$$\frac{\partial f_2}{\partial R_2} = 0$$

$$\frac{\partial f_2}{\partial R_2} = 0$$

$$\frac{\partial f_3}{\partial R_1} = \frac{1}{2}$$

$$\frac{\partial f_3}{\partial R_2} = -\frac{1}{2\sqrt{2}}$$

$$\frac{\partial f_3}{\partial R_2} = -\frac{1}{2\sqrt{2}}$$

$$\frac{\partial f_4}{\partial R_1} = \frac{1}{2}$$

$$\frac{\partial f_4}{\partial R_2} = \frac{1}{2\sqrt{2}}$$

$$\frac{\partial f_4}{\partial R_2} = \frac{1}{2\sqrt{2}}$$

$$\frac{\partial^2 U}{\partial R_1^2} = 8 \frac{1}{2} + 2 \frac{3}{4} \frac{1}{8} + 2 \frac{5}{2} \frac{1}{8} + 4 \frac{20}{4} \frac{1}{4} + 4 \frac{20}{4} \frac{1}{4} - 7 \frac{1}{2} \frac{1}{8} - 7 \frac{1}{2} \frac{1}{8}$$

$$= 4 \frac{1}{2} + .25 \frac{3}{4} + .25 \frac{5}{2} + 2 \frac{20}{4} - .25 \frac{1}{2} \frac{1}{8}$$

$$\frac{\partial^2 U}{\partial R_1 \partial R_2} = \frac{\partial^2 U}{\partial R_2 \partial R_1} \text{ because all } \frac{\partial f}{\partial R_1} = \frac{\partial f}{\partial R_2}$$

$$\frac{\partial^2 U}{\partial R_1 \partial R_2} = -2 \frac{3}{4} \frac{1}{4\sqrt{2}} + 2 \frac{5}{2} \frac{1}{2\sqrt{2}} - 4 \frac{21}{21\sqrt{2}} - 4 \frac{20}{20\sqrt{2}} - 4 \frac{1}{4\sqrt{2}} - 7 \frac{1}{4\sqrt{2}} + 7 \frac{1}{4\sqrt{2}}$$

$$= .707107 \left( - .5 \frac{3}{4} + .5 \frac{5}{2} - 2 \frac{21}{21} - 2 \frac{20}{20} - \frac{3}{4} - .25 \frac{1}{2} + .25 \frac{1}{2} \right)$$

$$\frac{\partial^2 U}{\partial R_2^2} = \frac{\partial^2 U}{\partial R_1^2} \text{, because all } \frac{\partial f}{\partial R_1} = \frac{\partial f}{\partial R_2}$$

$$\frac{\partial^2 U}{\partial R_1 \partial R_2} = \frac{\partial^2 U}{\partial R_2 \partial R_1} \text{, a must.}$$

$$\frac{\partial^2 U}{\partial R_2 \partial R_1} = \frac{\partial^2 U}{\partial R_1 \partial R_2} \text{, because all } \frac{\partial f}{\partial R_1} = \frac{\partial f}{\partial R_2}$$

$$\frac{\partial^2 U}{\partial R_1^2} = 2 \frac{1}{2} + 8 \frac{3}{4} \frac{1}{4} + 2 \frac{3}{4} \frac{1}{4} + 2 \frac{5}{2} \frac{1}{4} + 4 \frac{21}{21} \frac{1}{4} + 4 \frac{21}{21} \frac{1}{4} + 7 \frac{1}{4} + 7 \frac{1}{4}$$

$$= 2 \frac{1}{2} + 2 \frac{3}{2} + .5 \frac{3}{4} + .5 \frac{5}{2} + 2 \frac{21}{21} + .5 \frac{1}{2}$$

$$\frac{\partial R_1}{\partial R_1} = - \frac{\frac{\partial^2 U}{\partial R_1 \partial R_2}}{\frac{\partial^2 U}{\partial R_1^2}}$$

$$R_1 = 2 \frac{\partial R_2}{\partial R_1} R_1$$

$$\frac{\partial R_1}{\partial R_2} = - \frac{\frac{\partial^2 U}{\partial R_2 \partial R_1}}{\frac{\partial^2 U}{\partial R_1^2}} = \frac{\partial R_1}{\partial R_1}$$

$$\delta_1 = \delta_2 = 2 \frac{\partial \delta}{\partial R_1} R_1 = 2 R_1 \left[ \frac{\partial^2 U}{\partial R_1^2} + \frac{\partial^2 U}{\partial R_1 \partial R_2} \frac{\partial R_1}{\partial R_1} \right]$$

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## TECHNICAL DEPARTMENT (Aircraft)

REPORT NO 7-0558-B

SHEET NO C6

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Computations:  $g = 10^{-7}$ 

$$1 = \frac{(54.5894)^3}{4 \times 64 \times 2 \times 10^7 \times 2.9} = 1095.61 \text{ g}$$

$$2 = \frac{54}{10^7 \times 23072} = 1.60142 \text{ g}$$

$$3 = \frac{54}{9.471 \times 10^7} = 12.0778 \text{ g}$$

$$4 = \frac{54 \times 4.146}{9.471 \times 4 \times 10^7} = 125.1865 \text{ g}$$

$$5 = 1.60142 \text{ g} \times 1.33333 \times 27^2 + 125.1865 \text{ g} = 1681.767 \text{ g}$$

$$6 = \frac{1.60142 \times 3.2^2}{16.1985} + 12.0778 \text{ g} = 28.4763 \text{ g}$$

$$7 = 1.60142 \text{ g} \times 54 \times 3.2 = 276.722 \text{ g}$$

$$8 = \frac{27^3}{6 \times 10^7 \times 1.7382} = 1887.2972 \text{ g}$$

$$9 = \frac{27}{2 \times 1.2104 \times 10^7} = 11.1533 \text{ g}$$

$$10 = \frac{5.931 \times 27}{2 \times 1.2104 \times 4 \times 10^7} = 165.3755 \text{ g}$$

$$11 = 1887.2972 \text{ g} + 165.3755 \text{ g} = 2052.673 \text{ g}$$

$$12 = .14270$$

$$13 = .64270$$

$$14 = .29289$$

$$15 = .70711$$

$$16 = .50000$$

$$17 = .75 \times .78540 \times 1887.297 \text{ g} = 1111.712 \text{ g}$$

$$18 = 3 \times 1887.297 \text{ g} \times .14270 = 807.9519 \text{ g}$$

$$19 = 3 \times 1887.297 \text{ g} \times .64270 = 3638.597 \text{ g}$$

$$20 = 3 \times 1887.297 \text{ g} \times .29289 = 1658.311 \text{ g}$$

$$21 = 3 \times 1887.297 \text{ g} \times .70711 = 4003.580 \text{ g}$$

$$22 = 3 \times 1887.297 \text{ g} \times .50000 = 2830.9455 \text{ g}$$









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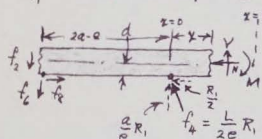
treated  
If we had not forces  $f_4$  and  $f_5$  as a pure moment acting at the midspan of the spar, would our answer have been much different?

$$U_{sp} = 2 \int_0^{2a-e} + 2 \int_{2a-e}^{2a} = U_{sp1} + U_{sp2} \quad \text{Say } \frac{2a-e}{2a} = \frac{35}{37}$$

$$U_{sp} = \frac{35^3}{37} (5-4) f_1^2 + \frac{35^2}{37} 7 f_2 f_1 + \frac{35}{37} (4-3) f_3^2 + \frac{35}{37} 3 f_3^2 + \frac{35}{37} 4 f_1^2$$

$$\frac{36}{37} = \frac{35}{37} \frac{6}{37} ; \quad \frac{37}{37} = \frac{35}{37} \frac{7}{37} ; \quad \frac{38}{37} = \frac{35}{37} \frac{3}{37} + \frac{35}{37} \frac{4}{37}$$

$$U_{sp1} = \frac{36}{37} f_1^2 + \frac{37}{37} f_2 f_1 + \frac{38}{37} f_1^2$$



$$N = f_3 - R_1 = -\frac{f_1}{2}$$

$$V = f_1 - \frac{a}{2e} R_1 = \frac{d}{2e} f_1 - R_1 \left( \frac{a}{2e} - \frac{1}{2} \right)$$

$$\begin{aligned} M &= f_1 \left( \frac{2a-e}{2} \right) + f_2 d + f_3 x - \frac{R_1}{2} d - \frac{a}{2e} R_1 x \\ &= \frac{39}{2a} \frac{d}{2} f_1 + \frac{39}{2} \frac{R_1}{2} + d \frac{R_1}{2} - d \frac{f_1}{2} - \frac{d}{2} \frac{R_1}{2} + \left( f_1 - \frac{a}{2e} R_1 \right) x \\ &= f_1 \left( \frac{39}{2a} \frac{d}{2} - \frac{d}{2} \right) + \frac{39}{2} \frac{R_1}{2} + Vx \end{aligned}$$

$$U_{sp2} = \int_0^e \left\{ \frac{4x^2 + 24Vx + V^2 x^2}{2E_{sp} I_{sp}} + \frac{N^2}{2A_{sp} E_{sp}} + \frac{V_{sp} V^2 x^2}{2A_{sp} G_{sp}} \right\} dx$$

$$\frac{40}{2a} = \frac{e}{2a} ; \quad \frac{41}{2a} = \frac{40}{2a} ; \quad \frac{42}{2a} = \frac{40}{2a} ; \quad \frac{43}{2a} = \frac{40}{2a} ; \quad \frac{44}{2a} = \frac{d}{2} \left( \frac{39}{2a} - 1 \right)$$

$$U_{sp2} = \frac{41}{2a} U^2 + \frac{41}{2a} eUV + \frac{41}{2a} \frac{e^2}{3} V^2 + \frac{42}{2a} N^2 + \frac{43}{2a} V^2$$

$$= \frac{41}{2a} \left( \frac{44}{2a} f_1^2 + \frac{39}{2a} \frac{44}{2a} f_1 R_1 + \frac{39}{2a} \frac{R_1^2}{4} \right) + \frac{41}{2a} e \left( \frac{44}{2a} f_1 V + \frac{39}{2a} \frac{R_1}{2} V \right) + \frac{45}{2a} V^2 + \frac{42}{2a} N^2$$

$$\begin{aligned} &= \frac{41}{2a} \frac{44}{2a} f_1^2 + \frac{39}{2a} \frac{41}{2a} \frac{44}{2a} f_1 R_1 + \frac{39}{2a} \frac{41}{2a} \frac{R_1^2}{4} + e \frac{41}{2a} \frac{44}{2a} \frac{d}{2a} f_1^2 - e \frac{41}{2a} \frac{44}{2a} \frac{35}{2a} f_1 R_1 \\ &+ e \frac{41}{2a} \frac{39}{2a} \frac{1}{4a} f_1 R_1 - e \frac{41}{2a} \frac{39}{2a} \frac{1}{2} \frac{35}{2a} \frac{e}{2a} R_1^2 + \frac{45}{2a} \frac{d^2}{4a^2} f_1^2 - \frac{45}{2a} \frac{d}{2a} \frac{35}{2a} f_1 R_1 + \frac{45}{2a} \frac{35}{2a} \frac{d^2}{2a} R_1^2 + \frac{42}{2a} \frac{f_1^2}{4} \\ &= f_1^2 \left( \frac{46}{2a} + \frac{49}{2a} + \frac{53}{2a} + 56 \right) + f_1 R_1 \left( \frac{47}{2a} - 50 + \frac{51}{2a} - 54 \right) + R_1^2 \left( \frac{48}{2a} - 52 + \frac{55}{2a} \right) \end{aligned}$$



AVRO AIRCRAFT LIMITED

## TECHNICAL DEPARTMENT (Aircraft)

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The strain energy of the spar in the other case was  $5f_8^2 + 2f_8f_9 + 5f_9^2$ .  
Then the difference in strain energy of the two cases is

$$U_1 - U_2 = (6 - 36)f_8^2 + (2 - 37)f_8f_9 + (5 - 38)f_9^2 - 57f_1^2 - 58f_1R_1 - 57R_1^2$$

$$U_2 = (1 + 51)R_1^2 + (417 + 57)f_1^2 + 432f_8^2 + (433 + 36)f_8^2 + 28f_9^2 - 421f_1f_8 - 420f_1f_9 + 421f_8f_9 + 37f_8f_9 + 58f_1R_1$$

$$\frac{\partial U}{\partial X} = 260R_1 \frac{\partial R_1}{\partial X} + 261f_1 \frac{\partial f_1}{\partial X} + 832f_8 \frac{\partial f_8}{\partial X} + 262f_9 \frac{\partial f_9}{\partial X} + 238f_1 \frac{\partial f_1}{\partial X} - 421f_1 \frac{\partial f_8}{\partial X} - 421f_1 \frac{\partial f_9}{\partial X} - 420f_1 \frac{\partial f_8}{\partial X} - 420f_1 \frac{\partial f_9}{\partial X} + 421f_8 \frac{\partial f_8}{\partial X} + 421f_8 \frac{\partial f_9}{\partial X} + 37f_8 \frac{\partial f_8}{\partial X} + 37f_9 \frac{\partial f_9}{\partial X} + 58f_1 \frac{\partial R_1}{\partial X} + 58R_1 \frac{\partial f_1}{\partial X}$$

$$\frac{\partial^2 U}{\partial X^2} = 260 \frac{\partial R_1}{\partial Y} \frac{\partial R_1}{\partial X} + 261 \frac{\partial f_1}{\partial Y} \frac{\partial f_1}{\partial X} + 832 \frac{\partial f_8}{\partial Y} \frac{\partial f_8}{\partial X} + 262 \frac{\partial f_9}{\partial Y} \frac{\partial f_9}{\partial X} + 238 \frac{\partial f_1}{\partial Y} \frac{\partial f_1}{\partial X} - 421 \frac{\partial f_1}{\partial Y} \frac{\partial f_8}{\partial X} - 421 \frac{\partial f_1}{\partial Y} \frac{\partial f_9}{\partial X} - 420 \frac{\partial f_1}{\partial Y} \frac{\partial f_8}{\partial X} - 420 \frac{\partial f_1}{\partial Y} \frac{\partial f_9}{\partial X} + 421 \frac{\partial f_8}{\partial Y} \frac{\partial f_8}{\partial X} + 421 \frac{\partial f_8}{\partial Y} \frac{\partial f_9}{\partial X} + 37 \frac{\partial f_8}{\partial Y} \frac{\partial f_8}{\partial X} + 37 \frac{\partial f_9}{\partial Y} \frac{\partial f_9}{\partial X} + 58 \frac{\partial f_1}{\partial Y} \frac{\partial R_1}{\partial X} + 58 \frac{\partial R_1}{\partial Y} \frac{\partial f_1}{\partial X}$$

$$\frac{\partial^2 U}{\partial R_1^2} = 61 + 25 \frac{62}{a} + 25 \frac{38}{a} \frac{d}{a} + 20 + 20 - 25 \frac{37}{a} \frac{d}{a}$$

$$\frac{\partial^2 U}{\partial R_1 \partial R_1} = -353553 \frac{62}{a} + 353553 \frac{38}{a} \frac{d}{a} - 1.414214 \frac{21}{a} - 1.414214 \frac{20}{a} - 707107 \frac{31}{a} - \frac{353553}{2} \frac{37}{a} + \frac{353553}{2} \frac{37}{a} \frac{d}{a} + 707107 \frac{58}{a}$$

$$\frac{\partial^2 U}{\partial R_1^2} = 260 + 238 + 5.62 + 5.38 + 31 + 31 + 2537 + 2527$$

$$35 = \frac{54-8}{54} = .851851; \quad 35^2 = .725651; \quad 35^3 = .618148$$

$$36 = .851851 \times 28.4763 g = 24.2576 g$$

$$37 = .725651 \times 276.722 g = 200.804 g$$

$$38 = .618148 (1681.767 - 125.187) g + .851851 \times 125.1865 g = 962.1968 g + 106.640 g = 1068.837 g$$

$$39 = 29 - e = 46$$

$$40 = \frac{8}{54} = .148148$$

$$41 = .148148 \times 160142 g = 23725 g$$



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$$42 = .148148 \times 12.0725 \text{ g} = 1.78930 \text{ g}$$

$$43 = .148148 \times 125.1865 \text{ g} = 18.5461 \text{ g}$$

$$44 = \frac{2.2}{2} \left( \frac{46}{27} - 1 \right) = 1.12593$$

$$45 = 1.23725 \text{ g} \times \frac{64}{3} + 18.5461 \text{ g} = 5.0613 \text{ g} + 18.5461 \text{ g} = 23.6064 \text{ g}$$

$$46 = 1.23725 \text{ g} \times 1.12593^2 = 30.0766 \text{ g}$$

$$47 = 46 \times 1.23725 \text{ g} \times 1.12593 = 12.2878 \text{ g}$$

$$48 = 46^2 \times 1.23725 \text{ g} \times .25 = 125.5053 \text{ g}$$

$$49 = 8 \times 1.23725 \text{ g} \times 1.12593 \times \frac{2.2}{54} = 1.26638 \text{ g}$$

$$50 = 1.23725 \text{ g} \times 1.12593 \times .851851 \times 27 = 6.1439 \text{ g}$$

$$51 = 8 \times 1.23725 \text{ g} \times 46 \times .25 \times \frac{3.2}{27} = 2.5869 \text{ g}$$

$$52 = 1.23725 \text{ g} \times 46 \times 5 \times .851851 \times 27 = 125.5052 \text{ g}$$

$$53 = 23.6064 \text{ g} \times \left( \frac{3.2}{54} \right) = .0828926 \text{ g}$$

$$54 = 23.6064 \text{ g} \times 3.2 \times .851851 \times .125 = 8.04352 \text{ g}$$

$$55 = 23.6064 \text{ g} \times .725651 \times \frac{2.2}{64} = 195.1211 \text{ g}$$

$$56 = 1.78930 \times .25 = .447325 \text{ g}$$

$$57 = (30.0766 + 1.266 + .0829 + .4473) \text{ g} = 30.7334 \text{ g}$$

$$58 = (12.2878 - 6.1439 + 2.5869 - 8.04352) \text{ g} = .6873 \text{ g}$$

$$59 = (125.5053 - 125.5052 + 195.1211) \text{ g} = 195.1211 \text{ g}$$

$$60 = 1095.61 \text{ g} + 195.12 \text{ g} = 1290.73 \text{ g}$$

$$61 = 4 \times 1111.712 + 30.7334 = 4477.581 \text{ g}$$

$$62 = 4 \times 2968.5033 + 24.2576 = 11898.27 \text{ g}$$

$$\frac{\partial^2 U}{\partial P_1^2} = 8(4477.581 + 2974.568 + 3.753 + 3316.622) = .00107725$$

$$\frac{\partial^2 U}{\partial P_1 \partial P_2} = 8(.353553) \times (-11,898.27 + 126.677 - 16,014.32 - 6633.24 - 5507.67 - 100.402 + 11.90 + 1.33) - 49,013.955 = -.001414705$$

$$\frac{\partial^2 U}{\partial P_1^2} = 8(2591.46 + 7361.635 + 5949.135 + 534.419 + 5507.668 + 100.402) = .002203472$$

$$\delta_1 = 2P_1 \left[ \frac{.000168961}{.00107725} + \left( -\frac{.001414705}{.002203472} - \frac{.642034}{.002203472} \right) \right] = .000337922 \text{ g}$$

$$\frac{P_1}{\delta_1} = 2959 \text{ #/IN (Does make a difference. @ } 2\frac{1}{4} \% \text{)}$$





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The  $j^{\text{th}}$  cofactor is identical to the column of coefficients of the  $j^{\text{th}}$   $R$  in the expression for  $\frac{\partial U}{\partial P}$  at the top of page "b." Observing that the coefficients of the  $\frac{\partial U}{\partial P}$   $R$ 's are mirrored about a diagonal through the right-hand portions of  $\left[\frac{\partial U}{\partial R_i}\right]$ , it must follow that  $\underline{U_i R_j}$  of the first line can be replaced by  $\frac{\partial R_j}{\partial P_i} (\underline{U_1 P_1} + \underline{U_2 P_2} + \dots + \underline{U_n P_n})$ .

Accordingly it may be seen that the expression for  $\frac{\partial U}{\partial P}$  on page "c" is equivalent to the expression for  $\delta_{i0}$  at the bottom of page "e". This peculiarity offers a desirable way of checking the results of a particular computation; e.g.,

$$f_i = \frac{\partial \delta_i}{\partial P_j} - \frac{\partial^2 U}{\partial P_i \partial P_j} = \frac{\partial^2 U}{\partial P_i \partial R_1} \frac{\partial R_1}{\partial P_j} + \dots + \frac{\partial^2 U}{\partial P_i \partial R_m} \frac{\partial R_m}{\partial P_j} = \frac{\partial^2 U}{\partial P_j \partial R_1} \frac{\partial R_1}{\partial P_i} + \dots + \frac{\partial^2 U}{\partial P_j \partial R_m} \frac{\partial R_m}{\partial P_i}$$

Rewriting this equality using the notation introduced on page 12,

$$\underline{U P R_1 R_1 P_j} + \dots + \underline{U P R_m R_m P_j} = \underline{U P_j R_1 R_1 P_i} + \dots + \underline{U P_j R_m R_m P_i}$$

Example! Let  $i = 2$ ; and  $j = 4$ ;

Using results on pages 24 to 30,

$$\underline{U P R_1 R_1 Q_2} + \underline{U P R_2 R_2 Q_2} + \underline{U P R_3 R_3 Q_2} = \underline{U Q_2 R_1 R_1 P_2} + \underline{U Q_2 R_2 R_2 P_2} + \underline{U Q_2 R_3 R_3 P_2}$$

$$(-50,211.14) \times (.000766357)$$

$$(16,503.03) \times (.000000000)$$

$$(72,152.15) \times (.000383176)$$

$$(-16.85307) \times (.642773)$$

$$(0.0) \times (.051070)$$

$$(0.0) \times (-.054695)$$

$$-38.47936 + 0 + 27.64697 = -10.83270 + 0 + 0$$

$$-10.8324 = -10.8327 \quad \text{OK.}$$

—



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$$\theta_1 = 180 - 2 \sin^{-1} \frac{a_2}{\sqrt{a_1^2 + a_3^2}} =$$

$$r_1 = \frac{a_3}{\sin \theta_1} =$$

$$\theta_3 = 180 - 2 \sin^{-1} \frac{a_5}{\sqrt{a_3^2 + a_4^2}} =$$

$$r_2 = \frac{a_5}{\sin \theta_3} =$$

$$\theta_2 = \theta_3 + \sin^{-1} \frac{a_6}{r_2} =$$

$$\beta = \tan^{-1} \frac{r_2 + a_2 - a_4}{r_1 + a_5 - a_3} =$$

$$3 = a_{25} - a_{20} =$$

$$4 = \frac{1}{2 \cos \theta} =$$

$$5 = \frac{1}{2 \sin \theta} =$$

$$6 = \cos \beta =$$

$$7 = \sin \beta =$$

$$8 = a_{20} + a_{17} + a_{12} + a_{13} =$$

$$9 = a_3 - a_{14} + a_{15} =$$

$$10 = 11 - 7 =$$

$$11 = \frac{68 + 29}{2 a_{16}} =$$

$$12 = \frac{a_{25}}{2 a_{16}} =$$

$$13 = \frac{1}{2 a_{16}} =$$

$$14 = a_2 + a_{13} =$$

$$15 = 2 a_{16} - 9 =$$

$$16 = 9 =$$

$$17 = a_{25} - a_{20} - a_{17} =$$

$$18 = \frac{715 - 614}{2 a_{16}} =$$

$$19 = - \frac{614 + 716}{2 a_{16}} =$$

$$20 = \frac{17}{2 a_{16}} =$$



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$$\underline{21} = \underline{11} =$$

$$\underline{22} = \underline{10} =$$

$$\underline{23} = \underline{19} + \underline{7} =$$

$$\underline{24} = \underline{18} - \underline{7} =$$

$$\underline{25} = \frac{\underline{L}}{2 A_{ST} E_{ST}} =$$

$$\underline{26} = 2 \underline{25} \underline{5}^2 =$$

$$\underline{27} = 2 \underline{25} \underline{4}^2 =$$

$$\underline{28} = \tan \alpha =$$

$$\underline{29} = \sin \alpha =$$

$$\underline{30} = \cos \alpha =$$

$$\underline{31} = \frac{\underline{Q_{27}}}{\underline{30}} + \underline{a_{20}} =$$

$$\underline{32} = \frac{\underline{1}}{2 \underline{30} E_{SP} I_{SP}} =$$

$$\underline{33} = \frac{\underline{a_{16}}}{2 \underline{30} A_{SP} E_{SP}} =$$

$$\underline{34} = \frac{\underline{Q_{16}} \underline{Q_{SP}}}{2 \underline{30} A_{SP} G_{SP}} =$$

$$\underline{35} = \underline{32} \underline{31}^2 \underline{Q_{16}} =$$

$$\underline{36} = \underline{32} \underline{31} \underline{Q_{16}}^2 =$$

$$\underline{37} = \underline{36} \underline{28} =$$

$$\underline{38} = \underline{32} \frac{\underline{Q_{16}}^3}{\underline{3}} =$$

$$\underline{39} = \underline{38} \underline{28}^2 =$$

$$\underline{40} = \underline{33} \underline{30}^2 =$$

$$\underline{41} = 2 \underline{38} \underline{28}^2 =$$

$$\underline{42} = 2 \underline{33} \underline{30} \underline{29} =$$

$$\underline{43} = \underline{33} \underline{29}^2 =$$

$$\underline{44} = \underline{34} \underline{28}^2 =$$

$$\underline{45} = 2 \underline{34} \underline{28} \underline{30} =$$

$$\underline{46} = \underline{34} \underline{30}^2 =$$

$$\underline{47} = \underline{35} + \underline{37} + \underline{39} + \underline{40} + \underline{43} =$$

$$\underline{48} = \underline{36} + \underline{29} - \underline{41} + \underline{44} =$$

$$\underline{49} = \underline{38} + \underline{42} + \underline{45} =$$

$$\underline{50} = \underline{10} + \underline{18} =$$

$$\underline{51} = \underline{11} + \underline{19} =$$

$$\underline{52} = \underline{11} + \underline{19} =$$



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$$51 = 20 - 12 =$$

$$52 = 21 + 24 =$$

$$53 = 22 + 23 =$$

$$55 = \tan \Omega = \frac{a_{14} - a_{15}}{a_{13}} =$$

$$56 = \sin \Omega =$$

$$57 = \cos \Omega =$$

$$82 = \frac{a_{13}^2}{4 E_{F0} I_{F0} 57} =$$

$$83 = \frac{a_{13}}{2 A_{F0} E_{F0} 57} =$$

$$84 = \frac{a_{13} \sqrt{E_{F0}}}{2 A_{F0} G_{F0} 57} =$$

$$85 = 82 + 83 56^2 + 84 57^2 =$$

$$58 = 2 55 82 + 2 56 57 (84 - 83) =$$

$$59 = 82 55^2 + 83 57^2 + 84 56^2 =$$

$$86 = r_1 + a_{15} - a_{14} =$$

$$87 = \frac{r_1}{2 E_{F0} I_{F0}} =$$

$$88 = \frac{r_1}{2 A_{F0} E_{F0}} =$$

$$89 = \frac{r_1 \sqrt{E_{F0}}}{2 A_{F0} G_{F0}} =$$

$$90 = .5 (8_1 - .5 \sin 28_1) =$$

$$91 = .5 (8_1 + .5 \sin 28_1) =$$

$$92 = 1 - \cos 8_1 =$$

$$93 = \sin 8_1 =$$

$$94 = .5 (1 - \cos 28_1) =$$

$$95 = 87 8_1 a_{13}^2 =$$

$$96 = 2 87 8_1 a_{13} 86 =$$

$$97 = 87 8_1 86^2 =$$

$$98 = 87 90 r_1^2 =$$

$$99 = 87 91 r_1^2 =$$

$$100 = 2 87 92 r_1 a_{13} =$$

$$101 = 2 87 92 r_1 86 =$$

$$102 = 2 87 93 r_1 a_{13} =$$

$$103 = 2 87 93 r_1 86 =$$







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$$135 = 117 \ 120 =$$

$$136 = 117 \ 123 =$$

$$137 = 118 \ 119 =$$

$$138 = 118 \ 120 =$$

$$139 = 118 \ 123 =$$

$$140 = 126 + 128 - 132 + 135 + 137 =$$

$$141 = 127 + 134 + 138 =$$

$$142 = -125 + 131 =$$

$$143 = 130 - 133 - 136 + 139 =$$

$$144 = 124 \ 14^2 =$$

$$145 = 124 \ 9^2 =$$

$$146 = 2 \ 124 \ 9 \ 14 =$$

$$147 = 140 \ 115^2 =$$

$$148 = 141 \ 14^2 =$$

$$149 = 143 \ 114 \ 115 =$$

$$150 = 147 + 148 + 149 =$$

$$151 = 140 \ 14^2 =$$

$$152 = 141 \ 115^2 =$$

$$153 = 143 \ 114 \ 115 =$$

$$154 = 151 + 152 - 153 =$$

$$155 = 2 \ 140 \ 114 \ 115 =$$

$$156 = 2 \ 141 \ 114 \ 115 =$$

$$157 = 143 \ (114^2 - 115^2) =$$

$$158 = 155 - 156 + 157 =$$

$$159 = 142 \ 14 \ 115 =$$

$$160 = 129 \ 14 \ 114 =$$

$$161 = 159 - 160 =$$

$$162 = 142 \ 14 \ 114 =$$

$$163 = 129 \ 14 \ 115 =$$

$$164 = 162 + 163 =$$

$$165 = 142 \ 9 \ 115 =$$

$$166 = 129 \ 9 \ 114 =$$

$$167 = -165 + 166 =$$

$$168 = 142 \ 9 \ 114 =$$

$$169 = 129 \ 9 \ 115 =$$

$$170 = -168 - 169 =$$

$$171 = 144 + 154 + 164 =$$



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$$172 = 145 + 150 + 167 =$$

$$173 = 7^2 150 + 6^2 154 - 6 \cdot 7 \cdot 158 =$$

$$174 = -146 + 158 + 161 + 170 =$$

$$175 = 2 \cdot 6 \cdot 154 - 7(158 + 161) + 6 \cdot 164 =$$

$$176 = 6(158 + 170) - 7(2 \cdot 150 + 167) =$$

$$177 = a_6 - a_7 =$$

$$178 = 14 + a_{29} =$$

$$179 = a_5 + a_6 =$$

$$180 = 6 a_{29} + 7 \cdot 179 =$$

$$181 = \frac{1}{2 E_{F0} I_{F0}} =$$

$$182 = \frac{a_7}{2 A_{F0} E_{F0}} =$$

$$183 = \frac{a_7 \sqrt{F0_2}}{2 A_{F0} G_{F0}} =$$

$$184 = 181 a_7 =$$

$$185 = 184 a_7 =$$

$$186 = \frac{185}{3} a_7 + 183 =$$

$$187 = 184 \cdot 178^2 =$$

$$188 = 184 \cdot 180^2 =$$

$$189 = 184 \cdot 177^2 =$$

$$190 = 2 \cdot 184 \cdot 178 \cdot 180 =$$

$$191 = 2 \cdot 184 \cdot 177 \cdot 177 =$$

$$192 = 2 \cdot 184 \cdot 180 \cdot 177 =$$

$$193 = 185 \cdot 178 =$$

$$194 = 185 \cdot 180 =$$

$$195 = 185 \cdot 177 =$$

$$196 = 185 \cdot 7 \cdot 178 =$$

$$197 = 185 \cdot 7 \cdot 180 =$$

$$198 = 185 \cdot 7 \cdot 177 =$$

$$199 = 2 \cdot 186 \cdot 7 =$$

$$200 = 186 \cdot 7^2 =$$

$$201 = 2 \cdot 182 \cdot 6 =$$

$$202 = 182 \cdot 6^2 =$$

$$203 = 187 + 182 =$$

$$204 = 188 + 197 + 200 + 202 =$$







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$$\begin{aligned}
 \underline{UP_2} &= + 301 & = \\
 &+ 2 \ 23 \ 214 & = \\
 &- 2 \ 6 \ 212 & = \\
 &+ 305 (19 + 23) & = \\
 &- 2 \ 6 \ 23 \ 213 & = \\
 &+ 6^2 \ 304 & = \\
 &- 2 \ 6 \ 47 \ 53 & = \\
 &+ 306 (50 + 53) & =
 \end{aligned}$$

$$\begin{aligned}
 \underline{UP_2 Q_1} &= + 20 \ 214 & = \\
 &+ 212 & = \\
 &+ 20 \ 305 (19 + 23) & = \\
 &+ 213 (23 - 6 \ 20) & = \\
 &- 6 \ 304 & = \\
 &- 47 (6 \ 51 - 53) & = \\
 &+ 51 \ 306 (50 + 53) & =
 \end{aligned}$$

$$\begin{aligned}
 \underline{UP_2 Q_2} &= + 6 \ 13 \ 47 & = \\
 &- 13 \ 306 (50 + 53) & =
 \end{aligned}$$

$$\begin{aligned}
 \underline{UP_2 R_1} &= + 20 \ 214 & = \\
 &+ 212 & = \\
 &+ 20 \ 305 (19 + 23) & = \\
 &+ 213 (23 - 6 \ 20) & = \\
 &- 6 \ 304 & = \\
 &- 47 (6 \ 20 - 53) & = \\
 &+ 20 \ 306 (50 + 53) & =
 \end{aligned}$$

$$\begin{aligned}
 \underline{UP_2 R_2} &= + .5 \ 214 & = \\
 &- .5 \ 305 (19 - 23) & = \\
 &- .5 \ 6 \ 213 & = \\
 &- .5 \ 6 \ 47 & = \\
 &- .5 \ 306 (50 - 53) & =
 \end{aligned}$$





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$$\begin{aligned}
 \underline{UR_3} &= -212 & = \\
 &+ 213 (19-23) & = \\
 &+ 6 \underline{304} & = \\
 &+ 47 (50-51) & =
 \end{aligned}$$

$$\begin{aligned}
 \underline{UR_1} &= 2 \underline{20^2 305} & = \\
 &+ 2 \underline{20 213} & = \\
 &+ \underline{304} & = \\
 &+ 2 \underline{47 51} & = \\
 &+ 2 \underline{51^2 306} & =
 \end{aligned}$$

$$\begin{aligned}
 \underline{UR_2} &= -13 \underline{47} & = \\
 &- 2 \underline{13 51 306} & =
 \end{aligned}$$

$$\begin{aligned}
 \underline{UR_1} &= 2 \underline{20^2 305} & = \\
 &+ 2 \underline{20 213} & = \\
 &+ \underline{304} & = \\
 &+ 47 (\underline{20 + 51}) & = \\
 &+ 2 \underline{20 51 306} & =
 \end{aligned}$$

$$\begin{aligned}
 \underline{UR_2} &= .5 \underline{213} & = \\
 &+ .5 \underline{47} & =
 \end{aligned}$$

$$\underline{UR_3} = -304 =$$

$$\underline{UR_2} = 2 \underline{13^2 306} =$$

$$\begin{aligned}
 \underline{UR_3} &= -2 \underline{13 20 306} & = \\
 &- \underline{13 47} & =
 \end{aligned}$$

$$\underline{UR_2 R_2} = 0 = \underline{UR_2 R_3}$$



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$$\begin{aligned}
 \underline{UR_1^2} &= + 302 = \\
 &+ 2 \underline{20^1 305} = \\
 &+ 2 \underline{30 213} = \\
 &+ \underline{304} = \\
 &+ 2 \underline{20 47} = \\
 &+ 2 \underline{20^1 306} =
 \end{aligned}$$

$$\begin{aligned}
 &= \\
 &= \\
 &= \\
 &= \\
 &= \\
 &=
 \end{aligned}$$

$$\underline{UR_1 R_2} = +.5(\underline{213} + \underline{47}) =$$

$$\underline{UR_1 R_3} = - \underline{304} =$$

$$\begin{aligned}
 \underline{UR_2^2} &= + \underline{303} = \\
 &+ .5(\underline{305} + \underline{306}) =
 \end{aligned}$$

$$\begin{aligned}
 &= \\
 &=
 \end{aligned}$$

$$\underline{UR_2 R_3} = - \underline{213} - \underline{47} =$$

$$\underline{UR_3^2} = 2 \underline{304} =$$

$$\begin{aligned}
 0 &= u_1 + \underline{UR_1^2} R_1 + \underline{UR_1 R_2} R_2 + \underline{UR_1 R_3} R_3 \\
 0 &= u_1 + \underline{UR_1 R_2} R_1 + \underline{UR_2^2} R_2 + \underline{UR_2 R_3} R_3 \\
 0 &= u_3 + \underline{UR_1 R_3} R_1 + \underline{UR_2 R_3} R_2 + \underline{UR_3^2} R_3
 \end{aligned}$$

$$u_i = \underline{UR_1 P_1} + \underline{UR_1 R_2} + \underline{UR_1 Q_1} + \underline{UR_1 Q_2}$$



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$$\begin{aligned} \delta_1 &= \underline{UP_1^2 P_1} + \underline{UP_1 P_2 P_2} + \underline{UP_1 Q_1 Q_1} + \underline{UP_1 Q_2 Q_2} + \underline{UP_1 R_1 R_1} + \underline{UP_1 R_2 R_2} + \underline{UP_1 R_3 R_3} \\ \delta_2 &= \underline{UP_2^2 P_1} + \underline{UP_2^2 P_2} + \underline{UP_2 Q_1 Q_1} + \underline{UP_2 Q_2 Q_2} + \underline{UP_2 R_1 R_1} + \underline{UP_2 R_2 R_2} + \underline{UP_2 R_3 R_3} \\ \delta_3 &= \underline{UP_3^2 P_1} + \underline{UP_3^2 P_2} + \underline{UP_3^2 Q_1} + \underline{UP_3^2 Q_2} + \underline{UP_3^2 R_1} + \underline{UP_3^2 R_2} + \underline{UP_3^2 R_3} \\ \delta_4 &= \underline{UP_4^2 P_1} + \underline{UP_4^2 P_2} + \underline{UP_4^2 Q_1} + \underline{UP_4^2 Q_2} + \underline{UP_4^2 R_1} + \underline{UP_4^2 R_2} + \underline{UP_4^2 R_3} \end{aligned}$$



AVRO AIRCRAFT LIMITED

## TECHNICAL DEPARTMENT (Aircraft)

AIRCRAFT

REPORT NO. 7-0558-8

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Station 742.5

Spar Properties:

Drawing No 7-0162-156. Referring to report # 7-0562-4, "Distribution of the Fin Roll Moment",

$$\int_0^{\frac{1}{2}} \frac{x^2}{I_y} dx = 6560 \text{ in}^{-1} = \frac{1}{I_c} \int_0^{\frac{1}{2}} x^2 dx = \frac{1}{I_c} \frac{x^3}{24}$$

$$\therefore I_c = \frac{114^3}{24 \times 6560} = 9.42 \text{ in}^4 \text{ (Equivalent spar of constant "I")}$$

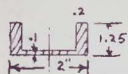
Say section 5, sheet 37 of ref. report for spar properties; i.e.,  $A = 2.1855$ ;  $I = 9.3179$ ;

$$\alpha_{sp} = \frac{A}{I} A y^2 = \frac{2.1855}{9.3179 \times 1.25} \left( \overset{114.3}{.755} \times 2.1765 + \overset{429}{.125} \times 1.989 + \overset{263}{.125} \times 2.0515 \times 1.025 \right) = \underline{4.75}$$

Former Properties:

$$A = 4 \times 1.25 + 1.6 \times 1 = .5 + .16 = .66 \text{ in}^2$$

Dwg. 7-0158-133



$$I = \frac{1}{12} (2.5 \times 4 - 1.6^3 \times 1.15) = \frac{1}{12} (10 - 4.715) = .440 \text{ in}^4$$

$$\alpha_{FO} = \frac{.66}{.44 \times 1} \left( \overset{.225}{.9 \times 2 \times 1.25} + \overset{.032}{.4 \times 1 \times .8} \right) = \underline{3.855}$$

These properties for  $FO_0$ ,  $FO_1$ , and  $FO_2$ .Change 2" width to 4" for  $FO_3$ .

$$A_{FO_3} = .66 + .1 \times 2 = .86$$

$$I_{FO_3} = \frac{1}{12} (1.25 \times 64 - 1.15 \times 3.6^3) = \frac{1}{12} (80 - 53.7) = \underline{2.19}$$

$$\alpha_{FO_3} = \frac{.86}{2.19 \times 1} \left( \overset{.475}{1.9 \times 2 \times 1.25} + \overset{.120}{0.95 \times 1 \times 1.9} \right) = \underline{1.16}$$

Strut Properties:

$$L = 42.5^\circ, \delta = 9.2^\circ$$

$$A_{ST} = .3136 \text{ in}^2 \text{ (a.d. = 1.75 ; .058 wall)}; E_{ST} = 29 \times 10^6 \text{ p.s.i.}$$

Geometry:

$$a_2 = 21.8$$

$$a_7 = 11.32$$

$$a_{17} = 7.24$$

$$a_{29} = -2.1''$$

$$a_3 = 8.8$$

$$a_{11} = 5.4$$

$$a_{20} = 2.4$$

$$a_4 = 7.5$$

$$a_{13} = 23''$$

$$a_{25} = 54.4$$

$$a_5 = 17.4$$

$$a_{15} - a_{14} = -.32$$

$$a_{26} = 47.9''$$

$$a_6 = 19.2$$

$$a_{16} = 56.4$$

$$a_{27} = .9$$





**INVS**

AVRO AIRCRAFT LIMITED

TECHNICAL DEPARTMENT (Aircraft)

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$$21 = 11 = .40083$$

$$22 = 10 = -.29013$$

$$23 = 19 + 7 = -.33905 + .69096 = .35191$$

$$24 = 18 - 7 = .35191 - .69096 = -.33905$$

$$25 = \frac{L}{2A_{ST}E_{ST}} = \frac{42.5}{2 \times 3136 \times 2.9 \times 10^7} = 23.366 \text{ g. } (\text{g} = 10^{-2})$$

$$26 = 2.25 \text{ g}^2 = 2 \times 23.366 \text{ g} \times 3.127345^2 = 457.052 \text{ g.}$$

$$27 = 2.25 \text{ g}^2 = 2 \times 23.366 \text{ g} \times .506513^2 = 11.9493 \text{ g.}$$

$$28 = \tan \alpha = \tan 4^\circ = .06993$$

$$29 = \sin \alpha = \sin 4^\circ = .06976$$

$$30 = \cos \alpha = \cos 4^\circ = .99756$$

$$31 = \frac{a_{27}}{30} + a_{20} = \frac{.90}{.99756} + 2.4 = 3.3022$$

$$32 = \frac{1}{2.30 E_{sp} I_{sp}} = \frac{1}{2 \times .99756 \times 10^7 \times 9.3179} = .0537914 \text{ g.}$$

$$33 = \frac{a_{16}}{2.30 A_{sp} E_{sp}} = \frac{56.4}{2 \times .99756 \times 2.1855 \times 10^7} = 12.9348 \text{ g.}$$

$$34 = \frac{a_{16} a_{sp}}{2.30 A_{sp} G_{sp}} = \frac{56.4 \times 4.75}{2 \times .99756 \times 2.1855 \times 4 \times 10^7} = 153.6008 \text{ g.}$$

$$35 = 2.25 \text{ g}^2 a_{16} = .0537914 \text{ g} \times 3.3022^2 \times 56.4 = 33.0425 \text{ g.}$$

$$36 = 2.25 \text{ g}^2 a_{16}^2 = .0537914 \text{ g} \times 3.3022 \times 56.4^2 = 565.0338 \text{ g.}$$

$$37 = 36 \text{ g}^2 = 565.0338 \text{ g} \times .06993 = 39.5128 \text{ g.}$$

$$38 = 2.25 \text{ g}^2 a_{16}^2 = .0537914 \text{ g} \times .33333 \times 56.4^2 = 3216.8325 \text{ g.}$$

$$39 = 38 \text{ g}^2 = 3216.8325 \text{ g} \times .06993^2 = 15.72095 \text{ g.}$$

$$40 = 33 \text{ g}^2 = 12.9348 \text{ g} \times .99756^2 = 12.8718 \text{ g.}$$

$$299 = 2.38 \text{ g}^2 = 2 \times 3216.8325 \text{ g} \times .06993 = 449.9062 \text{ g.}$$

$$41 = 2.33 \text{ g}^2 = 2 \times 12.9348 \text{ g} \times .99756 \times .06976 = 1.8003 \text{ g.}$$

$$42 = 37 \text{ g}^2 = 12.9348 \text{ g} \times .06976^2 = .062947 \text{ g.}$$

$$43 = 34 \text{ g}^2 = 153.6008 \text{ g} \times .06976^2 = .747492 \text{ g.}$$

$$44 = 2.34 \text{ g}^2 = 2 \times 153.6008 \text{ g} \times .06976 \times .99756 = 21.3781 \text{ g.}$$

$$45 = 34 \text{ g}^2 = 153.6008 \text{ g} \times .99756^2 = 152.8521 \text{ g.}$$

$$46 = 35 + 27 + 39 + 40 + 43 = \text{g} (33.0825 + 39.5128 + 15.73095 + 12.8718 + .7475) = 101.9456 \text{ g.}$$

$$47 = 36 + 299 - 41 + 44 = \text{g} (565.0338 + 449.9062 - 1.8003 + 21.3781) = 1034.5178 \text{ g.}$$

$$48 = 38 + 42 + 45 = \text{g} (3216.8325 + .0629 + 152.8521) = 3369.7475 \text{ g.}$$

$$49 = 10 + 18 = -.29013 + .35191 = +.06178$$

$$50 = 11 + 19 = .40083 - .33905 = +.06178$$



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## TECHNICAL DEPARTMENT (Aircraft)

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$$51' = 20 - 12 = .396885 - .48227 = -.08546$$

$$52 = 21 + 24 = .40083 - .33905 = +.06178$$

$$53 = 22 + 23 = -.29013 + .35191 = +.06178$$

$$55 = \tan \Omega = \frac{a_{14} - a_{15}}{a_{13}} = \frac{.32}{.23} = .013913 \quad (\Omega = 0^\circ 48')$$

$$56 = \sin \Omega = .013913$$

$$57 = \cos \Omega = .99990$$

$$82 = \frac{a_{12}^2}{6 E_{FO} I_{FO} 57} = \frac{23^2}{6 \times 10^7 \times .440 \times .9999} = 4,609.16 \text{ g}$$

$$83 = \frac{a_{12}}{2 A_{FO} E_{FO} 57} = \frac{23}{2 \times .66 \times 10^7 \times .9999} = 17.4260 \text{ g}$$

$$84 = \frac{a_{12} \phi_{FO}}{2 A_{FO} G_{FO} 57} = \frac{.23 \times 3.855}{2 \times .66 \times .4 \times 10^7 \times .9999} = 167.9431 \text{ g}$$

$$85 = 82 + 83 56^2 + 84 57^2 = \text{g} (4609.16 + 12.4260 \times .013913^2 + 167.9431 \times .9999^2) = 4,777.07 \text{ g}$$

$$58 = 2 55 82 + 2 56 57 (84 - 83) = \text{g} [2 \times .013913 \times 4609.16 + 2 \times .013913 \times .9999 (167.9431 - 17.4260)] = 132.4424 \text{ g}$$

$$59 = 82 55^2 + 83 57^2 + 84 56^2 = \text{g} (4609.16 \times .013913^2 + 12.4260 \times .9999^2 + 167.9431 \times .013913^2) = 18.3472 \text{ g}$$

$$86 = r_1 + a_{15} - a_{14} = 31.401 - .32 = 31.081$$

$$87 = \frac{r_1}{2 E_{FO} I_{FO}} = \frac{31.401}{2 \times 10^7 \times .44} = 35.6829 \text{ g}$$

$$88 = \frac{r_1}{2 A_{FO} E_{FO}} = \frac{31.401}{2 \times .66 \times 10^7} = 23.7886 \text{ g}$$

$$89 = \frac{r_1 \phi_{FO}}{2 A_{FO} G_{FO}} = \frac{31.401 \times 3.855}{2 \times .66 \times .4 \times 10^7} = 229.2626 \text{ g}$$

$$90 = .5 (\theta_1 - .5 \sin 2\theta_1) = .5 (.76736 - .5 \times .999935) = .13384$$

$$91 = .5 (\theta_1 + .5 \sin 2\theta_1) = .5 (.76736 + .5 \times .999935) = .63352$$

$$92 = 1 - \cos \theta_1 = 1 - .71974 = .28026$$

$$93 = \sin \theta_1 = .69424$$

$$94 = .5 (1 - \cos 2\theta_1) = .5 (1 - .02606) = .48197$$

$$95 = 87 \theta_1 Q_1^2 = 35.6829 \text{ g} \cdot .76736 \times 23^2 = 14,484.87 \text{ g}$$

$$96 = 2 87 \theta_1 Q_1 \theta_6 = 2 \times 35.6829 \text{ g} \cdot .76736 \times 23 \times 31.081 = 39,148.20 \text{ g}$$

$$97 = 87 \theta_1 \theta_6^2 = 35.6829 \text{ g} \cdot .76736 \times 31.081^2 = 26,451.41 \text{ g}$$

$$98 = 87 \theta_1 \theta_1^2 = 35.6829 \text{ g} \cdot .13384 \times 31.401^2 = 4,209.05 \text{ g}$$

$$99 = 87 \theta_1 \theta_1^2 = 35.6829 \text{ g} \cdot .63352 \times 31.401^2 = 22,289.86 \text{ g}$$

$$100 = 2 87 92 \theta_1 Q_1 = 2 \times 35.6829 \text{ g} \cdot .28026 \times 31.401 \times 23 = 14,445.17 \text{ g}$$

$$101 = 2 87 92 \theta_1 \theta_6 = 2 \times 35.6829 \text{ g} \cdot .28026 \times 31.401 \times 31.081 = 19,520.44 \text{ g}$$

$$102 = 2 87 93 \theta_1 Q_1 = 2 \times 35.6829 \text{ g} \cdot .69424 \times 31.401 \times 23 = 35,782.53 \text{ g}$$

$$103 = 2 87 93 \theta_1 \theta_6 = 2 \times 35.6829 \text{ g} \cdot .69424 \times 31.401 \times 31.081 = 48,354.64 \text{ g}$$

$$104 = 89 \cdot 94 \cdot \Gamma_1^2 = 35.6824 \text{ g} \cdot 4.4197 \times 31.40^2 = 16,957.70 \text{ g}$$

$$105 = 88 \cdot 90 = 23.7886 \text{ g} \cdot 1.3384 = 3.18387 \text{ g}$$

$$106 = 88 \cdot 91 = 23.7886 \text{ g} \cdot 6.3352 = 15.07055 \text{ g}$$

$$107 = 88 \cdot 94 = 23.7886 \text{ g} \cdot 4.4197 = 11.4654 \text{ g}$$

$$108 = 89 \cdot 90 = 229.2626 \text{ g} \cdot 1.3384 = 30.6645 \text{ g}$$

$$109 = 89 \cdot 91 = 229.2626 \text{ g} \cdot 6.3352 = 145.2424 \text{ g}$$

$$110 = 89 \cdot 94 = 229.2626 \text{ g} \cdot 4.4197 = 110.4977 \text{ g}$$

$$111 = 95 + 98 + 180 + 105 + 109 = \text{g} (14,484.87 + 4,709.05 + 14,445.17 + 3.18 + 145.24) = 33,787.51 \text{ g}$$

$$112 = -96 - 101 + 102 + 104 + 107 - 110 = \text{g} (-39,142.20 - 19,520.44 + 35,782.53 + 16,957.70 + 11.47 - 110.50) = -6,027.44 \text{ g}$$

$$113 = 97 + 99 - 103 + 106 + 108 = \text{g} (26,451.41 + 22,289.86 - 48,354.64 + 15.07 + 30.68) = 432.38 \text{ g}$$

$$114 = \cos \theta_3 = .68666$$

$$115 = \sin \theta_3 = .72697$$

$$116 = \frac{\Gamma_2}{2 E_{F0} I_{F0_2}} = \frac{23.935}{2 \times 10^7 \times .144} = 27.1984 \text{ g}$$

$$117 = \frac{\Gamma_2}{2 A_{F0_2} E_{F0}} = \frac{23.935}{2 \times .66 \times 10^7} = 18.1326 \text{ g}$$

$$118 = \frac{\Gamma_2 E_{F0}}{2 A_{F0_2} G_{F0}} = \frac{23.935 \times 3.855}{2 \times .66 \times .4 \times 10^7} = 174.7529 \text{ g}$$

$$119 = .5 (\theta_3 - .5 \sin 2\theta_3) = .5 (1.74483 - .5 [-.34109]) = .957688$$

$$120 = .5 (\theta_2 + .5 \sin 2\theta_2) = .5 (1.74483 + .5 [-.34109]) = .787143$$

$$121 = 1 - \cos \theta_2 = 1 - (-.17318) = 1.17318$$

$$122 = \sin \theta_2 = .98489$$

$$123 = .5 (1 - \cos 2\theta_2) = .5 (1 - [-.94005]) = .97003$$

$$124 = 116 \theta_2 = 27.1988 \text{ g} \cdot 1.74483 = 47.4573 \text{ g}$$

$$125 = 2 116 \theta_2 \Gamma_1 = 2 \times 27.1988 \text{ g} \cdot 1.74483 \times 23.935 = 2,271.78 \text{ g}$$

$$126 = 116 \theta_2 \Gamma_1^2 = 27.1988 \text{ g} \cdot 1.74483 \times 23.935^2 = 27,187.52 \text{ g}$$

$$127 = 116 118 \Gamma_1^2 = 27.1988 \text{ g} \cdot 95.7688 \times 23.935^2 = 14,922.46 \text{ g}$$

$$128 = 116 120 \Gamma_1^2 = 27.1988 \text{ g} \cdot 787.143 \times 23.935^2 = 12,265.07 \text{ g}$$

$$129 = 2 116 121 \Gamma_1 = 2 \times 27.1988 \text{ g} \cdot 1.17318 \times 23.935 = 1,527.49 \text{ g}$$

$$130 = 2 116 121 \Gamma_1^2 = 2 \times 27.1988 \text{ g} \cdot 1.17318 \times 23.935^2 = 36,560.42 \text{ g}$$

$$131 = 2 116 122 \Gamma_1 = 2 \times 27.1988 \text{ g} \cdot .98489 \times 23.935 = 1,282.33 \text{ g}$$

$$132 = 2 116 122 \Gamma_1^2 = 2 \times 27.1988 \text{ g} \cdot .98489 \times 23.935^2 = 30,692.60 \text{ g}$$

$$133 = 116 123 \Gamma_1^2 = 27.1988 \text{ g} \cdot 97.003 \times 23.935^2 = 15,114.77 \text{ g}$$

$$134 = 117 119 = 18.1326 \text{ g} \cdot .957688 = 17.3054 \text{ g}$$



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$$135 = 117 \ 120 = 18,1326 \ g \cdot 787143 = 14,2729 \ g$$

$$136 = 117 \ 123 = 18,1326 \ g \cdot 97003 = 17,5892 \ g$$

$$137 = 118 \ 119 = 174,7529 \ g \cdot 957668 = 167,3588 \ g$$

$$138 = 118 \ 120 = 174,7529 \ g \cdot 787143 = 137,5555 \ g$$

$$139 = 118 \ 123 = 174,7529 \ g \cdot 97003 = 169,5155 \ g$$

$$140 = 126 + 138 - 132 + 135 + 137 = g(27,18752 + 12,26507 - 30,69260 + 14,27 + 167,36) = 8,941,62 \ g$$

$$141 = 127 + 134 + 138 = g(14,92246 + 17,37 + 137,56) = 15,077,39 \ g$$

$$142 = -125 + 131 = g(-2,271,78 + 1,282,33) = -989,45 \ g$$

$$143 = 130 - 133 - 136 + 139 = g(36,56042 - 15,11477 - 17,59 + 169,52) = 21,597,58 \ g$$

$$144 = 124 \ 14^2 = 47,4573 \ g \cdot 448^2 = 95,248,70 \ g$$

$$145 = 124 \ 9^2 = 47,4573 \ g \cdot 8,48^2 = 3412,67 \ g$$

$$146 = 2 \ 128 \ 9 \ 14 = 2 \times 47,4573 \ g \cdot 8,48 \times 44,8 = 36058,44 \ g$$

$$147 = 140 \ 115^2 = 8941,62 \ g \cdot 72697^2 = 4,725,51 \ g$$

$$148 = 141 \ 114^2 = 15,077,39 \ g \cdot 68666^2 = 7,109,02 \ g$$

$$149 = 143 \ 114 \ 115 = 21,597,58 \ g \cdot 68666 \times 72697 = 10,781,10 \ g$$

$$150 = 147 + 148 + 149 = 22,615,63 \ g$$

$$151 = 140 \ 142^2 = 8941,62 \ g \cdot 68666^2 = 4,215,99 \ g$$

$$152 = 141 \ 115^2 = 15,077,39 \ g \cdot 72697^2 = 7,968,17 \ g$$

$$153 = 143 \ 114 \ 115 = 21,597,58 \ g \cdot 68666 \times 72697 = 10,781,10 \ g$$

$$154 = 151 + 152 - 153 = 1403,06 \ g$$

$$155 = 2 \ 140 \ 114 \ 115 = 2 \times 8941,62 \ g \cdot 68666 \times 72697 = 8926,97 \ g$$

$$156 = 2 \ 141 \ 114 \ 115 = 2 \times 15,077,39 \ g \cdot 68666 \times 72697 = 15,052,69 \ g$$

$$157 = 143 \ (142^2 - 115^2) = 21,597,58 \ g \cdot (68666^2 - 72697^2) = -1,230,69 \ g$$

$$158 = 155 - 156 + 157 = -7356,41 \ g$$

$$159 = 142 \ 14 \ 115 = -989,45 \ g \cdot 44,8 \times 72697 = -32,224,66 \ g$$

$$160 = 129 \ 14 \ 114 = 1527,49 \ g \cdot 44,8 \times 68666 = 46,989,21 \ g$$

$$161 = 159 - 160 = -79,213,87 \ g$$

$$162 = 142 \ 14 \ 114 = -989,45 \ g \cdot 44,8 \times 68666 = -30,437,83 \ g$$

$$163 = 129 \ 14 \ 115 = 1527,49 \ g \cdot 44,8 \times 72697 = 49,747,69 \ g$$

$$164 = 162 + 163 = 19,309,86 \ g$$

$$165 = 142 \ 9 \ 115 = -989,45 \ g \cdot 8,48 \times 72697 = -6099,67 \ g$$

$$166 = 129 \ 9 \ 114 = 1527,49 \ g \cdot 8,48 \times 68666 = 8894,39 \ g$$

$$167 = -165 + 166 = 14,994,06 \ g$$

$$168 = 142 \ 9 \ 114 = -989,45 \ g \cdot 8,48 \times 68666 = -5,761,45 \ g$$

$$169 = 129 \ 9 \ 115 = 1527,49 \ g \cdot 8,48 \times 72697 = 8,416,53 \ g$$

$$170 = -168 - 169 = -3,655,08 \ g$$

$$171 = 144 + 154 + 164 = g(95,248,70 + 1,403,06 + 19,309,86) = 115,961,62 \ g$$





AVRO AIRCRAFT LIMITED

TECHNICAL DEPARTMENT (Aircraft)

REVISION 7-0558-8

SHEET 7425-F8

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$$172 = 145 + 150 + 167 = g(3412.67 + 22,615.63 + 14,994.06) = 41,022.36 \text{ g}$$

$$173 = 7^{150} + 6^{154} - 6^{158} = g(471426 \times 22,615.63 + 5,22570 \times 1403.06 + 4,99408 \times 7356.41) = 15,204.93 \text{ g}$$

$$174 = -146 + 158 + 161 + 170 = g(-36,058.44 - 7356.41 - 79,213.87 - 3,455.08) = -126,283.80 \text{ g}$$

$$175 = 2 \cdot 6^{154} - 7^{158} + 161 + 6^{164} = g(1,44578 \times 1403.06 + 6,9096 \times 86,570.28 + 72289 \times 14,307.86) = 75,804.02 \text{ g}$$

$$176 = 6^{158} + 170 - 7^{150} + 167 = g(-72289 \times 11,011.49 - 6,9096 \times 60,225.32) = -49,573.39 \text{ g}$$

$$177 = Q_6 - Q_3 = 56.4 - 11.32 = 45.08$$

$$178 = 14 + Q_{39} = 44.8 - 2.1 = 42.7$$

$$179 = Q_5 + Q_6 = 17.4 + 19.2 = 36.6$$

$$180 = 6 Q_{39} + 7^{179} = -72289 \times 2.1 + 6,9096 \times 36.6 = 23.77107$$

$$181 = \frac{1}{2 E_{F0} I_{F0_3}} = \frac{1}{2 \times 10^3 \times 2.19} = .22831 \text{ g}$$

$$182 = \frac{Q_3}{2 A_{F0_3} E_{F0}} = \frac{4.32}{2 \times .86 \times 10^3} = 6.58139 \text{ g}$$

$$183 = \frac{Q_3 Q_{F0_3}}{2 A_{F0_3} E_{F0}} = \frac{11.32 \times 1.16}{2 \times .86 \times .4 \times 10^3} = 19.08603 \text{ g}$$

$$184 = 181 Q_3 = .22831 \text{ g} \times 11.32 = 2.584470 \text{ g}$$

$$185 = 184 Q_3 = 2.584470 \text{ g} \times 11.32 = 29.2562 \text{ g}$$

$$186 = 185 \frac{Q_3}{2} + 183 = 29.2562 \times 3.1933 \text{ g} + 19.08603 \text{ g} = 129.4793 \text{ g}$$

$$187 = 184 \frac{178^2}{2} = 2.58447 \text{ g} \times 1823.29 = 4712.24 \text{ g}$$

$$188 = 184 \frac{180^2}{2} = 2.58447 \text{ g} \times 565.0638 = 1460.39 \text{ g}$$

$$189 = 184 \frac{177^2}{2} = 2.58447 \text{ g} \times 2032.2064 = 5252.1765 \text{ g}$$

$$190 = 2 \frac{184}{2} \frac{178}{2} \frac{180}{2} = 5.16894 \times 42.7 \times 23.77107 = 5246.61 \text{ g}$$

$$191 = 2 \frac{184}{2} \frac{178}{2} \frac{177}{2} = 5.16894 \times 42.7 \times 45.08 = 9,949.79 \text{ g}$$

$$192 = 2 \frac{184}{2} \frac{180}{2} \frac{177}{2} = 5.16894 \times 23.77107 \times 45.08 = 5,534.02 \text{ g}$$

$$193 = 185 \frac{178^2}{2} = 29.2562 \text{ g} \times 42.7 = 1249.24 \text{ g}$$

$$194 = 185 \frac{180^2}{2} = 29.2562 \text{ g} \times 23.77107 = 695.45 \text{ g}$$

$$195 = 185 \frac{177^2}{2} = 29.2562 \text{ g} \times 45.08 = 1315.87 \text{ g}$$

$$196 = 185 \frac{177}{2} \frac{178^2}{2} = 29.2562 \text{ g} \times 6,9096 \times 42.7 = 863.17 \text{ g}$$

$$197 = 185 \frac{177}{2} \frac{180^2}{2} = 29.2562 \text{ g} \times 6,9096 \times 23.77107 = 440.53 \text{ g}$$

$$198 = 185 \frac{177}{2} \frac{177^2}{2} = 20.21446 \text{ g} \times 45.08 = 911.29 \text{ g}$$

$$199 = 2 \frac{186}{2} \frac{177}{2} = 2 \times 124.4793 \text{ g} \times 6,9096 = 178.93 \text{ g}$$

$$200 = 186 \frac{177^2}{2} = 129.4793 \text{ g} \times 47.446 = 61.8168 \text{ g}$$

$$201 = 2 \frac{182}{2} \frac{177}{2} = 2 \times 6.58139 \text{ g} \times 72289 = 9.5152 \text{ g}$$

$$202 = 182 \frac{177^2}{2} = 6.58139 \text{ g} \times 522570 = 3.4392 \text{ g}$$

$$203 = 182 + 182 = 4712.24 \text{ g} + 6.58 \text{ g} = 4718.82 \text{ g}$$

$$204 = 182 + 182 + 200 + 202 = g(1440.39 + 480.53 + 61.82 + 3.44) = 2,006.18 \text{ g}$$





ALCO AIRCRAFT LIMITED

TECHNICAL DEPARTMENT (Aircraft)

REPORT NO. 2-0558-8

DATE 742.5 - F9

REMARKS

DATE

147

$$\begin{aligned}
 205 &= 189 + 195 + 186 = q(5252.1765 + 1318.87 + 129.48) = 6700.53 \text{ g} \\
 206 &= 190 + 196 + 201 = q(5246.61 + 863.17 + 9.52) = 6119.30 \text{ g} \\
 207 &= -191 - 193 = q(-9,949.79 - 1249.24) = -11,199.03 \text{ g} \\
 208 &= -192 - 194 - 198 - 199 = q(-5539.02 - 695.45 - 911.29 - 178.93) = -7324.69 \text{ g} \\
 209 &= 85 + 111 + 171 + 203 = q(4777.07 + 33,787.51 + 115,961.62 + 4718.82) = 159,245.02 \text{ g} \\
 210 &= 173 + 304 = q(15,204.93 + 2006.18) = 17,211.11 \text{ g} \\
 211 &= 59 + 113 + 173 + 205 = q(18.35 + 922.36 + 41,022.36 + 6700.53) = 48,173.62 \text{ g} \\
 212 &= 125 + 206 = q(75,804.02 + 6,119.30) = 81,923.32 \text{ g} \\
 213 &= 59 + 112 + 174 + 207 = q(132.44 - 6027.44 - 126,283.80 - 11,199.03) = -143,377.83 \text{ g} \\
 214 &= 126 + 208 = q(-49,573.39 - 7,324.69) = -56,898.08 \text{ g} \\
 300 &= 209 + 46 = q(159,245.02 + 101.95) = 159,346.97 \text{ g} \\
 301 &= 210 = 34,422.22 \text{ g} \\
 302 &= 216 = 914,1040 \text{ g} \\
 303 &= 227 = 23,9786 \text{ g} \\
 304 &= 230 = 318,693.94 \text{ g} \\
 305 &= 211 = 96,347.24 \text{ g} \\
 306 &= 248 = 6739.50 \text{ g}
 \end{aligned}$$

$$\begin{aligned}
 UP_1^2 &= +301 = 34,422.22 \\
 +218 \ 214 &= 2 \times 35191(-56,898.08 \text{ g}) = -40,046.01 \\
 +305 (18^2 + 20^2) &= 96,347.24 \text{ g} (123841 + 114965) = 23,007.34 \\
 -2 \ 6 \ 24 \ 213 &= -2 \times 72289(-143,377.83) \text{ g} = -70,282.62 \\
 +6^2 \ 304 &= 522570 \times 318,693.94 \text{ g} = 166,539.89 \\
 -2 \ 6 \ 47 \ 52 &= -1.44578 \times 1034.5178 \text{ g} \times 0.06178 = -92.40 \\
 +306 (44^2 + 52^2) &= 6739.5 \text{ g} (100351677 \times 2) = 57.45 \\
 &= 113,599.87 \text{ g}
 \end{aligned}$$

$$\begin{aligned}
 UP_2 &= +214 (19 + 24) = -56,898.08 \text{ g} (-119305 \times 2) = 38,582.59 \\
 +205 (1819 + 2324) &= 96,347.24 \text{ g} (-119315 \times 2) = -22,991.34 \\
 -6 \ 213 (33 + 24) &= -72289 (-143,377.83) (01286) = 1,332.89 \\
 +6^2 \ 304 &= 166,539.89 \\
 -6 \ 312 &= -72289 \times 81,923.32 = -59,221.55 \\
 -6 \ 47 (52 + 53) &= -2 \ 6 \ 47 \ 52 = -92.40 \\
 +306 (44^2 + 52^2) &= 306 (44^2 + 52^2) = 57.45 \\
 &= 124,201.53 \text{ g}
 \end{aligned}$$



VICKERS AIRCRAFT LIMITED

## TECHNICAL DEPARTMENT (Aircraft)

SHEET NO.

Neglecting strain  
energy of struts and  
spar.

7-0558-B

742.5-FYA

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$$\begin{aligned}
 205 &= 189 + 195 + 186 = \text{Same} \\
 206 &= 190 + 196 + 201 = \\
 207 &= -191 - 193 = \\
 208 &= -192 - 194 - 198 - 199 = \\
 209 &= 85 + 111 + 171 + 203 = \\
 210 &= 173 + 204 = \\
 211 &= 59 + 113 + 172 + 205 = \\
 212 &= 175 + 206 = \text{Same} \\
 213 &= 58 + 112 + 174 + 207 = \text{Same} \\
 214 &= 176 + 208 = \text{Same} \\
 300 &= 209 + 46 = 209 = 158,245.02 \text{ g} \\
 301 &= 2 \cdot 210 = \text{Same} \\
 302 &= 2 \cdot 26 = 0 \\
 303 &= 2 \cdot 27 = 0 \\
 304 &= 2 \cdot 300 = 318,490.04 \text{ g} \\
 305 &= 2 \cdot 211 = \text{Same} \\
 306 &= 2 \cdot 46 = 0
 \end{aligned}$$

$$\begin{aligned}
 UP_1^2 &= +301 = \checkmark \\
 &+ 2 \cdot 18 \cdot 214 = \checkmark \\
 &+ 305 (18^2 + 214^2) = \checkmark \\
 &- 2 \cdot 6 \cdot 24 \cdot 213 = \checkmark \\
 &+ 6^2 \cdot 304 = .522570 \times 318,490.04 \\
 &- 2 \cdot 6 \cdot 47 \cdot 52 = \\
 &+ 306 (47^2 + 52^2) =
 \end{aligned}$$

$$\begin{aligned}
 UPP_2 &= +214 (19 + 24) = \checkmark \\
 &+ 205 (1819 + 3224) = \checkmark \\
 &- 6 \cdot 213 (23 + 24) = \checkmark \\
 &+ 6^2 \cdot 304 = \\
 &- 6 \cdot 47 \cdot 52 = \checkmark \\
 &- 6 \cdot 47 (52 + 53) = \\
 &+ 306 (47 \cdot 50 + 52 \cdot 53) =
 \end{aligned}$$

$$\begin{aligned}
 0 &= A_{ST} = A_{SP} = I_{SP} \\
 0 &= 26 = 27 = 302 = 303 \\
 &= 32 = 33 = 34 \\
 &= 46 = 47 = 48 \\
 &= 306
 \end{aligned}$$

$$\begin{aligned}
 &= 34,422.22 \\
 &= -40,046.01 \\
 &= 23,007.34 \\
 &= -70,282.62 \\
 &= 166,433.34 \\
 &= \\
 &= \\
 &= 113,534.27 \text{ g}
 \end{aligned}$$

$$\begin{aligned}
 &= 38,582.59 \\
 &= -22,991.34 \\
 &= 1332.89 \\
 &= 166,433.34 \\
 &= -59,221.55 \\
 &= \\
 &= \\
 &= 124,125.93 \text{ g}
 \end{aligned}$$



AERO AIRCRAFT LIMITED

## TECHNICAL DEPARTMENT (Aircraft)

REPORT NO. 7-0558-8

SHEET NO. 742.5 - F10

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$$\begin{aligned}
 \underline{UPQ}_1 &= +20 \ 214 &= .3968085 (-56,898,05) &= -22,577.64 \\
 &+20 \ 305 (18+24) &= .3968085 \times 96,347.24 \times .01286 &= 491.66 \\
 &+213 (24-6 \ 20) &= -143,377.83 (-37905 - .72289 \times .3968085) &= 89,740.04 \\
 &-6 \ 204 &= -.72289 \times 318,693.84 &= -230,380.66 \\
 &-47 (6 \ 51-52) &= -1034.5178 (-72289 \times .08546 - .06178) &= 127.83 \\
 &+306 \ 51 (49+52) &= 6739.5 (-.08546 \times .06178 \times 2) &= -71.17 \\
 &&&= -162,667.94 \text{ g}
 \end{aligned}$$

$$\begin{aligned}
 \underline{UPQ}_2 &= +6 \ 13 \ 47 &= .72289 \times .00886524 \times 1034.5178 &= 6.62805 \\
 &-13 \ 306 (49+52) &= -.07486524 \times 6739.5 \times .12356 &= -7.382378 \\
 &&&= .752573 \text{ g}
 \end{aligned}$$

$$\begin{aligned}
 \underline{UPR}_1 &= 20 \ 214 &= &= -22,577.64 \\
 &+20 \ 305 (18+24) &= &= 491.66 \\
 &+213 (24-6 \ 20) &= &= 89,740.04 \\
 &-6 \ 204 &= &= -230,380.66 \\
 &-47 (6 \ 20-52) &= -1034.5178 (.72289 \times .3968085 - .06178) &= -232.84 \\
 &+20 \ 306 (49+52) &= .3968085 \times 6739.5 \times .12356 &= 330.44 \\
 &&&= -162,629.00 \text{ g}
 \end{aligned}$$

$$\begin{aligned}
 \underline{UPR}_2 &= -5 \ 214 &= &= 28,449.04 \\
 &-5 \ 305 (18-24) &= -48,123.62 (35191 + .37905) &= -33,286.04 \\
 &-5 \ 6 \ 213 &= -361445 (-143,377.83) &= 51,823.20 \\
 &-5 \ 6 \ 47 &= -361445 \times 1034.5178 &= -373.92 \\
 &-5 \ 306 (49-52) &= &= 0.0 \\
 &&&= 46,612.28 \text{ g}
 \end{aligned}$$

$$\begin{aligned}
 \underline{UPR}_3 &= +212 &= &= 81,923.32 \\
 &+213 (18-24) &= -143,377.83 \times .69086 &= -99,068.35 \\
 &+6 \ 304 &= &= 230,380.66 \\
 &+47 (49-52) &= &= 0.0 \\
 &&&= 213,235.63 \text{ g}
 \end{aligned}$$









AERO AIRCRAFT LIMITED

## TECHNICAL DEPARTMENT (Aircraft)

AIRCRAFT

REPORT NO 7-0558-B

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$$\underline{UP_2^1} = + 301$$

$$+ 2 \ 23 \ 214$$

$$- 2 \ 6 \ 212$$

$$+ 305 (19^2 + 23^2)$$

$$- 2 \ 6 \ 23 \ 213$$

$$+ 6^2 \ 204$$

$$- 2 \ 6 \ 47 \ 53$$

$$+ 306 (50^2 + 53^2)$$

$$= 34,422.22$$

$$= - 40,046.01$$

$$= - 118,443.10$$

$$= 23,007.34$$

$$= 72,948.35$$

$$= 166,433.34$$

$$=$$

$$= 138,322.14 \text{ g}$$

$$\underline{UP_2 Q_1} = + 20 \ 214$$

$$+ 212$$

$$+ 20 \ 305 (19 + 23)$$

$$+ 213 (23 - 6 \ 20)$$

$$- 6 \ 304$$

$$- 47 (6 \ 51 - 53)$$

$$+ 51 \ 306 (50 + 53)$$

$$= - 22,577.64$$

$$= 81,923.32$$

$$= 491.66$$

$$= - 9,328.15$$

$$= - 230,233.27$$

$$=$$

$$= - 179,724.08 \text{ g}$$

$$\underline{UP_2 Q_2} = + 6 \ 13 \ 47$$

$$- 13 \ 306 (50 + 53)$$

$$=$$

$$=$$

$$\underline{UP_2 R_1} = + 20 \ 214$$

$$+ 212$$

$$+ 20 \ 305 (19 + 23)$$

$$+ 213 (23 - 6 \ 20)$$

$$- 6 \ 304$$

$$- 47 (6 \ 20 - 53)$$

$$+ 20 \ 306 (50 + 53)$$

$$= - 22,577.64$$

$$= 81,923.32$$

$$= 491.66$$

$$= - 9,328.15$$

$$= - 230,233.27$$

$$=$$

$$= - 179,724.08 \text{ g}$$

$$\underline{UP_2 R_2} = + .5 \ 214$$

$$- .5 \ 305 (19 - 23)$$

$$- .5 \ 6 \ 213$$

$$- .5 \ 6 \ 47$$

$$- .5 \ 306 (50 - 53) \times$$

$$= - 28,449.04$$

$$= 33,286.04$$

$$= 51,823.20$$

$$=$$

$$= 56,660.20$$

2786

AERO AIRCRAFT LIMITED

TECHNICAL DEPARTMENT (Aircraft)

REPORT NO. 7-0558-8

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$$\begin{aligned} U_{R_2} R_3 &= -212 &= &= -81,923.32 \\ &+ 213 (19-23) &= &= -143,377.83 (-.64096) \\ &+ 6 \underline{304} &= &= 230,280.66 \\ &+ 47 (50-53) &= &= 0.0 \\ &&&= 247,525.67 \text{ g} \end{aligned}$$

$$\begin{aligned} U_{Q_1}^L &= 2 \underline{20}^2 \underline{305} &= &= 2 \times .3968085^2 \times 96,347.24 &= &= 30,341.09 \\ &+ 2 \underline{20} \underline{213} &= &= 2 \times .3968085 (-143,377.83) &= &= -113,797.08 \\ &+ \underline{304} &= &= &= &= 318,693.94 \\ &+ 2 \underline{47} \underline{51} &= &= 2 \times 1034.5178 (-.08546) &= &= -176.82 \\ &+ 2 \underline{51}^2 \underline{306} &= &= 2 \times .08546^2 \times 6739.50 &= &= 88.44 \\ &&&&&= 235,164.57 \text{ g} \end{aligned}$$

$$\begin{aligned} U_{Q_1} Q_2 &= -13 \underline{47} &= &= -.00886524 \times 1034.5178 &= &= -9.171249 \\ &- 212 \underline{51} \underline{306} &= &= -2 \times .00886524 (-.08546) (6739.5) &= &= 10,212.007 \\ &&&&&= 1.040758 \text{ g} \end{aligned}$$

$$\begin{aligned} U_{Q_1} R_1 &= 2 \underline{20}^2 \underline{305} &= &= &= &= 30,341.09 \\ &+ 2 \underline{20} \underline{213} &= &= &= &= -113,797.08 \\ &+ \underline{304} &= &= &= &= 318,693.94 \\ &+ \underline{47} (29+51) &= &= 1034.5178 (.3968085 - .08546) &= &= 322.10 \\ &+ 2 \underline{20} \underline{51} \underline{306} &= &= 2 \times .3968085 (-.08546) (6739.5) &= &= -457.09 \\ &&&&&= 235,112.76 \text{ g} \end{aligned}$$

$$\begin{aligned} U_{Q_1} R_2 &= .5 \underline{213} &= &= &= &= -71,688.92 \\ &+ .5 \underline{47} &= &= &= &= 517.26 \\ &&&&&= -71,171.66 \text{ g} \end{aligned}$$

$$U_{Q_1} R_3 = -304 = -318,693.94 \text{ g}$$

$$U_{Q_2}^L = 2 \underline{13}^2 \underline{306} = 2 \times .00886524^2 \times 6739.5 = 1.057348 \text{ g}$$

$$\begin{aligned} U_{Q_2} R_1 &= -2 \underline{13} \underline{20} \underline{306} &= &= -2 \times .00886524 \times .3968085 \times 6739.5 &= &= -47.416461 \\ &- \underline{13} \underline{47} &= &= -.00886524 \times 1034.5178 &= &= -4.171249 \\ &&&&&= -56.587710 \text{ g} \end{aligned}$$

$$U_{Q_2} R_2 = 0 = U_{Q_2} R_3$$

17885

UKO AIRCRAFT LIMITED

TECHNICAL DEPARTMENT Aircraft

AIRCRAFT

REPORT NO. 70553-8

SHEET 742.5 - F12A

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$$\begin{aligned} \underline{UR_1} &= -212 = \\ &+ 213 (19-23) = \\ &+ 6 \underline{304} = \\ &+ 47 (50-53) = \end{aligned}$$

$$\begin{aligned} &= -81,923.32 \\ &= 99,068.35 \\ &= 230,233.27 \\ &= \\ &247,978.30 g \end{aligned}$$

$$\begin{aligned} \underline{UR_1^t} &= 2 \underline{20^2 305} = \\ &+ 2 \underline{20 213} = \\ &+ \underline{304} = \\ &+ 2 \underline{47 51} = \\ &+ 2 \underline{51^2 306} = \end{aligned}$$

$$\begin{aligned} &= 30,341.09 \\ &= -113,787.08 \\ &= 318,490.04 \\ &= \\ &= \\ &235,044.05 g \end{aligned}$$

$$\begin{aligned} \underline{UR_2} &= -13 \underline{47} = \\ &- 213 \underline{51 306} = \end{aligned}$$

$$\begin{aligned} &= \\ &= \\ &= \end{aligned}$$

$$\begin{aligned} \underline{UR_1} &= 2 \underline{20^2 305} = \\ &+ 2 \underline{20 213} = \\ &+ \underline{304} = \\ &+ 47 (20+51) = \\ &+ 2 \underline{20 51 306} = \end{aligned}$$

$$\begin{aligned} &= 30,341.09 \\ &= -113,787.08 \\ &= 318,490.04 \\ &= \\ &= \\ &235,044.05 g \end{aligned}$$

$$\begin{aligned} \underline{UR_2} &= .5 \underline{213} = \\ &+ .5 \underline{47} = \end{aligned}$$

$$\begin{aligned} &= -71,688.92 \\ &= \\ &= -71,688.72 g \end{aligned}$$

$$\underline{UR_1 R_3} = -304 = -318,490.04$$

$$\underline{UR_2^t} = 2 \underline{13^2 306} = 0$$

$$\begin{aligned} \underline{UR_2 R_1} &= -2 \underline{13 20 306} = \\ &- 13 \underline{47} = \end{aligned}$$

$$\begin{aligned} &= \\ &= \\ &= \end{aligned}$$

$$\underline{UR_2 R_2} = 0 = \underline{UR_2 R_3}$$

2085

100 AIRMAIL LIMITED

TECHNICAL DEPARTMENT Aircraft

7-0558-8

742.5 - F13

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$$\begin{aligned} \underline{UR_1^2} &= + 302 = \\ &+ 2 \underline{20^2 305} = \\ &+ 2 \underline{20 213} = \\ &+ 304 = \\ &+ 2 \underline{20 47} = 2 \times .3968085 \times 1034.5128 \\ &+ 2 \underline{20^2 306} = 2 \times .3968085^2 \times 6737.5 \end{aligned}$$

$$\begin{aligned} &= 914.10 \\ &= 30,341.09 \\ &= -113,757.08 \\ &= 318,693.94 \\ &= 821.01 \\ &= 2,122.36 \\ &237,105.42 g \end{aligned}$$

$$\underline{UR_1 R_2} = +.5(213 + 47) = -71,171.66 g$$

$$\underline{UR_1 R_3} = -304 = -318,693.94 g$$

$$\begin{aligned} \underline{UR_2^2} &= + 303 = \\ &+.5(305 + 306) = .5(103, 046.74) \end{aligned}$$

$$\begin{aligned} &= 23.98 \\ &= 51,543.37 \\ &51,567.35 g \end{aligned}$$

$$\underline{UR_2 R_3} = -213 - 47 = 142,343.31 g$$

$$\underline{UR_3^2} = 2 \underline{304} = 637,387.88 g$$

$$\begin{aligned} 0 &= u_1 + \underline{UR_1^2 R_1} + \underline{UR_1 R_2 R_2} + \underline{UR_1 R_3 R_3} \\ 0 &= u_2 + \underline{UR_2^2 R_1} + \underline{UR_2^2 R_2} + \underline{UR_2 R_3 R_3} \\ 0 &= u_3 + \underline{UR_3^2 R_1} + \underline{UR_3^2 R_2} + \underline{UR_3^2 R_3} \end{aligned} \quad \left. \begin{aligned} & \\ & \\ & \end{aligned} \right\} u_i = \underline{UR_i P_1 P_1} + \underline{UR_i P_2 P_2} + \underline{UR_i Q_1 Q_1} + \underline{UR_i Q_2 Q_2}$$

$$0 = u_1 + .023910542 R_1 - .007117166 R_2 - .031569394 R_3$$

$$0 = u_2 - .007117166 R_1 + .005156735 R_2 + .014234331 R_3$$

$$0 = u_3 - .031865944 R_1 + .014234331 R_2 + .063734788 R_3$$

$$0 = 41.82256 u_1 + R_1 - .2976581 R_2 - 1.3320596 R_3$$

$$0 = 140.50536 u_2 - R_1 + .724544 R_2 + 2.000000 R_3$$

$$0 = -31.37810 u_3 + R_1 - .446646 R_2 - 2.000000 R_3$$

$$.277903 R_2 = -140.50536 u_2 + 31.3781 u_3$$

$$R_2 = -505.5914 u_2 + 112.9103 u_3$$

2486

AERO AIRCRAFT LIMITED

TECHNICAL DEPARTMENT (Aircraft)

AIRCRAFT

REPORT NO. 7-0558-8

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$$\begin{aligned} \underline{UR_1^2} &= + \underline{302} = \\ &+ 2 \underline{20^2 305} = \\ &+ 2 \underline{20 213} = \\ &+ \underline{304} = \\ &+ 2 \underline{20 47} = \\ &+ 2 \underline{20^2 306} = \end{aligned}$$

$$\begin{aligned} &= \underline{\hspace{2cm}} \\ &= 30,341.09 \\ &= -113,787.08 \\ &= 318,490.04 \\ &= \underline{\hspace{2cm}} \\ &= 235,044.05 g \end{aligned}$$

$$\underline{UR_1 R_2} = +.5(\underline{313} + \underline{47}) = .5 \underline{213}$$

$$= -71,688.92 g$$

$$\underline{UR_1 R_3} = -\underline{304} = -318,490.04 g$$

$$\begin{aligned} \underline{UR_2^2} &= + \underline{303} = \\ &+ .5(\underline{305} + \underline{306}) = .5 \underline{305} \end{aligned}$$

$$\begin{aligned} &= \underline{\hspace{2cm}} \\ &= 48,173.62 \\ &= 48,173.62 g \end{aligned}$$

$$\underline{UR_2 R_3} = -\underline{213} - \underline{47} = -\underline{213}$$

$$= 143,377.83 g$$

$$\underline{UR_3^2} = 2 \underline{304} = 636,980.08 g$$

$$\begin{aligned} 0 &= u_1 + \underline{UR_1^2 R_1} + \underline{UR_1 R_2 R_2} + \underline{UR_1 R_3 R_3} \\ 0 &= u_2 + \underline{UR_2 R_1 R_1} + \underline{UR_2^2 R_2} + \underline{UR_2 R_3 R_3} \\ 0 &= u_3 + \underline{UR_3 R_1 R_1} + \underline{UR_3 R_2 R_2} + \underline{UR_3^2 R_3} \end{aligned}$$

$$u_i = \underline{UR_i P_i P_i} + \underline{UR_i P_i R_2} + \underline{UR_i Q_i Q_i} + \underline{UR_i Q_i Q_2}$$

$$0 = u_1 + .023504405 R_1 - .007168892 R_2 - .031849004 R_3$$

$$0 = u_2 - .007168892 R_1 + .004817362 R_2 + .014337783 R_3$$

$$0 = u_3 - .031849004 R_1 + .014337783 R_2 + .063698008 R_3$$

$$0 = 42.54521 u_1 + R_1 - .3050020 R_2 - 1.3550226 R_3$$

$$0 = 139.4915 u_2 - R_1 + .6719811 R_2 + 2.0000000 R_3$$

$$0 = -31.39815 u_3 + R_1 - .4501799 R_2 - 2.0000000 R_3$$

$$.2218012 R_2 = -139.4915 u_2 + 31.39815 u_3$$

$$R_2 = -628.9032 u_2 + 141.55987 u_3$$



7425

AERO AIRCRAFT LIMITED

TECHNICAL DEPARTMENT (Aircraft)

7-0558-8

742.5 - F138

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Same as 742.5-A except  
that struts have zero  
stiffness.  
 $\infty = 26 = 27 = 302 = 303$

$$\underline{UR_1^2} = + 302 = \infty$$

$$+ 2 \ 20^2 \ 305 =$$

$$+ 2 \ 20 \ 213 =$$

$$+ 304 =$$

$$+ 2 \ 20 \ 47 =$$

$$+ 2 \ 20^2 \ 306 =$$

$$= \infty$$

$$=$$

$$=$$

$$=$$

$$=$$

$$=$$

$$=$$

$$\infty$$

$$\underline{UR_1 R_2} = +.5(213 + 47) = -71,688.92 \ g$$

$$\underline{UR_1 R_3} = -304 = -318,490.04$$

$$\underline{UR_2^2} = + 303 = \infty$$

$$+.5(305 + 306) =$$

$$= \infty$$

$$=$$

$$=$$

$$\infty$$

$$\underline{UR_2 R_3} = -213 - 47 = 143,327.53 \ g$$

$$\underline{UR_3^2} = 2 \ 304 = 636,980.08 \ g$$

$$0 = u_1 + \underline{UR_1^2} R_1 + \underline{UR_1 R_2} R_2 + \underline{UR_1 R_3} R_3$$

$$0 = u_2 + \underline{UR_2 R_1} R_1 + \underline{UR_2^2} R_2 + \underline{UR_2 R_3} R_3$$

$$0 = u_3 + \underline{UR_3 R_1} R_1 + \underline{UR_3 R_2} R_2 + \underline{UR_3^2} R_3$$

$$u_i = \underline{UR_i P_1} + \underline{UR_i R_2} + \underline{UR_i Q_3} + \underline{UR_i Q_4}$$

$$0 = u_1 + \infty R_1 - .007168892 R_2 - .031849004 R_3$$

$$\therefore R_1 = 0$$

$$0 = u_2 - .007168892 R_1 + \infty R_2 + .0143327783 R_3$$

$$\therefore R_2 = 0$$

$$0 = u_3 - .031849004 R_1 + .0143327783 R_2 + .063698008 R_3$$

$$\therefore R_3 = -15.69907 u_3$$

$$= -15.69907 (.021308824 P_1 + .024777830 P_2 - .031849004 Q_1)$$

$$= -.3345287 P_1 - .3883609 P_2 + .5000000 Q_1$$

Next page is 742.5-F15B



AVRO AIRCRAFT LIMITED

## TECHNICAL DEPARTMENT (Aircraft)

AIRCRAFT

REPORT NO. 7-0558-8

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$$-41.22256 U_1 - 140.52536 U_2 - .426891 R_2 = .6671404 R_3$$

$$\begin{aligned} R_3 &= -62.68933 U_1 - 210.60850 U_2 - .639882 R_2 \\ &= -62.68933 U_1 - 210.60850 U_2 + 323.51884 U_2 - 72.24927 U_3 \\ &= -62.68933 U_1 + 112.91034 U_2 - 72.24927 U_3 \end{aligned}$$

$$\begin{aligned} P_1 &= 31.37810 U_3 + .446646 R_2 + 2 R_3 \\ &= \phantom{31.37810 U_3 + .446646 R_2 + 2 R_3} + 31.37810 U_3 \\ &\phantom{= } - 225.82038 U_2 + 50.43093 U_3 \\ &= -125.37866 U_1 + 225.82068 U_2 - 144.49854 U_3 \\ &= -125.37866 U_1 + .00030 U_2 - 62.68950 U_3 \end{aligned}$$

$$\begin{aligned} U_1 &= -.016262900 P_1 - .017977387 P_2 + .023511296 Q_1 - .000005658771 Q_2 \\ U_2 &= .004661228 P_1 + .005628628 P_2 - .007117166 Q_1 \\ U_3 &= .021232563 P_1 + .024752569 P_2 - .031869394 Q_1 \end{aligned}$$

$$\begin{aligned} P_1 &= 2.039021 P_1 + 2.253981 P_2 - 2.947815 Q_1 + .000709489 Q_2 & ++-+ \\ &+ .000001 P_1 + .000001 P_2 - .000002 Q_1 & +- -0 \\ &- 1.336764 P_1 - 1.551726 P_2 + 1.997876 Q_1 & --+0 \\ &= .702258 P_1 + .702256 P_2 - .949939 Q_1 + .000709489 Q_2 \end{aligned}$$

$$\begin{aligned} P_2 &= -2.356677 P_1 - 2.845786 P_2 + 3.598338 Q_1 & --+0 \\ &+ 2.407650 P_1 + 2.794820 P_2 - 3.598383 Q_1 & +- -0 \\ &= .050973 P_1 - .050966 P_2 \end{aligned}$$

$$\begin{aligned} R_3 &= 1.019510 P_1 + 1.126990 P_2 - 1.473907 Q_1 + .000354745 Q_2 & ++++ \\ &+ .526301 P_1 + .635530 P_2 - .803602 Q_1 & +- -0 \\ &- 1.540612 P_1 - 1.788355 P_2 + 2.302540 Q_1 & --+0 \\ &= .005199 P_1 - .025835 P_2 + .025031 Q_1 + .000354745 Q_2 \end{aligned}$$



AVRO AIRCRAFT LIMITED

## TECHNICAL DEPARTMENT (Aircraft)

REPORT NO. 7-0558-8

SHEET NO. 7425-F14A

AIRCRAFT:

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$$-42.54521 U_1 - 139.4915 U_2 - .3669791 R_2 = .6449774 R_3$$

$$\begin{aligned} R_3 &= -65.96384 U_1 - 216.27334 U_2 - .5689794 R_2 \\ &= -65.96384 U_1 - 216.27334 U_2 + 357.83297 U_2 - 80.54465 U_3 \\ &= -65.96384 U_1 + 141.55963 U_2 - 80.54465 U_3 \end{aligned}$$

$$\begin{aligned} R_1 &= 31.39815 U_3 + .4501799 R_2 + 2 R_3 \\ &= \quad \quad \quad + 31.39815 U_3 \\ &\quad \quad \quad - 283.11958 U_2 + 63.727408 U_3 \\ &\quad - 131.92768 U_1 + 283.11926 U_2 - 161.089300 U_3 \\ &= -131.92768 U_1 - .00032 U_2 - 65.96374 U_3 \end{aligned}$$

$$\begin{aligned} U_1 &= -.016257921 P_1 - .017972408 P_2 + .023504405 Q_1 \\ U_2 &= .004698620 P_1 + .005666020 P_2 - .007168892 Q_1 \\ U_3 &= .021308824 P_1 + .024737830 P_2 - .031849004 Q_1 \end{aligned}$$

$$\begin{aligned} R_1 &= +2.144870 P_1 + 2.371058 P_2 - 3.100882 Q_1 \\ &\quad - .000001 P_1 - .000001 P_2 + .000002 Q_1 \\ &\quad - 1.405610 P_1 - 1.631800 P_2 + 2.100879 Q_1 \\ &= .739259 P_1 + .739257 P_2 - 1.000001 Q_1 \end{aligned}$$

$$\begin{aligned} R_2 &= -2.954977 P_1 - 3.563378 P_2 + 4.508539 Q_1 \\ &\quad + 3.016474 P_1 + 3.501884 P_2 - 4.508541 Q_1 \\ &= .061497 P_1 - .061494 P_2 \end{aligned}$$

$$\begin{aligned} R_3 &= +1.072435 P_1 + 1.185528 P_2 - 1.550441 Q_1 \\ &\quad + .665735 P_1 + .802080 P_2 - 1.014826 Q_1 \\ &\quad - 1.716312 P_1 - 1.992500 P_2 + 2.565267 Q_1 \\ &= .021258 P_1 - .004892 P_2 \end{aligned}$$









AVRO AIRCRAFT LIMITED

## TECHNICAL DEPARTMENT (Aircraft)

AIRCRAFT

REVISION NO. 7-0558-B

PROJECT NO. 742.5 - F15B

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$$\begin{aligned}\delta_1 &= \frac{UP_1^2}{P_1} + \frac{UP_1 P_2}{P_1} + \frac{UP_1 Q_1}{P_1} + \frac{UP_1 Q_2}{P_1} + \frac{UP_1 R_1}{P_1} + \frac{UP_1 R_2}{P_1} + \frac{UP_1 R_3}{P_1} \\ \delta_2 &= \frac{UP_2^2}{P_2} + \frac{UP_2^2}{P_2} + \frac{UP_2 Q_1}{P_2} + \frac{UP_2 Q_2}{P_2} + \frac{UP_2 R_1}{P_2} + \frac{UP_2 R_2}{P_2} + \frac{UP_2 R_3}{P_2} \\ \delta_3 &= \frac{UP_3^2}{P_3} + \frac{UP_3 Q_1}{P_3} + \frac{UP_3 Q_2}{P_3} + \frac{UP_3 R_1}{P_3} + \frac{UP_3 R_2}{P_3} + \frac{UP_3 R_3}{P_3} \\ \delta_4 &= \frac{UP_4^2}{P_4} + \frac{UP_4 Q_1}{P_4} + \frac{UP_4 Q_2}{P_4} + \frac{UP_4 R_1}{P_4} + \frac{UP_4 R_2}{P_4} + \frac{UP_4 R_3}{P_4}\end{aligned}$$

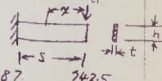
$$\begin{aligned}\delta_1 &= +.011358427 P_1 + .012413593 P_2 - .016257921 Q_1 \\ &\quad - .007128413 P_1 - .008275514 P_2 + .010654412 Q_1 \\ &= .00422501 P_1 + .004138079 P_2 - .005603509 Q_1\end{aligned}$$

$$\begin{aligned}\delta_2 &= .012413593 P_1 + .013832214 P_2 - .017972408 Q_1 \\ &\quad - .008275514 P_1 - .009607206 P_2 + .012368915 Q_1 \\ &= .004138079 P_1 + .00422501 P_2 - .005603493 Q_1\end{aligned}$$

$$\begin{aligned}\delta_3 &= -.016257921 P_1 - .017972408 P_2 + .023504405 Q_1 \\ &\quad + .010654406 P_1 + .012368908 P_2 - .015924502 Q_1 \\ &= -.005603515 P_1 - .005603500 P_2 + .007579903 Q_1\end{aligned}$$

Check: 1. When  $P_1 = P_2 = P$ , and  $Q_1 = Q_2 = 0$ ,  $\delta_1 = .00836309 P$  (119.6 #/in.)  
 $-P_1 = P_2 = -P$ ,  $Q_1 = Q_2 = 0$ ,  $\delta_1 = .000086931 P$  (11.503 #/in.)

2. When  $P_1 = P_2 = P$ , and  $Q_1 = Q_2 = 0$ ,  $Q_1 = 1.47452 P$   
 then,  $\delta_1 = (.00836309 - .00825490) P = .00000819 P$  (12.789 #/in.)

3. If  $-Q_1$  is the force at the end of a cantilever beam,   
 $\alpha = \frac{A}{I} \int y dA = \frac{h}{12} \times \frac{b}{2} \times \frac{h}{2} = 1.5$ ;  $S = 55.5$ "  
 $M = Q_1 x$   
 $U = \int_0^S \left\{ \frac{Q_1^2 x^2}{2EI} + \frac{Q_1^2}{2AG} \right\} dx = Q_1^2 \left( \frac{S^3}{6EI} + \frac{S}{2AG} \right)$  Suppose  $h = 2(a_1 + a_2) = 61$ "  
 and  $t = .031$ "  
 $\frac{\partial U}{\partial Q} = -\delta_3 = Q_1 \left( \frac{S^3}{3EI} + \frac{S}{AG} \right) = Q_1 \left( \frac{12 \times 55.5^3 \times 32}{3 \times 10^6 \times 61^3} + \frac{1.5 \times 55.5}{52 \times .4 \times 10^6} \right) = .00002056 Q_1$   
 $.0000096405 + .000109180$

Then  $-.0112070 P = -.007579903 Q_1 - .00002056 Q_1 = -.007600463 Q_1$   
 $Q_1 = 1.474516 P$

Then,  $\delta_1 = (.00836309 P - .00826246 P) = .00010063 P$  (9.937 #/in.)





