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VOLUME III

SECTION 2 OF 2

OPTIMIZATION OF HYDRAULIC THRUST VECTOR CONTROL SYSTEMS FOR LAUNCH VEHICLES

JANUARY, 1965

THE MARTIN-MARIETTA CORPORATION
DENVER DIVISION
POST OFFICE BOX 179
DENVER 1, COLORADO

D

IN-LINE PUMP AND INTENSIFIER

PW-6

IN-LINE PUMP

(See Description proceeding the Fixed Angle Pump Equations).

96-01 (8-64)

EQUATIONS

ITEM NAME: Pump Cylinder Block Fixed Wobble Plate

SYMBOL: P W B B

REQUIRED INPUTS: PRES, FLOW, PUMS, ANGL

REQUIRED OUTPUTS: PWBBP, PWBBJ, PWBBX, PWBBI, PWBBK

OUTPUTS:

STANDARD

Weight	PWBBW	=	.199*(((PWBBI**2.0) - .760*(PWBBP**2.0))*PWBBX-(95.5*(PWBBP**3.0)-13.5*(PWBBP**2.0)-3.08*PWBBP+.438)*TANA-9.0*PWBBX*(PWBBP**2.0))
Reliability $^{-1}$	PWBBR	=	1.74E-5.*PWBBP*TANF(ANGL)*PRES**2./FLOW
Life	L	=	
Response	S	=	
Cont. Oper. Time	O	=	
Devel. Time	T	=	
Devel. Cost	D	=	
Unit Cost	U	=	

OTHER

Cylinder Dia.	PWBBP	=	See Array page 5
Cyl. Location Dia.	PWBBJ	=	2.9*PWBBP+.523
Block Length	PWBBX	=	5.57*((2.9*PWBBP)+.523)*TANF(ANGL)
Block O.D.	PWBBI	=	PWBBP*(3.98+(2.46E-4*PRES))+.523
Block I.D.	PWBBK		.84*PWBBP

NOTES:

PW-1

ANALYSIS BY: C. E. Jones CHECKED BY: D. A. Tommaten

DERIVATION OF EQUATIONS

ITEM NAME: Pump Cylinder Block Fixed Wobble Plate

SYMBOL P W B B

The size of the cylinder block will be governed by the piston diameter and stroke. The stroke will depend on the piston diameter and the pump angle. The piston diameter will depend on the flow and pressure requirements and on the speed and angle of the pump.

The pump flow will equal the pump displacement minus leakage and compliance factors.

The equation for pump flow may be written as:

$$Q_{net} = Q_{total} - Q_{leakage} - Q_{compression}$$

Total flow

$$Q_{total} = \frac{9\pi}{4} \text{ PUMS (Diameter)}^2 \text{ (Stroke)}$$

<u>CYLINDER BASE DIAMETER</u>

The cylinder base diameter will equal the sum of the cylinder diameters and wall thickness. The wall thickness will not be proportional to the cylinder diameter and pressure since the minimum wall thickness will be governed by the clearance necessary to mount the compensator assembly.

The wall thickness between the cylinder walls will be constant and thus the cylinder base diameter will be 9 (diameter + wall)

Or

$$PWBBJ = K_1 \text{ (PWBBP+wall)}$$

ANALYSIS BY: C. E. Jones CHECKED BY: D. A. Tommater

For

$$PWBBP = .595, \quad PWBBJ = 2.25, \quad Wall = .180$$

$$K_1 = \frac{2.25}{.775} = 2.90$$

$$PWBBJ = 2.9\ PWBBP + .523$$

PISTON STROKE

The piston stroke will be a function of the cylinder base diameter and the pump angle.

$$Stroke = PWBBJ\ (\tan\Theta)$$

$$Stroke = (2.9\ PWBBP + .523) \tan\Theta$$

PISTON I.D.

The piston I.D. will be proportional to the piston O.D.

$$I.D. = K_2\ O.D.; \quad \text{For } I.D. = .31, \quad O.D. = .595$$

$$K_2 = \frac{.31}{.595} = .521$$

$$I.D. = .521\ PWBBP$$

INTERNAL PISTON DEPTH

The internal piston depth will be proportional to the piston stroke

$$Depth = K_3\ (Stroke) = K_3\ (2.9\ PWBBP + .523) \tan\Theta$$

For

$$Depth = 2.575, \quad Stroke = .605$$

$$K_3 = \frac{2.575}{.605} = 4.25$$

$$Depth = (4.25)\ (2.9\ PWBBP + .523) \tan\Theta$$

$$Depth = (12.35\ PWBBP + 2.24) \tan\Theta$$

COMPRESSION FLOW

The compression volume or flow will be proportional to the total volume of the piston and cylinder chambers.

$$Q_c = RPS(9)\ \frac{(Volume)}{\beta}\ PRES = K_4\ PUMS\ (PRES)\ (Vol.)$$

Total Volume = ((Piston Dia.)^2(Stroke) + (Piston I.D.)^2(Piston Depth)) .785

$$V_T = ((PWBBP)^2\ (2.9PWBBP+.523)\text{Tan}\ \theta + (.521PWBBP)^2\ (4.25)\ (2.9\ PWBBP + .523)\ \text{Tan}\ \theta)\ .785$$

$$V_T = (4.9\ PWBBP^3 + .884\ PWBBP^2)\ \text{Tan}\ \theta$$

$$Q_C = 9/230{,}000\ (PUMS)\ (PRES)\ \text{Tan}\ \theta)\ (4.9\ PWBBP^3 + .884\ PWBBP^2)$$

$$= (1.92 \times 10^{-4}\ PWBBP^3 + 3.46 \times 10^{-5}\ PWBBP^2)\ (PUMS)\ (PRES)\ (\text{Tan}\ \theta)$$

LEAKAGE FLOW

The piston leakage flow will be a combination of the travel and static leakages.

Travel Leakage = (9) (Diameter) (Clearance) (π) (Stroke) (Speed)

$$= K_5\ (PWBBP)\ (2.9\ PWBBP + .523)(\text{Tan}\ \theta)\ (PUMS)$$

Assuming the clearance and number of pistons will remain constant.

For clearance = .0003

$$K_5 = .0003\ (9)\ (\pi) = .0085$$

$$Q_{Travel} = (.0246\ PWBBP^2 + .00444\ PWBBP)\ (\text{Tan}\ \theta)(PUMS)$$

STATIC LEAKAGE

Using the static leakage for a small clearance annulus.

$$Q_5 = \frac{(\pi\ D\ b^3\ PRES\ \ (4)}{12\ \ (u)\ (Length}$$ for two leakage paths (rod end

and compensator sleeve) for 4 pistons per each revoluation.

The length will vary as piston stroke and can be taken as the average or: Length = Piston Stroke/$_2$

$$Q_5 = K_6\ \frac{(PWBBP)\ (PRES)}{(1.45\ PWBBP + .261)\ Tan\ \theta}$$

$$K_6 = \frac{(\pi\ )\ (.0003)^3\ (4)\ (2)}{(12)\ (1.72)\ (10)^{-6}} = 1.64\ X\ 10^{-5}$$

$$Q_5 = \frac{1.64\ X\ 10^{-5})\ PRES\ (PWBBP)}{(1.45\ PWBBP + .26)\ Tan\ \theta}$$

COMPENSATOR LEAKAGE

The compensator leakage will not vary to a large degree and it will be assumed as a constant of very small magnitude and will not be used in the calculation

$$Q_{Total} = .785\ (9)\ (PWBBP)^2\ (2.9\ PWBBP + .523)\ Tan\ \theta$$

$$= (20.5\ PWBBP^3 + 3.6\ PWBBP^2)\ (PUMS)\ (TANF\ ANGL)$$

$$Flow = Q_T - Q_{Travel} - Q_5 - Q_c$$

$$Flow = (20.5\ PWBBP^3 + 3.6\ PWBBP^2)\ (PUMS)\ Tan\ \theta) - .0246\ PWBBP^2 +$$

$$.00444\ (PWBBP))\ (TAN\ \theta)\ (PUMS) - (.000192\ PWBBP^3 + 3.46\ X\ 10^{-5}$$

$$PWBBP^2)\ (PUMS)\ (PRES)\ (Tan\ \theta) - \frac{(4.92\ X\ 10^{-5})\ (PRES)\ (PWBBP)}{(Tan\ \theta)\ (1.45\ PWBBP + .26)}$$

PWBBP = ((FLOW/(PUMS*Tan Θ*(20.5 - 1.92E-4*PRES)))

- (PWBB1**2.0)*((3.58 - 3.46E-5*PRES)/(20.5 - 1.92E-4*PRES))

+ PWBB1*((4.44E-3*PUMS*Tan Θ + ((1.64E-5*PRES)/(Tan Θ*

(1.45*PWBB1 + .26))))/(PUMS*Tan Θ*(20.5 - 1.92E-4*PRES)))

a. Assume a value for PWBB1; PRES, PUMS, ANGL and FLOW are given.

b. Calculate PWBBP

c. Determine $\left| \text{PWBBP} - \text{PWBB1} \right|$ - (1.E-5.*PWBBP)

d. If above is ≤ 0, use PWBBP and go to next part

e. If above is > 0 calculate PWBBP + PWBB1/2 and reset PWBB1 to the new value. Go back to start and repeat whole procedure.

BLOCK O.D.

I = J + P + 2E. Where E is the wall thickness and is proportional to the cylinder diameter and pressure

$$E = K_7 \text{ (Dia.) (PRES)}$$

For E = .220, Dia. = .595, PRES = 3000

$$K_7 = \frac{.220}{.595\ (3000)} = 1.23 \times 10^{-4}$$

$$E = 1.23 \times 10^{-4} \text{ Dia. (PRES)}$$

For E_1 = .080, $E_1 = 4.48 \times 10^{-5}$ Dia (PRES)

$$I = 2.98 \text{ PWBBP} + .523 + \text{PWBBP} + 2.46 \times 10^{-4} \text{ PWBBP PRES}$$

$$\text{PWBBI} = \text{PWBBP } (3.98 + 2.46 \times 10^{-4} \text{ PRES}) + .523$$

BLOCK I.D.

The I.D. will be proportional to the cylinder diameter.

$$K = K_8 \text{ (Dia.) for } K = .5$$

$$K_8 = \frac{.5}{.595} = .84$$

PWBBK = .84 PWBBP

BLOCK LENGTH

The block length will be proportional to the piston stroke

$$X = K_9 \text{ (Stroke)} \quad \text{For } X = 3.370$$

$$K_9 = \frac{3.37}{.605} = 5.57$$

$$PWBBX = 5.57\,(2.9\,PWBBP + .523)\,\text{Tan}\,\theta$$

The compensator cavity diameter will equal the base diameter plus the cylinder diameter plus .100.

$$\text{Cavity Dia.} = 3.9\,PWBBP + .623$$

The cavity length will be proportional to the piston stroke.

$$\text{Length} = K_{10} \text{ Stroke}$$

$$\text{For Length} = 1.21, \quad K_{10} = \frac{1.31}{.605} = 2.165$$

$$\text{Length} = 2.165\,(2.9\,PWBBP + .523)\,\text{Tan}\,\theta$$

BLOCK VOLUME

$$\begin{aligned}\text{Volume} &= \pi/4 \left[(PWBBI)^2 - (PWBBK)^2\right](PWBBX) \\ &- \pi/4 \left[(3.9\,PWBBP - .623)^2\, 2.165\,(2.9\,PWBBP + .523)\,\text{Tan}\,\theta\right] \\ &- \pi/4 \;(9) \quad (PWBBP)^2\,(PWBBX)\end{aligned}$$

$$\begin{aligned}\text{Volume} &= \pi/4 \Big\{ \left[(PWBBI)^2 - .706\,(PWBBP)^2\right](PWBBX) \\ &- \left[95.5\,(PWBBP)^3 - 13.5\,(PWBBP)^2 - 3.08\,(PWBBP) + .438\right] \text{Tan}\,\theta \\ &- \left[9.0\,(PWBBP)^2\,(PWBBX)\right]\Big\}\end{aligned}$$

WEIGHT

The weight of the block will be proportional to its voluem

$$\text{Weight} = K_{11} \text{ (Volume)}$$

For

PWBBI = 3.30, PWBBX = 3.41, PWBBP = .595

Weight = 3.80 θ = 15°

$$K_{11} = \frac{3.80}{\left[(3.3)^2 - .706(.595)^2\right](3.41) - \left[95.5(.595)^3 - 13.5(.595)^2 - 3.08(.595 + .438\right](2.68) - \left[9.0(.595)^2(3.41)\right]}$$

$$K_{11} = .199$$

Then:

$$\begin{aligned} PWBBW = .199 \Big\{ & \left[(PWBBI)^2 - .706\,(PWBBP)^2\right](PWBBX) \\ & - \left[95.5\,(PWBBP)^3 - 13.5\,(PWBBP)^2 - 3.08\,(PWBBP) + .438\right] \text{Tan}\,\theta \\ & - \left[9.0\,(PWBBP)^2\,(PWBBX)\right]\Big\} \end{aligned}$$

RELIABILITY

Most cylinder block failures will be due to wear or damage to the cylinder walls

$$\text{Cylinder F.R.} = K_{11}\ (\text{Effects of wear})$$

$$= K_{11}\ \frac{\text{Leakage due to wear}}{\text{Total Flow}} = K_{11}\ \frac{\text{Wear (PRES)}}{Q}$$

The wear or damage effects will be proportional to the side load of the piston divided by its reacting area and to the stroke of the piston.

$$\text{Cylinder F.R.} = K_{12}\ \frac{\frac{\text{Force}}{\text{Area}}\ (\text{Stroke})\ \text{PRES (PUMS)}}{Q}$$

$$= K_{13}\ \frac{\left(\frac{(PWBBP)^2\ (\text{Tan}\ \theta)\ (PRES)}{(\text{Stroke})\ (PWBBP)}\right.\ (\text{Stroke})\ (PRES)}{Q}$$

Derivation of Equations

$$\text{Total F.R.} = \frac{K_{14}\ (\text{PWBBP})\ (\text{Tan } \theta)\ (\text{PRES})^2}{\text{FLOW}}$$

For F.R. = .393, FLOW = 63.5, PRES = 3000, θ = 15°

$$K_{14} = \frac{.393\ (63.5) \times 10^{-6}}{(3000)^2\ (.595)\ (\text{Tan } \theta)} = 1.74 \times 10^{-5}$$

PWBBR = 1.74×10^{-5} - PWBBP*TANF ANGL*PRES**2.0/FLOW

TD-44-296-01 (8-64)

EQUATIONS

ITEM NAME: Pump Block "O" Ring
Fixed Wobble Plate

SYMBOL: P W V R

REQUIRED INPUTS: P W B B K
P R E S

REQUIRED OUTPUTS:

OUTPUTS:

STANDARD

Weight	P	W	V	R	W	=	SSWO(PWBBK)
Reliability $^{-1}$	P	W	V	R	R	=	SSSO(PWBBK,PRES)
Life					L	=	
Response					S	=	
Cont. Oper. Time					O	=	
Devel. Time					T	=	
Devel. Cost					D	=	
Unit Cost					U	=	

OTHER

NOTES:

PW-10

ANALYSIS BY: C. E. Jones CHECKED BY: D. A. Tcommater

TD-04-296-01(8-64)

EQUATIONS

ITEM NAME: Pump Piston Head
Fixed Wobble Plate

SYMBOL: P W P E

REQUIRED INPUTS: P W B B P
P R E S
P U M S

REQUIRED OUTPUTS: P W P E I

OUTPUTS:

STANDARD

WEIGHT	P	W	P	E	W	=	9.5E-7*(PWBBP**3.0)*(PRES**1.5)
RELIABILITY $^{-1}$	P	W	P	E	R	=	8.46E-5*PUMS/PWBBP**2.)
LIFE					L	=	
RESPONSE					S	=	
CONT. OPER. TIME					O	=	
DEVEL. TIME					T	=	
DEVEL. COST					D	=	
UNIT COST					U	=	

OTHER

Ball Dia.	P	W	P	E	I	=	.01535*PWBBP*PRES**.5
						=	
						=	
						=	

NOTES: Multiply the above quantities by nine.

PW-11

ANALYSIS BY: C. E. Jones CHECKED BY: D. A. Lommatzsch

DERIVATION OF EQUATIONS

ITEM NAME: Pump Piston Head
Fixed Wobble Plate

SYMBOL P W P E

The piston head ball will be in compression and its area will be proportional to the piston force or pressure and area.

$$\text{Ball Area} = K_1 \text{ Piston Area (PRES)}$$

$$\text{Ball Dia.} = K_2 \text{ (PWBBP (PRES)}^{1/2}$$

For

PWBBP = .595, PRES = 3000, Dia. = .500

$$K_2 = \frac{.500}{.595\ (3000)^{1/2}} = .01535$$

PWPEI = .01535*PWBBP*PRES**.5

The base diameter and the base to ball point areas will also be proportional to the force and the base thickness will be proportional to its diameter. Thus the volume of the ball and base will be proportional to piston diameter cubed and (PRES)$^{3/2}$

WEIGHT

The weight will be proportional to the volume.

$$\text{Weight} = K_3 \text{ (PWBBP}^3 \text{ (PRES)}^{3/2}$$

For Weight = .0372,

$$K_3 = \frac{.0327}{(.595)^3\ (3000)^{3/2}} = .95 \times 10^{-6}$$

PWPEW = .95 X 10^{-6} *(PWBBP**3.0)*(PRES**1.5)

ANALYSIS BY: C. E. Jones **CHECKED BY:** D. A. Lummatir

RELIABILITY

Failure of the piston head will be due to wear or damage to the ball and base.

$$F.R. = K_4 \text{ (Effect of damage to ball)}$$

Rotating of the pump will turn the head and the wear of the base and ball will be affected by the speed.

$$F.R. = K_5 \frac{\text{(Damage Area)}}{\text{Total Area}} \text{ (Speed)}$$

$$= K_5 \frac{(PUMS)}{(PWBBP)^2}$$

For

$$F.R. = .015, \quad PUMS = 62.7$$

$$K_5 = \frac{.015\ (.595)^2}{62.7} = 8.46 \times 10^{-5}$$

$$PWPER = 8.46 \times 10^{-5} \text{ *PUMS/PWBBP**2.}$$

TD-04-296-01 (8-64)

EQUATIONS

ITEM NAME: Pump Piston, Fixed Wobble Plate

SYMBOL: P W P D

REQUIRED INPUTS:

P	W	B	B	P
P	W	B	B	X
P	W	B	B	R
P	W	P	E	R
P	W	P	E	I

REQUIRED OUTPUTS:

OUTPUTS:

STANDARD

Weight	P	W	P	D	W	=	(.176*PWBBX*PWBBP**2.)+.248*PWPEI**3.
Reliability $^{-1}$	P	P	P	D	R	=	(.0038*PWBBR + .9*PWPER)
Life					L	=	
Response					S	=	
Cont. Oper. Time					O	=	
Devel. Time					T	=	
Devel. Cost					D	=	
Unit Cost					U	=	

OTHER

NOTES: Multiply the above quantities by nine.

PW-14

ANALYSIS BY: C. E. Jones CHECKED BY: D. A. Tommaticc

DERIVATION OF EQUATIONS

ITEM NAME: Pump Piston, Fixed Wobble Plate

SYMBOL P W P D

The piston diameter will equal the cylinder diameter. The piston length will equal the block length plus the piston head socket and the return collar mounting lengths.

The socket mounting diameter will be proportional to the piston ball diameter.

$$\text{Diameter} = K_1 \text{ (PWPEI)}$$

For

$$\text{Dia} = .66 \qquad \text{PWPEI} = .500$$

$$K_1 = \frac{.66}{.50} = 1.32$$

$$\text{Diameter} = 1.32 \text{ PWPEI}$$

The collar mounting length will be proportional to the ball diameter. The diameter will also be proportional to the ball diameter.

$$\text{Length} = K_2 \text{ (PWPEI)}$$

For

$$\text{Length} = .38 \qquad \text{Diameter} = .42$$

$$K_2 = \frac{.38}{.5} = .76$$

$$\text{Length} = .76 \text{ PWPEI}$$

$$\text{Diameter} = K_3 \text{ (PWPEI)}$$

$$K_3 = \frac{.42}{.5} = .84$$

$$\text{Diameter} = .84 \text{ (PWPEI)}$$

$$\text{Volume} = \frac{\pi}{4} (.536 \text{ PWPEI}^3)$$

ANALYSIS BY: C. E. Jones CHECKED BY: D. A. Lommatto

From the compression flow calculations it was shown that the piston cavity was:

$$\text{I.D.} = .521 \text{ PWBBP}$$

$$\text{Dpeth} = 4.25 \, (2.9 \text{ PWBBP} + .523) \tan \theta$$

$$= \frac{4.25}{5.57} \text{ PWBBX} = .763 \text{ PWBBX}$$

The socket volume will be 1/2 the volume of a hollow sphere based on the ball diameter and will be:

$$\text{Volume} = 1/2 \left(\left(\frac{\pi}{6}\right) (1.32)^3 d^3 - \frac{\pi}{6} (d)^3 \right)$$

$$= (.340) \text{ PWPEI}^3$$

WEIGHT

The weight will be proportional to the volumes.

$$\text{Weight} = K_4 \text{ (Volume)} = K_4 \text{ (Piston Volume + Collar Volume + Socket Volume)}$$

$$= K_4 \left(\frac{\pi}{4} (\text{PWBBP})^2 (\text{PWBBX}) - \left(\frac{\pi}{4}\right) .521\text{PWBBP})^2 (.763 \text{ PWBBX}) \right.$$

$$\left. + (.536 \text{ PWPEI}^3) + (.340) \text{ PWPEI}^3 \right)$$

$$= K_4 \, (.622 \text{ PWBBX } (\text{PWBBP})^2 + .876 \text{ PWPEI})^3$$

For Wt = .242, PWBBX = 3.37, PWBBP = .595 PWPEI = .5

$$K_4 = \frac{.242}{(.622)(3.37)(.595)^2 + (.876)(.5)^3} = .2835$$

$$\text{PWPDW} = .176 \text{ PWBBX } (\text{PWBBP})^2 + .248 \, (\text{PWPEI})^3$$

RELIABILITY

Failure of the piston will be due to wear of the piston which will be proportional to the cylinder reliability and also due to wear of the piston head socket head. The socket reliability will be proportional to the diameter)^2, pressure and speed of the pump or to the piston head reliability.

F.R. = K_5 (Failure rate of pistons + K_6 failure rate of piston head)

F.R. = K_5 (PWBBR) + K_6 (PWPER)

The failure rate for the pistons will be primarily (90%) due to the socket.

For F.R. = .015 PWBBR = .395, PWPER = .015

90% .015 = .0135

$K_5 = \frac{.0015}{.395} = .0038$ $K_6 = \frac{.0135}{.015} = .90$

PWPDR = .0038PWBBR + .9 PWPER

TD-04-296-01(8-64)

EQUATIONS

ITEM NAME: Pump Piston Sleeve
Fixed Wobble Plate

SYMBOL P W P C

REQUIRED INPUTS: P W B B P
P W B B R

REQUIRED OUTPUTS:

OUTPUTS:

STANDARD

Weight	P	W	P	C	W	=	TANF(ANGL)*((.206*PWBBP**3.)+(.0372*PWBBP**2.))
Reliability $^{-1}$	P	W	P	C	R	=	.0127*PWBBR
Life					L	=	
Response					S	=	
Cont. Oper. Time					O	=	
Devel. Time					T	=	
Devel. Cost					D	=	
Unit Cost					U	=	

OTHER

NOTES: Multiply the above quantities by nine.

PW-18

ANALYSIS BY: C. E. Jones CHECKED BY: D. A. Lommatzsch

DERIVATION OF EQUATIONS

ITEM NAME: Pump Piston Sleeve
Fixed Wobble Plate

SYMBOL P W P C

The I.D. of the sleeve will equal the cylinder port diameter. The sleeve O.D. will be proportional to the I.D. and the length will be proportional to the piston stroke.

WEIGHT

The weight will be proportional to the volume.

$$Wt = K_1 \text{ (Volume)} = K_2 \text{ (Diameter)}^2 \text{ (Length)}$$

$$= K_3 \text{ (PWBBP}^2\text{) (2.9 PWBBP + .523) Tan } \theta$$

Tan θ 15°, Wt. = .0154, PWBBP = .595

$$K_3 = \frac{.0154}{((2.9)(.595)^3 = (.523)(.595)^2) \text{ Tan } 10°} = .0712$$

```
PWPCW = TANF ANGL*((.206*PWBBP**3.) + (.0372*PWBBP**2.))
```

RELIABILITY

The failure rate of the sleeves will be proportional to the failure rate of the cylinder walls.

$$F.R. = K_4 \text{ (PWBBR)}$$

For

F.R. = .005, PWBBR = .393

$$K_4 = \frac{.005}{.393} = .0127$$

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PWPCR = .0127*PWBBR
```


ANALYSIS BY: C. E. Jones **CHECKED BY:** D. A. Lommatte

EQUATIONS

ITEM NAME: Pump Spyder Plate, Fixed Wobble Plate

SYMBOL: P W P A

REQUIRED INPUTS:

P	W	B	B	J
P	W	B	B	P
A	N	G	L	
P	W	B	B	K

REQUIRED OUTPUTS:

OUTPUTS:

STANDARD

Weight	P	W	P	A	W	=	(9.77E-3.*PWBBP*TANF(ANGL)*PWBBJ**3.)/PWBBK
Reliability^{-1}	P	W	P	A	R	=	.050
Life					L	=	
Response					S	=	
Cont. Oper. Time					O	=	
Devel. Time					T	=	
Devel. Cost					D	=	
Unit Cost					U	=	

OTHER

						=	
						=	
						=	
						=	

NOTES:

PW-20

ANALYSIS BY: C. E. Jones

CHECKED BY: [illegible]

TD-04-296-02(8-64)

DERIVATION OF EQUATIONS

ITEM NAME: Pump Spyder Plate, Fixed Wobble Plate SYMBOL P W P A

The thickness of the plate will be proportional to the force necessary to move the sleeves which will be proportional to the sleeve area.

$$\text{Thickness (Stem Dia.)} = K_1 \text{ (Area)}$$

$$\text{Stem Dia.} = K_2 \text{ (PWBBK)}, \quad \text{Area} = K_3 \text{ (PWBBP) (PWBBJ) Tan } \theta$$

$$\text{Thickness} = K_4 \frac{\text{PWBBP (PWBBJ) Tan } \theta}{\text{PWBBK}}$$

The O.D. of the plate will equal the base cylinder diameter and the I.D. will be proportional to the O.D. or Area $= K_5 \text{ (PWBBJ)}^2$

$$\text{Wt} = K_6 \text{ (Volume)} = K_7 \frac{\text{(PWBBP) (PWBBJ)}^3 \text{ Tan } \theta}{\text{PWBBK}}$$

For

Wt = .0356, PWBBP = .595, PWBBJ = 2.25 PWBBK = .5 θ = 15°

$$K_7 = \frac{.0356\ (.5)}{(2.25)^3\ (.595)\ (.268)} = .00977$$

PWPAW = (9.77E-3*PWBBP*TAN(ANGL)*PWBBJ**3.)/PWBBK

RELIABILITY

The reliability of the plate will be constant = .050

PW-21

ANALYSIS BY: C E Jones CHECKED BY: D A Tommaten

TD-04-296-01(8-64)

EQUATIONS

ITEM NAME: Pump Piston Return Collar, Fixed Wobble Plate

SYMBOL P W P F

REQUIRED INPUTS: P W P E I

P W P E R

REQUIRED OUTPUTS:

OUTPUTS:

STANDARD

WEIGHT	P	W	P	F	W	=	6.5E-2.*PWPEI**3.
RELIABILITY^{-1}	P	W	P	F	R	=	.667*PWPER
LIFE					L	=	
RESPONSE					S	=	
CONT. OPER. TIME					O	=	
DEVEL. TIME					T	=	
DEVEL. COST					D	=	
UNIT COST					U	=	

OTHER

NOTES: Multiply the above quantities by nine.

PW-22

ANALYSIS BY: C E Jones CHECKED BY: D. A. Lommatzsch

DERIVATION OF EQUATIONS

ITEM NAME: Pump Piston Return Collar, Fixed Wobble Plate **SYMBOL** P W P F

The collar I.D. will be equal proportional to the socket O.D. or to the piston head ball O.D. The collar O.D. and length will be proportional to its I.D.

Thus the volume will be proportional to the ball $(O.D.)^3$

WEIGHT

The weight will be proportional to the volume of the collar.

$$Wt = K_1 \text{ (Volume)}$$

$$= K_2 \text{ (PWPEI)}^3$$

For

$$Wt = .00814 \quad PWPEI = .5$$

$$K_2 = \frac{.00814}{(.5)^3} = .0651$$

PWPFW = 6.5E-2.*PWPEI**3.

RELIABILITY

The F.R. of the collar will be proportional to the F.R. of the piston socket or to the F.R. of the piston head.

$$F.R. = K_3 \text{ (PWPER)}$$

For

$$F.R. = .010, \quad PWPER = .015$$

$$K_3 = \frac{.010}{.015} = .667$$

PWPER = .667*PWPER

ANALYSIS BY: C. E. Jones **CHECKED BY:** R. A. Summutter

TD-04-296-01 (8-64)

EQUATIONS

ITEM NAME: Pump Nutating Plate Pivot, Fixed Wobble Plate

SYMBOL P W B N

REQUIRED INPUTS: P W B B J

P W B B P

P U M S

A N G L

REQUIRED OUTPUTS: P W B N P

OUTPUTS:

STANDARD

WEIGHT	P	W	B	N	W	=	.617*PWBBJ*TANF(ANGL)*(PWBNP**2.0)
RELIABILITY $^{-1}$	P	W	B	N	R	=	4.16E-4*PUMS/PWBNP**2.
LIFE					L	=	
RESPONSE					S	=	
CONT. OPER. TIME					O	=	
DEVEL. TIME					T	=	
DEVEL. COST					D	=	
UNIT COST					U	=	

OTHER

Pivot Diameter	P	W	B	N	P	=	9.13E-3*PUMS*PWBBP*(PWBBJ**0.5)
						=	
						=	
						=	

NOTES:

PW-24

ANALYSIS BY: C. E. Jones CHECKED BY: D. A. Tommaton

DERIVATION OF EQUATIONS

ITEM NAME: Pump Nutating Plate Pivot, Fixed Wobble Plate

SYMBOL P W B N

The nutating plate pivot area will be proportional to the diameter of the piston and to the $(\text{speed})^2$ since the stress will be maintained constant. Other diameters will be proportional to this diameter.

$$\text{Area} = K_1 \text{ (Piston Dia.) (Speed)}^2 \text{ (Moment Arm)}$$

$$\text{Dia.} = K_2 \text{ (Speed) (PWBBP) (PWBBJ)}^{1/2}$$

For Dia = .51, Speed = 62.5, PWBBP = .595 PWBBJ = 2.25

$$K_2 = \frac{.51}{(62.5)\,(.595)\,(2.25)^{1/2}} = 9.13 \times 10^{-3}$$

$$\text{PWBNP} = 9.13 \times 10^{-3} \text{ (PUMS) (PWBBJ)}^{1/2} \text{ (PWBBP)}$$

The length of the pivot will be proportional to the stroke. All other lengths will be proportional to it.

$$\text{Length} = K_3 \text{ (PWBBJ) Tan } \theta$$

For Length = .85, θ = 15, PWBBJ = 2.25

$$K_3 = \frac{.85}{(2.25\ (\text{Tan } 15°)} = 1.41$$

PWBNX = 1.41*PWBBJ*Tan θ

The volume will be proportional to the diameter^2 times the length.

ANALYSIS BY: C. E. Jones

CHECKED BY: D. A. Lommatzsch

WEIGHT

The weight will be proportional to the volume of the shaft.

$$Wt = K_4 \text{ (Volume)} = K_5 \text{ (PWBNP)}^2 \text{ (PWBNX)}$$

$$Wt = K_6 \text{ (PWBNP)}^2 \text{ (PWBBJ) Tan } \theta$$

For PWBNP = .51, PWBBJ = 2.25, θ = 15°

$$Wt = .0968$$

$$K_6 = \frac{.0968}{(.51)^2 (2.25) (.268)}$$

$$K_6 = .617$$

$$\text{PWBNW} = .617 \text{ (PWBNP)}^2 \text{ (PWBBJ) Tan } \theta$$

RELIABILITY

The failure rate of the pivot will be inversely proportional to the area and proportional to the speed.

$$\text{F.R.} = K_7 \text{ PUMS/(PWBNP)}^2$$

For F.R. = .100, PWBNP = .51

$$K_1 = \frac{.100 \ (.51)^2}{(62.5)} = .000416$$

PWBNR = 4.16E-4*PUMS/PWBNP**2.

TD-04-296-01(8-64)

EQUATIONS

ITEM NAME: Pump Nutating Plate

Fixed Wobble Plate

SYMBOL: P W P B

REQUIRED INPUTS:

P W B B J

P W P E I

P W B N R

P W B N B

REQUIRED OUTPUTS:

OUTPUTS:

STANDARD

Weight	P W P B W	=	(.0715*PWBNP*PWBBJ**2.)+(.27*PWBNP*PWBBJ *PWPEI)+(.428*PWBNP**3.)-(.705*PWBNP* *PWPEI**2.)
Reliability $^{-1}$	P W P B R	=	2.0*PWBNR
Life	L	=	
Response	S	=	
Cont. Oper. Time	O	=	
Devel. Time	T	=	
Devel. Cost	D	=	
Unit Cost	U	=	

OTHER

NOTES:

PW-27

ANALYSIS BY: C. E. Jones

CHECKED BY: D. A. Tommaso

TD-04-296-02(8-64)

DERIVATION OF EQUATIONS

ITEM NAME: Pump Nutating Plate Fixed Wobble Plate

SYMBOL P W P B

The thickness of the nutating plate will be proportional to the force or to the pivot diameter. The pivot area can be considered as a hollow half sphere and its diameter will be proportional to the pivot diameter.

The O.D. of the plate will equal the base cylinder diameter plus a proportional of the socket I.D.

The piston hole size and wall thickness will be proportional to the socket I.D.

External Dia $= K_1$ PWPEI

For

Dia $= .92$, PWPEI $= .5$

$$K_1 = \frac{.92}{.5} = 1.84$$

Dia. $= 1.84$ PWPEI

Hole Dia $= K_2$ PWPEI, Hole Dia $= .600$

$$K_2 = \frac{.6}{.5} = 1.2$$

Hole Dia $= 1.2$ PWPEI

Base Sphere Diameter $= K_3$ (Pivot Diameter)

For Sphere Dia $= .89$, Pivot Dia $= .51$

$K_3 = 1.75$

Sphere dia $= 1.75$ PWBNP

PW-28

ANALYSIS BY: C E Jones **CHECKED BY:** D. A. Lommatsch

Thickness = K_4 (PWBNP), For thickness = .175

$$K_4 = \frac{.175}{.51} = .343$$

Thickness = .343 PWBNP

WEIGHT

The weight of the plate will be proportional to its volume.

$$\text{Wt.} = K_5 \text{ (Volume)}$$

$$= K_5 \left(\left(\frac{\pi}{4}(\text{PWBBJ}+1.84\text{PWPEI})^2 - (1.75 \text{ PWBNP})^2\right)(.343 \text{ PWBNP}) + \frac{\pi}{12}\left((2.44 \text{ PWBNP})^3 - (1.75 \text{ PWBNP})^3 - \left(\frac{\pi}{4}(9)\ (1.2 \text{ PWPEI})^2\ (.343 \text{ PWBNP}\right)\right)\right)$$

$$\text{Wt.} = K_6 \left((.343 \text{ PWBBJ}^2 (\text{PWBNP})) + (1.26 (\text{PWBBJ})(\text{PWBNP})(\text{PWPEI})) - (3.29 (\text{PWBNP})(\text{PWPEI})^2 + (2.0 (\text{PWBNP})^3\right)$$

For

PWBBJ + 2.25, PWBNP = .51, PWPEI = .50, Wt. = .312

$$K_6 = \frac{.312}{(.343)(2.25)^2(.51)+1.26(2.25)(.5)(.51)+2.0(51)^3-3.29(.51)(.5)^2}$$

$$= .214$$

PWPBW = (.0715*PWBNP*PWBBJ**2.) + (.27*PWBBJ*PWBNP*PWPEI)
+ (.428*PWBNP**3.) - (.705*PWBNP*PWPEI**2.)

RELIABILITY

The failure rate of the plate will be proportional to the failure rate of the pivot.

F.R. = K_7 (PWBNR)

Derivation of Equations

For

F.R. = .200 PWBNR = .100

$$K_7 = \frac{.200}{.100} = 2.00$$

PWBPR = 2.0*PWBNR

TD-04-296-01 (8-64)

EQUATIONS

ITEM NAME: Pump Thrust Bearing
Fixed Wobble Plate

SYMBOL P W P J

REQUIRED INPUTS: P W B B P
P R E S
A N G L
P W B B J
P U M S

REQUIRED OUTPUTS: P W P J I
P W P J Y

OUTPUTS:

STANDARD

WEIGHT	P	W	P	J	W	=	.393*PWPJY*PWBBJ**2.
RELIABILITY $^{-1}$	P	W	P	J	R	=	.012*PUMS/PWBBJ**2.
LIFE					L	=	
RESPONSE					S	=	
CONT. OPER. TIME					O	=	
DEVEL. TIME					T	=	
DEVEL. COST					D	=	
UNIT COST					U	=	

OTHER

Bearing O.D.	P	W	P	J	I	=	1.333*PWBBJ
Bearing Thickness	P	W	P	J	Y	=	.0452*PWBBP*TANF(ANGL)*PRES**.5
						=	
						=	

NOTES:

PW-31

ANALYSIS BY: C. E. Jones CHECKED BY: D. A. Lommatic

TD-04-296-02(8-64)

DERIVATION OF EQUATIONS

ITEM NAME: Pump Thrust Bearing
Fixed Wobble Plate

SYMBOL P W P J

The bearing capacity in thrust will be

$$\text{Load Capacity} = K_1 \text{(PRES) (Bearing Area)}$$

and assuming the face pressure for a bearing will be constant.

$$\text{Load Capacity} = K_2 \text{(Bearing Area)} = \frac{\text{PRES(Piston Area)}}{\text{Tan } \Theta}$$

Assume the bearing O.D. will be proportional to the base cylinder location diameter.

$$\text{Bearing O.D.} = K_1 \text{ (PWBBJ)}$$

For

$$\text{O.D.} = 3.00 \quad \text{PWBBJ} = 2.25$$

$$K_1 = \frac{3.00}{2.25} = 1.333$$

$$\text{PWPJI} = 1.333 \text{ PWBBJ}$$

Since the O.D. is so large, the I.D. can be made proportional to the O.D. and the actual bearing area will be only that proportion dictated above by the load capacity.

$$\text{I.D.} = K_2 \text{ (O.D.)} = K_3 \text{ PWBBJ}$$

For

$$\text{I.D.} = 1.465,$$

$$K_3 = \frac{1.465}{2.25} = .65$$

$$\text{I.D.} = .65 \text{ PWBBJ}$$

ANALYSIS BY: C. E. Jones **CHECKED BY:** D. A. Tommaten

The load on the radial or journal portion of the bearing will be:

$$\text{Bearing Moment Load} = K_4 \ (\text{PWBBP})^2 \ \text{PRES} \ (\text{Tan } \theta) \ (\text{PWBBJ}) \ (\text{Tan } \theta)$$

$$\text{Bearing Capacity} = K_4 \ (\text{Diameter}) \ (\text{Thickness}) \ (\text{Moment Arm})$$

$$= K_4 \ (\text{PWBBJ}) \ (\text{Thickness})^2$$

The moment arm of the load will remain proportional to PWBBJ (Tan θ)

Thus:

$$(\text{Thickness})^2 = K_5 \frac{\text{PWBBP}^2 \ (\text{Tan } \theta)^2 \ (\text{PWBBJ}) \ (\text{PRES})}{\text{PWBBJ}}$$

$$\text{Thickness} = K_5 \ \text{PWBBP} \ (\text{Tan } \theta) \ (\text{PRES})^{1/2}$$

For

PWBBP = .595, Tan θ = .268, PRES = 3000, Thickness = .395

$$K_5 = \frac{.395}{(.595)\ (.268)\ (3000)^{1/2}} = .0452$$

PWPJY = .0452*PWBBP*Tan θ* PRES**.5

WEIGHT

The weight of the bearing will be proportional to the volume

$$\text{Wt} = K_6 \ (\text{Volume}) = K_7 \ (\text{PWBBJ})^2 \ (\text{PWPJY})$$

For

Wt = .726, PWBBJ = 2.25

$$K_6 = \frac{.726}{(2.25)^2 \ (.395)} = .363$$

PWPJW = .393 PWPJY (PWBBJ)^2

RELIABILITY

Failure of the bearing will be proportional to wear (speed) and damage.

P W P J - (Continued)
Page 3
Derivation of Equations

$$F.R. = K_7 \text{ (Effects of damage)}$$

$$K_8 \text{ (PUMS) } \frac{\text{(Damaged Area)}}{(\text{PWBBJ}^2)} = K_9 \text{ PUMS}/_{\text{PWBBJ}}{}^2$$

For

$$F.R. = .150 \quad \text{PUMS} = 62.7$$

$$K_8 = \frac{(.150)\ (2.25)^2}{62.7} = .0121$$

$$\text{PWPJR} = .012 \text{ PUMS}/(\text{PWBBJ})^2$$

EQUATIONS

ITEM NAME: Pump Shaft and Cam, Fixed Wobble Plate

SYMBOL: P W P G

REQUIRED INPUTS:
P W B B P
P R E S
A N G L
P W P J I
P W P J Y
P W P E R
P W P J R

REQUIRED OUTPUTS: P W P G P

OUTPUTS:

STANDARD

WEIGHT	P	W	P	G	W	=	.103*TANF(ANGL)*(PWPJI**3.0)+.054*(PWPJY+.33)*(PWPJI**2.0)+.191*(PWPGP**3.0)-.377*(PWPG1**3.0)
RELIABILITY $^{-1}$	P	W	P	G	R	=	2.0*PWPER+.8PWPJR
LIFE					L	=	
RESPONSE					S	=	
CONT. OPER. TIME					O	=	
DEVEL. TIME					T	=	
DEVEL. COST					D	=	
UNIT COST					U	=	

OTHER

Seal Mount Dia.	P	W	P	G	P	=	PWPG1 + .225
Spline Diameter	P	W	P	G	1	=	((3.32E-3*PWBBP**3.+6.E-4*PWBBP**2.)*TANF(ANGL)*PRES)**.333
						=	
						=	

NOTES:

PW-35

ANALYSIS BY: C E Jones **CHECKED BY:** D. A. Tommater

DERIVATION OF EQUATIONS

ITEM NAME: Pump Shaft And Cam, Fixed Wobble Plate **SYMBOL** P W P G

The shaft spline diameter will be governed by the torque required to drive the pump:

$$\text{Torque} = \text{cu.in}/_{\text{Rev.}} \text{ (PRES) (Pump Requirement)}$$

and

$$\text{Torque} = \frac{L\,(\text{Dia})^2\,(S_S)}{1.2732} \quad \text{(Spline Capacity)}$$

Assuming the spline length is proportional to the diameter and the stress level is constant:

$$\text{Torque (Spline)} = K_1\,(\text{Dia.})^3$$

From the block evaluation:

$$\text{Cu. In}/_{\text{Rev.}} = (20.5\ \text{PWBBP}^3 + 3.7\ \text{PWBBP}^2)\ \text{Tan}\ \theta$$

$$\text{Spline Dia} = K_2\ ((20.5\ \text{PWBBP}^3 + 3.7\ \text{PWBBP}^2)\ (\text{Tan}\ \theta)\ (\text{PRES}))^{1/3}$$

For Spline Dia = .90, Angle = 15°, PWBBP = .595 PRES = 3000

$$K_2 = \frac{.90}{(((20.5)\,(.595)^3 + 3.7\,(.595)^2)\ \text{Tan}\ 15°\ (3000))^{1/3}} = .0545$$

$$\text{PWPG1} = \text{Spline Pitch Diameter} = ((3.32 \times 10^{-3}\ \text{PWBBP}^3 + 6.0 \times 10^{-4}\ \text{PWBBP}^2)\ (\text{Tan}\ \theta)\ (\text{PRES}))^{1/3}$$

The minimum shaft wall thickness will remain constant.

<u>MINIMUM O.D.</u> = Spline Diameter + .225

PWPGP = (PWPG1 + .225)

PW-36

ANALYSIS BY: C. E. Jones **CHECKED BY:** D. A. Trommater

SPLINE LENGTH

The spline length will be proportional to the spline diameter

$$\text{Length} = K_3 \text{ (PWGP1)}$$

$$\text{For Length} = 1.48 \quad \text{PWPG1} = .90$$

$$K_3 = 1.651$$

$$\text{Length} = 1.65 \text{ PWPG1}$$

SEAL MOUNTING LENGTH

The seal area length will be proportional to the shaft diameter.

$$\text{Length} = K_4 \text{ (PWPGP)}$$

$$\text{For PWPGP} = 1.125 \quad \text{Length} = .95$$

$$K_4 = \frac{.95}{1.125} = .84$$

$$\text{Length} = .84 \text{ PWPGP}$$

Assume the O.D. of the cam equals the bearing O.D. and the I.D. is proportional to the O.D.

$$\text{O.D.} = \text{PWPJI}$$

$$\text{I.D.} = K_5 \text{ (O.D.)}$$

$$\text{For O.D.} = 3.0 \quad \text{I.D.} = .9$$

$$K_5 = \frac{.9}{3} = .300$$

$$\text{I.D.} = .3 \text{ PWPJI}$$

WEIGHT

The weight of the shaft will be proportional to the volume.

$$Wt = K_6 \text{ (Volume)} = K_6 \text{ (Cam Volume + Shaft Volume)}$$

$$Wt = K_6 \left\{ \left[((PWPJI)^2 - (.3\ PWPJI)^2)\ \pi/_4\ \frac{(PWPJI)}{2}\ \text{Tan}\ \theta \right] \right.$$
$$+ \pi/_4 \left[(.488\ PWPJI)^2\ (PWPJY + .33) \right]$$
$$+ \pi/_4 \left[(PWPGP)^2\ (.84\ PWPGP) \right]$$
$$\left. - \pi/_4 \left[1.65\ (PWPG1)\ (PWPG1)^2 \right] \right\}$$

$$Wt = K_7 \left\{ \left[.455\ (PWPGI)^3\ \text{Tan}\ \theta \right] + \left[.238\ (PWPJI)^2\ (PWPJY + .33) \right] \right.$$
$$\left. + \left[.84\ (PWPGP)^3 \right] - \left[1.65\ (PWPG1)^3 \right] \right\}$$

For:

$$PWPJI = 3.00, \quad \theta = 15°, \quad PWPJY = .45$$

$$PWPGP = 1.125, \quad PWPG1 = .90 \quad Wt. = 1.30$$

$$K_7 = \frac{1.30}{.455\ (3.0)^3\ (.268) + .238\ (3.0)^2\ (.45 + .33) + .84\ (1.125)^3 - 1.65(.9)^3}$$

$$K_7 = .227$$

$$PWPGW = .103\ (PWPJI)^3\ \text{Tan}\ \theta + .054\ (PWPJI)^2\ (PWPJY + .33)$$
$$+ .191\ (PWPGP)^3 - .377\ (PWPG1)^3$$

RELIABILITY

Failure of the shaft will be proportional to failure of the creep bearing, thrust bearing, and

$$F.R. = K_7 \text{ (Piston head F.R.)} + K_8 \text{ (Thrust Bearing F.R.)}$$

80% of the failures will be due to the bearing,

$$.80\ F.R. = K_8\ (PWPJR)$$

For F.R. = .15, PWPJR = .15

Derivation of Equations

$$K_8 = \frac{.80\ (.150)}{.150} = .8$$

$$.20\ F.R. = K_7\ (PWPER)$$

For PWPER = .015

$$K_7 = \frac{.02\ (.150)}{.015} = 2.0$$

$$PWPGR = 2.0\ PWPER + .8\ PWPJR$$

TD-04-296-01 (8-64)

EQUATIONS

ITEM NAME: Pump Mating Seal Ring
Fixed Wobble Plate

SYMBOL P W P P

REQUIRED INPUTS: P W P G P

REQUIRED OUTPUTS: P W P P P

OUTPUTS:

STANDARD

WEIGHT	P	W	P	P	W	=	.0277*PWPGP**3.
RELIABILITY $^{-1}$	P	W	P	P	R	=	.1333*PWPGP
LIFE					L	=	
RESPONSE					S	=	
CONT. OPER. TIME					O	=	
DEVEL. TIME					T	=	
DEVEL. COST					D	=	
UNIT COST					U	=	

OTHER

"O"-Ring Face Dia.	P	W	P	P	P	=	1.133*PWPGP
						=	
						=	
						=	

NOTES:

PW-40

ANALYSIS BY: C E Jones CHECKED BY: D. A. Lommatic

TD-04-296-02(8-64)

DERIVATION OF EQUATIONS

ITEM NAME: Pump Mating Seal Ring
Fixed Wobble Plate

SYMBOL P W P P

All dimensions of the seal ring will be proportional to the shaft O.D. or Ring I.D.

"O" Ring Mounting Face

$$\text{Face Dia.} = K_1 \ \text{I.D.} = K_1 \ (\text{PWPGP})$$

For

$$\text{Face Dia.} = 1.275 \quad \text{PWPGP} = 1.125$$

$$K_1 = \frac{1.275}{1.125} = 1.133$$

$$\text{PWPPP} = 1.133{*}\text{PWPGP}$$

WEIGHT

The weight of the ring will be proportional to the volume.

$$\text{Wt} = K_2 \ (\text{Volume}) = K_3 \ (\text{PWPGP})^3$$

$$\text{Wt} = .0395$$

$$K_3 = \frac{.0395}{(1.125)^3} = .0277$$

$$\text{PWPPW} = .0277 \ (\text{PWPGP})^3$$

RELIABILITY

Failure of the seal ring will be proportional to its length.

$$\text{F.R.} = K_4 \ (\text{PWPGP})$$

For

$$\text{F.R.} = .150 \qquad K_4 = \frac{.150}{1.125} = .1333$$

$$\text{PWPPR} = .1333 \ \text{PWPGP}$$

ANALYSIS BY: C. E. Jones PW-41 **CHECKED BY:** R. A. Lommatsch

TD-04-296-01 (8-64)

EQUATIONS

ITEM NAME: Pump Seal Ring
Fixed Wobble Plate

SYMBOL P W P O

REQUIRED INPUTS: P W P G P

REQUIRED OUTPUTS:

OUTPUTS:

STANDARD

WEIGHT	P	W	P	O	W	=	.0452*PWPGP**3.
RELIABILITY $^{-1}$	P	W	P	O	R	=	.089 *PWPGP
LIFE					L	=	
RESPONSE					S	=	
CONT. OPER. TIME					O	=	
DEVEL. TIME					T	=	
DEVEL. COST					D	=	
UNIT COST					U	=	

OTHER

NOTES:

PW-42

ANALYSIS BY: C E Jones CHECKED BY: [illegible signature]

DERIVATION OF EQUATIONS

ITEM NAME: Pump Seal Ring
Fixed Wobble Plate

SYMBOL P W P O

All ring dimensions will be proportional to the ring I.D. which will equal the shaft O.D. (PWPGP).

WEIGHT

The weight of the ring will be proportional to its volumes.

$$Wt = K_1 \text{ (Volume)} = K_2 \text{ (PWPGP)}^3$$

For

$$Wt = .0644, \quad PWPGP = 1.125$$

$$K_1 = \frac{.0644}{(1.125)^3} = .0452$$

$$PWPOW = .0452 \text{ (PWPGP)}^3$$

RELIABILITY

Failure of the seal will be due to any damage or wear path in the seal face. The seal face width will remain approximately constant and any leakage will constitute a failure.

$$F.R. = K_2 \text{ (Face Length)}$$

$$= K_3 \text{ (PWPGP)}$$

For

$$F.R. = .100$$

$$K_3 = \frac{.100}{1.125} = .089$$

$$PWPOR = .089 \text{ (PWPGP)}$$

PW-43

ANALYSIS BY: C. E. Jones **CHECKED BY:** D. A. Lommatzsch

TD-04-296-01 (8-64)

EQUATIONS

ITEM NAME: Pump Seal Ring "O" Ring Fixed Wobble Plate

SYMBOL P W P R

REQUIRED INPUTS: P W P P P P R E S

REQUIRED OUTPUTS:

OUTPUTS:

STANDARD

WEIGHT	P	W	P	R	W	=	SSWO(PWPPP)
RELIABILITY $^{-1}$	P	W	P	R	R	=	SSSO(PWPPP,PRES*.0133)
LIFE					L	=	
RESPONSE					S	=	
CONT. OPER. TIME					O	=	
DEVEL. TIME					T	=	
DEVEL. COST					D	=	
UNIT COST					U	=	

OTHER

=

=

=

=

NOTES:

ANALYSIS BY: C E Jones PW-44 **CHECKED BY:** R. A. Lommatzsch

TD-04-296-01 (8-64)

EQUATIONS

ITEM NAME: Pump Shaft Seal "O" Ring Fixed Wobble Plate

SYMBOL P W P N

REQUIRED INPUTS: P W P G P P R E S

REQUIRED OUTPUTS: P W P N W P W P N R

OUTPUTS:

STANDARD

Weight	P	W	P	N	W	=	SSWO(PWPGP)
Reliability $^{-1}$	P	W	P	N	R	=	SSSO(PWPGP,PRES*.0133)
Life					L	=	
Response					S	=	
Cont. Oper. Time					O	=	
Devel. Time					T	=	
Devel. Cost					D	=	
Unit Cost					U	=	

OTHER

NOTES:

PW-45

ANALYSIS BY: C E Jones

CHECKED BY: R. A. Lommatter

TD-04-296-01 (8-64)

EQUATIONS

ITEM NAME: Pump Shaft Seal Teflon Ring Fixed Wobble Plate

SYMBOL: P W P M

REQUIRED INPUTS: P W P N W
P W P N R

REQUIRED OUTPUTS:

OUTPUTS:

STANDARD

WEIGHT	P	W	P	M	W	=	1.3*PWPNW
RELIABILITY^{-1}	P	W	P	M	R	=	PWPNR
LIFE					L	=	
RESPONSE					S	=	
CONT. OPER. TIME					O	=	
DEVEL. TIME					T	=	
DEVEL. COST					D	=	
UNIT COST					U	=	

OTHER

NOTES:

ANALYSIS BY: C. E. Jones

PW-46

CHECKED BY: D. A. Tommaten

TD-04-296-01 (8-64)

EQUATIONS

ITEM NAME: Pump Creep Collar, Fixed Wobble Plate

SYMBOL: P W P I

REQUIRED INPUTS:

P U M S
P W B B P
A N G L
P R E S

REQUIRED OUTPUTS:

OUTPUTS:

STANDARD

WEIGHT	P W P I W	= 4.23E-5.*PRES*PWBBP**2./TANF(ANGL)
RELIABILITY $^{-1}$	P W P I R	= 1.58*PUMS*TANF(ANGL)/(PRES*PWBBP**2.)
LIFE	L	=
RESPONSE	S	=
CONT. OPER. TIME	O	=
DEVEL. TIME	T	=
DEVEL. COST	D	=
UNIT COST	U	=

OTHER

NOTES:

ANALYSIS BY: C E Jones PW-47 CHECKED BY: D. R. Lammater

DERIVATION OF EQUATIONS

ITEM NAME: Pump Creep Collar
Fixed Wobble Plate

SYMBOL P W P I

The collar O.D. will equal the thrust bearing O.D. (PWPJI).

The I.D. will be governed by the bearing load requirement.

$$\text{Bearing Area} = K_7 \left(\text{PWPJI}^2 - (\text{I.D.})^2\right) = K_2 \frac{(\text{PWBBP})^2 \ (\text{PRES})}{\text{Tan } \theta}$$

$$\text{I.D.} = \left(\text{PWPJI}^2 - K_3 \ \text{PWBBP}^2 \ \text{PRES}/_{\text{Tan } \theta}\right)^{1/2}$$

For

$$\text{PWPJI} = 3.00 \quad \text{PWBBP} = .595 \quad \text{PRES} = 3000$$

$$\theta = 15° \quad \text{I.D.} = 1.81$$

$$K_3 = \frac{(3.00)^2 - (1.81)^2) \quad .268}{(.595)^2 \ (3000)} = 1.44 \text{ X } 10^{-3}$$

$$\text{PWPIK} = \left[(\text{PWPJI**2-1.44E-3*PRES*PWBBP**2./Tan } \theta\right]^{1/2}$$

WEIGHT

The weight of the collar will be proportional to the volume. With the thickness remaining constant:

$$\text{Wt} = K_4 \ (\text{Volume}) = K_5 \ (\text{O.D.}^2 - \text{I.D.}^2)$$

$$= K_6 \ \text{PWBBP}^2 \ \text{PRES}/_{\text{Tan } \theta}$$

For Wt = .1674

$$K_6 = \frac{.1674 \ (2.68)}{3000 \ (.595)^2} = .0000423$$

PWPIW = 4.23E-5*PRES*PWBBP**2./TANF ANGL

PW-48

ANALYSIS BY: C. E. Jones CHECKED BY: D. A. [signature]

RELIABILITY

Failure of the bearing will be proportional to wear speed and damage

$$F.R. = K_7 \text{ (Effects of damage)}$$

$$= K_8 \text{ (PUMS) } \frac{\text{(Danaged Area)}}{\text{Total Area}}$$

$$= \frac{K_9 \text{ (PUMS) (Tan } \Theta)}{(PWBBP)^2 \text{ (PRES)}}$$

For $F.R. = .025$

$$K_9 = \frac{.025\ (.595)^2\ (3000)}{62.7\ (.268)} = 1.58$$

PWPIR = 1.58*PUMS*TANF (ANGL)/(PRES*PWBBP**2.)

TD-04-296-01 (8-64)

EQUATIONS

ITEM NAME: Pump Creep Bearing Fixed Wobble Plate

SYMBOL P W P H

REQUIRED INPUTS: P W P I R
P W P J I
P W B B P
P R E S
A N G L

REQUIRED OUTPUTS:

OUTPUTS:

STANDARD

Weight	P	W	P	H	W	=	(.0157*PWPJI**2.)-(4.65E-6PRES*PWBBP**2/TANF(ANGL)
Reliability $^{-1}$	P	W	P	H	R	=	4.0*PWPIR
Life					L	=	
Response					S	=	
Cont. Oper. Time					O	=	
Devel. Time					T	=	
Devel. Cost					D	=	
Unit Cost					U	=	

OTHER

NOTES:

PW-50

ANALYSIS BY: C E Jones

CHECKED BY: D. G. Lommatez

TD-04-296-02(8-64)

DERIVATION OF EQUATIONS

ITEM NAME: Pump Creep Bearing Fixed Wobble Plate **SYMBOL** P W P H

The creep bearing thickness will be a constant. The O.D. will equal the thrust bearing O.D. and the I.D. will be proportional to the O.D.

$$I.D. = K_1 \; O.D.$$

For

$$I.D. = 1.475 \quad PWPJI = 3.00$$

$$K_1 = \frac{1.475}{3.00} = .492$$

$$I.D. = .492 \; PWPJI$$

WEIGHT

The weight of the bearing will be proportional to the volume.

$$Wt = K_2 \text{ (Volume)} = K_3 \left((PWPJI^2 - (.492)\; PWPJI^2)\; (.18) - \right.$$

$$\left. (.090 (\frac{.00045 \; PWBBP^2 \; (PRES)}{\text{Tan } \theta} \right)$$

$$= K_3 \left(.1363 \; PWPJI^2 - \frac{.0000405 \; PWBBP^2 \; (PRES)}{\text{Tan } \theta} \right)$$

For Wt = .1225, PWPJI = 3.00, PWBBP = .595, PRES = 3000, θ = 15°

$$K_3 = \frac{.1225}{(.1363)\,(3.0)^2 - \frac{.0000405\,(.595)^2\,(3000)}{.268}} = .115$$

$$PWPHW = .0157 * PWPJI^2 - 4.65 \times 10^{-6} \; PWBBP^2 \; (PRES) / \text{Tan } \theta$$

PW-51

ANALYSIS BY: C. E. Jones **CHECKED BY:** D. A. Tommatic

RELIABILITY

The failure rate of the creep bearing will be proportional to the failure rate of the collar.

$$F.R. = K_4 \text{ (PWPIR)} \qquad \text{For F.R.} = .100 \quad \text{PWPIR} = .025$$

$$K_4 = \frac{1.00}{.25} = 4 \qquad \text{PWPHR} = 4.0 \text{ PWPIR}$$

TD-04-296-01 (8-64)

EQUATIONS

ITEM NAME: Pump Seal Plate
Fixed Wobble Plate

SYMBOL P W P S

REQUIRED INPUTS: P W P G P

REQUIRED OUTPUTS:

OUTPUTS:

STANDARD

Weight	P	W	P	S	W	=	.0568*PWPGP**2.
Reliability^{-1}	P	W	P	S	R	=	.0133*PWPGP
Life					L	=	
Response					S	=	
Cont. Oper. Time					O	=	
Devel. Time					T	=	
Devel. Cost					D	=	
Unit Cost					U	=	

OTHER

NOTES:

ANALYSIS BY: C E Jones

PW-53

CHECKED BY: D A Lunmatic

DERIVATION OF EQUATIONS

ITEM NAME: Pump Seal Plate

Fixed Wobble Plate

SYMBOL P W P S

The seal plate I.D. will be proportional to the seal ring O.D. or to the shaft O.D. The O.D. of the seal plate will approximately be the I.D. plus a constant. The thickness will be proportional to the I.D. Thus the volume will approximately $= K_1\ (PWPGP)^2$

WEIGHT

The weight will be proportional to the volume

$$Wt = K_2\ (Volume) = K_3\ (PWPGP)^2$$

For

$$Wt = .0719 \quad PWPGP = 1.125$$

$$K_2 = \frac{.0719}{(1.125)^2} = .0568$$

$$PWPSW = .0568\ (PWPGP)^2$$

RELIABILITY

Failure of the seal plate would be due to leakage past the gasket and "O" ring. Since any leakage will cause a failure and the seal face lengths are proportional to (PWPGP)

$$F.R. = K_3\ (PWPGP)$$

For

$$F.R. = .015, \quad K_3 = \frac{.015}{1.125} = .0133$$

$$PWPSR = .0133\ PWPGP$$

ANALYSIS BY: C E Jones CHECKED BY: D. A. Tommaton

TD-04-296-01 (8-64)

EQUATIONS

ITEM NAME: Pump Seal Plate Gasket, Fixed Wobble Plate

SYMBOL P W P T

REQUIRED INPUTS: P W P G P

REQUIRED OUTPUTS:

OUTPUTS:

STANDARD

WEIGHT	P	W	P	T	W	=	3.32E-3.*PWPGP
RELIABILITY $^{-1}$	P	W	P	T	R	=	.01775*PWPGP
LIFE					L	=	
RESPONSE					S	=	
CONT. OPER. TIME					O	=	
DEVEL. TIME					T	=	
DEVEL. COST					D	=	
UNIT COST					U	=	

OTHER

NOTES:

ANALYSIS BY: C E Jones

PW-55

CHECKED BY: D. A. Coomnate

DERIVATION OF EQUATIONS

ITEM NAME: Pump Seal Plate Gasket, Fixed Wobble Plate

SYMBOL P W P T

The gasket mean diameter will be approximately proportional to the shaft O.D. (PWPGP). The width and thickness will be constant.

WEIGHT

The weight will be proportional to the volume.

$$Wt = K_1 \text{ (Volume)} = K_2 \text{ (PWPGP)}$$

For

$$Wt. = .00373, \quad PWPGP = 1.125$$

$$K_1 = \frac{.00373}{1.125} = .00332$$

$$PWPTW = .00332 \text{ PWPGP}$$

RELIABILITY

Failure of the gasket would be due to any leakage and so the failure rate will be proportional to the total length.

$$F.R. = K_2 \text{ (PWPGP)}$$

For F.R. = .020

$$K_2 = \frac{.020}{1.125} = .01775$$

$$PWPTR = .01775 \text{ PWPGP}$$

PW-56

ANALYSIS BY: C E Jones **CHECKED BY:** D. A. Lommatto

TD-04-296-01 (8-64)

EQUATIONS

ITEM NAME: Pump Seal Spring

Fixed Wobble Plate

SYMBOL P W P L

REQUIRED INPUTS: P W P G P

REQUIRED OUTPUTS:

OUTPUTS:

STANDARD

WEIGHT	P	W	P	L	W	=	.0138*PWPGP**2.
RELIABILITY $^{-1}$	P	W	P	L	R	=	.0562/PWPGP
LIFE					L	=	
RESPONSE					S	=	
CONT. OPER. TIME					O	=	
DEVEL. TIME					T	=	
DEVEL. COST					D	=	
UNIT COST					U	=	

OTHER

NOTES:

PW-57

ANALYSIS BY: C E Jones CHECKED BY: D. A. Tommatee

DERIVATION OF EQUATIONS

ITEM NAME: Pump Seal Spring Fixed Wobble Plate **SYMBOL** P W P L

The I.D. of the rotor spring will be equal to the seal I.D.

Assuming the force on the seal will increase proportional to its diameter and the spring length will increase proportional to the spring I.D.,

$$\text{Spring Force} = K_1 \text{ (Wire Diameter)}^2$$

and

$$\text{Seal Force} = K_2 \text{ (Diameter)}$$

$$\text{Wire Diameter} = K_2 \text{ (Spring Diameter)}^{1/2}$$

For Wire Dia = .075, Spring Dia. = 1.125

$$K_2 = \frac{.075}{(1.125)^{1/2}} = .0706$$

$$\text{PWPLP} = \text{Wire Dia.} = .0706 \text{ (PWPGP)}^{1/2}$$

The length will be proportional to the I.D. or (PWPGP)

WEIGHT

The weight of the spring will be proportional to its volume.

$$Wt = K_3 \text{ (Volume)} = K_4 \text{ (Diameter)}^2 \text{ (Length)}$$

$$= K_4 \text{ (PWPGP)}^2$$

For Wt = .0175 PWPGP = 1.125

$$K_4 = \frac{.0175}{(1.125)^2} = .0138$$

PWPLW = .0138*PWPGP**2.

RELIABILITY

Failure of the spring will be due to a stress concentration in the spring. Assuming the damaged area will remain constant.

PW-58

ANALYSIS BY: C E Jones **CHECKED BY:** [signature]

Derivation of Equations

$$F.R. = K_5 \text{ (Effects of Damage)} = K_6 \frac{\text{Damage Area}}{\text{Total Area}}$$

$$= \frac{K_7}{(PWPLP)^2} = \frac{K_8}{PWPGP}$$

For

$F.R. = .050, \quad PWPGP = 1.125$

$K_7 = .050 \text{ (X 125)} = .0562$

$PWPLR = .0562/PWPGP$

EQUATIONS

ITEM NAME: Pump Orifice Cartridge
Fixed Wobble Plate

SYMBOL P W C C

REQUIRED INPUTS: F L O W
P R E S

REQUIRED OUTPUTS:

OUTPUTS:

STANDARD

Weight	P	W	C	C	W	=	(2.E-3.)*FLOW**1.5/PRES**.75
Reliability $^{-1}$	P	W	C	C	R	=	(9.7 E-2.)*FLOW**.5/PRES**.25
Life					L	=	
Response					S	=	
Cont. Oper. Time					O	=	
Devel. Time					T	=	
Devel. Cost					D	=	
Unit Cost					U	=	

OTHER

NOTES:

PW-60

ANALYSIS BY: C. E. Jones CHECKED BY: D. A. Trommeter

DERIVATION OF EQUATIONS

ITEM NAME: Pump Orifice Cartridge Fixed Wobble Plate **SYMBOL** P W C C

The orifice size will be governed by the flow demand of the compensator which will be proportional to the flow of the pump.

$$Q = K_1 \text{ Area } (\text{PRES})^{1/2}$$

$$\text{Orifice Diameter} = K_2 \frac{(\text{FLOW})^{1/2}}{(\text{PRES})^{1/4}}$$

The length diameters of the orifice assembly will be proportional to the orifice diameter.

WEIGHT

The weight of the orifice assembly will be proportional to the volume.

$$\text{Weight} = K_3 (\text{Volume}) = K_4 (\text{Orifice Dia.})^3$$

$$= K_5 \frac{(\text{FLOW})^{1.5}}{(\text{PRES})^{.75}}$$

For

$$\text{Wt.} = .00252, \quad \text{FLOW} = 63.5, \quad \text{PRES} = 3000$$

$$K_5 = \frac{.00252\ (3000)^{.75}}{(63.5)^{1.5}} = .002$$

PWCCW = 2.E-4.*FLOW**1.5/PRES**.75

RELIABILITY

Failure of the orifice will be proportional to the orifice size.

$$\text{F.R.} = K_6 (\text{Orifice Size}) = K_7 (\text{FLOW})^{1/2}/\text{PRES})^{.25}$$

For

$$\text{F.R.} = .105, \quad \text{FLOW} = 63.5, \quad \text{PRES} = 3000$$

$$K_7 = .105 \frac{(3000)^{.25}}{(63.5)^{.5}} = .0975$$

$$\text{PWCCR} = .0975 (\text{FLOW})^{.5}/(\text{PRES})^{.25}$$

ANALYSIS BY: C. E. Jones PW-61 **CHECKED BY:** D. R. Lowmaster

TD-04-296-01 (8-64)

EQUATIONS

ITEM NAME: Pump Compensator Bushing Fixed Wobble Plate

SYMBOL P W C B

REQUIRED INPUTS: P W B B K
P W B B X

REQUIRED OUTPUTS:

OUTPUTS:

STANDARD

WEIGHT	P	W	C	B	W	=	.057*PWBBX*PWBBK**2.
RELIABILITY $^{-1}$	P	W	C	B	R	=	.0125/PWBBK
LIFE					L	=	
RESPONSE					S	=	
CONT. OPER. TIME					O	=	
DEVEL. TIME					T	=	
DEVEL. COST					D	=	
UNIT COST					U	=	

OTHER

NOTES:

PW-62

ANALYSIS BY: C. E. Jones CHECKED BY: D. A. Tsammatic

DERIVATION OF EQUATIONS

ITEM NAME: Pump Compensator Bushing
Fixed Wobble Plate

SYMBOL P W C B

The compensator bushing O.D. will equal the cylinder block I.D. The I.D. will be proportional to the O.D. The sleeve length will be proportional to the block length or piston stroke.

WEIGHT

The weight of the sleeve will be proportional to the volume.

$$Wt = K_1 \text{ (Volume)} = K_2 \text{ (PWBBK)}^2 \text{ (PWBBX))}$$

For

$$Wt = .0444, \quad PWBBK = .500, \quad PWBBX = 3.37$$

$$K_2 = \frac{.0444}{(.500)^2 (3.37)} = .057$$

PWCBW = .0527*PWBBK**2.*PWBBX

RELIABILITY

Failure of the sleeve will be due to damage of the I.D.

$$F.R. = K_3 \text{ (Effects of damage)} = K_4 \frac{\text{(Damage Area)}}{\text{Total Area}}$$

$$= K_5\text{/PWBBK}$$

For

$$F.R. = .025$$

$$K_5 = .025 (.5) = .0125$$

PWCB R = .0125/PWBBK

ANALYSIS BY: C E Jones PW-63 **CHECKED BY:** D. G. Tommate

TD-04-296-01 (8-64)

EQUATIONS

ITEM NAME: Pump Comp. Bushing "O" Ring Fixed Wobble Plate

SYMBOL P W C O

REQUIRED INPUTS: P W B B K P R E S

REQUIRED OUTPUTS:

OUTPUTS:

STANDARD

WEIGHT	P	W	C	O	W	=	SSWI(PWBBK)
RELIABILITY $^{-1}$	P	W	C	O	R	=	SSRI(PWBBK,PRES)
LIFE					L	=	
RESPONSE					S	=	
CONT. OPER. TIME					O	=	
DEVEL. TIME					T	=	
DEVEL. COST					D	=	
UNIT COST					U	=	

OTHER

NOTES: Multiply the above quantities by two.

ANALYSIS BY: C E Jones PW-64 CHECKED BY: R. A. Lommatz

TD-04-296-01 (8-64)

EQUATIONS

ITEM NAME: Pump Compensator Spring
Fixed Wobble Plate

SYMBOL P W C H

REQUIRED INPUTS: P W B B J
P W B B K
P R E S

REQUIRED OUTPUTS: P W C H I

OUTPUTS:

STANDARD

WEIGHT	P	W	C	H	W	=	6.67E-4*PWBBJ**1.67*PWBBK**1.333*PRES **.667
RELIABILITY $^{-1}$	P	W	C	H	R	=	4.05E-3./PWCHI**2.
LIFE					L	=	
RESPONSE					S	=	
CONT. OPER. TIME					O	=	
DEVEL. TIME					T	=	
DEVEL. COST					D	=	
UNIT COST					U	=	

OTHER

Wire Dia.	P	W	C	H	I	=	.0125*(PWBBJ*PRES)**.333 *PWBBK **.667

NOTES:

ANALYSIS BY: C. E. Jones

PW-65

CHECKED BY: D. A. Lommatzsch

DERIVATION OF EQUATIONS

ITEM NAME: Pump Compensator Spring Fixed Wobble Plate **SYMBOL** P W C H

The compensator spring diameter will be equal to the base cylinder block diameter (PWBBJ). The spring diameter will be governed by the compensator force which will be proportional to the cylinder block I.D. Assume the spring stress will remain constant.

$$\text{Spring Force} = K_1 \frac{d^3}{D} = K_2 \frac{(\text{Wire Dia})^3}{\text{PWBBJ}}$$

$$\text{Compensator Force} = K_3 (\text{PWBBK})^2 (\text{PRES})$$

$$\text{Wire Dia.} = K_4 (\text{PWBBJ}) (\text{PWBBK})^2 \text{PRES})^{1/3}$$

For Wire Dia = .15 PWBBJ = 2.25, PWBBK = .5, PRES = 3100

$$K_4 = \frac{.15}{(2.25)^{.333} (3000)^{.333} (.5)^{.667}} = .0125$$

$$\text{PWCHI} = .0125 (\text{PWBBJ})^{.333} (\text{PWBBK})^{.667} (\text{PRES})^{.333}$$

<u>WEIGHT</u>

The weight will be proportional to the volume of the spring. Assume the number of spring coils will remain constant.

$$\text{Wt} = K_5 (\text{Volume}) = K_6 (\text{PWBBJ}) (\text{PWBBJ}) (\text{PWBBK}^2) \text{PRES})^{2/3}$$

$$= K_6 (\text{PWBBJ})^{5/3} (\text{PWBBK})^{4/3} \text{PRES}^{2/3}$$

For PWBBJ = 2.25, PWBBK = .500, PRES = 3100 Wt. = .235

$$K_6 = \frac{.235}{(2.25)^{1.667} (.5)^{1.333} (3000)^{.667}} = 6.67 \times 10^{-4}$$

$$\text{PWCHW} = 6.67 \times 10^{-4} \text{PWBBJ}^{5/3} \text{PWBBK}^{4/3} \text{PRES}^{2/3}$$

ANALYSIS BY: C E Jones PW-66 **CHECKED BY:** D. A. Tommaso

RELIABILITY

Failure of the spring would be caused by damage which would result in a stress concentration.

$$F.R. = K_7 \text{ (Effects od Damage)} = K_7 \frac{\text{(Damage Area)}}{\text{Total Area}}$$

$$= K_8/(PWCHI)^2$$

For F.R. = .180, PWCHI = .15

$$K_8 = (.18)(.15)^2 = .00405$$

PWCHR = 4.05E-3./PWCHI**2.

TD-04-296-01 (8-64)

EQUATIONS

ITEM NAME: Pump Compensator Spring Seat, Fixed Wobble Plate

SYMBOL P W C G

REQUIRED INPUTS: P W C H I
P W B B J

REQUIRED OUTPUTS:

OUTPUTS:

STANDARD

WEIGHT	P	W	C	G	W	=	98.0*PWCHI**3.
RELIABILITY^{-1}	P	W	C	G	R	=	1.333E-4.*PWBBJ**2./PWCHI**3.
LIFE					L	=	
RESPONSE					S	=	
CONT. OPER. TIME					O	=	
DEVEL. TIME					T	=	
DEVEL. COST					D	=	
UNIT COST					U	=	

OTHER

NOTES:

ANALYSIS BY: C E Jones

PW-68

CHECKED BY: R. A. Lammatee

DERIVATION OF EQUATIONS

ITEM NAME: Pump Compensator Spring Seat, Fixed Wobble Plate **SYMBOL** P W C G

The compensator spring seats diameter will be proportional to the spring diameter (PWBBJ). The thickness times the diameter (area) will be proportional to the spring force ($K_1 \frac{(PWCHI)^3}{PWBBJ}$)

$$\text{Thickness} = K_2 \frac{PWCHI^3}{PWBBJ^2}$$

All other hole dias. will be proportional to the O.D.

WEIGHT

The weight will be proportional to the volume.

$$\text{Wt.} = K_3 \text{ (Volume)} = K_3 \, (PWBBJ)^2 \frac{(PWCHI)^3}{PWBBJ^2}$$

For Wt = .331, PWBBJ = 2.25 PWCHI = .15

$$K_3 = \frac{.331}{(.15)^3} = 98.0$$

$$PWCGW = 98.0 \, (PWCHI)^3$$

RELIABILITY

Failure of the seat will be due to a stress riser or damage to the thickness of the seat.

$$\text{F.R.} = K_4 \text{ (Effect of Damage)} = K_5 \frac{\text{(Damage Depth)}}{\text{Thickness}}$$

$$= K_6 \frac{PWBBJ^2}{PWCHI^3} \quad \text{for PWBBJ} = 2.25, \; \text{F.R.} = .200$$

$$K_6 = \frac{.2\,(.15)^3}{(2.25)^2} = 1.333 \times 10^{-4}$$

$$PWCGR = 1.333 \times 10^{-4} * PWBBJ**2./PWCHI**3.$$

ANALYSIS BY: C E Jones PW-69 CHECKED BY: D.A. Tommatie

TD-04-296-01 (8-64)

EQUATIONS

ITEM NAME: Pump Compensator Cap
Fixed Wobble Plate

SYMBOL P W C I

REQUIRED INPUTS: P W B B J
P W C H I

REQUIRED OUTPUTS: P W C I I

OUTPUTS:

STANDARD

WEIGHT	P	W	C	I	W	=	.546*PWCH1*PWBBJ**2.
RELIABILITY^{-1}	P	W	C	1	R	=	.1125/PWBBJ
LIFE					L	=	
RESPONSE					S	=	
CONT. OPER. TIME					O	=	
DEVEL. TIME					T	=	
DEVEL. COST					D	=	
UNIT COST					U	=	

OTHER

Cap O.D.	P	W	C	1	I	=	1.225*PWBBJ
						=	
						=	
						=	

NOTES:

ANALYSIS BY: C. E. Jones

PW-70

CHECKED BY: D. A. Lammatio

DERIVATION OF EQUATIONS

ITEM NAME: Pump Compensator Cap Fixed Wobble Plate

SYMBOL P W C I

The cap O.D. and I.D. will be proportional to the spring diameter or PWBBJ. The cap length and end thickness will be proportional to the wire diameter.

$$\text{Cap O.D.} = K_5 \text{ (PWBBJ)}$$

$$\text{For O.D.} = 2.66$$

$$K_5 = \frac{2.75}{2.25} = 1.225$$

PWCII = 1.225*PWBBJ

WEIGHT

The weight will be proportional to the volume.

$$Wt = K_1 \text{ (Volume)} = K_2 \text{ (PWBBJ)}^2 \text{ (PWCHI)}$$

For

$$\text{PWBBJ} = 2.25, \quad \text{PWCHI} = .15$$

$$K_2 = \frac{.413}{(2.25)^2 (.15)} = .546$$

PWCIW = .546 *PWCHI*PWBBJ**2.

RELIABILITY

Failure of the cap will be due to damage to the threads.

$$\text{F.R.} = K_3 \text{ (Effect of damage)}$$

$$= K_4/\text{PWBBJ}$$

For

$$\text{F.R.} = .050$$

$$K_4 = .050 (2.25) = .1125$$

PWCIR = .1125/PWBBJ

ANALYSIS BY: C E Jones **CHECKED BY:** D. A. Lumm[illegible]

TD-04-296-01 (8-64)

EQUATIONS

ITEM NAME: Pump Comp. Cap "O" Ring
Fixed Wobble Plate

SYMBOL P W C J

REQUIRED INPUTS: P W C I I
P R E S

REQUIRED OUTPUTS:

OUTPUTS:

STANDARD

WEIGHT	P	W	C	J	W	=	SSWO(PWCII)
RELIABILITY^{-1}	P	W	C	J	R	=	SSSO(PWCII,PRES)
LIFE					L	=	
RESPONSE					S	=	
CONT. OPER. TIME					O	=	
DEVEL. TIME					T	=	
DEVEL. COST					D	=	
UNIT COST					U	=	

OTHER

NOTES:

PW-72

ANALYSIS BY: C. E. Jones CHECKED BY: [signature]

TD-04-296-01 (8-64)

EQUATIONS

ITEM NAME: Pump Connecting Rod

Fixed Wobble Plate

SYMBOL P W C E

REQUIRED INPUTS: P W C H I

REQUIRED OUTPUTS:

OUTPUTS:

STANDARD

Weight	P	W	C	E	W	=	4.06*PWCHI**3.
Reliability $^{-1}$	P	W	C	E	R	=	.014
Life					L	=	
Response					S	=	
Cont. Oper. Time					O	=	
Devel. Time					T	=	
Devel. Cost					D	=	
Unit Cost					U	=	

OTHER

						=	
						=	
						=	
						=	

NOTES:

ANALYSIS BY: C E Jones

PW-73

CHECKED BY: D. A. Trommater

TD-04-296-02(8-64)

DERIVATION OF EQUATIONS

ITEM NAME: Pump Connecting Rod Fixed Wobble Plate

SYMBOL P W C E

The connecting rod length will be proportional to the spring wire diameter. The rod diameter will also be proportional to the wire diameter.

WEIGHT

The weight of the rod will be proportional to the volume.

$$Wt = K_1 \text{ (Volume)} = K_2 \text{ (PWCHI)}^3$$

For

$$Wt = .01376 \quad PWCHI = .15$$

$$K_1 = \frac{.01373}{(.15)^3} = 4.06$$

$$PWCEW = 4.06 \ PWCHI^3$$

RELIABILITY

The reliability of the rod will be constant = .014

ANALYSIS BY: C. E. Jones PW-74 **CHECKED BY:** D. A. Trommatter

TD-04-296-01 (8-64)

EQUATIONS

ITEM NAME: Pump Compensator Adj. Screw Fixed Wobble Plate

SYMBOL P W C L

REQUIRED INPUTS: P W C H I / P W B B J

REQUIRED OUTPUTS: P W C L I

OUTPUTS:

STANDARD

WEIGHT	P	W	C	L	W	=	4.69E-2.*PWCHI*PWBBJ**2.
RELIABILITY $^{-1}$	P	W	C	L	R	=	3.375E-2./PWBBJ
LIFE					L	=	
RESPONSE					S	=	
CONT. OPER. TIME					O	=	
DEVEL. TIME					T	=	
DEVEL. COST					D	=	
UNIT COST					U	=	

OTHER

Screw O.D.	P	W	C	L	I	=	.189*PWBBJ
						=	
						=	
						=	

NOTES:

ANALYSIS BY: C E Janies

PW-75

CHECKED BY: R. A. Lommatic

DERIVATION OF EQUATIONS

ITEM NAME: Pump Compensator Adj. Screw Fixed Wobble Plate **SYMBOL** P W C L

The compensator adj. screw diameter will be proportional to the spring seat diameter or to PWBBJ. The length will be proportional to the wire diameter.

SCREW DIAMETER

$$O.D. = K_6 \text{ (PWBBJ)}$$

For Dia. = .425 , PWBBJ = 2.25

$$K_6 = \frac{.425}{2.25} = .189$$

PWCLI = .189*PWBBJ

WEIGHT

The weight will be proportional to the volume.

$$Wt = K_1 \text{ (Volume)} = K_2 \text{ (PWBBJ)}^2 \text{ (PWCHI)}$$

For

Wt = .0356, PWBBJ = 2.25 PWCHI = .15

$$K_2 = \frac{.0356}{(2.25)^2 \, (.15)} = .0469$$

PWCLW = .0469*PWCHI*PWBBJ**2.

RELIABILITY

Failure of the screw will be proportional to the damage effects

$$F.R. = K_3 \text{ (Effects of damage)} = K_4 \frac{\text{(Damage Area)}}{\text{Screw Area}}$$

$$= K_5/\text{PWBBJ}$$

For

F.R. = .015, PWBBJ = 2.25

$$K_5 = .015 \, (2.25) = .03375$$

PWCLR = 3.375E-2./PWBBJ

PW-76

ANALYSIS BY: C. E. Jones **CHECKED BY:** R. A. Lammster

TD-04-296-01 (8-64)

EQUATIONS

ITEM NAME: Pump Adj. Screw "O" Ring
Fixed Wobble Plate

SYMBOL P W C M

REQUIRED INPUTS: P W C L I
P R E S

REQUIRED OUTPUTS:

OUTPUTS:

STANDARD

WEIGHT	P	W	C	M	W	=	SSWO(PWCLI)
RELIABILITY^{-1}	P	W	C	M	R	=	SSSO(PWCLI,PRES)
LIFE					L	=	
RESPONSE					S	=	
CONT. OPER. TIME					O	=	
DEVEL. TIME					T	=	
DEVEL. COST					D	=	
UNIT COST					U	=	

OTHER

NOTES:

ANALYSIS BY: C. E. Jones PW-77 CHECKED BY: D. A. Licommatie

TD-04-296-01 (8-64)

EQUATIONS

ITEM NAME: Pump Comp. Adj. Bearing
Fixed Wobble Plate

SYMBOL P W C K

REQUIRED INPUTS: P W C L W
P W C L R

REQUIRED OUTPUTS:

OUTPUTS:

STANDARD

WEIGHT	P	W	C	K	W	=	.147*PWCLW
RELIABILITY $^{-1}$	P	W	C	K	R	=	.667*PWCLR
LIFE					L	=	
RESPONSE					S	=	
CONT. OPER. TIME					O	=	
DEVEL. TIME					T	=	
DEVEL. COST					D	=	
UNIT COST					U	=	

OTHER

=

=

=

=

NOTES:

ANALYSIS BY: C. E. Jones

PW-78

CHECKED BY: R. A. Lommatter

DERIVATION OF EQUATIONS

ITEM NAME: Pump Comp. Adj. Bearing Fixed Wobble Plate

SYMBOL P W C K

WEIGHT

The bearing size will be proportional to the screw size and the weight will be proportional to its weight.

$$Wt = K_1 (PWCLW)$$

For

$$Wt = .00523 \quad PWCLW = .0356$$

$$K_1 = \frac{.00523}{.0356} = .147$$

$$PWCKW = .147\ PWCLW$$

RELIABILITY

The failure rate will be proportional to the screw failure rate.

$$F.R. = K_2 (PWCLR)$$

For

$$F.R. = .010, \quad PWCLR = .015$$

$$K_2 = \frac{.010}{.015} = .667$$

$$PWCKW = .667*PWCLR$$

ANALYSIS BY: C E Jones

PW-79

CHECKED BY: D. A. Tommatee

TD-04-296-01 (8-64)

EQUATIONS

ITEM NAME: Pump Compensator Stem Fixed Wobble Plate

SYMBOL P W C S

REQUIRED INPUTS:

P W B B K

P W B B X

P W C B R

REQUIRED OUTPUTS:

OUTPUTS:

STANDARD

WEIGHT	P	W	C	S	W	=	.0575*PWBBX*PWBBK**2.
RELIABILITY $^{-1}$	P	W	C	S	R	=	2.0*PWCBR
LIFE					L	=	
RESPONSE					S	=	
CONT. OPER. TIME					O	=	
DEVEL. TIME					T	=	
DEVEL. COST					D	=	
UNIT COST					U	=	

OTHER

NOTES:

ANALYSIS BY: C E Jones PW-80

CHECKED BY: D. A. Lammater

DERIVATION OF EQUATIONS

ITEM NAME: Pump Compensator Stem
Fixed Wobble Plate

SYMBOL P W C S

The stem O.D. will equal the sleeve I.D. or it will be proportional to the block I.D. The stem length will be proportional to stroke required to the block length.

WEIGHT

The weight will be proportional to the volume.

$$Wt = K_1 \text{ (Volume)} = K_2 \text{ (PWBBK)}^2 \text{ (PWBBX)}$$

For

$$Wt = .0475, \text{ PWBBK} = .500, \text{ PWBBX} = 3.37$$

$$K_2 = \frac{.0484}{(.500)^2 (3.37)} = .0575$$

PWCSW = .0575 *PWBBX*PWBBK**2.

RELIABILITY

The failure rate of the stem will be proportional to the reliability of the bushing.

$$F.R. = K_3 \text{ (PWCBR)}$$

For

$$F.R. = .050, \text{ PWCBR} = .025$$

$$K_3 = \frac{.050}{.025} = 2$$

PWCSR = 2. PWCBR

ANALYSIS BY: C. E. Jones PW-81 **CHECKED BY:** D. A. Lommatic

TD-04-296-01 (8-64)

EQUATIONS

ITEM NAME: Pump Block "O" Rings
Fixed Wobble Plate

SYMBOL P W V O

REQUIRED INPUTS: P W B B I
P R E S

REQUIRED OUTPUTS: P W V O W
P W V O R

OUTPUTS:

STANDARD

Weight	P	W	V	O	W	=	SSWO(PWBBI)
Reliability $^{-1}$	P	W	V	O	R	=	SSSO(PWBBI.PRES)
Life					L	=	
Response					S	=	
Cont. Oper. Time					O	=	
Devel. Time					T	=	
Devel. Cost					D	=	
Unit Cost					U	=	

OTHER

NOTES: Multiply the above quantities by three.

ANALYSIS BY: C. E. Jones

PW-82

CHECKED BY: D. A. Lammester

TD-04-296-01 (8-64)

EQUATIONS

ITEM NAME: Pump Block "O" Ring Backup Fixed Wobble Plate

SYMBOL P W V T

REQUIRED INPUTS: P W V O W
P W V O R

REQUIRED OUTPUTS:

OUTPUTS:

STANDARD

Weight	P	W	V	T	W	=	.394*PWVOW
Reliability $^{-1}$	P	W	V	T	R	=	PWVOR
Life					L	=	
Response					S	=	
Cont. Oper. Time					O	=	
Devel. Time					T	=	
Devel. Cost					D	=	
Unit Cost					U	=	

OTHER

=

=

=

=

NOTES:

ANALYSIS BY: C E Jones PW-83 **CHECKED BY:** D. A. Tommasi

TD-04-296-01 (8-64)

EQUATIONS

ITEM NAME: Pump Check Valve
Fixed Wobble Plate

SYMBOL P W V V

REQUIRED INPUTS: P W B B P

REQUIRED OUTPUTS:

OUTPUTS:

STANDARD

Weight	P	W	V	V	W	=	.067*PWBBP**3.
Reliability $^{-1}$	P	W	V	V	R	=	5.9E-3./PWBBP
Life					L	=	
Response					S	=	
Cont. Oper. Time					O	=	
Devel. Time					T	=	
Devel. Cost					D	=	
Unit Cost					U	=	

OTHER

NOTES: Multiply the above quantities by nine.

ANALYSIS BY: C E Jones

PW-84

CHECKED BY: D. A. Lommatee

TD-04-296-02(8-64)

DERIVATION OF EQUATIONS

ITEM NAME: Pump Check Valve

Fixed Wobble Plate

SYMBOL P W V V

The volume diameters (guide and plate) and the value thickness and guide length will all be proportional to the cylinder diameter.

WEIGHT

The weight of the valve will be proportional to the volume.

$$Wt. = K_1 \text{ (Volume)} = K_2 \text{ (PWBBP)}^3$$

For Wt = .0141, PWBBP = .595

$$K_2 = \frac{.0141}{(.595)^3} = .067$$

$$PWVVW = .067 \text{ (PWBBP)}^3$$

RELIABILITY

Failure of the valve would be due to leakage past the valve face caused by damage.

$$F.R. = K_3 \text{ (Effects of damage)} = K_4 \frac{\text{Damage Area}}{\text{Face Area}}$$

$$= K_5/\text{Face Diameter} = K_6/\text{PWBBP}$$

For F.R. = .010

$$K_6 = (.01)(.595) = .00595$$

$$PWVVR = 5.95E\text{-}3./_{PWBBP}$$

ANALYSIS BY: C.E. Jones PW-85 **CHECKED BY:** D. A. Lommatie

TD-04-296-01 (8-64)

EQUATIONS

ITEM NAME: Pump Check Valve Spring Fixed Wobble Plate

SYMBOL P W V S

REQUIRED INPUTS: P W B B P P R E S

REQUIRED OUTPUTS:

OUTPUTS:

STANDARD

WEIGHT	P	W	V	S	W	=	9.5E-5.*PWBBP**3.*PRES**.667
RELIABILITY^{-1}	P	W	V	S	R	=	1.11/(PWBBP**2.*PRES**.667
LIFE					L	=	
RESPONSE					S	=	
CONT. OPER. TIME					O	=	
DEVEL. TIME					T	=	
DEVEL. COST					D	=	
UNIT COST					U	=	

OTHER

NOTES: Multiply the above quantities by nine.

ANALYSIS BY: C. E. Jones

PW-86

CHECKED BY: D. A. Tommasini

DERIVATION OF EQUATIONS

ITEM NAME: Pump Check Valve Spring Fixed Wobble Plate SYMBOL P W V S

The spring diameter will equal the piston diameter.

The wire diameter will be governed by the force necessary to keep the piston closed until the cylinder pressure is reached. With the number of turns remaining constant, the spring length will be proportional to the wire diameter. Assuming the spring stress will be constant,

$$\text{Spring Force} = K_1 \frac{(\text{Wire Diameter})^3}{\text{Spring Diameter}}$$

$$\text{System Force} = K_2 \ (\text{PRES}) \ (\text{Piston Diameter})^2$$

$$\frac{(\text{Wire Dia.})^3}{(\text{Piston Dia.})} = K_3 \ (\text{PRES}) \ (\text{Piston Dia.})^2$$

$$\text{Wire Dia} = K_3 \ \text{PWBBP} \ (\text{PRES})^{1/3}$$

The length will be proportional to the spring diameter (PWBBP).

WEIGHT

The weight will be proportional to the volume of the spring.

$$\text{Wt.} = K_4 \ (\text{Volume}) = K_5 \ (\text{PWBBP})^2 \ (\text{PRES})^{2/3} \ (\text{PWBBP})$$

$$= K_5 \ (\text{PWBBP})^3 \ (\text{PRES})^{2/3}$$

For Wt. = .00417, PWBBP = .595, PRES = 3000

$$K_5 = \frac{.00417}{(.595)^3 \ (3000)^{2/3}} = .000095$$

PWVSW = 9.5E-5*PWBBP**3.*PRES**.667

ANALYSIS BY: C. E. Jones PW-87 CHECKED BY: D. A. Tommasini

RELIABILITY

Failure of the spring would be due to a stress concentration caused by damage.

$$F.R. = K_6 \text{ (Effects of damage)} = K_6 \frac{\text{(Damaged Area)}}{\text{Total Area}}$$

$$= K_7/(PWBBP)\ (PRES)^{1/3})^2$$

For F.R. = .015,

$$K_7 = .015\ (.595)^2\ (PRES)^{2/3} = 1.11$$

$$PWVSR = 1.11/(PWBBP)^2\ (PRES)^{2/3}$$

TD-04-296-01 (8-64)

EQUATIONS

ITEM NAME: Pump Head

Fixed Wobble Plate

SYMBOL P W V H

REQUIRED INPUTS:

F	L	O	W	
P	R	E	S	
P	W	B	B	I
P	W	C	I	I
P	W	C	I	R

REQUIRED OUTPUTS: P W V H I

OUTPUTS:

STANDARD

WEIGHT	P	W	V	H	W	=	(.15*FLOW**1.5/PRES**.75)+(.023*PWCII**3.) +(PWBBI**3.*PRES*((1.03E-5.)+((1.875E-9. *PRES)+((1.1E-13.)*PRES**2.)))
RELIABILITY $^{-1}$	P	W	V	H	R	=	(1.36*PWCIR)+(.224/PWBBI)
LIFE					L	=	
RESPONSE					S	=	
CONT. OPER. TIME					O	=	
DEVEL. TIME					T	=	
DEVEL. COST					D	=	
UNIT COST					U	=	

OTHER

Head O.D.	P	W	V	H	I	=	PWBBI/1+(1.516E-4.)*PRES)
						=	
						=	
						=	

NOTES:

ANALYSIS BY: [illegible signature] PW-89 **CHECKED BY:** [illegible signature]

DERIVATION OF EQUATIONS

ITEM NAME: Pump Head
Fixed Wobble Plate

SYMBOL P W V H

The Cap I.D. will equal the cylinder block O.D. (PWBBI). The cap depth over the cylinder block will be proportional to the block O.D. and the wall thickness will be proportional to the I.D. and the pressure.

$$\text{Wall Thickness} = K_1 \text{ (I.D.) (PRES)}$$

For

$$\text{I.D.} = \text{PWBBI} = 3.30, \quad \text{PRES} = 3000, \quad \text{Wall} = .75$$

$$K_1 = \frac{.75}{(3.3)\ (3000)} = 7.58 \times 10^{-5}$$

$$\text{Wall Thickness} = 7.58 \times 10^{-5} \text{ PWBBI*PRES}$$

$$\text{Head O.D.} = \text{PWVHI} = \text{PWBBI} \left(1 + 1.516 \times 10^{-4} \text{ PRES}\right)$$

$$\text{Cap Length} = \frac{.925}{3.3} \text{ PWBBI} = .28 \text{ PWBBI}$$

The cap end thickness will equal the wall thickness.

The compensator cap housing I.D. will equal the cap O.D. (PWCII). The O.D. will be proportional to the I.D. and the length will be proportional to the I.D.

For

$$\text{I.D.} = 2.75, \quad \text{O.D.} = 3.25, \quad \text{Length} = .84$$

$$\text{O.D.} = \frac{3.25}{2.75} \text{ (I.D.)} = 1.18 \text{ (I.D.)}, \quad \text{Length} = \frac{.84}{2.75} = .305$$

$$\text{Volume} = 1.18\ (.305)\ \text{O.D.}^3 \left(\frac{\pi}{4}\right) = .36 \text{ PWCII}^3 \left(\frac{\pi}{4}\right)$$

The outlet port area will depend on the pump flow rate and pressure.

ANALYSIS BY: C E Jones PW-90 **CHECKED BY:** R.A. Lammeter

Derivation of Equations

$$\text{Port Area} = K_2\ (\text{FLOW})/(\text{PRES})^{1/2}$$

$$\text{Port Dia.} = K_3\ (\text{FLOW})^{.5}/(\text{PRES})^{.25}$$

For

Dia. = 1.05, FLOW = 63.5, PRES = 3000

$$K_3 = \frac{1.05\ (3000)^{2.5}}{(63.5).5} = 1.13$$

$$\text{Port Dia.} = 1.13\ (\text{FLOW})^{.5}/(\text{PRES})^{.25}$$

The O.D. will be approximately proportional to the I.D.

$$\text{O.D.} = K_4\ (\text{I.D.})$$

For

O.D. = 1.75

$$K_4 = \frac{1.75}{1.05} = 1.667$$

$$\text{O.D.} = 1.667\ (\text{I.D.}) = 1.88\ (\text{FLOW})^{.5}/(\text{PRES})^{.25}$$

The length will be proportional to the I.D.

For

Length = .825

$$\text{Length} = \frac{.825}{1.05}\ (1.3)\ (\text{FLOW})^{.5}/(\text{PRES})^{.25} = 1.043\ (\text{FLOW})^{.5}/(\text{PRES})^{.25}$$

<u>VOLUME</u>

The volume of the port will be:

$$\text{Volume} = ((1.88)^2 - (1.13)^2\ (1.043)\ (\text{FLOW})^{1/2}/(\text{PRES})^{1/4})^3$$

$$= \left(\frac{\pi}{4}\right) 2.35\ (\text{FLOW})^{3/2}/(\text{PRES})^{3/4}$$

WEIGHT

The weight will be proportional to the volume.

$$Wt = K_5 \text{ (Volume)} = K_5 \left(2.35 \text{ (FLOW)}^{1.5}/\text{(PRES)}^{.75}\right) +$$

$$.36 \text{ PWCCI}^3 + ((.28 \text{ PWBBI}) (\text{PWBBI}^2)$$

$$((1 + 1.516 \times 10^{-4} \text{ PRES})^2 - 1) + ((7.58 \times 10^{-5} \text{ PWBBI*PRES})$$

$$(\text{PWBBI}^2) (1 + 1.516 \times 10^{-4}) (\text{PRES})^2)$$

$$= K_5 \left(((2.35) (\text{FLOW})^{1.5}/(\text{PRES})^{.75}) + (.36 (\text{PWCII})^3) + (\text{PWBBI}^3\right.$$

$$\left.(\text{PRES}) (1.61 \times 10^{-4} + 2.94 \times 10^{-8} \text{ PRES} + 1.73 \times 10^{-12} (\text{PRES})^2)\right)$$

For

Wt = 2.419, FLOW = 63.5, PRES = 3000, PWCCI = 2.75, PWBBI = 3.3

$$K_5 = \frac{2.419}{\frac{2.35(63.5)^{1.5}}{(3000)^{.75}} + .36(2.75)^3 + (3.3)^3(3000)(1.61 \times 10^{-4} + 2.94(3000) \times 10^{-8} + 1.73 \times 10^{-12} (3000)^2} = .0637$$

PWVHW = (.15*FLOW**1.5/PRES**.75) + (.0229*PWCII**3.) +
(PWBBI**3.*PRES*((1.025E-5) + ((1.875E-9)*PRES) +
((1.1E-13)*PRES**2.)))

RELIABILITY

Failure of the cap will be due to damage to the compensator cap threads or "O" ring seat and/or failure of the block "O" ring.

$$\text{F.R.} = K_6 \text{ (Effects of Damage)}$$

$$\text{F.R.} = K_7 \frac{\text{(Damage area of compensator)}}{\text{(Compesantor Cap Area)}} = K_8 \frac{\text{(Block seat Damage)}}{\text{Block Area}}$$

$$= K_9 \text{ (Cap Failure Rate} = K_{10}/\text{PWBBI}$$

Failure of the cap will be about 50/50

For Failure rate = .136, PWCIR = .050

$K_9 = \frac{.5(.136)}{.05} = 1.36$ $K_{10} = (.5)\,(.136)\,(3.3)$

PWVHR = 1.36 (PWCIR) + .224/PWBBI

TD-04-296-01 (8-64)

EQUATIONS

ITEM NAME: Pump Bleed Plug
Fixed Wobble Plate

SYMBOL P W H F

REQUIRED INPUTS: F L O W

REQUIRED OUTPUTS: P W H F I

OUTPUTS:

STANDARD

Weight	P	W	H	F	W	=	2.34E-6.*(FLOW**1.5)
Reliability $^{-1}$	P	W	H	F	R	=	7.25E-4./PWHFI
Life					L	=	
Response					S	=	
Cont. Oper. Time					O	=	
Devel. Time					T	=	
Devel. Cost					D	=	
Unit Cost					U	=	

OTHER

Plug Dia.	P	W	H	F	I	=	.0911*FLOW**.5
						=	
						=	
						=	

NOTES:

PW-94

ANALYSIS BY: C. E. Jones **CHECKED BY:** D. P. Lummate

DERIVATION OF EQUATIONS

ITEM NAME: Pump Bleed Plug

Fixed Wobble Plate

SYMBOL P W H F

The bleed plug volume will be proportional to the diameter cubed. The diameter will be proportional to the $(\text{FLOW})^{1/2}$

$$\text{Dia.} = K_1 \, (\text{FLOW})^{1/2}$$

For

$$\text{Flow} = 63.5, \quad \text{Dia.} = .725$$

$$K_1 = \frac{.725}{(63.5)^{.5}} = .0911$$

PWHFI = .0911*FLOW**.5

WEIGHT

The weight will be proportional to the volume.

$$\text{Wt} = K_2 \, (\text{Volume}) = K_3 \, (\text{FLOW})^{1.5}$$

For

$$\text{Wt} = .00119, \quad \text{FLOW} = 63.5$$

$$K_3 = \frac{.00119}{(63.5)^{1.5}} = 2.34 \times 10^{-6}$$

PWHFW = 2.34E-6.*FLOW**1.5

RELIABILITY

Failure of the plug will be due to thread or seal face damage.

$$\text{F.R.} = K_4 \, (\text{Effects of Damage}) = K_4/\text{PWHFI}$$

For

$$\text{F.R.} = .001 \quad K_4 = .001\,(.725) = 7.25 \times 10^{-4}$$

PWHFR = 7.25E-4./PWHFI

ANALYSIS BY: C. E. Jones PW-95 **CHECKED BY:** D. A. Tomm[illegible]

TD-04-296-01 (8-64)

EQUATIONS

ITEM NAME: Pump Bleed Plug "O" Ring
Fixed Wobble Plate

SYMBOL P W H G

REQUIRED INPUTS: P W H F I
P R E S

REQUIRED OUTPUTS:

OUTPUTS:

STANDARD

Weight	P	W	H	G	W	=	SSWO (PWHFI)
Reliability $^{-1}$	P	W	H	G	R	=	SFSO (PWHFI,PRES*.0133)
Life					L	=	
Response					S	=	
Cont. Oper. Time					O	=	
Devel. Time					T	=	
Devel. Cost					D	=	
Unit Cost					U	=	

OTHER

NOTES:

ANALYSIS BY: C. E. Jones PW-96 CHECKED BY: D. A. Licommatie

TD-04-296-01 (8-64)

EQUATIONS

ITEM NAME: Pump Housing Body Fixed Wobble Plate

SYMBOL: P W H A

REQUIRED INPUTS:
PWVHI
PWBBI
PWBBX
PWHFI
PWPGP
FLOW
PRES
PWPJY
PWPJI

REQUIRED OUTPUTS:

OUTPUTS:

STANDARD

Weight	P	W	H	A	W	=	(.232*FLOW**1.5/PRES**.75)+(.140*PWHFI**3.) +(.011*PWVHI**3.)+((PWBBI**2.)*((.0298*PWBBX)+(.15*PWPJY*+(.0477*PWBBI)-(.011*PWVHI)))-(.097*PWPJY*PWPJI**2.)-(.044* *PWBBI*PWPGP**2.)
Reliability $^{-1}$	P	W	H	A	R	=	.33/PWBBI
Life					L	=	
Response					S	=	
Cont. Oper. Time					O	=	
Devel. Time					T	=	
Devel. Cost					D	=	
Unit Cost					U	=	

OTHER

NOTES:

ANALYSIS BY: C. E. Jones PW-97 CHECKED BY: [illegible signature]

DERIVATION OF EQUATIONS

ITEM NAME: Pump Housing Body
Fixed Wobble Plate

SYMBOL P W H A

The pump housing will be a combination of the head mounting volume which will be proportional to the block (I.D.) and cap $(O.D.)^2$ the return port housing, the main case and the mounting flange volumes.

$$\text{Head Mounting Length} = \frac{.6}{4.27} S\ (O.D.) = .126\ PWVHI$$

$$\text{Head Mounting Volume} = (.785)\ (PWVHI^2 - PWBBI^2)\ (.126\ PWVHI)$$

The return port volume will be proportional to the $(I.D.)^3 = K_1 \dfrac{(FLOW)^{1.5}}{(PRES)^{.75}}$

For

$$I.D. = 1.3, \quad O.D. = 1.92, \quad \text{Length} = .875$$

$$\text{Vol} = (.785)\ ((1.92)^2 - (1.3)^2)\ (.875) = 1.365$$

$$\text{Vol} = K_2 \frac{(FLOW)^{1.5}}{(PRES)^{.75}}$$

$$K_2 = \frac{1.365\ (3000)^{.75}}{(63.3)^{1.5}} = 1.085$$

$$\text{Return Port Vol.} = 1.085\ (FLOW)^{1.5}/(PRES)^{.75}$$

The test port volume will be proportional to the $(I.D.^3).785$

For O.D. = 1.3 PWHFI = .725

Length = .625

$$\text{Port Volume} = \frac{(1.3)}{(.725)} \frac{(.625)}{(.625)} PWHFI^3\ (.785) = 1.21\ PWHFI^3$$

The main body length will be proportional to the block length and the housing O.D. and I.D. will be proportional to the block O.D. (PWBBI).

ANALYSIS BY: C. E. Jones PW-98 **CHECKED BY:** D. A. Lammater

The mounting face O.D. will be proportional to the body O.D. or PWBBI. The I.D. will be proportional to the shaft O.D. The thickness will be proportional to the O.D.

For

O.D. = .595, Thickness = .500 I.D. = 1.94

Shaft O.D. = 1.125, PWBBI = 3.3

$$\text{Mount Flange Volume} = \frac{\left(\frac{(5.95)^2}{3.3} PWBBI^2 - \frac{(1.94)^2}{1.125} PWPGP^2\right).785 \frac{(.5)}{3.3}}{PWBBI}$$

$$= (.387\ PWBBI^3\ 0\ .354\ PWBBI\ (PWPGP)^2$$

The thrust bearing housing O.D. will equal the housing O.D. and the I.D. and thickness will equal the bearing O.D. and thickness.

For

O.D. = 4.1

$$\text{Volume} = \left(\left(\frac{4.1}{3.3}\right)^2 PWBBI^2 - PWPJI^2\right) .785\ PWPJY$$

$$\text{Thurst Bear. Housing Vol.} = 1.215\ PWPJY(PWBBI)^2 - .785 PWPJY(PWPJI)^2$$

For body length = 4.1, I.D. = 3.75, Block Length = 3.37

$$\text{Main Housing Volume} = \left(\frac{4.1}{3.37}\right) PWBBX\ (.785)\ \frac{4.1}{3.3}^2\ \ \frac{3.75}{3.3}^2\ PWBBI^2$$

$$= .242\ PWBBX\ (PWBBI)^2$$

WEIGHT

The weight of the housing will be proportional to its volume.

$Wt = K_3$ (Volume) $= K_3$ ((Return port Vol) + (Bleed port Vol.)

+ (Cap Mounting Vol.) + (Body Vol.) + (Bearing Mount. Vol.)

= (Mount. Flange Vol.))

$$= K_3\ ((1.085\ (FLOW^{1.5}/PRES^{.75}) + 1.21\ (PWHFI)^3 + .099\ (PWVHI)^3 +$$

$$(PWBBI^2\ (.242\ PWBBX + 1.22\ PWPJY + .387\ PWBBI - .099\ PWVHI)) - (.785\ PWPJY\ (PWPJI)^2) - (.354\ PWBBI\ (PWPGP)^2)$$

For

Wt. = 3.81, PWVHI = 4.725, PWHFI = .725, PWBBI = 3.3, PWBBX = 3.37, PWPJY = .395, PWPJI = 3.00, PWPGP = 1.125

$$K_3 = \frac{3.81}{(1.085(\frac{510}{405}) + 1.21\ (.725)^3 + .099\ (4.725)^3 + ((3.3)^2\ (.242(3.37) + 1.22\ (.395) + .387\ (3.3) - .099\ (4.725)) - .785\ (.395)\ (3.0)^2 - (.354)\ (3.3)\ (1.125)^2} = .123$$

```
PWHAW = (.232*FLOW**1.5/PRES**.75) + (.140*PWHFI**3.) + (.011*
        PWVHI**3.) + ((PWBBI**2.)*((.0298*PWBBX) + (.15*
        PWPJY) + (.0477*PWBBI) - (.011*PWVHI))) - (.0967*PWPJY
        *PWPJI**2.) - (.0436*PWBBI*PWPGP**2.)
```

RELIABILITY

Failure of the housing will be due to leakage past the seals and will be primarily a function of the Main I.D.

$$F.R. = K_4\ (\text{Effects of Damage}) = K_4\ \frac{\text{Damage Area}}{\text{Total Area}} = K_5/PWBBI$$

For

F.R. = .100

K_5 = .100 (3.3) = .33

PWHAW = .33/PWBBI

PW-100

TD-04-296-01 (8-64)

EQUATIONS

ITEM NAME: Pump Operating Time

Fixed Wobble Plate

SYMBOL P W O P

REQUIRED INPUTS: A C T Q L
A C U M B
P R E S
V H Y S W

REQUIRED OUTPUTS:

OUTPUTS:

STANDARD

WEIGHT					W	=	
RELIABILITY^{-1}					R	=	
LIFE					L	=	
RESPONSE					S	=	
CONT. OPER. TIME					O	=	
DEVEL. TIME					T	=	
DEVEL. COST					D	=	
UNIT COST					U	=	

OTHER

Operating Time	P	W	O	P		=	1.26E-3.*ACTQL*ACUMB*PRES/VHYSW
						=	
						=	
						=	

NOTES:

ANALYSIS BY: C. E. Jones PW-101 CHECKED BY: D. P. Lammatie

DERIVATION OF EQUATIONS

ITEM NAME: Pump Operating Time
Fixed Wobble Plate

SYMBOL P W O P

The pump operating time for this pump will be the same as the fixed angle except the constant effeciency will change from the fixed angle calculations:

$$\text{Operating Time} = K_1 \frac{(\text{Pump effeciency})\ (\text{FLOW})\ (\text{PRES})}{\text{System Volume}}$$

For

$$\text{Time} = 1.35E{-}3\ (\text{ACTQL})\ (\text{ACUMB})\ (\text{PRES})/\text{VHYSW}$$

$$\text{Effeciency} = 86\%\ \text{instead of}\ 92\%$$

$$K_1 = .00135\ \frac{(86)}{(92)} = .00126$$

$$\text{PWOP} = 1.26E{-}3.{*}\text{ACTQL}{*}\text{ACUMB}{*}\text{PRES}/\text{VHYSW}$$

ANALYSIS BY: C. E. Jones PW-102 **CHECKED BY:** D. A. Tammatie

TD-04-296-01 (8-64)

EQUATIONS

ITEM NAME: Pump Displacement
Fixed Wobble Plate

SYMBOL P W D S

REQUIRED INPUTS:					**REQUIRED OUTPUTS:**				
A	N	G	L		P	W	D	S	
P	W	B	B	P	P	W	D	S	1
T	O	I	L	W					

OUTPUTS:

STANDARD

Weight	P	W	D	S	W	=	TOILW*PWDS1
Reliability^{-1}					R	=	
Life					L	=	
Response					S	=	
Cont. Oper. Time					O	=	
Devel. Time					T	=	
Devel. Cost					D	=	
Unit Cost					U	=	

OTHER

Displacement	P	W	D	S		=	TANF(ANGL)*((20.5*PWBBP**3)+(3.7*PWBBP **2.))
Volume	P	W	D	S	1	=	17.2*PWDS
						=	
						=	

NOTES:

ANALYSIS BY: C. E. Jones PW-103 **CHECKED BY:** D. R. Lammatia

TD-04-296-02(8-64)

DERIVATION OF EQUATIONS

ITEM NAME: Pump Displacement Fixed Wobble Plate

SYMBOL P W D S

The pump displacement will be:

Displacement = (Piston Area) (Stroke) (9)

PWDS = TANF(ANGL)*((20.5*PWBBP** 3.) + (3.7*PWBBP**2.))

The pump oil volume will be proportional to the displacement.

Oil Volume = K_1 (PWDS)

For

PWDS = 1.51, Oil Volume = 26

$K_1 = \frac{26}{1.51} = 1.72$

PWDS1 = 17.2*PWDS

WEIGHT

Weight = K_2 (PWDS1)

PWDSW = TOILW*PWDS1

PW-104

ANALYSIS BY: C. E. Jones **CHECKED BY:** D. A. Lammaster

TD-04-296-01 (8-64)

EQUATIONS

ITEM NAME: Pump Life Fixed Wobble Plate

SYMBOL P W L F

REQUIRED INPUTS: P U M S

REQUIRED OUTPUTS:

OUTPUTS:

STANDARD

WEIGHT					W	=	
RELIABILITY^{-1}					R	=	
LIFE	P	W	L	F	L	=	3175./PUMS
RESPONSE					S	=	
CONT. OPER. TIME					O	=	
DEVEL. TIME					T	=	
DEVEL. COST					D	=	
UNIT COST					U	=	

OTHER

=

=

=

=

NOTES:

PW-105

ANALYSIS BY: C. E. Jones CHECKED BY: D. A. Lammater

DERIVATION OF EQUATIONS

ITEM NAME: Pump Life SYMBOL P W L F

Fixed Wobble Plate

The pump bearing size was optimumized such that the load was constant. Failure of the pump will be due to bearing wear failure which in turn will cause head and cam play and resulting in failure.

$$\text{Life} = K_1 (\text{Rated Load})^4$$

$$\text{Load} = \frac{K_2}{(\text{PUMS})^{1/4}}$$

$$\text{Life} = K_3/\text{PUMS}$$

For a pump speed of 63.5, Life = 50 hours

$$K_3 = 50\ (63.5) = 3175.$$

$$\text{PWLFL} = 3175./\text{PUMS}$$

ANALYSIS BY: C. E. Jones PW-106 CHECKED BY: D. A. Lemmatre

E

FILTER

FILTER

The airborne filter weight and reliability equations were derived using the following assumption:

The sizing of the filter was governed by the filter required flow rate and system pressure. The filtration micron rating was assumed constant for all equations. A differential pressure indicator without a by-pass valve were included.

The specific filter used in the analysis was a standard off-the-shelf airborne type that is presently being used on launch vehicles. In programming the equations, a parameter was included in the flow in order to allow investigation of a filter in the system which is sized as a percentage of the actuator maximum flow rate.

CONTENTS OF FILTER EQUATIONS

Contents of Filter Equations - (Continued)
Page 2

TD-04-296-01 (8-64)

EQUATIONS

ITEM NAME: Filter Bowl

SYMBOL F O B O

REQUIRED INPUTS: F L O W / P R E S / F O B O J / F O B O W

REQUIRED OUTPUTS: F O B O J / F O B O W

OUTPUTS:

STANDARD

Weight	F	O	B	O	W	=	.00000205*PRES*FLOW**1.5
Reliability^{-1}	F	O	B	O	R	=	.0001814*FLOW/FOBOW
Life					L	=	
Response					S	=	
Cont. Oper. Time					O	=	
Devel. Time					T	=	
Devel. Cost					D	=	
Unit Cost					U	=	

OTHER

Bowl I.D.	F	O	B	O	J	=	.324*FLOW**0.5
Bowl O.D.	F	O	B	O	1	=	FOBOJ+.0000227*FLOW**0.5*PRES
						=	
						=	

NOTES:

F-4

ANALYSIS BY: R. T. Kibiloski CHECKED BY: D. R. Moody

TD-04-296-02(8-64)

DERIVATION OF EQUATIONS

ITEM NAME: Filter Bowl SYMBOL F O B O

Assume I.D. is a function of the square root of the flow rate:

$$I.D. = K_1 \sqrt{Q}$$

For present system, Q = 13.475 cis and I.D. = 1.188 inches.

Therefore

$$K_1 = \frac{I.D.}{\sqrt{Q}} = \frac{1.188}{3.68} = .324$$

Hoop force is a function of I.D. and pressure

$$F = (I.D.)(P)$$

Since I.D. is proportional to the square root of the flow rate

$$F = K_2 \sqrt{Q} \quad (P)$$

Also ratio of force to wall thickness should be constant

$$t = K_2 \sqrt{Q} \quad (P)$$

From analysis of element it was shown that height and diameter are also a function of flow.

$$H = \text{Const} \times \sqrt{Q}$$

$$D = \text{Const} \times \sqrt{Q}$$

ANALYSIS BY: [signature] CHECKED BY: D. R. Moody

Weight of the element is equal to the height X wall thickness X circumference times a constant

$$W_B + (H)\ (t)\ (\pi\ D)$$

substituting

$$W_B = \left\{ \left[(\sqrt{Q})\ \sqrt{Q}\ \ (P) \right] \pi \sqrt{Q} \right\}\ K_3$$

$$W_B = K_3\ (PRES)\ (FLOW)^{3/2}$$

For the present system parameters with PRES = 3000 and W_B = .3056,

$$K_3 = \frac{W_B}{(P)\ (Q)^{3/2}} = \frac{.3056}{(3000)\ (13.475)^{3/2}} = \frac{.3056}{(3000)\ (49.5)} = .00000205$$

and

FOBOW = .00000205*PRES*FLOW**1.5

The O.D. of the bowl is equal to the inside diameter plus twice the wall thickness.

$$O.D. = I.D. + 2t$$

$$\underline{I.D. = FOBOJ}$$

$$t = K_1 \sqrt{Q}\ P$$

$$K_1 = \frac{t}{\sqrt{Q}\ \ P}$$

$$K_1 = \frac{.125}{(3.67)\ (3000)}$$

$$K_1 = .00001135$$

$$2K_1 = .0000227$$

Substituting

$$O.D. = FOBOJ + .0000227* FLOW**0.5*PRES$$

FILTER BOWL RELIABILITY

The failure of the filter bowl could occur from inadequate stress levels at the threads and the bowl itself or from damage due to handling. It can be assumed then that the stresses will remain a constant, i.e. the design is sound, so the only failures should be due to damage.

1) F.R. = K_1 effects of damage or the total damage divided by the volume of metal. Therefore:

2) $$F.R. = K_2 \frac{\text{Total Damage}}{\text{Volume}}$$

The total damage can be expressed as the surface area of the bowl and the volume as the weight.

3) $$FR = K_3 \frac{\text{Surface Area}}{\text{Weight}}$$

Surface area is equal to the height times the circumference of the bowl.

$$\text{Sur Area} = (H)(\pi D) K_4$$

$$H = K_5 \sqrt{Q}$$

$$D = K_6 \sqrt{Q}$$

$$\text{Surface Area} = K_7 \; Q$$

$$FR = K_8 \frac{Q}{W}$$

Derivation of Equations

For a filter bowl with a weight of .3056 and a flow rate of 13.475 cis, the generic failure rate is .008 and

$$K_8 = F.R. \Big/ \frac{Q}{W}$$

$$K_8 = \frac{.008}{13.475/.3056} \quad \text{or} \quad \frac{(.008)\,(.3056)}{13.475}$$

$$K_8 = 1.814 \times 10^{-4}$$

$\therefore$ FOBOR = .001814*FLOW/FOBOW

TD-04-296-01 (8-64)

EQUATIONS

ITEM NAME: Filter Element

SYMBOL F O E O

REQUIRED INPUTS: F L O W

REQUIRED OUTPUTS: F O E O W

OUTPUTS:

STANDARD

Weight	F	O	E	O	W	=	.0202*FLOW
Reliability $^{-1}$	F	O	E	O	R	=	.1834*FOEOW
Life					L	=	
Response					S	=	
Cont. Oper. Time					O	=	
Devel. Time					T	=	
Devel. Cost					D	=	
Unit Cost					U	=	

OTHER

NOTES:

F-6

ANALYSIS BY: L. J. Kikiloski CHECKED BY: D. R. Moody

TD-04-296-02 (8-64)

DERIVATION OF EQUATIONS

EM NAME: Filter Element **SYMBOL** F O E C

The surface area of the filter for a given pressure drop is proportional to flow.

The circumference times the height equals the surface area and would also be proportional to flow.

The height of the element is equal to some constant times the diameter, thus making the diameter proportional to flow or $D = K_1 \sqrt{Q}$.

The weight of the element is a function of length and height and therefore a function of flow.

The weight of the end pieces are a function of the diameter squared, therefore, they too become a function of flow.

Therefore we can say that the weight of the entire element assembly is a function of flow.

$$W_e = K_2 Q$$

For the present system with a flow rate of 13.475 cis, the weight is .2725 and

$$K_2 = \frac{W_e}{Q} = \frac{.2725}{13.475} = .0202$$

Thus the weight of the element is

$$W_e = .0202 \times \text{FLOW}$$

FOEOW = .0202*FLOW

ANALYSIS BY: F. J. Kikuloski F-7 **CHECKED BY:** D. R. Moody

F O E O - (Continued)
Page 2
Derivation of Equations

RELIABILITY

$$FR = K_1 \text{ (Surface Area)}$$

$$\text{Surface Area} \approx \text{Weight}$$

$$FR = K_2 \text{ (Weight)}$$

For an element weighing .2725, the failure rate is .050 and K_2 =

$$K_2 = \frac{FR}{WT} = \frac{.050}{.2725} = .1834$$

then

$$FOEOR = .1834*FOEOW$$

TD-04-206-01 (8-64)

EQUATIONS

ITEM NAME: Washer- Bellville

SYMBOL F 0 W 0

REQUIRED INPUTS: F 0 B 0 J REQUIRED OUTPUTS:

OUTPUTS:

STANDARD

WEIGHT	F	0	W	0	W	=	FOBOJ**3.0*.0048
RELIABILITY $^{-1}$	F	0	W	0	R	=	.012/FOBOJ
LIFE					L	=	
RESPONSE					S	=	
CONT. OPER. TIME					O	=	
DEVEL. TIME					T	=	
DEVEL. COST					D	=	
UNIT COST					U	=	

OTHER

NOTES:

F-9

ANALYSIS BY: L. J. Kibiloski CHECKED BY: D. R. Moody

DERIVATION OF EQUATIONS

ITEM NAME: Washer - Bellville **SYMBOL** F 0 W 0

O.D. (Washer) $\approx$ I.D. (Bowl)

O.D. Washer = I.D. Bowl X K_1 Area of washer $\approx$ $(O.D.)^2$

To maintain same spring rate, thickness is also proportional to diameter

Weight of washer is a function of Volume which is $\approx$ to the $(dia)^3$

Then

$$W_W = (O.D.)^3 \; K_1 = (FOBOJ)^3 \, (K_1) = FOWOW$$

For the present system,

$$K_1 = \frac{FOWOW}{D^3} = \frac{.008}{(1.188)^3}$$

$$K_1 = .0048$$

$$\therefore \; FOWOW = .0048 \, (FOBOJ)^3$$

RELIABILITY

The reliability of the Bellville washer or spring is dependent on the inside diameter of the bowl. As the bowl increases in size the O.D. of washer increases and becomes more reliable (Ref. FOBO). Therefore, the failure rate varies inversely to the I.D. of the bowl.

$$F.R. = \frac{K}{I.D.\ Bowl}$$

For an I.D. of 1.188 the failure rate is .010 and

$$K = (F.R.)\,(I.D.\ Bowl)$$

$$K = (.010)\,(1.188)$$

$$K = .01188 \approx .012$$

$$F.R. = .012/I.D.$$

$$FOWOR = .012/FOBOJ$$

ANALYSIS BY: F. J. Kibiloski **CHECKED BY:** D. R. Moody

TD-04-296-01 (8-64)

EQUATIONS

ITEM NAME: Washer Plug

SYMBOL F O W P

REQUIRED INPUTS: F O W O W
F O B O J

REQUIRED OUTPUTS:

OUTPUTS:

STANDARD

Weight	F	O	W	P	W	=	.225*FOWOW
Reliability $^{-1}$	F	O	W	P	R	=	.0083/FOBOJ
Life					L	=	
Response					S	=	
Cont. Oper. Time					O	=	
Devel. Time					T	=	
Devel. Cost					D	=	
Unit Cost					U	=	

OTHER

=

=

=

=

NOTES:

ANALYSIS BY: L. J. Kibiloski

F-11

CHECKED BY: D. R. Moody

DERIVATION OF EQUATIONS

ITEM NAME: Washer Plug **SYMBOL** F O W P

The plug varies in size as to the I.D. of the washer. The weight of the plug is proportional to the weight of the washer

$$W_P = K_1 \quad (FOWOW) = FOWPW$$

For the representative unit, FOWOW = .0080 and FOWPW = .0018, Therefore

$$K_1 = \frac{.0018}{.008} = .225$$

$$FOWPW = .225 * FOWOW$$

The reliability of the plug to the Belleville washer is dependent on the I.D. of the bowl i.e. the plug O.D. is $\approx$ to the I.D. of the washer or plug O.D. is $\approx$ to the O.D. of the washer

$\therefore$ Plug O.D. is $\approx$ to the I.D. of bowl

The failure rate then is inversely proportional to the I.D. of bowl i.e. as the I.D. of bowl increases the plug I.D. increase thus reducing number of failures. (Ref. FOBO).

$$\therefore FR = \frac{K}{\text{I.D. of Bowl}}$$

$$K_1 = (\text{I.D. of bowl}) \quad (\text{F.R.})$$

$$K_1 = (.007) \ (1.188)$$

$$K_1 = .0083$$

$$FOWPR = \frac{.0083}{FOBOJ}$$

ANALYSIS BY L. J. Kibilosk **CHECKED BY:** D. R. Moody

TD-04-296-01 (8-64)

EQUATIONS

ITEM NAME: Element Removal Spring

SYMBOL F 0 S 0

REQUIRED INPUTS: F 0 B 0 J

REQUIRED OUTPUTS:

OUTPUTS:

STANDARD

WEIGHT	F 0 S 0 W	= .00161 *FOBOJ**2.33
RELIABILITY $^{-1}$	F 0 S 0 R	= .019/FOBOJ
LIFE	L	=
RESPONSE	S	=
CONT. OPER. TIME	O	=
DEVEL. TIME	T	=
DEVEL. COST	D	=
UNIT COST	U	=

OTHER

NOTES:

ANALYSIS BY: L. J. Kubiloski

F-13

CHECKED BY: D. R. Moody

DERIVATION OF EQUATIONS

ITEM NAME: Element Removal Spring **SYMBOL** F O S O

The required spring force varies proportional to the force$_{(max.)}$ required for unseating the element when the bowl is removed or

(1) $\text{Force}_{(max)} = K_1 \dfrac{d^3}{\text{Mean dia}}$ here d = wire dia (ref. Mark's Handbook).

The O.D. of spring is the same as the filter element O.D. which is proportional to the bowl I.D.

(2) $\text{Mean dia} = K_2 \text{ Bowl I.D.}$

The force required to overcome seal friction is equal to the O-ring squeeze force. This force is in turn proportional to the seal length which is proportional to the I.D. of bowl. Therefore:

(3) $\text{Force} = K_3 \text{ (I.D. of Bowl)}$

(4) $K_1 \dfrac{d^3}{\text{mean dia}} = K_3 \text{ of I.D. of Bowl}$

(5) $d^3 = K_4 \text{ (I.D. of Bowl)}^2$

The weight of the spring is equal to the cross sectional area of wire times wire length which is proportional to the circumference X cross sectional area or:

$$W = \frac{\pi d^2}{4} (K_5 \text{ mean dia})$$

$$W = K_6 d^2 \text{ (mean dia)} = K_7 \text{ (I.D. of bowl)}^{2.33}$$

For a bowl I.D. of 1.188, FOSOW = .0024 and

$$K_7 = \frac{.0024}{(1.188)^{2.33}}, \quad \text{FOSOW} = .00161\text{*FOBOJ**}2.33$$

RELIABILITY

The failure rate of the element removal spring is dependent on effects of handling times a constant

ANALYSIS BY: T. J. Kubiloski **CHECKED BY:** D. R. Moody

Derivation of Equations

F.R. = effects of handling or total damage. Therefore:

F.R. = $K_2 \dfrac{\text{Total Damage}}{\text{Volume}}$. The total damage will be proportional to the surface area and the volume to the weight. Therefore:

F.R. = $K_3 \dfrac{\text{Surface Area}}{\text{Weight}}$ or

$$\text{F.R.} = K_4 \frac{(\text{I.D. of Bowl})^{5/3}}{(\text{I.D. of Bowl})^{7/3}} = \frac{K_4}{(\text{I.D. of Bowl})^{2/3}}$$

For a bowl I.D. of 1.188, the generic failure rate is .017 and

$$(\text{F.R.})\ (\text{I.D.}) = K_5$$

$$(.017)\ (1.188)^{2/3} = .019$$

Then

FOSOR = .019/FOBOJ

TD-04-296-01 (8-64)

EQUATIONS

ITEM NAME: Filter Head

SYMBOL F O H O

REQUIRED INPUTS: F O B O W

F O B O R

REQUIRED OUTPUTS:

OUTPUTS:

STANDARD

WEIGHT	F O H O W	= 2.12*FOBOW
RELIABILITY^{-1}	F O H O R	= FOBOR
LIFE	L	=
RESPONSE	S	=
CONT. OPER. TIME	O	=
DEVEL. TIME	T	=
DEVEL. COST	D	=
UNIT COST	U	=

OTHER

=

=

=

=

NOTES:

ANALYSIS BY: L. T. Kibiloski

F-16

CHECKED BY: D. R. Moody

DERIVATION OF EQUATIONS

ITEM NAME: Filter Head SYMBOL F O H O

WEIGHT

The filter head weight is dependent on and proportional to the weight of the filter bowl. The inside diameter of the outlet port is proportional to inside diameter of element I.D. (head outlet port) I.D. (element) (1)

The inside diameter of the inlet port is proportional to the inside diameter of bowl.

I.D. (head inlet port) $\approx$ I.D. (Bowl) (2)

Inside diameters of ports are equal

I.D. (Head outlet Port) = I.D. (Head inlet port) (3)

$\therefore$ I.D. (Head outlet port) $\approx$ I.D. (Bowl) (4)

Since the diameters are proportional and both see the same pressure, then the minimum wall thickness's are also proportional.

It therefore follows that

Weight of head = Weight of Bowl X Constant

$$W_H = W_B K_1$$

$$K_1 = \frac{W_H}{W_B}$$

from present System

$$K_1 = \frac{.65}{.3056} = 2.12$$

FOHOW = (2.12) (FOBOW)

ANALYSIS BY: L. J. Kubiloski F-17 CHECKED BY: D. R. Moody

Similar to the bowl, the reliability of the filter head is dependent on handling or damage due to handling so F.R. = K_1 effects of damage

or

$$F.R. = K_2 \frac{\text{Total Damage}}{\text{Volume}}$$

Since the weight of the head is equal to a constant times the weight of the bowl the F.R. of head should also be proportional to F.R. of bowl.

$$\text{F.R. of head} = K_3 \text{ FR of bowl}$$

$$K_3 = \frac{FOHOR}{FOBOR}$$

For the present system FOHOR = FOBOR = .008

$$K_3 = \frac{.008}{.008}$$

$$K_3 = 1$$

$$\therefore FOHOR = FOBOR$$

TD-04-296-01 (8-64)

EQUATIONS

ITEM NAME: Filter Head O-Ring

SYMBOL F O H P

REQUIRED INPUTS: F O B O J

F O B O I

P R E S

REQUIRED OUTPUTS:

OUTPUTS:

STANDARD

WEIGHT	F	O	H	P	W	=	SSWI (FOBOI)
RELIABILITY^{-1}	F	O	H	P	R	=	SSSI(FOBOI,PRES)
LIFE					L	=	
RESPONSE					S	=	
CONT. OPER. TIME					O	=	
DEVEL. TIME					T	=	
DEVEL. COST					D	=	
UNIT COST					U	=	

OTHER

=

=

=

=

NOTES:

ANALYSIS BY: L. T. Kibiloski

F-19

CHECKED BY: D. R. Moody

TD-04-296-02(8-64)

DERIVATION OF EQUATIONS

ITEM NAME: Filter Head O-Ring SYMBOL F O H P

The seal weight is based on the subroutine SSWI which is standard seal weight based on the I.D. of the ring.

So

Weight of seal = SSWI (I.D. of ring)

The ring I.D. is equal to the O.D. of the bowl thus

$I.D._r$ = I.D. Bowl

Wt of seal = SSWI (I.D. Bowl)

FOHPW = SSWI (FOBOJ)

The maximum differential pressure across the "O" ring is equal to the standard pressure (PRES). The "O" ring is a static shaft seal and therefore

FOHPR = SSSI (FOBOI, PRES)

ANALYSIS BY: L. J. Kilikoske F-20 CHECKED BY: D. R. Moody

TD-04-296-01 (8-64)

EQUATIONS

ITEM NAME: Filter Head Back Up Ring

SYMBOL F O H Q

REQUIRED INPUTS: F O H P W
F O H P R

REQUIRED OUTPUTS:

OUTPUTS:

STANDARD

WEIGHT	F	O	H	Q	W	=	1.125*FOHPW
RELIABILITY $^{-1}$	F	O	H	Q	R	=	.33*FOHPR
LIFE					L	=	
RESPONSE					S	=	
CONT. OPER. TIME					O	=	
DEVEL. TIME					T	=	
DEVEL. COST					D	=	
UNIT COST					U	=	

OTHER

						=	
						=	
						=	
						=	

NOTES:

F-21

ANALYSIS BY: L. T. Kibilocki CHECKED BY: D. R. Moody

TD-04-296-02 (8-64)

DERIVATION OF EQUATIONS

ITEM NAME: Filter Head Back Up Ring **SYMBOL** F O H Q

WEIGHT

Weight of the back up ring should be equal to a constant times the weight of the "O" ring.

$$W_{BU} = K_1 W_o$$

Present system $W_{BJ} = .0009 \quad W_o = .0008$

$$K_1 = \frac{.0009}{.0008} = 1.125$$

$$W_{BU} = 1.125 \; W_o$$

FOHQW = 1.125*FOHPW

RELIABILITY

The failure rate of the back up was determined to be 1/3 of the "O" ring thus

FOHQR = .33* FOHPR

ANALYSIS BY: L. T. Kibiloski **CHECKED BY:** D. R. Moody

TD-04-296-01 (8-64)

EQUATIONS

ITEM NAME: Shut Off Diaphram Body

SYMBOL F D B O

REQUIRED INPUTS: F O B O W
F O B O J

REQUIRED OUTPUTS: F D B O W
F D B O R

OUTPUTS:

STANDARD

WEIGHT	F	D	B	O	W	=	.087*FOBOW
RELIABILITY $^{-1}$	F	D	B	O	R	=	.008/FOBOJ
LIFE					L	=	
RESPONSE					S	=	
CONT. OPER. TIME					O	=	
DEVEL. TIME					T	=	
DEVEL. COST					D	=	
UNIT COST					U	=	

OTHER

=

=

=

=

NOTES:

ANALYSIS BY: L. T. Kibiloski CHECKED BY: D. R. Moody

TD-04-296-02(8-64)

DERIVATION OF EQUATIONS

ITEM NAME: Shut Off Diaphram Body

SYMBOL F D B O

The body diameter and height will increase in size in direct proportion to the filter element. The weight should therefore follow

$$W_B = K\ W_E$$

$$K = \frac{W_B}{W_E} \quad \frac{.024}{.2725} = .087$$

$\therefore$ FDBOW = .087*FOBOW

Similarly: F.R. = K_1 I.D. of Bowl

For

F.R. = .007 and I.D. = 1.188

There

$$K_1 = (.007)\ (1.188)$$

$$K_1 = .008$$

$\therefore$ FDBOR = .008/FOBOJ

ANALYSIS BY: D. T. Kubaloski

CHECKED BY: D. R. Moody

TD-04-296-01 (8-64)

EQUATIONS

ITEM NAME: Shut Off Diaphram Body
O Ring

SYMBOL F D B K

REQUIRED INPUTS: F O B O J
P R E S

REQUIRED OUTPUTS:

OUTPUTS:

STANDARD

WEIGHT	F	D	B	K	W	=	SSWI(.623*FOBOJ)
RELIABILITY^{-1}	F	D	B	K	R	=	SSSI(.623*FOBOJ,20.)
LIFE					L	=	
RESPONSE					S	=	
CONT. OPER. TIME					O	=	
DEVEL. TIME					T	=	
DEVEL. COST					D	=	
UNIT COST					U	=	

OTHER

NOTES:

ANALYSIS BY: L. T. Kubiloski

F-25

CHECKED BY: D. R. Moody

DERIVATION OF EQUATIONS

ITEM NAME: Shut Off Diaphram Body O Ring

SYMBOL F D B K

The "O" ring inside diameter is proportional to the inside diameter of the bowl.

$$I.D. = (K_1)\ (I.D.\ of\ Bowl)$$

For the representative unit, the I.D. of the O-ring is .739 and

$$K_1 = \frac{I.D._o}{I.D._b} = \frac{.739}{1.188} = .623$$

So

$$I.D._o = (.623)\ (I.D._b)$$

The seal weight is based on the subroutine SSWI which is standard seal weight based on the I.D. of the ring.

$$Weight\ of\ Seal = SSWI\ (I.D._o)$$

Then

FDBKW = SSWI (.623*FOBOJ)

RELIABILITY

The maximum pressure across the O-ring is equal to 20 psi and the seal is a static shaft type. Therefore

FDBKR = SPSI (.623*FOBOJ, 20.0)

ANALYSIS BY: A. J. Kibiloski

CHECKED BY: D. R. Moody

TD-04-296-01 (8-64)

EQUATIONS

ITEM NAME: Shut Off Diaphram Body-O Ring

SYMBOL F D B L

REQUIRED INPUTS: F O B O J
S S W I
S P S I

REQUIRED OUTPUTS:

OUTPUTS:

STANDARD

WEIGHT	F	D	B	L	W	=	2*SSWI(.413*FOBOJ)
RELIABILITY $^{-1}$	F	D	B	L	R	=	2[SSSI(.413*FOBOJ, 20.0)]
LIFE					L	=	
RESPONSE					S	=	
CONT. OPER. TIME					O	=	
DEVEL. TIME					T	=	
DEVEL. COST					D	=	
UNIT COST					U	=	

OTHER

NOTES:

ANALYSIS BY: L. T. Kibiloski

F-27

CHECKED BY: D. R. Moody

DERIVATION OF EQUATIONS

EM NAME: Shut Off Diaphram Body
O-Ring

SYMBOL F D B L

Ring I.D. is proportional to the I.D. of Bowl

$$I.D._R = K_1 \; I.D._B$$

$$K_1 = \frac{I.D._R}{I.D._B} = \frac{.489}{1.188} = .413$$

Therefore:

$$FDBLW = 2 \left[SSWI \; (.413*FOBOJ) \right]$$

RELIABILITY

The nominal pressure on this O-ring is 20 psi and the O-ring is a static shaft type. Therefore

FDBLR = SPSI (.413 *FOBOJ, 20.)

ANALYSIS BY: D. J. Kubitoski

F-28

CHECKED BY: D. R. Moody

TD-04-296-01 (8-64)

EQUATIONS

ITEM NAME: Shut Off Diaphram

Body Backup Ring

SYMBOL F D B M

REQUIRED INPUTS: F D B L W

F D B L R

REQUIRED OUTPUTS:

OUTPUTS:

STANDARD

WEIGHT	F	D	B	M	W	=	FDBLW/2.
RELIABILITY $^{-1}$	F	D	B	M	R	=	.33*FDBLR/2.
LIFE					L	=	
RESPONSE					S	=	
CONT. OPER. TIME					O	=	
DEVEL. TIME					T	=	
DEVEL. COST					D	=	
UNIT COST					U	=	

OTHER

NOTES:

ANALYSIS BY: L. T. Kibiloski

F-29

CHECKED BY: D. R. Moody

DERIVATION OF EQUATIONS

EM NAME: Shut Off Diaphram Body Backup Ring SYMBOL F D B M

Weight of backup is equal to a constant times weight of "O" ring

$$W_{BW} = K_1 \, W_U$$

$$K_1 = \frac{W_{BW}}{W_U} = \frac{.0003}{.0003} = 1.0$$

$\therefore$ FDBMW = FDBLW/2.

RELIABILITY

Failure rate of the backup ring has been determined to be 1/3 of that of the "O" ring it is used with, thus

FDBMR = .33*FDBLR/2.

ANALYSIS BY: L. T. Kebiloski F-30 CHECKED BY: D. R. Mordy

TD-04-296-01 (8-64)

EQUATIONS

ITEM NAME: Shut Off Diaphram Spring

SYMBOL F D S O

REQUIRED INPUTS: F O B O J
F O S O W

REQUIRED OUTPUTS:

OUTPUTS:

STANDARD

WEIGHT	F	D	S	O	W	=	3.2*FOSOW
RELIABILITY $^{-1}$	F	D	S	O	R	=	.030/FOBOJ
LIFE					L	=	
RESPONSE					S	=	
CONT. OPER. TIME					O	=	
DEVEL. TIME					T	=	
DEVEL. COST					D	=	
UNIT COST					U	=	

OTHER

						=	
						=	
						=	
						=	

NOTES:

ANALYSIS BY: L. T. Kikiloski

CHECKED BY: D. R. Moody

TD-04-296-02(8-64)

DERIVATION OF EQUATIONS

ITEM NAME: Shut Off Diaphram Spring **SYMBOL** F D S O

Spring size varies as to the max. force required to close the shut off diaphram. This force is spring force and is equal to

$$F_{max} = K_1 \frac{d^3}{\text{Mean Dia}} \qquad d = \text{wire dia}$$

The O.D. of the spring is the same as the seat O.D. in the diaphram body which is proportional to head I.D. which is proportional to Bowl I.D.

$$\text{Mean Dia} = K_2 \text{ Bowl I.D.}$$

The max force is equal to the force required to overcome seal friction. This force is proportional to the seal length which is proportional to the I.D. of bowl.

$$F_1 = K_3 \text{ (Bowl I.D.)}$$

$$F_{max} = F_1$$

$$K_1 \frac{d^3}{\text{mean dia}} = K_3 \text{ (Bowl I.D.)}$$

$$d^3 = K_4 \text{ (Bowl I.D.)}^2$$

The weight of the spring is equal to the cross sectional area of wire times wire length which is area times circumference.

$$W = \frac{\pi d^2}{4} (K_5 \text{ mean dia})$$

$$W = K_6 \text{ (Bowl I.D.)}^{7/3}$$

ANALYSIS BY: L. T. Kibiloski F-32 **CHECKED BY:** D. R. Moody

Derivation of Equations

Since

$$FOSOW = .00161\ (FOBOJ)^{7/3}$$

$$FDSOW = K_7\ (FOSOW)$$

For $FOSOW = .0024$, $FDSOW = .0077$

And

$$K_7 = \frac{.0077}{.0024} = 3.2$$

FDSOW = 3.2*FOSOW

RELIABILITY (REF. FOSOR)

$$F.R. = K_1\ I.D.\ \text{of Bowl}$$

$$K_1 = (FR)\ (I.D.)$$

When

$$FR = .025 \quad I.D. = 1.188$$

$$K_1 = (.025)\ (1.188)$$

$$K_1 = .030$$

$$\therefore\ FDSOR = .030\ \ FOBOJ$$

TD-04-296-01 (8-64)

EQUATIONS

ITEM NAME: Shut Off Diaphram Retainer

SYMBOL F D R O

REQUIRED INPUTS: F D B O W

F D B O R

REQUIRED OUTPUTS:

OUTPUTS:

STANDARD

WEIGHT	F	D	R	O	W	=	.0875*FDBOW
RELIABILITY $^{-1}$	F	D	R	O	R	=	FDBOR
LIFE					L	=	
RESPONSE					S	=	
CONT. OPER. TIME					O	=	
DEVEL. TIME					T	=	
DEVEL. COST					D	=	
UNIT COST					U	=	

OTHER

NOTES:

ANALYSIS BY: L. T. Kubilaske

F-34

CHECKED BY: D. R Moody

DERIVATION OF EQUATIONS

ITEM NAME: Shut Off Diaphram Retainer SYMBOL F D R O

Weight of the retainer will vary directly with the diaphram body weight or

$$W_R = K_1 \; W_B$$

For

$$W_B = .024, \quad W_R = .0021 \text{ and}$$

$$K_1 = \frac{.0021}{.024} = .0875$$

Therefore

FDROW = .0875* FDBOW

RELIABILITY

It has been determined that the failure rate of the retainer is equal to that of the shut off diaphram body, so

$$FR_r = K_1 \; FR \text{ Body}$$

Or

FDROR = FDBOR

ANALYSIS BY: L. S. Kibiloski CHECKED BY: D. R. Moody

TD-04-296-01 (8-64)

EQUATIONS

ITEM NAME: Shut Off Diaphram Retainer Screw

SYMBOL F D R N

REQUIRED INPUTS: F D R O W
F D B O R

REQUIRED OUTPUTS:

OUTPUTS:

STANDARD

Weight	F	D	R	N	W	=	FDROW
Reliability $^{-1}$	F	D	R	N	R	=	.428*FDBOR
Life					L	=	
Response					S	=	
Cont. Oper. Time					O	=	
Devel. Time					T	=	
Devel. Cost					D	=	
Unit Cost					U	=	

OTHER

NOTES:

F-36

ANALYSIS BY: L. T. Kibilocki

CHECKED BY: D. R. Moody

TD-04-296-02(8-64)

DERIVATION OF EQUATIONS

ITEM NAME: Shut Off Diaphram Retainer Screw

SYMBOL F D R N

The screw weight varies durectly with the retainer weight or:

$$W_E = K_1 W_R$$

For

$$W_R = .0021, \quad W_E = .0021$$

and

$$K_1 = \frac{W_E}{W_R} = \frac{.0021}{.0021} = 1$$

Therefore

$$FDRNW = FDROW$$

RELIABILITY

Similarly,

$$FR_{RS} = K_1 \; FR_B$$

$$K_1 = \frac{FR_{RS}}{FR_B} = \frac{.003}{.007} = .428$$

$$FDRNR = .428 \; FDBOR$$

ANALYSIS BY: R. T. Kihiloski **CHECKED BY:** D. R. Moody

TD-04-296-01 (8-64)

EQUATIONS

ITEM NAME: A P Indicator Body

SYMBOL F I B O

REQUIRED INPUTS: P R E S

REQUIRED OUTPUTS:

OUTPUTS:

STANDARD

WEIGHT	F	I	B	O	W	=	.0106+.00000353*PRES
RELIABILITY $^{-1}$	F	I	B	O	R	=	.0035+.00077/(FIBOW**.333)
LIFE					L	=	
RESPONSE					S	=	
CONT. OPER. TIME					O	=	
DEVEL. TIME					T	=	
DEVEL. COST					D	=	
UNIT COST					U	=	

OTHER

						=	
						=	
						=	
						=	

NOTES:

ANALYSIS BY: L. T. Kibiloski

F-38

CHECKED BY: D. R. Moody

DERIVATION OF EQUATIONS

ITEM NAME: Δ P Indicator Body SYMBOL F 1 B 0

The Δ P Indicator body weight will remain constant in all areas except for the flange. The flange thickness should increase with pressure. It is assumed that the weight of the flange is equal to 1/2 the weight of the body for the representative unit. Therefore the weight of the body is equal to a constant plus a constant times the pressure. Where K_1 = 1/2 wt. of body

$$W_B = K_1 + K_2 \text{ PRES}$$

For a system where the weight of the Body = .0212 and K_1 = .0106

Weight of flange is equal to a constant times the pressure

$$W_f = K_2 \text{ Pressure}$$

$$W_2 = \frac{W_f}{\text{Pres.}}$$

$$K_2 = \frac{.0106}{3000} = .00000353$$

Weight of Body then equals

$$W_B = K_1 + K_2 \text{ (PRES)}$$

FIBOW = .0106 + .00000353*PRES

RELIABILITY

Since this is a structural part, the failure mode will primarily be due to damage as before.

ANALYSIS BY: L. J. Kibiloski F-39 CHECKED BY: D. R. Moody

Derivation of Equations

$$FR = K_3 \text{ (Effects of damage)}$$

$$= K_4 + \frac{K_5}{(FIBOW)^{1/3}}$$

$$= .0035 + \frac{K_5}{(FIBOW)^{1/3}}$$

For

$$FIBOW = .0106, \quad F.R. = .007 \text{ and}$$

$$K_5 = (.0035)\ (.0106)^{1/3}$$

$$= .00077$$

FIBOW = .0035 + .00077/(FIBOW**.333)

TD-04-296-01 (8-64)

EQUATIONS

ITEM NAME: ΔP Indicator Body O Ring SYMBOL F I B A

REQUIRED INPUTS:

REQUIRED OUTPUTS: F I B A W

F I B A R

OUTPUTS:

STANDARD

WEIGHT	F	I	B	A	W	=	.0004
RELIABILITY $^{-1}$	F	I	B	A	R	=	SPSI(.551,PRES)
LIFE					L	=	
RESPONSE					S	=	
CONT. OPER. TIME					O	=	
DEVEL. TIME					T	=	
DEVEL. COST					D	=	
UNIT COST					U	=	

OTHER

=

=

=

=

NOTES:

ANALYSIS BY: L. J. Kibiloski F-41 CHECKED BY: D. R. Moody

TD-04-296-02(8-64)

DERIVATION OF EQUATIONS

ITEM NAME: ΔP Indicator Body O Ring **SYMBOL** F I B A

WEIGHT

The part of the body where the "O" ring fits should remain constant for any system, thus the weight should also remain constant.

The weight was measured as .0004.

$\therefore$ FIBAW = .0004

RELIABILITY

The O-ring is a static piston type with pressure equal to system pressure and a constant O.D. of .551. Therefore

$\therefore$ FIBAR = .020

FIBAR = SPSI (.551,PRES)

ANALYSIS BY: D. J. Kibiloski

CHECKED BY: D. R. Moody

TD-04-296-01 (8-64)

EQUATIONS

ITEM NAME: ΔP Indicator Body Seal Ring

SYMBOL F I B B

REQUIRED INPUTS:

REQUIRED OUTPUTS:

OUTPUTS:

STANDARD

WEIGHT	F	I	B	B	W	=	.0001
RELIABILITY^{-1}	F	I	B	B	R	=	.009
LIFE					L	=	
RESPONSE					S	=	
CONT. OPER. TIME					O	=	
DEVEL. TIME					T	=	
DEVEL. COST					D	=	
UNIT COST					U	=	

OTHER

=

=

=

=

NOTES:

F-43

ANALYSIS BY: L. T. Kibiloski CHECKED BY: D. R. Moody

TD-04-296-02 (8-64)

DERIVATION OF EQUATIONS

ITEM NAME: Δ P Indicator Body Seal Ring

SYMBOL F I B B

The part of the body where this ring fits should remain constant regardless of flow or pressure thus this ring weight also remains constant or:

Weight of Ring = .0001

FIBBW = .0001

Since both the size and pressure of the O-ring are constant, F.R. Remains constant or:

FIBBR = .009

ANALYSIS BY: L. T. Kabiloski

CHECKED BY: D. R. Moody

TD-04-296-01 (8-64)

EQUATIONS

ITEM NAME: ΔP Indicator Body "O" Ring

SYMBOL F I B C

REQUIRED INPUTS:

REQUIRED OUTPUTS:

OUTPUTS:

STANDARD

WEIGHT	F	I	B	C	W	=	.0003
RELIABILITY $^{-1}$	F	I	B	C	R	=	.030
LIFE					L	=	
RESPONSE					S	=	
CONT. OPER. TIME					O	=	
DEVEL. TIME					T	=	
DEVEL. COST					D	=	
UNIT COST					U	=	

OTHER

=

=

=

=

NOTES:

ANALYSIS BY: L. T. Kibiloski

F-45

CHECKED BY: D. R. Moody

DERIVATION OF EQUATIONS

ITEM NAME: Δ P Indicator Body "O" Ring **SYMBOL** F I B C

WEIGHT (Ref. FIBBW)

The part of the body where this "O" ring fits should remain constant for any system thus the weight should also remain constant.

The weight as measured was .0003#.

$\therefore$ FIBCW = .0003

RELIABILITY (Ref. FIBBR)

F.R. Constant

$\therefore$ FIBCR = .030

ANALYSIS BY: L. T. Kikiloski F-46 **CHECKED BY:** D. R. Moody

TD-04-296-01 (8-64)

EQUATIONS

ITEM NAME: ΔP Indicator Body

Backup Ring

SYMBOL F I B D

REQUIRED INPUTS: F I B O W

REQUIRED OUTPUTS:

OUTPUTS:

STANDARD

WEIGHT	F	I	B	D	W	=	1.0*FIBAW
RELIABILITY $^{-1}$	F	I	B	D	R	=	.333*FIBAR
LIFE					L	=	
RESPONSE					S	=	
CONT. OPER. TIME					O	=	
DEVEL. TIME					T	=	
DEVEL. COST					D	=	
UNIT COST					U	=	

OTHER

NOTES:

ANALYSIS BY: L. T. Kibilaski

F-47

CHECKED BY: D. R. Moody

DERIVATION OF EQUATIONS

EM NAME: ΔP Indicator Body Backup Ring **SYMBOL** F I B D

WEIGHT

The weight of the backup ring should be equal to a constant times the weight of the "O" ring

$$W_{BU} = K_1 \; W_O$$

For present system $W_o = .0004$ $W_{BU} = .0004$

$$K_1 = \frac{W_B}{W_O}$$

$$K_1 = \frac{.0004}{.0004} = 1.0$$

$\therefore$ FIBAW = 1.0*FIBOW

RELIABILITY (Ref. FIBAW)

The backup ring was determined to have approximately 1/3 the failure rate of the associated O-ring.

Therefore:

FIBDR = .333 (FIBAR)

ANALYSIS BY: D. T. Kibiloski F-48 **CHECKED BY:** D. R. Moody

TD-04-296-01 (8-64)

EQUATIONS

ITEM NAME: ΔP Indicator Body "O" Ring

SYMBOL F I B E

REQUIRED INPUTS:

REQUIRED OUTPUTS:

OUTPUTS:

STANDARD

WEIGHT	F	I	B	E	W	=	.0003
RELIABILITY^{-1}	F	I	B	E	R	=	.030
LIFE					L	=	
RESPONSE					S	=	
CONT. OPER. TIME					O	=	
DEVEL. TIME					T	=	
DEVEL. COST					D	=	
UNIT COST					U	=	

OTHER

						=	
						=	
						=	
						=	

NOTES:

ANALYSIS BY: L. J. Kibiloski

F-49

CHECKED BY: D. R. Moody

DERIVATION OF EQUATIONS

ITEM NAME: ΔP Indicator Body "O" Ring

SYMBOL F I B E

WEIGHT

The part of the body where this "O" ring fits should remain constant for any system and pressure, thus the weight and reliability should also remain constant.

The weight was measured as .0003#.

$$\therefore \text{FIBEW} = .0003$$

and

$$\text{FIBER} = .030$$

ANALYSIS BY: L. T. Kibiloski F-50 CHECKED BY: D. R. Moody

TD-04-296-01 (8-64)

EQUATIONS

ITEM NAME: Δ P Indicator Cap Button Cover

SYMBOL F I C G

REQUIRED INPUTS:

REQUIRED OUTPUTS:

OUTPUTS:

STANDARD

Weight	F	I	C	G	W	=	.0038
Reliability^{-1}	F	I	C	G	R	=	.001
Life					L	=	
Response					S	=	
Cont. Oper. Time					O	=	
Devel. Time					T	=	
Devel. Cost					D	=	
Unit Cost					U	=	

OTHER

NOTES:

F-51

ANALYSIS BY: L. T. Kibiloski CHECKED BY: D. R. Moody

DERIVATION OF EQUATIONS

EM NAME: ΔP Indicator Cap Button Cover

SYMBOL F I C G

The cap button cover will not change. Therefore

Weight = .0038

FICGW = .0038

Failure Rate = Constant

FICGR = .001

ANALYSIS BY: L. T. Kubiloski

CHECKED BY: D. R. Moody

TD-04-296-01 (8-64)

EQUATIONS

ITEM NAME: Δ P Indicator Cap Hold Down Plate

SYMBOL F I C H

REQUIRED INPUTS:

REQUIRED OUTPUTS:

OUTPUTS:

STANDARD

WEIGHT	F	I	C	H	W	=	.0017
RELIABILITY $^{-1}$	F	I	C	H	R	=	.002
LIFE					L	=	
RESPONSE					S	=	
CONT. OPER. TIME					O	=	
DEVEL. TIME					T	=	
DEVEL. COST					D	=	
UNIT COST					U	=	

OTHER

						=	
						=	
						=	
						=	

NOTES:

ANALYSIS BY: L. T. Kibiloski

F-53

CHECKED BY: D. R. Moody

DERIVATION OF EQUATIONS

ITEM NAME: ΔP Indicator Cap Hold Down Plate

SYMBOL F I C H

Indicator will not change thus hold down plate remains constant

Weight = .0017

FICHW = .0017

F.R. = Constant

$\therefore$ = FICHR = .002

ANALYSIS BY: L. J. Kubiloski

CHECKED BY: D. R. Moody

TD-04-296-01 (8-64)

EQUATIONS

ITEM NAME: ΔP Indicator Cap Mounting Pins

SYMBOL F I C I

REQUIRED INPUTS:

REQUIRED OUTPUTS:

OUTPUTS:

STANDARD

WEIGHT	F	I	C	I	W	=	.0004*2
RELIABILITY $^{-1}$	F	I	C	I	R	=	.002*2
LIFE					L	=	
RESPONSE					S	=	
CONT. OPER. TIME					O	=	
DEVEL. TIME					T	=	
DEVEL. COST					D	=	
UNIT COST					U	=	

OTHER

=

=

=

=

NOTES:

ANALYSIS BY: L. T. Kibiloski

F-55

CHECKED BY: D. R. Moody

TD-04-296-02(8-64)

DERIVATION OF EQUATIONS

ITEM NAME: ΔP Indicator Cap Mounting Pins

SYMBOL F I C I

The indicator will not change thus the pins remain constant

Weight of each = .0004

$\therefore$ FICIW = .0004*2

Failure Rate = Constant

$\therefore$ FICIR = .002*2

ANALYSIS BY: L. J. Kibiloski CHECKED BY: D. R. Moody

TD-04-296-01 (8-64)

EQUATIONS

ITEM NAME: 4 P Indicator Cap Screws

SYMBOL F I C J

REQUIRED INPUTS: P R E S

REQUIRED OUTPUTS:

OUTPUTS:

STANDARD

Weight	F	I	C	J	W	=	4.0E-13*PRES**3.0
Reliability $^{-1}$	F	I	C	J	R	=	4.*4.2/PRES
Life					L	=	
Response					S	=	
Cont. Oper. Time					O	=	
Devel. Time					T	=	
Devel. Cost					D	=	
Unit Cost					U	=	

OTHER

NOTES:

ANALYSIS BY: L. J. Kibiloski

F-57

CHECKED BY: D. R. Moody

DERIVATION OF EQUATIONS

ITEM NAME: ΔP Indicator Cap Screws **SYMBOL** F I C J

The length and diameter of the screws will be proportional to the system pressure. Therefore

$$W_S = K_1 \text{ (Pressure)}^3$$

$$K_1 = \frac{W_S}{\text{(Pressure)}^3}$$

$$K_1 = \frac{.0027}{(3000)^3} = 1 \times 10^{-13}$$

$$\text{FICJW} = 4\ (10^{-13})\ (\text{PRES})^3$$

RELIABILITY

Failure would be primarily due to damage. Therefore, as before

$$\text{F.R.} = K/_{(\text{FICJW})^{1/3}}$$

$$= K/_{(\text{PRES})}$$

For PRES = 3000, F.R. = .0014 and

$$K = 4.2$$

$$\text{FICJR} = 4*4.2/\text{PRES}$$

F-58

ANALYSIS BY: L. J. Kibiloski **CHECKED BY:** D. R. Moody

TD-04-296-01 (8-64)

EQUATIONS

ITEM NAME: Δ P Indicator Button

SYMBOL F I I 0

REQUIRED INPUTS:

REQUIRED OUTPUTS:

OUTPUTS:

STANDARD

WEIGHT	F	I	I	0	W	=	.0032
RELIABILITY $^{-1}$	F	I	I	0	R	=	.008
LIFE					L	=	
RESPONSE					S	=	
CONT. OPER. TIME					O	=	
DEVEL. TIME					T	=	
DEVEL. COST					D	=	
UNIT COST					U	=	

OTHER

=

=

=

=

NOTES:

ANALYSIS BY: L. J. Kibiloski

F-59

CHECKED BY: D. R. Moody

TD-04-296-02 (8-64)

DERIVATION OF EQUATIONS

ITEM NAME: ΔP Indicator Button

SYMBOL F I I O

The indicator weight and reliability remains constant, consequently, the same is true for the button or

Weight = .0032

$\therefore$ FIIOW = .0032

Failure Rate = Constant

FIIOR = .008

ANALYSIS BY: L. J. Kibiloski

CHECKED BY: D. R. Moody

TD-04-296-01 (8-64)

EQUATIONS

ITEM NAME: ΔP Indicator Button Spring

SYMBOL: F I I F

REQUIRED INPUTS:

REQUIRED OUTPUTS:

OUTPUTS:

STANDARD

Weight	F	I	I	F	W	=	.0001
Reliability $^{-1}$	F	I	I	F	R	=	.025
Life					L	=	
Response					S	=	
Cont. Oper. Time					O	=	
Devel. Time					T	=	
Devel. Cost					D	=	
Unit Cost					U	=	

OTHER

NOTES:

ANALYSIS BY: R. T. Kubiloski

CHECKED BY: D. R. Moody

TD-04-296-02(8-64)

DERIVATION OF EQUATIONS

ITEM NAME: ΔP Indicator Button Spring

SYMBOL F I I F

The spring weight and reliability will remain constant since the button parameters remain constant.

FIIFW = .0001

Failure rate remains constant

FIIFR = .025

ANALYSIS BY: L. T. Kibiloski

F-62

CHECKED BY: D. R. Moody

TD-04-296-01 (8-64)

EQUATIONS

ITEM NAME: ΔP Indicator Plunger

SYMBOL F I P O

REQUIRED INPUTS:

REQUIRED OUTPUTS:

OUTPUTS:

STANDARD

Weight	F	I	P	O	W	=	.0179
Reliability $^{-1}$	F	I	P	O	R	=	.009
Life					L	=	
Response					S	=	
Cont. Oper. Time					O	=	
Devel. Time					T	=	
Devel. Cost					D	=	
Unit Cost					U	=	

OTHER

NOTES:

ANALYSIS BY: L. T. Kubiloski

CHECKED BY: D. R. Moody

TD-04-296-02 (8-64)

DERIVATION OF EQUATIONS

ITEM NAME: ΔP Indicator Plunger

SYMBOL F I P 0

Indicator remains constant thus plunger remains constant.

Weight = .0179

$\therefore$ FIPOW = .0179

Failure Rate remain constant

FIPOR = .009

ANALYSIS BY: L. J. Kihiloski

CHECKED BY: D. R. Moody

TD-04-296-01 (8-64)

EQUATIONS

ITEM NAME: Δ P Indicator
Plunger-Spring

SYMBOL F I P E

REQUIRED INPUTS:

REQUIRED OUTPUTS:

OUTPUTS:

STANDARD

WEIGHT	F	I	P	E	W	=	.0036
RELIABILITY $^{-1}$	F	I	P	E	R	=	.0100
LIFE					L	=	
RESPONSE					S	=	
CONT. OPER. TIME					O	=	
DEVEL. TIME					T	=	
DEVEL. COST					D	=	
UNIT COST					U	=	

OTHER

=

=

=

=

NOTES:

F-65

ANALYSIS BY: L. T. Kubiloski

CHECKED BY: D. R. Moody

TD-04-296-02 (8-64)

DERIVATION OF EQUATIONS

ITEM NAME: ΔP Indicator Plunger-Spring SYMBOL F I P E

Plunger remain constant thus spring will remain constant.

Weight = .0036

FIPEW = .0036

Failure rate remains constant

FIPER = .010

ANALYSIS BY: L. J. Kibiloski F-66 CHECKED BY: D. R. Moody

TD-04-296-01 (8-64)

EQUATIONS

ITEM NAME: Filter Oil Volume

SYMBOL F I V O W

REQUIRED INPUTS: A C T Q A / A N U M B

REQUIRED OUTPUTS: F I V O W / T O I L W

OUTPUTS:

STANDARD

WEIGHT	F I V O W	= FIVOL*TOILW
RELIABILITY⁻¹	R	=
LIFE	L	=
RESPONSE	S	=
CONT. OPER. TIME	O	=
DEVEL. TIME	T	=
DEVEL. COST	D	=
UNIT COST	U	=

OTHER

	F I V O L	= .095525*ACTQA*ANUMB**1.5-07071*ACTQA*ANUMB
	T O I L W	= Density of Hydraulic Fluid

NOTES:

ANALYSIS BY: M. Nakai

F-67

CHECKED BY: J. J. Harrington

DERIVATION OF EQUATIONS

ITEM NAME: Filter Oil Volume SYMBOL F I V O W

The volume of oil in the filter is proportional to the filter bowl inside diameter, (I.D.) times its height (H) less the volume of the filter element.

$$V_t = V_b - V_e$$

V_b = volume of the bowl

V_e = volume of the filter element

$$V_b = \frac{\pi (I.D.)^2}{4} (H)$$

From previous weight analysis it was shown that the

$$I.D. = K_1 \sqrt{Q}$$

and

$$H = K_2 \sqrt{Q}$$

Where Q = maximum system flow

$$V_b = \frac{\pi}{4} \left(K_1 \sqrt{Q}\right)^2 \quad (K_2 \sqrt{Q})$$

$$= K_3 \, (Q)^{3/2}$$

For a flow of 13.475 cis

$$H = 3.85 \text{ in.}$$

$$I.D. = 1.25 \text{ in.}$$

$$V_b = \frac{\pi (1.25)^2}{4} 3.85 = (1.227185)(3.85) = 4.72466$$

$$K_3 = \frac{V_b}{Q^{3/2}} = \frac{4.72466}{(13.475)^{3/2}}$$

ANALYSIS BY: M. Nakai CHECKED BY: J. J. Harrington

$$\text{Log} = (13.475)^{1.5} = 1.5 \log 13.475$$

$$= (1.5)\ (1.12\ 953) = 1.694295$$

$$(13.475)^{1.5} = 49.46$$

$$K_3 = \frac{4.72466}{49.46} = .095525$$

$$V_b = (.095525)Q^{3/2}$$

The filter element volume is proportional to its weight and from the previous weight analysis it was found that the weight was proportional to the maximum system flow.

$$Wt = K_4 \quad Q$$

$$V = \frac{Wt}{\rho} = K_5\ Q$$

$$\rho = \text{density of filter material} = .286$$

The weight of a filter element was found to be .2725 pounds for a system flow of 13.475 cubic inches per second.

$$V_e = \frac{Wt}{\rho} = \frac{.2725}{.286} = .95280$$

$$V_e = K_5\ Q$$

$$K_4 = \frac{V_e}{Q} = \frac{.95280}{13.475} = .070709$$

$$V_e = .070709\ Q$$

$$V_t = V_b - V_e$$

$$V_t = (.095525)\ Q^{3/2} - .070709\ Q$$

Q = maximum system flow rate

Q = (ACTQA) (ANUMB)

Where ACTQA = maximum flow rate of (1) actuator

ANUMB = number of actuators per pump

FIVOL = $(.095525)\ (ACTQA)\ (ANUMB)^{1.5} - .07071\ (ACTQA)\ (ANUMB)$

FIVOW = PIVOL*TOILW

TOILW = Density of hydraulic fluid.

F

RESERVOIR ACCUMULATOR

RESERVOIR-ACCUMULATOR

The reservoir-accumulator weight and reliability equations were derived in the following order: 1) reservoir piston, 2) bootstrap piston, 3) accumulator piston, and 4) body, end caps and associated parts.

The reservoir piston L/D ratio was held constant at 2, (i.e. the stroke is assumed to be one-half the piston dia.). The reservoir volume and return pressure are the input variables used for sizing the reservoir.

A bootstrap piston area ratio of seventy to one (one square inch bootstrap piston area to seventy square inch reservoir piston area) was used throughout the analysis. The reservoir, bootstrap and accumulator piston sizes vary with the system and return pressure along with the required reservoir and accumulator volumes.

The bootstrap piston O.D. is used to determine the accumulator piston I.D. The accumulator L/D ratio was held constant at .5.

During the programming, the accumulator portion of the reservoir-accumulator was multiplied by a constant which is either set to one or zero at the start of the program. If this factor is one, an accumulator-reservoir will be included in the system. If it is zero, only a bootstrap reservoir will be included.

The equations were also programmed such that, if the total number of pumps in the system is zero (such as the F1 engine system), no reservoir or accumulator will be used in the system and the associated parameters will be automatically set to zero.

CONTENTS OF RESERVOIR EQUATIONS

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Page 2

Contents of Reservoir Equations - (Continued)
Page 3

TD-04-296-01 (8-64)

EQUATIONS

ITEM NAME: Reservoir Piston Assembly - Piston

SYMBOL R P A P

REQUIRED INPUTS: R V O L
R P R E

REQUIRED OUTPUTS: R P A P I

OUTPUTS:

STANDARD

Weight	R	P	A	P	W	=	See next page
Reliability $^{-1}$	R	P	A	P	R	=	7.49/RPRE * RPAPI ** 2.0
Life					L	=	
Response					S	=	
Cont. Oper. Time					O	=	
Devel. Time					T	=	
Devel. Cost					D	=	
Unit Cost					U	=	

OTHER

Piston O.D.	R	P	A	P	I	=	See next page
						=	
						=	
						=	

NOTES:

RS-1

ANALYSIS BY: J. J. Harrington CHECKED BY: M. Nakai

TD-04-296-02(8-64)

DERIVATION OF EQUATIONS

ITEM NAME: Reservoir Piston Assembly - Piston

SYMBOL R P A P

The following method shall be used for determining the piston O.D.

1) $$\text{vol} = \frac{\pi}{4} \overset{\text{area}}{(D^2 - K^2)} \frac{D}{2} \quad \text{length} \qquad L/D = \tfrac{1}{2}$$

$$\text{vol} = \frac{\pi}{4} \left(\frac{D^3}{2} - \frac{D}{2} K^2\right)$$

2) $$\frac{\pi}{4} \frac{D^3}{2} = \text{Vol} + \frac{\pi}{4} \frac{D}{2} K^2$$

$$\frac{D^3}{2} = \frac{4}{\pi} \text{Vol} + \frac{D}{2} K^2$$

3) $$D = \left[\left(\frac{4}{\pi} \text{Vol} + \frac{D}{2} K^2\right)2\right]^{1/3}$$

K^2 = Area of pot will remain constant

$$A = \frac{\pi}{4} (.570)^2$$
$$.3249$$

4) Solve the following equation

$$\overset{A}{\text{RPAPI}} = \left[\left(\frac{4}{\pi} \text{R Vol} + \overset{B}{\frac{\text{RPAPI}}{2}} (.3249)\right)2\right]^{1/3}$$

5) Solve

$$A - B \quad -.0000001 \; A = - \;,0,\; +$$

If this is greater than – or 0 continue to step 7.

If ans is + go to step 6

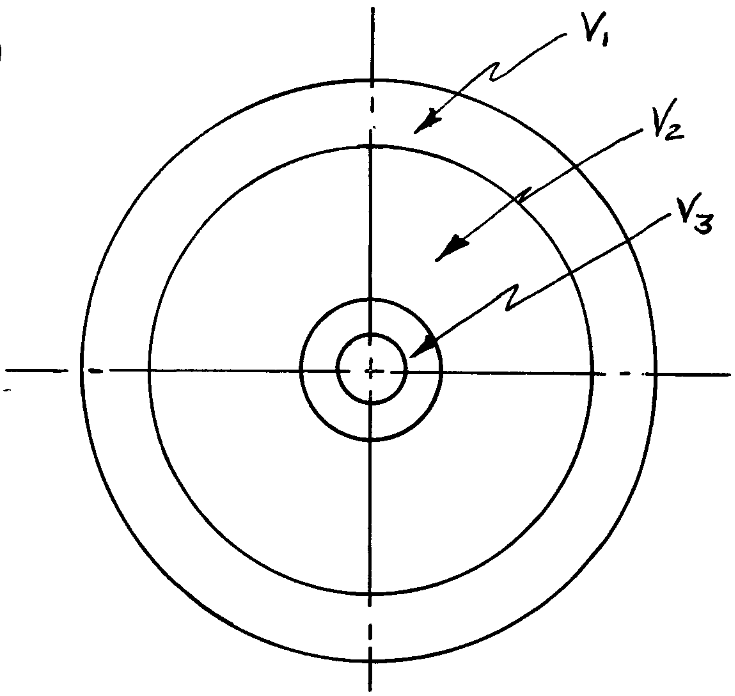
6) A = B go to step 5

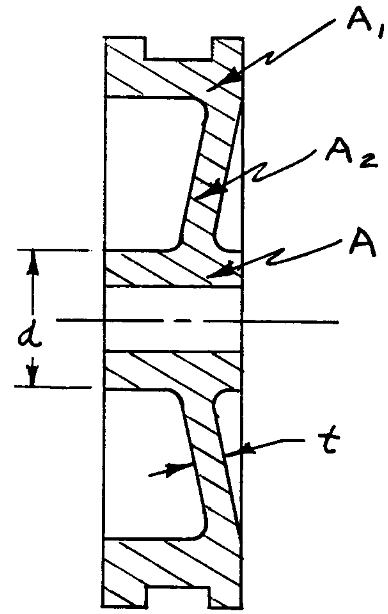
7) RPAPW = .0093 * (RPAPI) ** 2 +

+ 6.8E-6 * (RPRE) * (RPAPI) ** 4 + .046

RS-2

ANALYSIS BY: J. J. Harrington CHECKED BY: M. Makai





The weight of the piston is the sum of the weight of the three volumes V_1, V_2, and V_3. The weight W_3 of volume V_3 is constant since the diameter of the switch - potentiometer housing is constant the volume V_3 is assumed to be constant. It was previously determined that the volume $V_1 = K_2$ (piston area)

$$W_1 = K_1 \frac{\pi}{4} (RPAPI)^2$$

$$W_1 = K_2 \, {}^{4}(RPAPI)^2$$

where RPAPI = piston diameter. The weight of W_2, of volume V_2 is dependent upon the force on the piston.

$$S_s = \frac{F}{A_d}$$

where: S_s is the design shear stress F is the piston force

A_d = area of material at diameter d.

$F = P\ A$

$-P$ = pressure = RPRES

A = piston area = $\frac{\pi}{4}$ (RPAPI)^2

$A_d = (\pi d)\ (t)$ t = thickness

$$S_s = \frac{PA}{A_d} = \frac{P \frac{\pi}{4} (RPAPI)^2}{\pi\ d\ t}$$

$$t = \frac{(RPRE)\ \ (RPAPI)^2}{4\ d\ S_s}$$

Let $K_3 = \dfrac{1}{4\ d\ S_s}$

$$t = K_3\ (RPRE)\ (RPAPI)^2$$

The weight of $W_2 = K_4$ (piston area) x thickness

$$W_2 = K_3\ \frac{\pi}{4}\ (RPAPI)^2\ \ K_5\ RPRES\ (APAPI)^2$$

$$W_2 = K_6\ (RPRES)\ (RPAPI)^4$$

The total piston weight $W = W_1 + W_2 + W_3$

It was determined that a reservoir with a 40 psi return pressure and a piston diameter of 6.118 inches

$W = .773$ lb

$W_3 = .046$ lb

$W_1 = .347$ lb

$W_2 = .38$ lb

$$W_1 = K_2 \, (RPAPI)^2$$

$$K_2 = \frac{.347}{(6.118)^2} = .0093$$

$$W_2 = K_6 \, (RPRE) \, (RPAPI)^4$$

$$K_6 = \frac{.38}{(40)\,(6.118)^4} = 6.8 \times 10^{-6}$$

$$RPAPW = .0093 \, (RPAPI)^2 + 6.8 \times 10^6 \, (RPRE) \, (RPAPI)^4 + .046$$

<u>RELIABILITY</u>

The principle mode of failure will be due to fatigue occuring at the intersection of the web and hub of the piston. The fatigue failure will be caused by stress risers due to machining errors. Since the hub diameter is constant the effects of the machining errors is inversely proportional to the web thickness t

Therefore $FR = \frac{K}{t}$

It was previously determined that

$$t = K_3 \text{ (RPRE) } \text{ (RPAPI)}^2$$

$$FR = \frac{K}{K_3 \text{ (RPRE) (RPAPI)}^2}$$

$$FR = \frac{K4}{\text{(RPRE) (RPAPI)}^2}$$

It was found that the failure rate of a 6.118 in diameter reservoir was .005 for a 40 psi reservoir pressure

$$K_4 = (.005)\ (40)\ (6.118)^2 = 7.49$$

$$\text{RPAPR} = \frac{7.49}{\text{(RPRE) (RPAPI)}^2}$$

TD-04-296-01 (8-64)

EQUATIONS

ITEM NAME: Reserovir Piston Assembly Rod

SYMBOL: R P A R

REQUIRED INPUTS: R P R E; R P A P I

REQUIRED OUTPUTS: R P A R I

OUTPUTS:

STANDARD

WEIGHT	R	P	A	R	W	=	See next page
RELIABILITY^{-1}	R	P	A	R	R	=	1.07 E-4.0(RPAPI)**2.0
LIFE					L	=	
RESPONSE					S	=	
CONT OPER. TIME					O	=	
DEVEL. TIME					T	=	
DEVEL. COST					D	=	
UNIT COST					U	=	

OTHER

	R	P	A	R	I	=	See next page
						=	
						=	
						=	

NOTES:

RS-7

ANALYSIS BY: J. J. Harrington

CHECKED BY: M. Nakai

TD-04-296-02 (8-64)

DERIVATION OF EQUATIONS

ITEM NAME: Reservoir Piston Assembly Rod

SYMBOL R P A R

The L/D or Stroke to reservoir piston rod mean diameter was found to be approximately 3.66

$$L/D = 3.66$$

$$D = \frac{L}{3.66}$$

Since the stroke $L = (.5)(RPAPI)$ $D = \frac{.5 \text{ RPAPI}}{3.666} = .1365 \text{ RPAPI}$

The length of the piston rod will be

$$l = L + 3.5 = .5 \text{ RPAPI} + 3.5$$

The volume of the piston rod will be

$$Vol = l\,(\pi D)\,t$$

t = wall thickness

$$Vol = (.5 \text{ RPAPI} + 3.5)\,\pi\, .1365 \text{ RPAPI}\ \ t$$

The thickness of the piston rod will depend upon the shear stress

$$S_s = \frac{F}{A}$$

F = Reservoir pressure X Reservoir piston area

A = Cross sectional area of the piston rod at the weakest section

$$A = \pi D t - 4\left(\frac{5}{16}\right) t$$

$$= \left(\pi D - \frac{5}{4}\right) t$$

RS-8

ANALYSIS BY: J. J. Harrington CHECKED BY: M. Nakai

Derivation of Equations

$$D = \frac{L}{3.66} = .1365 \text{ RPAPI}$$

$$A = \left(\pi \; .1365 \text{ RPAPI} - \frac{5}{4}\right) t$$

$$S_S = \frac{(\text{RPRE}) \left(\frac{\pi \text{ RPAPI}^2}{4}\right)}{(\pi .1365 \text{ RPAPI} - 5/4) \quad t}$$

$$t = \frac{(\text{RPRE}) \; (\text{RPAPI}^2)}{S_s \; (\pi \; .1365 \text{ RPAPI} - 5/4)} = \frac{.1365 \; (\text{RPRE}) \; (\text{RPAPI}^2)}{S_s \; \left(\text{RPAPI} - \frac{5}{(4) .1365}\right)}$$

$$t = \frac{7.33 \; (\text{RPRE} \; (\text{RPAPI})^2}{S_s \; (\text{RPAPI} - 2.92)} = \frac{K_1 \; (\text{RPRE}) \; (\text{RPAPI})^2}{(\text{RPAPI} - 2.92)}$$

$$K_1 = \frac{.123 \; (\text{RPAPI} - 2.92)}{(\text{RPRE}) \; (\text{RPAPI})^2} = \frac{.123 \; (6.118 - 2.92)}{(40) \; (6.118)^2}$$

$$K_1 = \frac{(.123) \; (3.198)}{(40) \; (6.118)^2} = 4.55 \times 10^{-4}$$

$$W_t = K_2 \text{ Vol}$$

$$= \frac{K_2 \; (.5 \text{ RPAPI} + 3.5) \pi \; .1365 \text{ RPAPI } K_1 \text{ RPRE } (\text{RPAPI})^2}{(\text{RPAPI} - 2.92)}$$

$$W_t = \frac{K_3 \; (\text{RPAPI} + 7) \; (\text{RPAPI}^3) \; (\text{RPRE})}{(\text{RPAPI} - 2.9)}$$

for a reservoir piston of 6.118 in diameter and 40 psi the piston rod weight was found to be .2444

Derivation of Equations

$$K_3 = \frac{(.2444)\ (RPAPI - 2.9)}{(RPAPI + 7)\ (RPAPI^3)\ (RPRE)}$$

$$= \frac{.2444\ (6.118 - 2.9)}{(6.118 + 7)\ (6.118^3)\ (40)}$$

$$= \frac{.2444\ (3.218)}{(13.118)\ (229)\ (40)} = 6.55 \times 10^{-5}$$

$$RPARW = \frac{6.55 \times 10^{-5}\ (RPAPI + 7)\ (RPAPI)^3\ (RPRE)}{RPAPI - 2.9}$$

RPARI, piston rod outside diameter

$$RPARI = D + 2t$$

$$= .1365\ RPAPI + \frac{4.55 \times 10^{-4}\ (RPRE)\ (RPAPI)^2}{(RPAPI - 2.92)}$$

Reservoir Piston Rod

F.R. in proportion to surface area.

$$F.R. = \pi\ d\ (stroke)\ (k) \qquad Stroke = .5D$$

$$= .5\ RPAPI$$

$$F.R. = \pi\ (RPAPI)\ .5\ (RPAPI)\ K$$

$$F.R. = .004$$

$$F.R. = K_1\ (RPAPI)^2$$

$$K_1 = \frac{.004}{(RPAPI)^2} = \frac{.004}{(6.118)^2} = 1.07 \times 10^{-4}$$

$$RPARR = 1.07 \times 10^{-4}\ (RPAPI)^2$$

TD-04-296-01 (8-64)

EQUATIONS

ITEM NAME: Reservoir Piston "O" Ring Large

SYMBOL: R P O L

REQUIRED INPUTS: R P R E
R P A P I

REQUIRED OUTPUTS:

OUTPUTS:

STANDARD

Weight	R	P	O	L	W	=	SSWO, RPAPI
Reliability $^{-1}$	R	P	O	L	R	=	SPLO, RPAPI, RPRE
Life					L	=	
Response					S	=	
Cont. Oper. Time					O	=	
Devel. Time					T	=	
Devel. Cost					D	=	
Unit Cost					U	=	

OTHER

NOTES:

ANALYSIS BY: J. J. Harrington

RS-11

CHECKED BY: M. Nakai

DERIVATION OF EQUATIONS

ITEM NAME: Reservoir Piston "O" Ring Large SYMBOL R P O L

Dynamic piston seal reservoir pressure (RPRE) the "O" ring is proportional to O.D. of piston (RPAPI).

O.D. "O" ring = RPAPI

RPOLW = SSWO, RPAPI

RPOLR = SPLO, RPAPI, RPRE

RS-12

ANALYSIS BY: J. J. Harrington CHECKED BY: M. Nakai

TD-04-296-01 (8-64)

EQUATIONS

ITEM NAME: Reservoir Piston "O" Ring Back Up

SYMBOL R P B U

REQUIRED INPUTS: R P O L W
R P O L R

REQUIRED OUTPUTS:

OUTPUTS:

STANDARD

WEIGHT	R	P	B	U	W	=	.436 RPOLW*2
RELIABILITY^{-1}	R	P	B	U	R	=	.0333RPOLR*2
LIFE					L	=	
RESPONSE					S	=	
CONT. OPER. TIME					O	=	
DEVEL. TIME					T	=	
DEVEL. COST					D	=	
UNIT COST					U	=	

OTHER

NOTES:

RS-13

ANALYSIS BY: J. J. Harrington CHECKED BY: M. Nakai

DERIVATION OF EQUATIONS

ITEM NAME: Reservoir Piston "O" ring Back up

SYMBOL R P B U

The back up is proportional to weight of the "O" ring and back up

$$W_B = K_1 W_O$$

$$K_1 = \frac{W_B}{W_O} = \frac{.0188}{.0431} = .436$$

RPBUW = .436 RPOLW *2

since 2 back-up rings are required.

RELIABILITY

$$R_W = K_1 R_O$$

$$K_1 = \frac{R_W}{R_O} = \frac{.010}{.300} = .0333$$

RPBUR = .0333 RPOLR *2

since 2 back-up rings are required.

ANALYSIS BY: Y. Y. Harrington CHECKED BY: M. Nakai

TD-04-296-01 (8-64)

EQUATIONS

ITEM NAME: Reservoir Piston "O" Ring Small

SYMBOL R P O S

REQUIRED INPUTS: R P R E

REQUIRED OUTPUTS:

OUTPUTS:

STANDARD

WEIGHT	R	P	O	S	W	=	.0028
RELIABILITY^{-1}	R	P	O	S	R	=	SSSI . 1.50. RPRE
LIFE					L	=	
RESPONSE					S	=	
CONT. OPER. TIME					O	=	
DEVEL. TIME					T	=	
DEVEL. COST					D	=	
UNIT COST					U	=	

OTHER

NOTES:

RS-15

ANALYSIS BY: J. J. Harrington

CHECKED BY: M. Nakai

TD-04-296-02 (8-64)

DERIVATION OF EQUATIONS

ITEM NAME: Reservoir Piston "O" Ring Small

SYMBOL R P O S

The "O" ring will remain constant for all sizes of reservoirs

RPOSW = .0028

RELIABILITY

O.D. Guide remains constant 1.50

Pressure (RPRE)

RPOSR = SSSI (O.D.) RPRE

RPOSR = SSSI, 1.50, RPRE

RS-16

ANALYSIS BY: J. J. Hamington CHECKED BY: M. Nakai

TD-04-296-01 (8-64)

EQUATIONS

ITEM NAME: Reservoir Piston Assembly Nut

SYMBOL R P N X

REQUIRED INPUTS: R P R E
R P A P I

REQUIRED OUTPUTS:

OUTPUTS:

STANDARD

WEIGHT	R	P	N	X	W	=	1.375 E-5.0 * (RPRE) * (RPAPI) ** 2
RELIABILITY $^{-1}$	R	P	N	X	R	=	2.5 E-4.0 * (RPRE) * (RPAPI) ** 2
LIFE					L	=	
RESPONSE					S	=	
CONT. OPER. TIME					O	=	
DEVEL. TIME					T	=	
DEVEL. COST					D	=	
UNIT COST					U	=	

OTHER

=

=

=

=

NOTES:

ANALYSIS BY: J.J. Harrington

RS-17

CHECKED BY: M. Nakai

TD-04-296-02(8-64)

DERIVATION OF EQUATIONS

ITEM NAME: Reservoir Piston Assembly Nut SYMBOL R P N X

The reservoir piston nut is inversity proportional to the reservoir pressure (RPRE) times the reservoir piston

O.D.^{2} (RPAPI)

$$RPNXW = K_1 \text{ (RPRE) } \text{(RPAPI)}^2$$

$$K_1 = \frac{.0206}{(40)\ (6.118)^2} = 1.375 \times 10^{-5.0}$$

RPNXW K_1 = 1.375 E-5.0* (RPRE) * (RPAPI) ** 2

Failure rate is inversity proportional to the nut thickness

$$FR = \frac{K}{t}$$

$$K_1 = FR\ (t)$$

$$K_1 = .001\ (.25)$$

$$K_1 = 2.5 \times 10^{-4}$$

RPNXR = 2.5 E-4.0* (RPRE) * (RPAPI) ** 2

RS-18

ANALYSIS BY: J. J. Harrington CHECKED BY: M. Nakai

TD-04-296-01 (8-64)

EQUATIONS

ITEM NAME: Reservoir Piston Rod "O" Ring I.D.

SYMBOL R P O X

REQUIRED INPUTS: R P R E

REQUIRED OUTPUTS:

OUTPUTS:

STANDARD

Weight	R	P	O	X	W	=	.0004
Reliability $^{-1}$	R	P	O	X	R	=	DSL[illegible] , .55, RPRE
Life					L	=	
Response					S	=	
Cont. Oper. Time					O	=	
Devel. Time					T	=	
Devel. Cost					D	=	
Unit Cost					U	=	

OTHER

NOTES:

RS-19

ANALYSIS BY: J. J. Harrington CHECKED BY: M. Nakai

TD-04-296-02 (8-64)

DERIVATION OF EQUATIONS

EM NAME: Reservoir Piston Rod "O" Ring I.D.

SYMBOL R P O X

The reservoir piston rod will remain constant therefore the "O" ring will remain constant for all sizes of reservoir.

RPOXW = .0004

RELIABILITY Dynamic Shaft Seal

"O" ring is proportional to O.D. potentiometer times the stroke and pressure.

RPOXR = DSLT (Dia) (RPRE)

= DSLT (.55) RPRE

= DSLT, .55, RPRE

RS-20

ANALYSIS BY: J. J. Harrington CHECKED BY: M. Nakai

TD-04-296-01 (8-64)

EQUATIONS

ITEM NAME: Reservoir Piston Rod "O" Ring O.D.

SYMBOL R P O D

REQUIRED INPUTS: R H P P I / P R E S / R P A P I / R P A R I

REQUIRED OUTPUTS: R H P P I

OUTPUTS:

STANDARD

WEIGHT	R	P	O	D	W	=	SSWO, RHPPI
RELIABILITY $^{-1}$	R	P	O	D	R	=	SPLO, RHPPI, PRES
LIFE					L	=	
RESPONSE					S	=	
CONT. OPER. TIME					O	=	
DEVEL. TIME					T	=	
DEVEL. COST					D	=	
UNIT COST					U	=	

OTHER

High pressure Piston O.D.	R	H	P	P	I	=	See next page
						=	
						=	
						=	

NOTES:

RS-21

ANALYSIS BY: J. J. Harrington CHECKED BY: M. Nakai

TD-04-296-02(8-64)

DERIVATION OF EQUATIONS

ITEM NAME: Reservoir Piston Rod "O" Ring O.D. SYMBOL R P O D

The reservoir piston rod O.D. shall be determined first

reservoir area time pressure = system pressure times reservoir

piston rod O.D. area.

$$\frac{\pi}{4}(D^2 - d^2)\ (RPRE) = PRES\ \frac{\pi}{4}(D_1^2 - (RPARI^2))$$

$$(RPAPI^2 - .3249)\ (RPRE) = PRES\ (D^2 - RPARI^2)$$

$$RHPPI = \left[\frac{(RPAPI^2 - .3249)\ (RPRE)}{PRES} + RPARI^2\right]^{1/2}$$

RPODW = SSWO, RHPPI

RPODR = SPLO, RHPPI, PRES

ANALYSIS BY: J. J. Harrington RS-22 CHECKED BY: M. Nakai

TD-04-296-01 (8-64)

EQUATIONS

ITEM NAME: Reservoir Piston Rod
Back Up

SYMBOL R P B P

REQUIRED INPUTS: R P O D R

REQUIRED OUTPUTS:

OUTPUTS:

STANDARD

WEIGHT	R	P	B	P	W	=	.0017
RELIABILITY $^{-1}$	R	P	B	P	R	=	.5 RPODR
LIFE					L	=	
RESPONSE					S	=	
CONT. OPER. TIME					O	=	
DEVEL. TIME					T	=	
DEVEL. COST					D	=	
UNIT COST					U	=	

OTHER

						=	
						=	
						=	
						=	

NOTES:

RS-23

ANALYSIS BY: J. J. Harrington CHECKED BY: M. Nakai

DERIVATION OF EQUATIONS

ITEM NAME: Reservoir Piston Rod Back up   SYMBOL R P B P

The back up is proportional to the "O" ring weight and reliability therefore

the "O" ring weight is constant as the back up will be constant

RPBUW = .0017

$R_B = K_2 R_o$

$K_2 = \frac{R_B}{RO} = \frac{.010}{.020} = .5$

RPBUR = .5 RPODR

RS-24

ANALYSIS BY: J. J. Harrington   CHECKED BY: M. Nakai

Equations

$$RPARW = \frac{6.55 \times 10^{-5}\ (RPAPI+7)\ (RPAPI)^{3} RPRE}{(RPAPI - 2.9)}$$

$$RPARI = .1365\ RPAPI + \frac{4.55 \times 10^{-4}\ (RPRE)\ (RPAPI)^{2}}{(RPAPI - 2.92)}$$

EQUATIONS

ITEM NAME: Accumulator Piston Assembly
Piston

SYMBOL S P A P

REQUIRED INPUTS: S P A G I
S P A P I
P R E S
R H P P I

REQUIRED OUTPUTS: S P A G I
S P A P I

OUTPUTS:

STANDARD

WEIGHT	S	P	A	P	W	=	See next page
RELIABILITY $^{-1}$	S	P	A	P	R	=	7.099 E + 3.0 (SPAGI)/PRES [(SPAPI) ** 2 - (SPAGI) ** 2] **2
LIFE					L	=	
RESPONSE					S	=	
CONT. OPER. TIME					O	=	
DEVEL. TIME					T	=	
DEVEL. COST					D	=	
UNIT COST					U	=	

OTHER

O.D. Piston Guide	S	P	A	G	I	=	RHPPI + .224
O.D. Piston	S	P	A	P	I	=	See next page
						=	
						=	

NOTES:

ANALYSIS BY: J. J. Harrington

RS-26

CHECKED BY: M. Nakai

DERIVATION OF EQUATIONS

ITEM NAME: Accumulator Piston Assembly SYMBOL S P A P

Piston

The following method shall be used for determining the piston O.D.

1) $Vol = \frac{\pi}{4} (D^2 - d^2) \frac{D}{5}$ $\frac{L}{D} = \frac{1}{5}$

$Vol = \frac{\pi}{4} (\frac{D^3}{5} - \frac{Dd^2}{5})$ D = SPAPI
d = SPAGI

2) $\frac{\pi}{4} \frac{D^3}{5} = Vol + \frac{\pi}{4} \frac{Dd^2}{5}$

$\frac{D^3}{5} = \frac{4}{\pi} Vol + \frac{Dd^2}{5}$

3) $D = \left[(\frac{4}{\pi} \underline{Vol} + \frac{Dd^2}{5}) 5 \right]^{1/3}$

4) Solve the following equation

$SPAPI = \left[\frac{20}{\pi} SVOL + SPAPI\ (SPAGI)^2 \right]^{1/3}$

5) Solve

A - B - .0000001 A = -, o, +

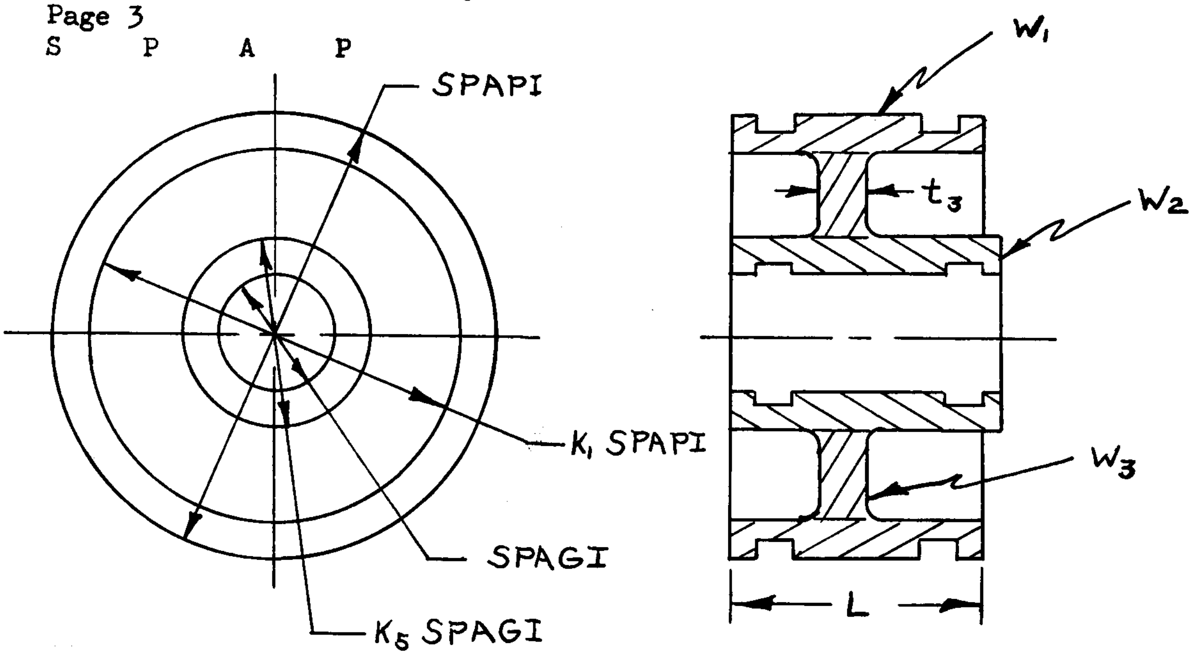
If this is greater than - or o continue to step 7
If ANS is + go to step 6

6) A = B go to step 5

7) SPAPW = .012184 SPAPI**3.0+.04383*SPAGI**2.0*SPAPI+(3.5286 E-7*PRES*(SPAPI**2.0-SPAGI**2.0)**2.0/SPAGI)SSSI

ANALYSIS BY: J. J. Harrington RS-27 CHECKED BY: M. Nakai

Accumulator Piston Assembly Piston (Continued)
Page 3
S P A P



SPAGI = RHPPI + .224

W_1 = Weight of the piston rim

$$W_1 = K_2 \frac{\pi}{4} \left(SPAPI^2 - K_1\, SPAPI^2\right) L$$

$$L = .2\ SPAPI$$

$$W_1 = K_2 \frac{\pi}{4} \left(SPAPI^2 - K_1\, SPAPI^2\right) .2\ SPAPI$$

$$= K_2 \frac{\pi}{4} (1 - K_1)\ (.2)\ (SPAPI^3)$$

$$W_1 = K_3\ SPAPI^3$$

W_1 = .6348 + 1.2541 for an accumulator piston diameter of 5.372"

$$K_3 = \frac{1.8889}{(5.372)^3} = \frac{1.8889}{155.0272} = .012184$$

$$W_1 = .012184\ SPAPI^3$$

$$W_2 = K_4 \frac{\pi}{4} (K_5 \, SPAGI^2 - SPAGI^2) \, L$$

$$= \frac{\pi}{4} K_4 (K_5 - 1) \, SPAGI^2 \, (.2) \, SPAPI$$

$$= K_6 \, (SPAGI^2) \, (SPAPI)$$

W_2 = .0812 + .408 + .0384 = .5276 for a piston diameter of 5.372 and a high pressure reservoir piston guide diameter of 1.497.

$$K_6 = \frac{W_2}{(SPAGI^2)(SPAPI)} = \frac{.3276}{(1.497)^2 \, (4.372)} = \frac{.5276}{12.0387} = .04383$$

$$W_2 = .04383 \, (SPAGI^2) \, (SPAPI)$$

$$W_3 = A_3 \, t_3$$

$$A_3 = K_7 \frac{\pi}{4} \, (SPAPI^2) - SPAGI^2)$$

$S_S = \frac{F}{A}$ piston shear stress

F = maximum force on piston

= PA

P = proof pressure

$A = K_8 \pi \, (SPAGI) \, t$

$$F = (2) \, (PRES) \frac{\pi}{4} (SPAPI^2 - SPAGI^2)$$

$$S_S = \frac{2 \frac{\pi}{4} (PRES) \, (SPAPI^2 - SPAGI^2)}{K_8 \pi \, (SPAGI) \, t}$$

$$t = K_9 \frac{(PRES) \, (SPAPI^2 - SPAGI^2)}{SPAGI}$$

$$W_3 = K_7 \frac{\frac{\pi}{4}(SPAPI^2 - SPAGI^2)\ K_9\ (PRES\ )\ (SPAPI^2 - SPAGI^2)}{SPAGI}$$

$$W_3 = K_{10} \frac{(SPAPI^2 - SPAGI^2)^{\ 2}\ (PRES)}{SPAGI}$$

for
SPAPI = 5.372
SPAGI = 1.497
PRES = 3000
W_3 = .501

$$K_{10} = \frac{(.501)\ (1.497)}{(5.372^2 - 1.497^2)^2\ (3000)} = \frac{(.501)\ (1.497)}{(28.8584 - 2.241009)\ (3000)}$$

$$= \frac{.501\ (1.\ 497)}{(26.6174)^2\ (3000)} = \frac{(.501)\ (1.497)}{(7.08486)\ (3.000)\ x\ 10^{-5}}$$

$$= \frac{.75}{21.2546\ X\ 10^{-5}} = 3.5286\ X\ 10^{-7}$$

$$W_3 = (3.5286\ x\ 10^{-7})\ \frac{PRES\ (SPAPI^2 - SPAGI^2)^2}{SPAGI}$$

$$SPAPW = W_1 + W_2 + W_3$$

$$= .012184\ SPAPI^3 + .04383\ (SPAGI)^2\ SPAPI + \frac{3.5286\ x\ 10^{-7}\ PRES\ (SPAPI^2 - SPAGI^2)^2}{SPAGI}$$

```
SPAPW = .012184 (SPAPI) ** 3 + .04383 (SPAGI) **2*SPAPI + 3.5286
        E-7.0*(PRES)* [(SPAPI)**2 - (SPAGI)**2] **2/SPAGI
```

RELIABILITY:

The primary mode of failure will be due to the fatigue failure of stress risers caused by machining errors at the web and hub.

The failure rate will be proportional to the circumference of the hub and inversely proportional to the stress area.

$$F.R. = K \frac{\pi d}{\pi d t} = \frac{K}{t} = \frac{K}{K_9 \frac{(PRES)(SPAPI^2 - SPAGI^2)}{SPAGI}}$$

It was determined that the failure rate for an accumulator piston having web thickness of .50 was .005

$$F.R. = \frac{K_{11} (SPAGI)}{(PRES)(SPAPI^2 - SPAGI^2)^2}$$

$$K_{11} = \frac{(.005)(3000)(5.372^2 - 1.497^2)^2}{(1.497)}$$

$$K_{11} = \frac{(.005)(21.2546 \times 10^5)}{1.497} = \frac{1.0627 \times 10^4}{1.497}$$

$$K_{11} = 7.099 \times 10^3$$

$$SPAPR = \frac{7.099 \times 10^3 \ SPAGI}{(PRESI)(SPAPI^2 - SPAGI^2)^2}$$

TD-04-296-01 (8-64)

EQUATIONS

ITEM NAME: Accumulator Piston Assembly Guide

SYMBOL S P A G

REQUIRED INPUTS: R P A P I
R H P P I
S P A G I
S P A P I

REQUIRED OUTPUTS:

OUTPUTS:

STANDARD

WEIGHT	S	P	A	G	W	=	.129 * RPAPI * (RHPPI + .112)
RELIABILITY $^{-1}$	S	P	A	G	R	=	2.532 E - 4 * [RHPPI*RPAPI+SPAGI*SPAPI]
LIFE					L	=	
RESPONSE					S	=	
CONT. OPER. TIME					O	=	
DEVEL. TIME					T	=	
DEVEL. COST					D	=	
UNIT COST					U	=	

OTHER

NOTES:

RS-32

ANALYSIS BY: J. J. Harrington

CHECKED BY: M. Nakai

DERIVATION OF EQUATIONS

ITEM NAME: Accumulator Piston Assembly Guide

SYMBOL S P A G

The weight of the guide, SPAGW is proportional to its volume

SPAGW = K 1 A

1 = length

A = cross sectional area

$$A = \frac{\pi}{4}\left[(d_p + 2t)^2 - d_p^2)\right]$$

$$= \frac{\pi}{4}(d_p^2 + 4\, d_p t + 4t^2 - d_p^2)$$

$$+ 4\,\frac{\pi}{4}\, t\, (d_p + t), \quad d_p = \text{RHPPI}$$

$1 = .5\, d_r, \ d_r = \text{RPAPI}$

$t = .112$ and remains constant

SPAGW = K (.5) (RPAPI) π t (RHPPI + .112)

SPAGW = K_1 (RPAPI) (RHPPI +.112)

$$K_1 = \frac{1.09}{(6.118)\,(1.27 + .112)} = .129$$

SPAGW = .129 (RPAPI) (RHPPI +.112)

RELIABILITY:

The primary failure mode will be due to scratches on the dynamic sealing surfaces. The failure rate will be proportional to areas of the dynamic sealing surfaces.

A_R = Area of the reservoir high pressure piston sealing surface

$A_R = K_2 \pi(\text{RHPPI})\ 1$

$= K_2 \pi(\text{RHPPI})\ (.5)\ (\text{RPAPI})$

$= K_3 \pi(\text{RHPPI})\ (\text{RPAPI})$

ANALYSIS BY: J. J. Harrington CHECKED BY: M. Nakai

A_A = Area of the accumulator piston sealing surface

$= K_4 \pi (SPAGI)\ L$

$L = (.2)\ (SPAPI)$

$A_A = K_4 \pi (SPAGI)\ (.2)\ (SPAPI)$

$= K_5\ (SPAGI)\ (SPAPI)$

$FR = K_6 \left[(RHPPI)\ (RPAPI) + (SPAGI)\ (SPAPI)\right]$

For an accumulator reservoir having the following parameters

RHPPI = 1.27

RPAPI = 6.118

SPAGI = 1.494

SPAPI = 5.372

The failure rate was .004

$$K_6 = \frac{F.R.}{(RHPPI)\ (RPAPI) + (SPAGI)\ (SPAPI)}$$

$$= \frac{.004}{(1.27)\ (6.118) + (1.494)\ (5.372)} = \frac{.004}{7.77 + 8.026}$$

$$K_6 = \frac{.004}{15.796} = .0002532$$

$$SPAGR = 2.532 \times 10^{-4} \left[(RHPPI)\ (RPAPI) + (SPAGI)\ (SPAPI)\right]$$

TD-04-296-01 (8-64)

EQUATIONS

ITEM NAME: Accumulator Piston Guide Nut

SYMBOL S P G N

REQUIRED INPUTS: S P A G I

REQUIRED OUTPUTS:

OUTPUTS:

STANDARD

Weight	S	P	G	N	W	=	.093 (SPAGI)
Reliability $^{-1}$	S	P	G	N	R	=	.0015/(SPAGI)
Life					L	=	
Response					S	=	
Cont. Oper. Time					O	=	
Devel. Time					T	=	
Devel. Cost					D	=	
Unit Cost					U	=	

OTHER

NOTES:

RS-35

ANALYSIS BY: J. J. Harrington

CHECKED BY: M. Nakai

DERIVATION OF EQUATIONS

ITEM NAME: Accumulator Piston Guide Nut SYMBOL S P G N

The guide nut is proportional to the accumulator piston guide O.D. (SPAGI) times ratio of nut O.D./I.D. (1.39) times the nut width/O.D.

$$W = K_1 \left[(SPAGI)\ 1.39 \right] .25$$

$$W = K_1 \ (SPAGI)\ .3475$$

$$K_1 = \frac{W}{SPAGI\ (3.475)} = \frac{.1394}{(1.497)\ .3475} = .268$$

$$SPGNW = .268\ (SPAGI) \cdot 3475$$

$$SPGNW = .093\ (SPAGI)$$

F.R. is inversely proportional to piston guide O.D.

$$O.D. = SPAGI$$

$$F.R. = K_2 \ \frac{1}{SPAGI}$$

$$K_2 = .001\ (1.497) = .001497$$

$$SPGNR = .0015/SPAGI$$

ANALYSIS BY: J. J. Harrington RS-36 CHECKED BY: M. Nakai

TD-04-296-01 (8-64)

EQUATIONS

ITEM NAME: Accumulator Piston Guide "O" Ring

SYMBOL S P G O

REQUIRED INPUTS: P R E S
R P A R I

REQUIRED OUTPUTS:

OUTPUTS:

STANDARD

WEIGHT	S	P	G	O	W	=	SSWI, RPARI
RELIABILITY $^{-1}$	S	P	G	O	R	=	DSLI, RPARI, PRES
LIFE					L	=	
RESPONSE					S	=	
CONT. OPER. TIME					O	=	
DEVEL. TIME					T	=	
DEVEL. COST					D	=	
UNIT COST					U	=	

OTHER

=
=
=
=

NOTES:

RS-37

ANALYSIS BY: J. J. Harrington

CHECKED BY: M. Nakai

TD-04-296-02 (8-64)

DERIVATION OF EQUATIONS

EM NAME: Accumulator Piston Guide "O" Ring   SYMBOL S P G O

The weight of the "O" ring is proportional to the reservoir piston rod O.D.

SPGOW = SSWI, RPARI

Reliability

System pressure = PRES

F.R. =

SPGOR = DSLT, RPARI, PRES

RS-38

ANALYSIS BY: J.J. Harrington   CHECKED BY: M. Nakai

TD-04-296-01 (8-64)

EQUATIONS

ITEM NAME: Accumulator Piston Guide Back Up

SYMBOL: S P G B

REQUIRED INPUTS: S P G O W
S P G O R

REQUIRED OUTPUTS:

OUTPUTS:

STANDARD

Weight	S	P	G	B	W	=	.68 SPGOW
Reliability $^{-1}$	S	P	G	B	R	=	.05 SPGOR
Life					L	=	
Response					S	=	
Cont. Oper. Time					O	=	
Devel. Time					T	=	
Devel. Cost					D	=	
Unit Cost					U	=	

OTHER

NOTES:

ANALYSIS BY: J. J. Harrington

RS-39

CHECKED BY: M. Nakai

TD-04-296-02 (8-64)

DERIVATION OF EQUATIONS

ITEM NAME: Accumulator Piston Guide Back Up

SYMBOL S P G B

The back-up in proportional to "O" ring

$$W_B = K_1 W_o$$

$$K_1 = \frac{W_B}{W_o} \quad \frac{.0017}{.0025} = .68$$

SPGBW = .68 SPGOW

RELIABILITY

$$K_2 = \frac{R_B}{R_0} = \frac{.010}{.200} = .05$$

SPGBR = .05 SPGOR

RS-40

ANALYSIS BY: J. J. Harrington CHECKED BY: M. Nakai

TD-04-296-01 (8-64)

EQUATIONS

ITEM NAME: Accumulator Piston "O" Ring Dynamic Large

SYMBOL S P R L

REQUIRED INPUTS: S P A P I P R E S

REQUIRED OUTPUTS:

OUTPUTS:

STANDARD

WEIGHT	S	P	R	L	W	=	SSWO, SPAPI
RELIABILITY $^{-1}$	S	P	R	L	R	=	DPIO, SPAPI, PRES
LIFE					L	=	
RESPONSE					S	=	
CONT. OPER. TIME					O	=	
DEVEL. TIME					T	=	
DEVEL. COST					D	=	
UNIT COST					U	=	

OTHER

NOTES: Multiply SPRLW & SPRLR by 2

RS-41

ANALYSIS BY: J.J. Harrington **CHECKED BY:** M. Nakai

TD-04-296-02 (8-64)

DERIVATION OF EQUATIONS

EM NAME: Accumulator Piston "O" ring Dynamic Large

SYMBOL S P R L

The "O" ring is proportional to O.D. of accumulator piston (SPAPI)

SPRLOW = SSWO, SPAPI

SPRLR = DPLO, SPAPI, PRES

ANALYSIS BY: J. J. Hampton

RS-42

CHECKED BY: M. Nakai

TD-04-296-01(8-64)

EQUATIONS

ITEM NAME: Accumulator Piston Back Up Large

SYMBOL S P B L

REQUIRED INPUTS: S P R L W

S P R L R

REQUIRED OUTPUTS:

OUTPUTS:

STANDARD

Weight	S	P	B	L	W	=	.872*SPRLW
Reliability^{-1}	S	P	B	L	R	=	0.2* SPRLR
Life					L	=	
Response					S	=	
Cont. Oper. Time					O	=	
Devel. Time					T	=	
Devel. Cost					D	=	
Unit Cost					U	=	

OTHER

NOTES:

ANALYSIS BY: J. J. Harrington

RS-43

CHECKED BY: M. Nakai

DERIVATION OF EQUATIONS

ITEM NAME: Accumulator Piston Back Up Large

SYMBOL S P B L

Weight of backup proportional to weight "O" ring, two "O" ring per piston

$$W_B = K_1 W_o$$

$$K_1 = \frac{W_B}{W_O} = \frac{.0188}{.0431} = .436$$

SPBLW = .436 * SPRLW * 2

SPBLW = .872 * SPRLW

Reliability

Is proportional to reliability of "O" ring, two back up per piston.

$$R_B = K_1 R_o$$

$$K_1 = \frac{R_B}{R_o} = \frac{.01}{.1} = .1 \quad x\ 2 = .2$$

SPBLR = .2 * SPRLR

RS-44

ANALYSIS BY: J. J. Harrington CHECKED BY: M. Nakai

TD-04-296-01 (8-64)

EQUATIONS

ITEM NAME: Accumulator Piston "O" Ring Dynamic Small

SYMBOL S P R S

REQUIRED INPUTS: P R E S S P A G I

REQUIRED OUTPUTS:

OUTPUTS:

STANDARD

WEIGHT	S	P	R	S	W	=	SSWI. (SPAGI)
RELIABILITY $^{-1}$	S	P	R	S	R	=	DSLI. SPAGI. PRES
LIFE					L	=	
RESPONSE					S	=	
CONT. OPER. TIME					O	=	
DEVEL. TIME					T	=	
DEVEL. COST					D	=	
UNIT COST					U	=	

OTHER

NOTES:

Multiply by 2

RS-45

ANALYSIS BY: J. J. Harrington CHECKED BY: M. Nakai

TD-04-296-02(8-64)

DERIVATION OF EQUATIONS

ITEM NAME: Accumulator Piston "O" ring Dynamic Small

SYMBOL S P R S

The weight of the "O" ring is determined by the O.D. of the accumulator piston guide (SPAGI), two "O" rings per piston.

SPRSW = SSWI, (SPAGI)

multiply SPRSW by 2 for 2 "O" Rings

RELIABILITY

SPRSR = DSLI, SPAGI, PRES

Multiply SPRSR by 2 for 2 "O" rings.

ANALYSIS BY: J. J. Harrington

RS-46

CHECKED BY: M. Nakai

TD-04-296-01 (8-64)

EQUATIONS

ITEM NAME: Accumulator Piston Back Up Small

SYMBOL S P S B

REQUIRED INPUTS: S P R S W

S P R S R

REQUIRED OUTPUTS:

OUTPUTS:

STANDARD

WEIGHT	S	P	S	B	W	=	1.778*SPRSW
RELIABILITY $^{-1}$	S	P	S	B	R	=	0.2 SPRSR
LIFE					L	=	
RESPONSE					S	=	
CONT. OPER. TIME					O	=	
DEVEL. TIME					T	=	
DEVEL. COST					D	=	
UNIT COST					U	=	

OTHER

=

=

=

=

NOTES:

RS-47

ANALYSIS BY: J. J. Harrington CHECKED BY: M. Nakai

DERIVATION OF EQUATIONS

ITEM NAME: Accumulator Piston Back Up Small SYMBOL S P S B

Weight of the back up are proportional to weight of "O" ring, two back up's.

$$W_B = K_1 W_o$$

$$K_1 = \frac{.0012}{.0135} =$$

SPSBW = .889*SPRSW*2

SPSBW = 1.778*SPRSW

RELIABILITY

Proportional to reliability of "O" rings, two back ups per piston.

$$R_B = K_2 R_o$$

$$K_2 = \frac{.01}{.10} = .1$$

SPSBR = .1 *SPRSR*2

= .2*SPRSR

ANALYSIS BY: J. J. Harrington RS-48 CHECKED BY: M. Nakai

TD-04-296-01 (8-64)

EQUATIONS

ITEM NAME: ACCUMULATOR HIGH PRESSURE CAP

SYMBOL S H P C

REQUIRED INPUTS: S P A P I / S P A G I / P R E S

REQUIRED OUTPUTS: S C A C I

OUTPUTS:

STANDARD

WEIGHT	S	H	P	C	W	=	See next page
RELIABILITY $^{-1}$	S	H	P	C	R	=	See next page
LIFE					L	=	
RESPONSE					S	=	
CONT. OPER. TIME					O	=	
DEVEL. TIME					T	=	
DEVEL. COST					D	=	
UNIT COST					U	=	

OTHER

	S	C	A	C	I	=	SPAPI + 3.102E10^{-5} (PRES) (SPAPI)

NOTES:

RS-49

ANALYSIS BY: J. J. Harrington CHECKED BY: M. Nakai

DERIVATION OF EQUATIONS

ITEM NAME: Accumulator High Pressure Cap SYMBOL S H P C

$$SHPCW = .44 + \left[9.678 \times 10^{-6} (SPAPI)^2 + 4.6624 \times 10^{-6} (SPAPI^2 - SPAGI^2)\right](PRES)(SPAPI)$$

$$SHPCR = 3.4652 \times 10^{-5}\ SPAPI$$

SHPCW

Since the hoop stress is greater than the end stress the wall thickness will depend upon the design hoop stress. The weight of the accumulator end cap may be broken down into sections, the cylinder and end cap.

$$W_c = K_1 \frac{\pi}{4} \left[(SPAPI + 2t)^2 - SPAPI^2\right] 1$$

$$= K_1 \frac{\pi}{4} \left[SPAPI^2 + 4\ (SPAPI)\ t + 4t^2 - SPAPI^2\right] .2\ SPAPI$$

$$= K_1 \frac{\pi}{4}\ .2\ (4\ SPAPI\ t + 4t^2)\ SPAPI$$

$$S_{hoop} = \frac{F}{A}$$

$$F = (PRES)\ (SPAPI)\ (.2\ SPAPI)$$

$$A = 2t\ (.2\ SPAPI)$$

$$S_{hoop} = \frac{(PRES)\ (SPAPI)\ (.2\ SPAPI)}{2t\ (.2\ SPAPI)}$$

$$t = \frac{(PRES)\ (SPAPI)}{2\ S_{hoop}} = K_2\ (PRES)\ (SPAPI)$$

For a piston diameter of 5.372" and a pressure of 3000 the thickness $t = .25$.

$$K_2 = \frac{.25}{(3000)\ (5.372)} = \frac{.25}{1.61 \times 10^{-4}} = 1.551 \times 10^{-5}$$

$$SCACI = SPAPI + 2t = SPAPI + 3.102 \times 10^{-5}\ (PRES)\ (SPAPI)$$

ANALYSIS BY: J. J. Harrington RS-50 CHECKED BY: M. Nakai

Accumulator High Pressure Cap (Continued)
Page 3
S H P C

$$W_c = K_1 \frac{\pi}{4} \quad (.2)\ (4)\ (SPAPI + t) \quad t\ (SPAPI)$$

$$W_c = K_1 \pi \quad .2 \left[SPAPI + 1.551 \times 10^{-5}\ (PRES)\ (SPAPI) \right] K_2\ (PRES)\ (SPAPI)^2$$

$$W_c = K_3\ SPAPI^3 (PRES) \quad (1 + 1.55 \times 10^{-5}\ PRES)$$

Since the maximum pressure being considered is less than 10,000 psi the term $(1 + 1.551 \times 10^{-5}\ PRES)$ is approximately 1.

$$W_c \cong K_3\ (SPAPI)^3\ (PRES)$$

$$W_e = K \frac{\pi}{4} \left[(SPAPI + 2T)^2 - SPAGI^2 \right] t + .4413$$

$$= K \frac{\pi}{4} \left[\left[SPAPI + 2\ (K_2)\ (PRES)\ (SPAPI) \right]^2 - SPAGI^2 \right] K_2\ (PRES)\ (SPAPI) + .44$$

$$= K \frac{\pi}{4} \left[SPAPI^2\ (1 + 2K_2\ PRES)^2 - SPAGI^2 \right] K_2\ (PRES)\ (SPAPI) + .44$$

$$= K_4 \left[(SPAPI^2\ (1 + 2K_2\ PRES)^2 - SPAGI^2 \right] (PRES)\ (SPAPI) + .44$$

Since the maximum pressure is less than 10,000 psi $\left[1 + (2)\ (K_2)\ (PRES) \right] \cong 1$

$$W_e = K_4 \left[SPAPI^2 - SPAGI^2 \right] (PRES) \quad (SPAPI) \quad + .44$$

For an accumulator - reservoir with the following parameters, the weight was $W_e = 2.44$ and $W_c = 4.46$

SPAPI = 5.372
SPAGI = 1.497
PRES = 3000

S H P C

$$K_3 = \frac{W_c}{(SPAPI)^3\ (PRES)} = \frac{4.46}{(5.372)^3\ (3000)}$$

$$K_3 = 9.678 \times 10^{-6}$$

$$K_4 = \frac{W_e - .44}{(PRES)\ (SPAPI)\ (SPAPI^2 - SPAGI^2)} = \frac{2.44 - .44}{(3000)\ (5.372)\ (5.372^2 - 1.497^2)}$$

$$K_4 = \frac{2.0}{1.6116 \times 10^4\ (28.8584 - 2.24109} = \frac{2.0}{1.6116 \times 10^4\ (26.6173)}$$

$$K_4 = 4.6624 \times 10^{-6}$$

$$W = W_c + W_e$$

$$SHPCW = \left[K_3 + K_4\ (SPAPI^2 - SPAGI^2)\right]\ (PRES)\ (SPAPI) + .44$$

$$SHPCW = .44 + \left[9.678 \times 10^{-6}\ SPAPI^2 + 4.6624 \times 10^{-6}\ (SPAPI^2 - SPAGI^2)\right]$$
$$(PRES)\ (\ SPAPI)$$

RELIABILITY

The primary mode of failure will be piston leakage due to surface scratches. The failure rate will therefore be proportional to the surface sealing area.

$$F.R. = K_1\ A$$
$$= K_1\ \pi\ (SPAPI)\ l$$
$$l = \text{stroke} = k_2\ SPAPI$$
$$F.R. = K_1\ \pi\ (SPAPI)\ K_2\ (SPAPI)$$
$$F.R. = K_3\ (SPAPI)^2$$

S H P C

For an accumulator with a 5.372" piston diameter the failure rate was .001

$$K_3 = \frac{.001}{(5.372)^2} = \frac{.001}{28.8584} = 3.4652 \times 10^{-5}$$

SHPCR = 3.4652×10^{-5} SPAPI

TD-Q4-296-01(8-64)

EQUATIONS

ITEM NAME: Accumulator High Pressure Cap "O" Ring Large

SYMBOL S P O L

REQUIRED INPUTS: S C A C I P R E S

REQUIRED OUTPUTS:

OUTPUTS:

STANDARD

WEIGHT	S	P	O	L	W	=	SSWO,SCACI
RELIABILITY $^{-1}$	S	P	O	L	R	=	SPSO,SCACI,PRES
LIFE					L	=	
RESPONSE					S	=	
CONT. OPER. TIME					O	=	
DEVEL. TIME					T	=	
DEVEL. COST					D	=	
UNIT COST					U	=	

OTHER

=

=

=

=

NOTES:

RS-54

ANALYSIS BY: J. J. Harrington CHECKED BY: M. Nakai

TD-04-296-02(8-64)

DERIVATION OF EQUATIONS

ITEM NAME: Accumulator High Pressure Cap "O" Ring Large

SYMBOL S P O L

Static Seal, Piston

SPOLW = SSWO, SCACI

SPOLR = SPSO, SCACI, PRES

RS-55

ANALYSIS BY: J. J. Harrington CHECKED BY: M. Nakai

TD-04-296-01 (8-64)

EQUATIONS

ITEM NAME: Accumulator High Pressure Cap Back Up

SYMBOL S P B U

REQUIRED INPUTS: S P O L R

S P O L W

REQUIRED OUTPUTS:

OUTPUTS:

STANDARD

Weight	S	P	B	U	W	=	.0541*SPOLW
Reliability $^{-1}$	S	P	B	U	R	=	.333*SPOLR
Life					L	=	
Response					S	=	
Cont. Oper. Time					O	=	
Devel. Time					T	=	
Devel. Cost					D	=	
Unit Cost					U	=	

OTHER

						=	
						=	
						=	
						=	

NOTES:

RS-56

ANALYSIS BY: J. J. Harrington CHECKED BY: M. Nakai

TD-04-296-02(8-64)

DERIVATION OF EQUATIONS

ITEM NAME: Accumulator High Pressure Cap Back up

SYMBOL S P B U

Back up is proportional to "O" ring static seal, piston

$$SPBUW = K_1 \; SPOLW$$

$$K_1 \; \frac{SPBUW}{SPOLW} = \frac{.0044}{.0813} = .0541$$

Reliability

The back up reliability is proportional to the "O" ring reliability

$$SPBUR = K_1 \; SPOLR$$

$$K_1 = \frac{SPBUR}{SPOLR} = \frac{.005}{.015} = .333$$

$$SPBUR = .333*SPOLR$$

ANALYSIS BY: J. J. Harrington

RS-57

CHECKED BY: M. Nakai

TD-04-296-01 (8-64)

EQUATIONS

ITEM NAME: Accumulator High Pressure Cap "O" Ring Small

SYMBOL S P O S

REQUIRED INPUTS: P R E S

REQUIRED OUTPUTS:

OUTPUTS:

STANDARD

WEIGHT	S	P	O	S	W	=	.0037
RELIABILITY $^{-1}$	S	P	O	S	R	=	DSLT, 1.5, PRES
LIFE					L	=	
RESPONSE					S	=	
CONT. OPER. TIME					O	=	
DEVEL. TIME					T	=	
DEVEL. COST					D	=	
UNIT COST					U	=	

OTHER

NOTES:

ANALYSIS BY: J. J. Harrington

RS-58

CHECKED BY: M. Nakai

TD-04-296-02 (8-64)

DERIVATION OF EQUATIONS

EM NAME: Accumulator High Pressure "O" ring Small

SYMBOL S P O S

The size of the piston guide will remain constant for all sizes of accumulators

SPOSW = .0037

<u>Reliability</u>

O.D. guide SPAGI remain constant 1.50

SPOSR = DSLI (O.D. Guide) (PRESS)

SPOSR = DSLT, 1.5, PRES

ANALYSIS BY: J. J. Harrington

RS-59

CHECKED BY: M. Nakai

TD-04-296-01 (8-64)

EQUATIONS

ITEM NAME: Accumulator High Pressure Cap Back Up Small

SYMBOL S P B S

REQUIRED INPUTS: S P O S W / S P O S R

REQUIRED OUTPUTS:

OUTPUTS:

STANDARD

WEIGHT	S	P	B	S	W	=	.649*SPOSW
RELIABILITY^{-1}	S	P	B	S	R	=	.333*SPOSR
LIFE					L	=	
RESPONSE					S	=	
CONT. OPER. TIME					O	=	
DEVEL. TIME					T	=	
DEVEL. COST					D	=	
UNIT COST					U	=	

OTHER

NOTES:

ANALYSIS BY: J. J. Harrington RS-60 CHECKED BY: M. Nakai

DERIVATION OF EQUATIONS

EM NAME: Accumulator High Pressure Cap Back Up Small SYMBOL S P B S

Back up is proportional to "O" ring

$$SPBSW = K_1 \; SPOSW$$

$$K_1 = \frac{SPBSW}{SPOSW} = \frac{.0024}{.0037} = .649$$

Reliability back up in proportional to "O" ring

$$SPBSR = K_1 \; SPOSR$$

$$K_1 = \frac{SPBSR}{SPOSR} = \frac{.005}{.015} = .333$$

RS-61

ANALYSIS BY: J. J. Harrington CHECKED BY: M. Nakai

TD-04-296-01 (8-64)

EQUATIONS

ITEM NAME: Accumulator High Pressure Gas Charging Valve

SYMBOL S P C V

REQUIRED INPUTS:

REQUIRED OUTPUTS:

OUTPUTS:

STANDARD

Weight	S	P	C	V	W	=	.0106
Reliability $^{-1}$	S	P	C	V	R	=	.010
Life					L	=	
Response					S	=	
Cont. Oper. Time					O	=	
Devel. Time					T	=	
Devel. Cost					D	=	
Unit Cost					U	=	

OTHER

NOTES:

RS-62

ANALYSIS BY: J. J. Harrington CHECKED BY: M. Nakai

TD-04-296-02 (8-64)

DERIVATION OF EQUATIONS

ITEM NAME: Accumulator High Pressure Cap Charging Valve

SYMBOL S P C V

The charging valve will remain constant for all pressure from 150 - 10,000 psi.

SPCUW = .0106

SPCVR = .010

RS-63

ANALYSIS BY: J. J. Harrington

CHECKED BY: M. Nakai

TD-04-256-01 (8-64)

EQUATIONS

ITEM NAME: Accumulator Charging Valve "O" Ring

SYMBOL S P V O

REQUIRED INPUTS:

REQUIRED OUTPUTS:

OUTPUTS:

STANDARD

Weight	S	P	V	O	W	=	.0003
Reliability $^{-1}$	S	P	V	O	R	=	SSSI, .5, PRES
Life					L	=	
Response					S	=	
Cont. Oper. Time					O	=	
Devel. Time					T	=	
Devel. Cost					D	=	
Unit Cost					U	=	

OTHER

=

=

=

=

NOTES:

ANALYSIS BY: J. J. Harrington

RS-64

CHECKED BY: M. Nakai

DERIVATION OF EQUATIONS

EM NAME: Accumulator Charging Valve "O" Ring

SYMBOL S P V C

The charging valve "O" ring seal will remain constant for all pressures.

SPVOW = .0003

SPVOR = SSSI, .5, PRES

ANALYSIS BY: J. J. Harrington

RS-65

CHECKED BY: M. Nakai

TD-04-296-01(8-64)

EQUATIONS

ITEM NAME: Reservoir Cover and Screws

SYMBOL R C A S

REQUIRED INPUTS: R P A P I

R P R E

REQUIRED OUTPUTS:

OUTPUTS:

STANDARD

WEIGHT	R	C	A	S	W	=	1.722 E-4 (RPAPI) ** 3.0 * RPRE
RELIABILITY^{-1}	R	C	A	S	R	=	2.69/RPAPI * RPRE
LIFE					L	=	
RESPONSE					S	=	
CONT. OPER. TIME					O	=	
DEVEL. TIME					T	=	
DEVEL. COST					D	=	
UNIT COST					U	=	

OTHER

NOTES:

ANALYSIS BY: J. J. Harrington

RS-66

CHECKED BY: M. Nakai

DERIVATION OF EQUATIONS

ITEM NAME: Reservoir Cover and Screws SYMBOL R C A S

The cross sectional area of the cover and screws are proportional to cross sectional area of the reservoir piston.

$$\text{Area} = K_1 \ (\text{RPAPI})^2$$

The screw thickness and length proportional to cross sectional area times the pressure divide by the circumference

$$\text{Thickness} = K_2 \ (\text{RPAPI}) \ (\text{RPRE})$$

RPAPI = 6.118 Dia

RPRE = 40 psi

$$\text{RCASW} = K_3 \ (\text{RPAPI})^3 \ (\text{RPRE})$$

$$K_3 = \frac{1.5778}{(6.118)^3 \ (40)} = .00001722 = 1.722 \times 10^{-4}$$

RCASW = 1.722E - 4 (RPAPI) ** 3.0 *RPRE

Reliability

Failure due to damage

$$\text{RCASR} = K_4 \ \frac{\text{Total Damage}}{\text{Volume}}$$

$$K_5 \ \frac{\text{Face Area}}{\text{Weight}}$$

$$K_6 \ \frac{\text{RPAPI}^2}{\text{RPAPI}^3 \ (\text{RPRE})} = \frac{1}{\text{RPAPI} \ (\text{RPRE})}$$

RCASR = .001

RPAPI = 6.118

RPRE = 40 K_6 = .011 (6.118) (40)

K_6 = 2.69

RCASR = 2.69 /(RPAPI) (RPRE)

ANALYSIS BY: J. J. Harrington RS-67 CHECKED BY: M. Nakai

TD-04-296-01 (8-64)

EQUATIONS

ITEM NAME: Reservoir Cover "O" Ring

SYMBOL R C O R

REQUIRED INPUTS: R P A P I
R P R E

REQUIRED OUTPUTS:

OUTPUTS:

STANDARD

WEIGHT	R	C	O	R	W	=	SSWO,RPAPI
RELIABILITY^{-1}	R	C	O	R	R	=	SPSO,RPAPI,RPRE
LIFE					L	=	
RESPONSE					S	=	
CONT. OPER. TIME					O	=	
DEVEL. TIME					T	=	
DEVEL. COST					D	=	
UNIT COST					U	=	

OTHER

=

=

=

=

NOTES:

RS-68

ANALYSIS BY: J.J. Harrington CHECKED BY: M. Nakai

TD-04-296-02 (8-64)

DERIVATION OF EQUATIONS

ITEM NAME: Reservoir Cover "O" Ring SYMBOL R C O R

Static seal, piston reservoir pressure (RPRE) I.D. of "O" ring is proportional to O.D. of cover.

O.D. cover = RPAPI

RCORW = SSOW, RPAPI

RCORW = SPSO, RPAPI, RPRE

RS-69

ANALYSIS BY: J. J. Harrington CHECKED BY: M. Nakai

TD-04-296-01 (8-64)

EQUATIONS

ITEM NAME: Reservoir Cover Back Up

SYMBOL R C B U

REQUIRED INPUTS: R C O R W
R C O R R

REQUIRED OUTPUTS:

OUTPUTS:

STANDARD

WEIGHT	R	C	B	U	W	=	.748*RCORW
RELIABILITY $^{-1}$	R	C	B	U	R	=	.333*RCORR
LIFE					L	=	
RESPONSE					S	=	
CONT. OPER. TIME					O	=	
DEVEL. TIME					T	=	
DEVEL. COST					D	=	
UNIT COST					U	=	

OTHER

=

=

=

=

NOTES:

RS-70

ANALYSIS BY: J. J. Harrington

CHECKED BY: M. Nakai

DERIVATION OF EQUATIONS

ITEM NAME: Reservoir Cover Back Up

SYMBOL R C B U

Back up proportional to "O" ring

$$W_B = K_1 W_o$$

$$K_1 = \frac{W_B}{W_o} = \frac{.0098}{.0131} = .748$$

RCBUW = .748*RCORW

$$R_B = K_2 R_o$$

$$K_2 = \frac{R_B}{R_o} = \frac{.005}{.015} = .333$$

RCBUR = .333 * RCORR

ANALYSIS BY: J. J. Harrington

RS-71

CHECKED BY: M. Nakai

TD-04-296-01 (8-64)

EQUATIONS

ITEM NAME: Reservoir Cover Plug

SYMBOL R C P X

REQUIRED INPUTS:

REQUIRED OUTPUTS:

OUTPUTS:

STANDARD

WEIGHT	R	C	P	X	W	=	.0925
RELIABILITY $^{-1}$	R	C	P	X	R	=	.0001 * RPRE
LIFE					L	=	
RESPONSE					S	=	
CONT. OPER. TIME					O	=	
DEVEL. TIME					T	=	
DEVEL. COST					D	=	
UNIT COST					U	=	

OTHER

						=	
						=	
						=	
						=	

NOTES:

ANALYSIS BY: J. J. Harrington

RS-72

CHECKED BY: M. Nakai

DERIVATION OF EQUATIONS

ITEM NAME: Reservoir Cover Plug SYMBOL R C P X

The reservoir cover plug size and function will remain constant for all sizes of reservoir

RCPXW = .0925

RCPXR = K_1 area x RPRE

area constant $\frac{\pi d^2}{4}$ = .785 ($.625^2$)

.785 (.390) = .3061

$K_1 = \frac{.004}{.3061\ (40)}$ = .0003267 or 3.267×10^{-4} (area)

= .001

RCPXR = .001 (RPRE)

RS-73

ANALYSIS BY: J. J. Harrington CHECKED BY: M. Nakai

TD-04-296-01 (8-64)

EQUATIONS

ITEM NAME: Reservoir Cover Plug "O"-Ring

SYMBOL R C P O

REQUIRED INPUTS:

REQUIRED OUTPUTS:

OUTPUTS:

STANDARD

WEIGHT	R	C	P	O	W	=	.0006
RELIABILITY $^{-1}$	R	C	P	O	R	=	SSSI, .644, RPRE
LIFE					L	=	
RESPONSE					S	=	
CONT. OPER. TIME					O	=	
DEVEL. TIME					T	=	
DEVEL. COST					D	=	
UNIT COST					U	=	

OTHER

=

=

=

=

NOTES:

RS-74

ANALYSIS BY: J. J. Harrington **CHECKED BY:** M. Nakai

TD-04-296-02 (8-64)

DERIVATION OF EQUATIONS

ITEM NAME: ~~Reservoir Cover Plug "O" Ring~~ SYMBOL R C P O

The reservoir cover plug "O" ring size and function will remain constant for all sizes of reservoir.

RCPOW = .0006

RCPOR = SSSI, .644, RPRE

RS-75

ANALYSIS BY: J. J. Harrington CHECKED BY: M. Nakai

TD-04-296-01 (8-64)

EQUATIONS

ITEM NAME: Reservoir Housing

SYMBOL R H X X

REQUIRED INPUTS: R P A X I

R P R E

P R E S

S P A P I

S P A G I

REQUIRED OUTPUTS:

OUTPUTS:

STANDARD

WEIGHT	R	H	X	X	W	=	See next page.
RELIABILITY $^{-1}$	R	H	X	X	R	=	1.17 E-2 (RPAPI) ** 2
LIFE					L	=	
RESPONSE					S	=	
CONT. OPER. TIME					O	=	
DEVEL. TIME					T	=	
DEVEL. COST					D	=	
UNIT COST					U	=	

OTHER

NOTES:

ANALYSIS BY: J. J. Harrington

RS-76

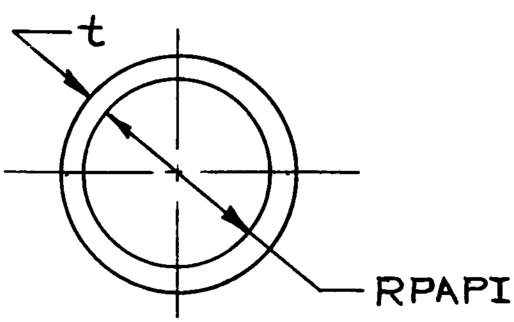
CHECKED BY: M. Nakai

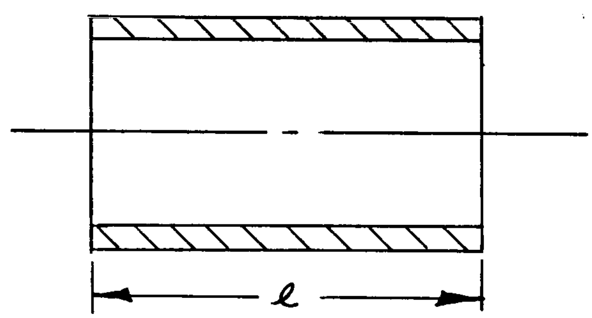
DERIVATION OF EQUATIONS

EM NAME: Reservoir Housing   SYMBOL R H X X

```
RHXXW = 4.7167 E-6 * RPRE *RPAPI ** 3.0 * (1 + 0.007662 * RPRE) +
        2.597  E-7 * (((1.256 * SPAPI - 2.125) ** 2.0 - 2.1 ** 2.0) ** 2.0)
        * PRES/ (1.256 * SPAPI - 2.125) + 0.0848 + .46383 * SPAPI
        + (2.186 E-6  * PRES * SPAPI * ( SPAPI ** 2.0 - SPAGI ** 2.0) * SSS1
```

The reservoir housing can be considered to be a cylinder open at both ends since an end is covered by a end cover and the other end by the accumulator. The weight is therefore proportional to the volume of the cylinder.





$W_t = K_1 A_c l$

A_c = cross sectional area

l = cylinder length = K_2 stroke

$$A_c = \frac{\pi}{4} \left((RPAPI + 2t)^2 - RPAPI^2 \right)$$

$$= \frac{\pi}{4} (RPAPI^2 + 4\ RPAPI\ t + 4t^2 - RPAPI^2)$$

$$= \frac{\pi}{4} (4)\ t\ (RPAPI + t)$$

$l = .5\ RPAPI$

ANALYSIS BY: J. J. Harrington   RS-77
CHECKED BY: M. Nakai

$$S_{hoop} = \frac{F}{A}$$

$$F = (RPRE)\ (RPAPI)\ 1$$

$$A = 2\ t\ 1$$

$$S_{hoop} = \frac{(RPRE)\ (RPAPI)\ 1}{2\ t\ 1}$$

$$t = \frac{(RPRE)\ (RPAPI)}{2\ S_{hoop}}$$

$$t = K_2\ (RPRE)\ (RPAPI)$$

From a previous design it was found that t = .1875 for a reservoir pressure of 40 psi and reservoir piston diameter 6.118

$$K_2 = \frac{.1875}{(40)\ (6.118)} = \frac{.1875}{244.72} \quad .007662$$

$$t = .007662\ (RPRE)\ (RPAPI)$$

$$W_t = K_1 \pi\ t\ (RPAPI + t)\ .5\ RPAPI$$

$$= K_1 \pi .007662\ (RPRE)\ (RPAPI) \left[(RPAPI + .007662\ (RPRE)\ (RPAPI) \right]$$
$$.5\ RPAPI$$

$$W_t = K_3\ (RPRE)\ (RPAPI)^3\ (\ 1 + .007662\ RPRE)$$

For a reservoir having RPRE = 40, RPAPI = 6.118 the weight was found to be 1.7414

$$K_3 = \frac{1.7414}{(40)\ (6.118)^3 \left[1 + (.007662)\ (40)\right]} = 4.7167 \times 10^{-6}$$

$$W_R = 4.7167 \times 10^{-6}\ (RPRE)\ (RPAPI)^3\ (\ 1 + .007662\ RPRE)$$

The accumulator housing can be considered to be a cylinder. Since the end cover also is the piston cylinder, the load on the accumulator can be assumed to be in tension.

$$W_A = \frac{\pi}{4}\left[(SPAPI + 2t)^2 - SPAPI^2\right] 1$$

$$1 = .36\ SPAPI$$

$$S_t = \frac{F}{A}$$

$$F = 2\ (PRES)\ \frac{\pi}{4}\ (SPAPI^2 - SPAGI^2)$$

$$A = \frac{\pi}{4}\left[(SPAPI + 2t)^2 - SPAPI^2\right]$$

$$S_t = \frac{2\ \frac{\pi}{4}(PRES)\ (SPAPI^2 - SPAGI^2)}{\frac{\pi}{4}\left[(SPAPI + 2t)^2 - SPAPI^2\right]}$$

$$\left[(SPAPI + 2t)^2 - SPAPI^2\right] = \frac{2\ (PRES)\ (SPAPI^2 - SPAGI^2)}{S_t}$$

$$W_A = \frac{\pi}{4}\left[2\ (PRES)\ \left[(SPAPI)^2 - (SPAGI)^2\right]\right] .36\ SPAPI$$

$$W_A = K_1\ PRES\ (SPAPI^2 - SPAGI^2)\ SPAPI$$

W_A = 1.29 lb. for an accumulator with

PRES = 3000

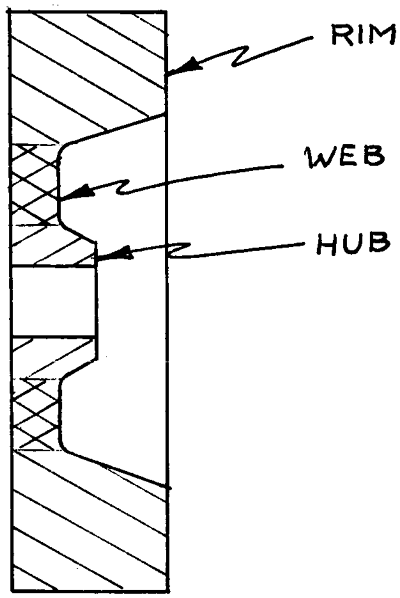
SPAPI = 5.372

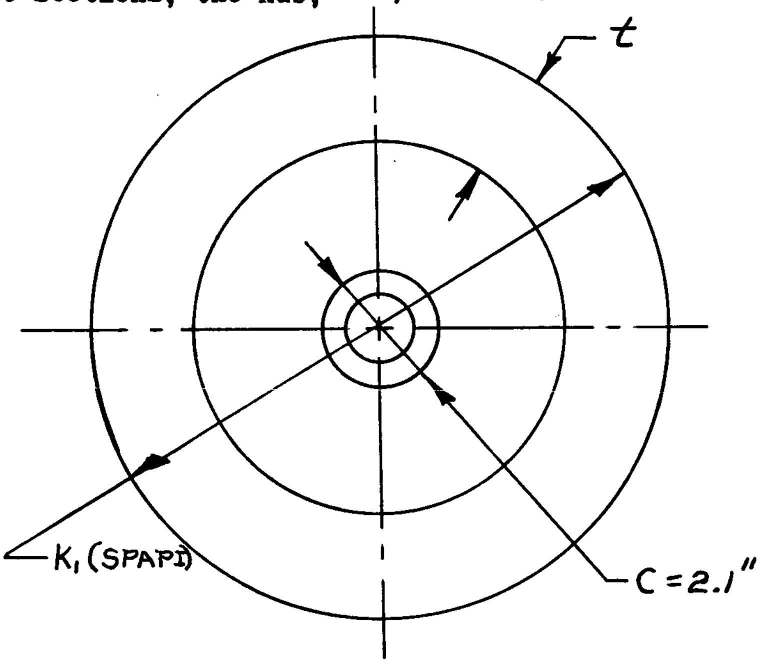
SPAGI = 1.494

$$K_1 = \frac{1.29}{(3000)\ (5.372^2 - 1.494^2)\ 5.372} = 2.186 \times 10^{-6}$$

$$W_A = 2.186 \times 10^{-6} (PRES)(SPAPI)(SPAPI^2 - SPAGI^2)$$

The partitian between the accumulator and reservoir may be considered to be made up of three sections, the hub, Web, and Rim.





With the ranges of pressures under consideration the diameter and thickness of the hub will remain constant, therefore the weight will remain constant.

$$W_{ph} = 0.0848 \text{ lb.}$$

The rim thickness and width will also remain constant and weight will be proportional to the accumulator piston O.D.

$$W_{pr} = K \text{ SPAPI}$$

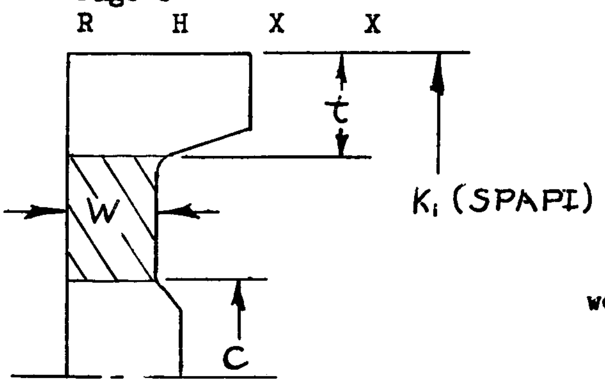
$$W_{pr} = 2.4917$$

for a piston diameter of

$$K = \frac{2.4917}{5.372} = .46383$$

$$W_{pr} = .46383 \text{ SPAPI}$$

Reservoir Housing (Continued)
Page 6



web is equal to area times system pressure

$$\text{Force} = \frac{\pi}{4}\left[(K_1 \text{ SPAPI} = 2t)^2 - C^2\right] \text{PRES}$$

$$\text{Area} = \pi(K_1 \text{ SPAPI} - 2t)\ w$$

$$S_s = \frac{F}{A} = \frac{\frac{\pi}{4}\left[(K_1 \text{ SPAPI} - 2t)^2 - C^2\right] \text{PRES}}{\pi\ (K_1 \text{ SPAPI} - 2t)\ w}$$

$$W = \frac{\left[(K_1 \text{ SPAPI} - 2t)^2 - C^2\right]^2 \ (\text{PRES})}{4\ S_s\ (K_1 \text{ SPAPI} - 2t)}$$

$$W = K_2 \ \frac{\left[(K_1 \text{ SPAPI} - 2t)^2 - C^2\right]^2 \ \text{PRES}}{K_1 \text{ SPAPI} - 2t}$$

K_1 = 1.256

SPAPI = 5.372

2t = 2.125

PRES = 3,000

C = 2.1

$$K_2 = \frac{.04849\ \left[(1.256)\ (5.472) - 2.125\right]}{\left[\left[(1.256)\ (5.372) - 2.125\right]^2 - (2.1^2)\right]^2 \ (3{,}000)}$$

$K_2 = 2.597 \times 10^{-7}$

$$W = 2.597 \times 10^{-7} \ \frac{\left[\left[(1.256)\ (\text{SPAPI}) - (2.125)\right]^2 - (2.1)^2\right]^2 \ (\text{PRES})}{\left[(1.256)\ (\text{SPAPI}) - 2.125\right]}$$

The total weight of the partitian

$$W_p = W_{pH} + W_{pr} + W_{pw}$$

$$W_p = 0.0848 + .46383 \text{ SPAPI} + \frac{2.597 \times 10^{-7} \left[\left[(1.256)(\text{SPAPI}) - 2.125 \right]^2 - 2.1^2 \right]^2 \text{ PRES}}{(1.256)(\text{SPAPI}) - 2.125}$$

The total weight of the accumulator-reservoir housing

$$W = 4.7167 \times 10^{-6} (\text{RPRE}) (\text{RPAPI})^3 (1 + 0.007662 \text{ RPRE})$$

$$+ \left[2.186 \times 10^{-6} (\text{PRES}) (\text{SPAPI}) (\text{SPAPI}^2 - \text{SPAGI}^2) \right] (\text{SSS1})$$

$$+ \frac{2.597 \times 10^{-7} \left[\left[(1.256)(\text{SPAPI}) - 2.125 \right]^2 - 2.1^2 \right]^2 \text{ PRES}}{1.256 (\text{SPAPI}) - 2.125}$$

$$+ 0.0848 + .46383 \text{ SPAPI}$$

Reliability:

The primary failure mode of the reservoir-accumulator housing will be leakage at the reservoir piston sealing surface. The leakage would be primarily due to sealing surface sctaches.

$$\text{F.R.} = K \text{ (Sealing Surface Area)}$$

$$A = \pi D \, l$$

where l = piston stroke and is equal to .5 D.

$$A = \pi D \frac{D}{2} \qquad \frac{\pi}{2} (D)^2$$

$$\text{F.R.} = K_1 (D)^2$$

$$K_1 = \frac{\text{F.R.}}{D^2}$$

$$K_1 = \frac{.004}{(.6118)^2} = 1.17 \times 10^{-2}$$

$$\text{F.R.} = 1.17 \times 10^{-2} \text{ RPAPI}^2$$

$$\text{RHXX } R = 1.17 \times 10^{-2} \text{ RPAPI}^2$$

TD-04-296-01(8-64)

EQUATIONS

ITEM NAME: Reservoir Housing "O" Ring Return Ports

SYMBOL R H O R

REQUIRED INPUTS: R P R E

REQUIRED OUTPUTS:

OUTPUTS:

STANDARD

WEIGHT	R	H	O	R	W	=	.0045
RELIABILITY $^{-1}$	R	H	O	R	R	=	SSSI, 1.0625, RPRE
LIFE					L	=	
RESPONSE					S	=	
CONT. OPER. TIME					O	=	
DEVEL. TIME					T	=	
DEVEL. COST					D	=	
UNIT COST					U	=	

OTHER

NOTES:

RS-83

ANALYSIS BY: J. J. Harrington

CHECKED BY: M. Nakai

TD-04-296-02(8-64)

DERIVATION OF EQUATIONS

ITEM NAME: Reservoir Housing "O" Ring Return Ports SYMBOL R H O R

The return ports will remain constant for all sizes of reservoir therefore the weight will remain constant

Three "O" ring per reservoir.

RHORW = .0015 (3) = .0045

The reliability will change with pressure for the static shaft seal

RHORR = SSSI, 1.0625, RPRE

RS-84

ANALYSIS BY: J. J. Harrington CHECKED BY: M. Nakai

TD-04-296-01 (8-64)

EQUATIONS

ITEM NAME: Reservoir Housing Filter Seal Test

SYMBOL R H F V

REQUIRED INPUTS:

REQUIRED OUTPUTS:

OUTPUTS:

STANDARD

WEIGHT	R	H	F	V	W	=	.0002
RELIABILITY $^{-1}$	R	H	F	V	R	=	.010
LIFE					L	=	
RESPONSE					S	=	
CONT. OPER. TIME					O	=	
DEVEL. TIME					T	=	
DEVEL. COST					D	=	
UNIT COST					U	=	

OTHER

NOTES:

ANALYSIS BY: J. J. Harrington

RS-85

CHECKED BY: M. Nakai

TD-04-296-02 (8-64)

DERIVATION OF EQUATIONS

ITEM NAME: Reservoir Housing Filter Seal Vent   SYMBOL R H F V

The reservoir housing filter seal vent will remain constant for all sizes of reservoir therefore

RHFVW = .0002

RHFVR = .010

RS-86

ANALYSIS BY: J. J. Harrington   CHECKED BY: M. Nakai

TD-04-296-01 (8-64)

EQUATIONS

ITEM NAME: Accumulator Housing Ring And Pin

SYMBOL S H R X

REQUIRED INPUTS: S P A P I

S P A G I

P R E S

REQUIRED OUTPUTS:

OUTPUTS:

STANDARD

WEIGHT	S	H	R	X	W	=	See next page
RELIABILITY $^{-1}$	S	H	R	X	R	=	.007
LIFE					L	=	
RESPONSE					S	=	
CONT. OPER. TIME					O	=	
DEVEL. TIME					T	=	
DEVEL. COST					D	=	
UNIT COST					U	=	

OTHER

NOTES:

ANALYSIS BY: J. J. Harrington

RS-87

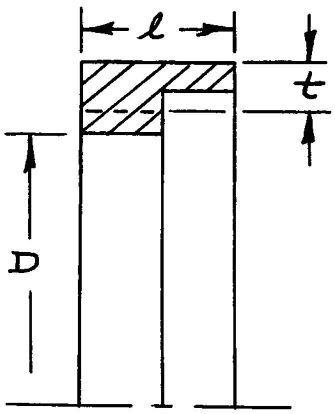
CHECKED BY: M. Nakai

DERIVATION OF EQUATIONS

ITEM NAME: Accumulator Housing Ring and Pin

SYMBOL S H R X

The housing ring I.D. is proportional to the accumulator piston O.D. (SPAPI) plus the pins' weight.



$$S_s = \frac{F}{A}$$ F = press (accumulator piston area)

A = cross section of ring (l) (t)

$$l = \frac{L}{D} = \underline{.677}$$

$$S_s = \frac{\text{pres}\ \frac{\pi}{4}\ (\text{SPAPI}^2 - \text{SPAGI}^2)}{l\ (t)}$$

$$t = K_1\ \frac{\text{pres}\ \frac{\pi}{4}(\text{SPAPI}^2 - \text{SPAGI}^2)}{l}$$

$$K_1 = \frac{.677\ (.250)}{3000\ (.785)\ (5.372^2 - 1.5^2)} = \frac{.16925}{62{,}660.8} = 2.701\text{x}10^{-6}$$

$$t = 2.701 \times 10^{-6}\ \frac{(\text{SPAPI}^2 - \text{SPAGI}^2)}{l}$$

SPAPI = 5.372"

SPAGI = 1.50"

l = .677

t = .250

D = SPAPI + (3.102×10^{-5}) (pres) (SPAPI)

ANALYSIS BY: J. J. Harrington RS-88 CHECKED BY: M. Nakai

S H R X

$$W = (\pi D)\ (1)\ (t)$$

$$W = K_2 \pi \left[SPAPI + 3.102 \times 10^{-5}\ (PRES)\ (SPAPI)\right] (1) \left[2.701 \times 10^{-6} \frac{(SPAPI^2 - SPAGI^2)}{1}\right]$$

$$K_2 = \frac{W}{\left[SPAPI + 3.102 \times 10^{-5}\ (PRES)\ (SPAPI)\right]\left[2.701 \times 10^{-6}\ (SPAPI^2 - SPAGI^2)\right]}$$

$$K_2 = \frac{.7188}{\left[(5.372 + 3.102 \times 10^{-5})\ (3000)\ (5.372)\right]\left[2.701 \times 10^{-6}\ (5.372^2 - 1.5^2)\right]}$$

8.474×10^{-5} $\qquad$ 26.6084

$(.2542)\ (5.372)$

1.366 $\qquad$ 98.1735×10^{-5} $\qquad$ 71.8693×10^{-5}

$$K_2 = 732.173$$

$$SHRXW = 732.173 \left[SPAPI + 3.102 \times 10^{-5}\ (PRES)\ (SPAPI)\right]\left[2.701 \times 10^{-6}\ (SPAPI^2 - SPAGI^2)\right] + .003$$

The failure rate will remain constant because the length and width are proportional to the accumulator piston O.D. plus the pins will remain constant

SHRXR = .003 + .004

SHRXR = .007

TD-04-296-01 (8-64)

EQUATIONS

ITEM NAME: ...umulator Housing
...ssure Plug

SYMBOL S H P P

REQUIRED INPUTS:

REQUIRED OUTPUTS:

OUTPUTS:

STANDARD

Weight	S	H	P	P	W	=	.0925
Reliability^{-1}	S	H	P	P	R	=	.004
Life					L	=	
Response					S	=	
Cont. Oper. Time					O	=	
Devel. Time					T	=	
Devel. Cost					D	=	
Unit Cost					U	=	

OTHER

NOTES:

ANALYSIS BY: J. J. Harrington

RS-90

CHECKED BY: M. Nakai

TD-04-296-02(8-64)

DERIVATION OF EQUATIONS

EM NAME: Accumulator Housing Pressure Plug

SYMBOL S H P P

The accumulator housing pressure plug will remain constant for all sizes of accumulators.

SHPPW = .0925

SHPPR = .004

RS-91

ANALYSIS BY: J. J. Harrington CHECKED BY: M. Nakai

TD-04-296-01 (8-64)

EQUATIONS

ITEM NAME: Accumulator Housing "O" Ring Pressure Ports

SYMBOL S H O P

REQUIRED INPUTS: P R E S

REQUIRED OUTPUTS:

OUTPUTS:

STANDARD

WEIGHT	S	H	O	P	W	=	.0024
RELIABILITY $^{-1}$	S	H	O	P	R	=	.SSSI, .75, PRES
LIFE					L	=	
RESPONSE					S	=	
CONT. OPER. TIME					O	=	
DEVEL. TIME					T	=	
DEVEL. COST					D	=	
UNIT COST					U	=	

OTHER

NOTES:

ANALYSIS BY: J. J. Harrington

RS-92

CHECKED BY: M. Nakai

TD-04-296-02 (8-64)

DERIVATION OF EQUATIONS

EM NAME: Accumulator Housing "O" Ring Pressure Ports

SYMBOL S H O P

The pressure ports will remain constant for all sizes of accumulators therefore the weight will remain constant.

Four "O" ring per accumulators.

SHOPW = .0006 (4) = .0024

The reliability will change with pressure for the static shaft seal

SHOPR = SSSI, .75, PRES * 4

RS-93

ANALYSIS BY: J. J. Harrington CHECKED BY: M. Nakai

TD-04-296-01 (8-64)

EQUATIONS

ITEM NAME: Accumulator Pressure Switch Body

SYMBOL S P S X

REQUIRED INPUTS: P R E S

REQUIRED OUTPUTS:

OUTPUTS:

STANDARD

WEIGHT	S	P	S	X	W	=	$.4737\left[1-\left(1-2.066\,E{-5}\,(PRES)\,(2)\right)^2\right]$
RELIABILITY $^{-1}$	S	P	S	X	R	=	.003
LIFE					L	=	
RESPONSE					S	=	
CONT. OPER. TIME					O	=	
DEVEL. TIME					T	=	
DEVEL. COST					D	=	
UNIT COST					U	=	

OTHER

NOTES:

RS-94

ANALYSIS BY: J. J. Harrington

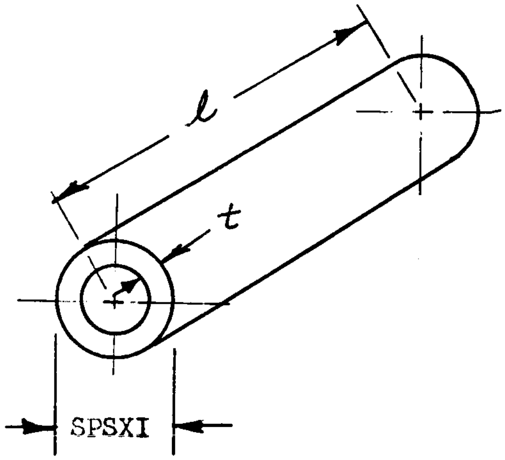
CHECKED BY: M. Nakai

DERIVATION OF EQUATIONS

EM NAME: Accumulator Pressure Switch Body

SYMBOL S P S X

The pressure switch body case wall thickness will increase with pressure.



$$1 = C_1 \quad (2.575)$$

$$SPSXI = C_2$$

$$SPSXJ = C_2 - 2t$$

$$W = K_1 \; A \; L$$

A = cross section area

$$1 = C_1$$

$$A = \frac{\pi}{4} \left[SPSXI^2 - (SPSXI - 26)^2 \right]$$

$$S_h = \frac{F}{A}$$

$$F = (PRES)\;(SPSXI)\;1$$

$$A = 2\;t\;1$$

$$S_h = \frac{pres\;(SPSXI)\;t}{2\;t\;1}$$

$$t = K_2 \; \frac{pres\;(SPSXI)}{2\;S_n}$$

$$K_2 = \frac{t}{Pres\quad(C_2)} = \frac{.062}{3000\;(1.000)} = 2.066 \times 10^{-5}$$

$$t = 2.066 \times 10^{-5}\;(pres) = 2.066 \times 10^{-5}\;(3000) = .062$$

$$W = K_1\;(A)\;(1)$$

$$W = K_1\;\frac{\pi}{4} \left[(1)^2 \quad \begin{matrix} (1 - 2t)^2 \\ (1 - .124)^2 \end{matrix} \right] (2.575)$$

$$W = 2.0214 \left[1^2 - (.938)^2 \right]$$

$$2.0214\;(.1202) = .24297$$

ANALYSIS BY: J. J. Harrington

RS-95

CHECKED BY: M. Nakai

S P S X

$$K_1 = \frac{.1151}{.2430} = .4737$$

$$SPSXW = .4737 \left[1 - (1 - 2.066 \times 10^{-5} (PRES)(2))^2 \right]$$

The reliability of the body case will remain constant because the same relationship between the thickness, length and pressure are constant therefore:

$$SPSXR = .003$$

TD-04-296-01 (8-64)

EQUATIONS

ITEM NAME: Accumulator Pressure Switcn Constant

SYMBOL S P S C

REQUIRED INPUTS:

REQUIRED OUTPUTS:

OUTPUTS:

STANDARD

Weight	S	P	S	C	W	=	.1986
Reliability $^{-1}$	S	P	S	C	R	=	.062
Life					L	=	
Response					S	=	
Cont. Oper. Time					O	=	
Devel. Time					T	=	
Devel. Cost					D	=	
Unit Cost					U	=	

OTHER

NOTES:

ANALYSIS BY: J. J. Harrington

RS-97

CHECKED BY: M. Nakai

TD-04-296-02(8-64)

DERIVATION OF EQUATIONS

ITEM NAME: Accumulator Pressure Switch Constant

SYMBOL S P S C

The following pressure switch part remain constant for all sizes of accumulators

	Constant	Weight	Reliability
1)	Connector	.0875	.020
2)	"O" Ring	.0002	.010
3)	Liner	.0094	.001
4)	Post	.0161	.003
5)	Wiper Head	.0038	.025
6)	End Fitting	.0816	.003
		.1986	.062

SPSCW = .1986

SPSCR = .062

RS-98

ANALYSIS BY: J. J. Harrington CHECKED BY: M. Nakai

TD-04-296-01 (8-64)

EQUATIONS

ITEM NAME: Accumulator Pressure Switch Bourdon Tube

SYMBOL S P S T

REQUIRED INPUTS:

REQUIRED OUTPUTS:

OUTPUTS:

STANDARD

WEIGHT	S	P	S	T	W	=	.0142
RELIABILITY $^{-1}$	S	P	S	T	R	=	.030
LIFE					L	=	
RESPONSE					S	=	
CONT. OPER. TIME					O	=	
DEVEL. TIME					T	=	
DEVEL. COST					D	=	
UNIT COST					U	=	

OTHER

						=	
						=	
						=	
						=	

NOTES:

ANALYSIS BY: J. J. Harrington

RS-99

CHECKED BY: M. Nakai

TD-04-296-02(8-64)

DERIVATION OF EQUATIONS

ITEM NAME: Accumulator Pressure Switch Bourdon Tube

SYMBOL S P S T

The weight and reliability of the Bourdon tube will remain constant therefore

SPSTW = .0142

SPSTR = .030

ANALYSIS BY: J. J. Harrington

RS-100

CHECKED BY: M. Nakai

TD-04-296-01 (8-64)

EQUATIONS

ITEM NAME: Reservoir Electrical Connector and Potting

SYMBOL R E C P

REQUIRED INPUTS:

REQUIRED OUTPUTS:

OUTPUTS:

STANDARD

WEIGHT	R	E	C	P	W	=	.0587
RELIABILITY $^{-1}$	R	E	C	P	R	=	.013
LIFE					L	=	
RESPONSE					S	=	
CONT. OPER. TIME					O	=	
DEVEL. TIME					T	=	
DEVEL. COST					D	=	
UNIT COST					U	=	

OTHER

NOTES:

ANALYSIS BY: J. J. Harrington

RS-101

CHECKED BY: M. Nakai

TD-04-296-02 (8-64)

DERIVATION OF EQUATIONS

ITEM NAME: Reservoir Electrical Connector and Potting

SYMBOL R E C P

The electrical connector will remain constant for all size of reservoir. Therefore the weight and reliability will remain constant.

	WEIGHT	RELIABILITY
Connector and Potting	.0394	.003
Connector Gasket	.0003	.001
Connector Screws	.0044	.004
Connector Boot	.0146	.005
	.0587	.013

ANALYSIS BY: J. J. Harrington

RS-102

CHECKED BY: M. Nakai

TD-04-296-01 (8-64)

EQUATIONS

ITEM NAME: Reservoir Electrical Mounting Cap

SYMBOL R E M C

REQUIRED INPUTS:

REQUIRED OUTPUTS:

OUTPUTS:

STANDARD

Weight	R	E	M	C	W	=	.1432
Reliability $^{-1}$	R	E	M	C	R	=	.005
Life					L	=	
Response					S	=	
Cont. Oper. Time					O	=	
Devel. Time					T	=	
Devel. Cost					D	=	
Unit Cost					U	=	

OTHER

						=	
						=	
						=	
						=	

NOTES:

RS-103

ANALYSIS BY: J. J. Harrington CHECKED BY: M. Nakai

TD-04-296-02(8-64)

DERIVATION OF EQUATIONS

ITEM NAME: Reservoir Electrical Mounting Cap SYMBOL R E M C

The electrical connector mounting cap and screw will remain constant for all sizes of reservoir, therefore the weight and reliability will also remain constant.

	WEIGHT	RELIABILITY
Mounting Cap	.1363	.002
Mounting Screws	.0069	.003
	.1432	.005

RS-104

ANALYSIS BY: J. J. Harrington CHECKED BY: M. Nakai

TD-04-296-01 (8-64)

EQUATIONS

ITEM NAME: Resevoir Accumulator D.C. Potentiometer Fixed Value Parts

SYMBOL R S P A

REQUIRED INPUTS:

REQUIRED OUTPUTS:

OUTPUTS:

STANDARD

WEIGHT	R	S	P	A	W	=	.252 * RSPA3
RELIABILITY $^{-1}$	R	S	P	A	R	=	RSPA3 * (.0968+RSPA1 * .250 + RSPA2 * .150)
LIFE					L	=	
RESPONSE					S	=	
CONT. OPER. TIME					O	=	
DEVEL. TIME					T	=	
DEVEL. COST					D	=	
UNIT COST					U	=	

OTHER

	R	S	P	A	1	=	see next page
	R	S	P	A	2	=	see next page
	R	S	P	A	3	=	see next page
						=	

NOTES:

RS-105

ANALYSIS BY: J.J. Harrington

CHECKED BY: M. Nakai

TD-04-296-02(8-64)

DERIVATION OF EQUATIONS

ITEM NAME: Res. Accumulator D.C. Pot Fired Value Parts

SYMBOL R S P A

The following parts will remain unchanged in size or reliability for variations in reservoir accumulation size.

1. Pot shaft end
2. Screws
3. "O" - rings
4. Paddle and nut
5. Wiper
6. Retainer ring
7. End caps

The combined weight of these parts is .252 lbs.

RSPAW = .252*RSPA3

RSPA1 = 1.0 if a D.C. pot. position instr . is used and 0 if not.

RSPA2 = 1.0 if a position switch is used and 0 if not.

RSPA3 = 1.0 unless the above are all zero, in which case RSPA3 is zero.

The reliability of these parts will remain unchanged except the number of wipers will vary depending on the number of elements used in the unit (i.e., position inst., or switches). Each set of potentiometer contacts is accredited with a $(G.F.)_R$ of .250 and .15 for each set of switch contacts. The $(G.F.)_R$ of .250 for all other parts is .0968.

RSPAR = RSPA3*(.0968+RSPA1*.250+RSPA2*.150)

ANALYSIS BY: J. J. Harrington

RS-106

CHECKED BY: M. Nakai

TD-04-296-01 (8-64)

EQUATIONS

ITEM NAME: Res. Accum. D.C.
Potentiometer Variable Parts

SYMBOL R S P B

REQUIRED INPUTS:
R P A P I
R S P A 1
R S P A 2
R S P A 3

REQUIRED OUTPUTS:

OUTPUTS:

STANDARD

WEIGHT	R	S	P	B	W	=	.3138 * RPAPI * RSPA3
RELIABILITY $^{-1}$	R	S	P	B	R	=	RSPA3 * RPAPI/2 * (.152 + RSPA1 * .242 + RSPA2 * .196)
LIFE					L	=	
RESPONSE					S	=	
CONT. OPER. TIME					O	=	
DEVEL. TIME					T	=	
DEVEL. COST					D	=	
UNIT COST					U	=	

OTHER

						=	
						=	
						=	
						=	

NOTES:

RS-107

ANALYSIS BY: J. J. Harrington **CHECKED BY:** M. Nakai

TD-04-296-02 (8-64)

DERIVATION OF EQUATIONS

EM NAME: Res. Accumulator D.C. Pot Variable Parts **SYMBOL** R S P B

The parts that will vary with the reservoir stroke include:

1. Shaft
2. Mandrels
3. Wire
4. Shorting bars
5. Switch elements
6. Element mounting pad
7. Body

The weight of these parts will not change appreciably with the number of elements in the unit since the elements fit into cutouts in the mounting pads and replace this material.

$$RSPBW = K_1 \ (TRAL) \qquad TRAL = \frac{D}{2} \qquad D = RPAPI$$

$$K_1 = \frac{.192}{3.059} = .6276 \qquad RSPBW = .192$$

RSPBW = .6276*RPAPI/2*RSPA3

RSPBW = .3138*RPAPI*RSPA3

The failure modes of all the variable parts are associated with the part length, the failure rate increases with the length. The mounting pads, body and shaft will all be essentially independent of the internal configuration for these parts

$$(F.R.)_1 = K_2 \ (TRAL) \qquad F.R._1 = .465$$

$$K_2 = \frac{.465}{3.059} = .152$$

RS-108

ANALYSIS BY: J. J. Harrington **CHECKED BY:** M. Nakai

For each pot element and shorting bar, the associated failure rate is .740

$$(F.R.)_2 = K_3 \text{ (TRAL)}$$

$$K_3 = \frac{.740}{3.059} = .242$$

For the switch element and shorting bar, the associated failure rate is .60.

$$(F.R.)_3 = K_4 \text{ (TRAL)}$$

$$K_4 = \frac{.60}{3.059} = .196$$

RSPBR = RSPA3*RPAPI/2*(.152+ RSPA1*.242+RSPA2*.196)

TD-04-296-01 (8-64)

EQUATIONS

ITEM NAME: Accumulator Valve Seat

SYMBOL S V S X

REQUIRED INPUTS:

REQUIRED OUTPUTS:

OUTPUTS:

STANDARD

Weight	S	V	S	X	W	=	4999
Reliability $^{-1}$	S	C	S	X	R	=	,032
Life					L	=	
Response					S	=	
Cont. Oper. Time					O	=	
Devel. Time					T	=	
Devel. Cost					D	=	
Unit Cost					U	=	

OTHER

=

=

=

=

NOTES:

RS-110

ANALYSIS BY: J. J. Harrington CHECKED BY: M. Nakai

The accumulator valve seal size and function will remain constant for all sizes of accumulators. Therefore the weight and reliability will also remain constant.

	WEIGHT	RELIABILITY
Valve Seal	.2213	.003
Plug	.2744	.004
Gasket	.0025	.010
"O" Ring	.0015	.015
	.4999	.032

SVSXW = .4999

SVSXR = .032

TD-04-296-01 (8-64)

EQUATIONS

ITEM NAME: Accumulator Check Valve Screw, Nut and Washer

SYMBOL S C V N

REQUIRED INPUTS:

REQUIRED OUTPUTS:

OUTPUTS:

STANDARD

WEIGHT	S	C	V	N	W	=	.0148
RELIABILITY $^{-1}$	S	C	V	N	R	=	.005
LIFE					L	=	
RESPONSE					S	=	
CONT. OPER. TIME					O	=	
DEVEL. TIME					T	=	
DEVEL. COST					D	=	
UNIT COST					U	=	

OTHER

=

=

=

=

NOTES:

RS-112

ANALYSIS BY: J. J. Harrington

CHECKED BY: M. Nakai

DERIVATION OF EQUATIONS

ITEM NAME: Accumulator Check Valve Screw, Nut and Washer   SYMBOL S C V N

The accumulator check valve screw, nut and washer will remain constant for all sizes of accumulator. Therefore:

$$SCVNW = S_W + N_W + W_W$$

$$SCVNW = .0092 + .0043 + .0013$$

$$SCVNW = .0148$$

$$SCUNR = S_R + N_R + W_R$$

$$SCVNR = .001 + .003 + .001$$

$$SCVNR = .005$$

RS-113

ANALYSIS BY: J. J. Harrington   CHECKED BY: M. Nakai

TD-04-296-01 (8-64)

3

EQUATIONS

ITEM NAME: Accumulator Check Valve Plunger and Seal

SYMBOL S C V P

REQUIRED INPUTS:

REQUIRED OUTPUTS:

OUTPUTS:

STANDARD

WEIGHT	S	C	V	P	W	=	.026
RELIABILITY $^{-1}$	S	C	V	P	R	=	.018
LIFE					L	=	
RESPONSE					S	=	
CONT. OPER. TIME					O	=	
DEVEL. TIME					T	=	
DEVEL. COST					D	=	
UNIT COST					U	=	

OTHER

NOTES:

RS-114

ANALYSIS BY: J. J. Harrington

CHECKED BY: M. Nakai

TD-04-296-02 (8-64)

DERIVATION OF EQUATIONS

ITEM NAME: Accumulator Check Valve Plunger and Seal

SYMBOL S C V P

The accumulator check valve plunger and seal will remain constant for all sizes of accumulators. Therefore:

$$SCVPW = W_P + W_S$$

$$= .0244 + .0016$$

$$SCVPW = .026$$

$$SCVPR = R_P + R_S$$

$$= .003 + .015$$

$$SCVPR = .018$$

RS-115

ANALYSIS BY: J. J. Harrington CHECKED BY: M. Nakai

TD-04-296-01 (8-64)

EQUATIONS

ITEM NAME: Accumulator Check Valve Retaining Cap and Spring

SYMBOL S C V C

REQUIRED INPUTS:

REQUIRED OUTPUTS:

OUTPUTS:

STANDARD

WEIGHT	S	C	V	C	W	=	.050
RELIABILITY $^{-1}$	S	C	V	C	R	=	.012
LIFE					L	=	
RESPONSE					S	=	
CONT. OPER. TIME					O	=	
DEVEL. TIME					T	=	
DEVEL. COST					D	=	
UNIT COST					U	=	

OTHER

=

=

=

=

NOTES:

ANALYSIS BY: J.J. Harrington

RS-116

CHECKED BY: M. Nakai

TD-04-296-02 (8-64)

DERIVATION OF EQUATIONS

ITEM NAME: Accumulator Check Valve Retaining Cap and Spring

SYMBOL S C V C

The accumulator check valve retaining cap and spring function and size will remain constant for all sizes of accumulators.

$$SCVCW = W_c + W_s$$

$$= .0250 + .0250$$

$$SCVCW = .05$$

$$SCVCR = R_c + R_s$$

$$= .002 + .010$$

$$SCVCR = .012$$

RS-117

ANALYSIS BY: J. J. Harrington CHECKED BY: M. Nakai

TD-04-296-01 (8-64)

EQUATIONS

ITEM NAME: Reservoir Volume

SYMBOL R V O L

REQUIRED INPUTS: S V O L
F V O L
A N U M B
A C V O L
F I V O L
P A D S 1
P W D S 1
P I D S 1
T O I L W

REQUIRED OUTPUTS:

OUTPUTS:

STANDARD

Weight	R	V	O	L	W	=	RVOL*TOILW
Reliability^{-1}					R	=	
Life					L	=	
Response					S	=	
Cont. Oper. Time					O	=	
Devel. Time					T	=	
Devel. Cost					D	=	
Unit Cost					U	=	

OTHER

	R	V	O	L		=	RVOL = SVOL + (.20+1.667X10^{-6})* [SVOL+FVOL +(ANUMB*ACVOL)+FIVOL+PADS1 + PWDS1 + PIDS1]
						=	
						=	
						=	

NOTES:

RS-118

ANALYSIS BY: M. Nakai **CHECKED BY:** J. J. Harrington

DERIVATION OF EQUATIONS

ITEM NAME: Reservoir Volume SYMBOL R V O L

The reservoir volume must be large enough to receive the sum of the following volumes.

a. Total accumulator oil volume, SVOL

b. Oil volume due to thermal expansion

c. Volume change due to pressure changes

d. Volume of oil equivalent to the loss of oil due to external leakage.

The volume change in (b) above was found to be approximately 15% of the total system volume for a temperature range from -65° to 275°F.

$$V_{temp} = (.15)\,(V_{sys.})$$

$$V_{sys} = SVOL + FVOL + (ANUMB)\,(ACVOL) + FIVOL + PADS1 + PWDS1 + PIDS1$$

SVOL + Accumulator fluid volume

FVOL = Tubing and fitting fluid

(ANUMB) (ACVOL) = Actuator fluid volume

FIVOL = Filter fluid volume

PADS1 + PWDS1 = Pump fluid volume

$$V_{temp} = (.15)\ SVOL + FVOL + (ANUMB)\,(ACVOL) + FIVOL + PADS1 + PWDS1$$

The volume change due to pressure changes is proportional to the system operating pressure and total system volume.

$$V_{pres} = K_1\,(PRES)\,(V_{sys})$$

ANALYSIS BY: M. Nakai

RS-119

CHECKED BY: J. J. Harrington

Derivation of Equations

From previously designed system V was calculated to be .5% of the total system volume for a 3000 psi system.

$$V_{pres} = (.5\%)\ V_{sys} = K_1\ (3000)\ (V_{sys})$$

$$K_1 = \frac{.5\%\ (V/_{sys})}{(3000)\ (V/_{sys})} = 1.6667 \times 10^{-6}$$

$$V_{pres} = 1.6667 \times 10^{-6}\ (PRES)\ (V_{sys})$$

The volume of oil equivalent to the loss of oil due to external leakage is proportional to the system volume.

$$V_{leak} = K_2\ V_{sys}$$

On previous programs K_2 was calculated to be approximately 5% of the system volume.

$$V_{leak} = (.05)\ V_{sys}$$

The total volume of the reservoir is

$$RVOL = SVOL + V_{temp} + V_{pres} + V_{leak}$$

$$= SVOL + .15\ V_{sys} + 1.6667 \times 10^{-6}\ (PRES)\ (V_{sys}) + .05\ V_{sys}.$$

$$= SVOL + (.20 + 1.6667 \times 10^{-6}\ PRES)\ (V_{sys})$$

$$= SVOL + (.20 + 1.6667 \times 10^{-6})\quad SVOL + FVOL + (ANUMB)\ (ACVOL) + FIVOL + PADSI + PWDSI$$

RVOLW = RVOL*TOILW

TOILW = Density of hydraulic fluid

TD-04-296-01 (8-64)

EQUATIONS

ITEM NAME: Accumulator Oil Volume

SYMBOL S V O L

REQUIRED INPUTS: A C T Q A
A C T I M
A N U M B
T O I L W
R R R 1

REQUIRED OUTPUTS:

OUTPUTS:

STANDARD

Weight	S	V	O	L	W	=	SVOL*TOILW
Reliability $^{-1}$					R	=	
Life					L	=	
Response					S	=	
Cont. Oper. Time					O	=	
Devel. Time					T	=	
Devel. Cost					D	=	
Unit Cost					U	=	

OTHER

	S	V	O	L		=	ACTQA * ACTIM * ANUMB * RRR1
						=	
						=	
						=	

NOTES:

ANALYSIS BY: M. Nakai

RS-121

CHECKED BY: J. J. Harrington

TD-04-296-02(8-64)

DERIVATION OF EQUATIONS

ITEM NAME: Accumulator Oil Volume   SYMBOL S V O L

The accumulator volume is determined by the total volume of oil displacement by the all actuator piston moving from one end of the stroke to the other.

SVOL = (ACTQA) (ACTIM) (ANUMB)

Where ACTQA = Max. flow rate for (1) unloaded actuator

ACTIM = Time for piston to travel full stroke

ANUMB = Total number of actuators per pump or closed system.

SVOLW = SVOL*TOILW

TOILW = Density of hydraulic fluid

RRR1 = Fraction of total actuator flow demand

ANALYSIS BY: M. Nakai   RS-122   CHECKED BY: J. J. Harrington

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TUBING

TUBES AND FITTING SYSTEM

The tubing equations were derived under the assumption that there would be two actuators per prime mover. The prime mover may actually take on the form of two, one for ground checkout and one for flight, but only one is in use at any particular time. All tubing sizes were first calculated as a function of pressure and flow, and the next Standard size was used.

The weight of the fittings was found to be a function of connecting tube size and number of ports on the fittings.

The analysis has taken into account the varying tube lengths as the truss dimensions are changed according to the actuator requirements.

CONTENTS OF TUBING EQUATIONS

TD-04-296-01 (8-64)

EQUATIONS

ITEM NAME: Metal Tube System

SYMBOL: T M T S

REQUIRED INPUTS:

F L O W
P R E S
T M T L 1
T M T L 2
T M T L 3

REQUIRED OUTPUTS:

T M T 1 J
T M T 2 J

OUTPUTS:

STANDARD

WEIGHT	T	M	T	S	W	=	.222*((1.366E-4*PRES)/(1.0-6.83E-5*PRES))*((TMTL1)*(TMT1J**2.0)+2. *(TMTL2)*(TMT2J**2.0))
RELIABILITY $^{-1}$	T	M	T	S	R	=	2.8E-6*((TMTLN*TMTNI)/TMTNT)+1.05E-6*(TMTIN/(TMTNT*TMTNI))
LIFE					L	=	
RESPONSE					S	=	
CONT. OPER. TIME					O	=	
DEVEL. TIME					T	=	
DEVEL. COST					D	=	
UNIT COST					U	=	

OTHER

Tube (I.D.$_2$)	T	M	T	2	J	=	((1.02E-2.0*FLOW*(.794*TMTL1+TMTL2))/(PRES))**.25
Tube (I.D.$_1$)	T	M	T	1	J	=	TMT2J*1.26
						=	
						=	

NOTES: An array of standard O.D. wall thickness and fitting weights will be built in at this point.

T-1

ANALYSIS BY: D.A. Lommatter CHECKED BY: D.R. Moody

ITEM NAME: Metal Tube System

SYMBOL T M T S

WEIGHT AND SIZE

The weight of a tube is a function of the tube's length, O.D., wall thickness, and the material from which the tube is constructed. It will be considered in this analysis that the tubing system can be broken into two separate parts, mainly that of the low pressure lines and the high pressure lines. It is also considered that the high pressure tube splits into two tubes lending to two separate actuators. The low pressure return lines emerge separately from the actuators and join together to form a single line. This arrangement is shown below

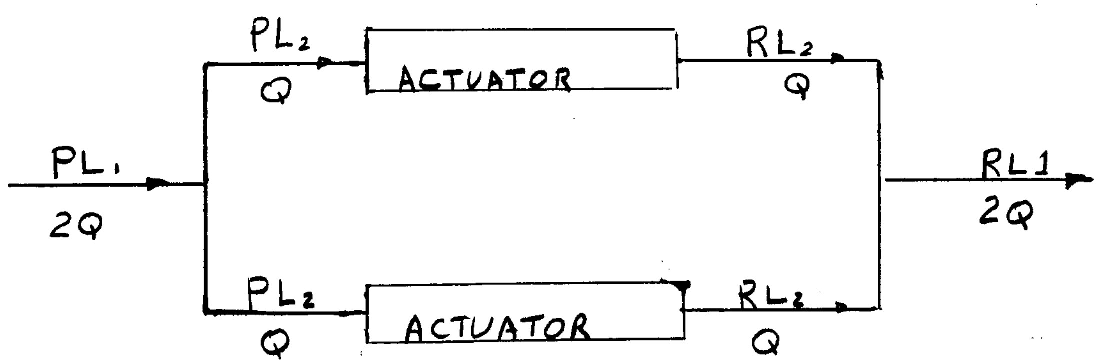

Figure 1

Because the return low pressure portion of the analysis will be identical to the high pressure portion, we will examine the general case, and use the solution for both portions of the system. This

ANALYSIS BY: [signature] CHECKED BY: [signature] breakdown is shown below.

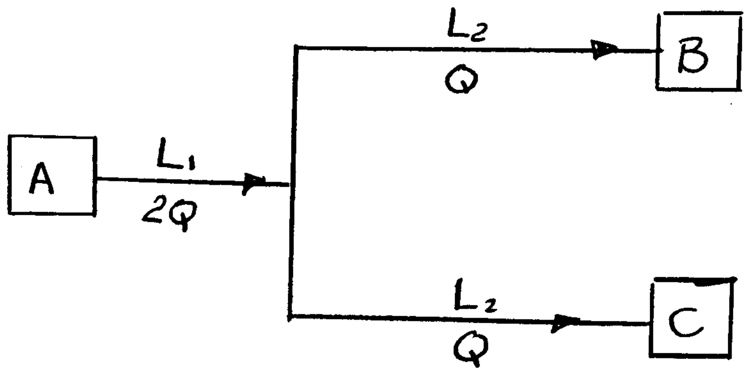

Figure 2

The cross sectional area of the metal portion of a tube can be expressed as follows:

$$A = \frac{1}{4}\pi\left[(O.D.)^2 - (I.D.)^2\right]$$

The volume of material is a tube of length L may be expressed as

$$V = \frac{1}{4}\pi\left[(O.D.)^2 - (I.D.)^2\right] L$$

From this one may see that the weight of a tube of length L may be given as

$$\text{Weight} = K_1 \; L \left[(O.D.)^2 - (I.D.)^2\right]$$

The weight of the tube system shown in Figure 2 may be expressed as shown in the following function.

$$(1) \quad W = K_1 \left\{ L_1 \left[(O.D._1)^2 - (I.D._1)^2\right] + 2L_2 \left[(O.D._2)^2 - I.D._2)^2\right]\right\}$$

The line loss of pressure in tube L_1 can be expressed as shown below (Ref. Hydraulics and Pneumatics Design Manual, The Glenn L. Martin Company.)

$$\Delta P_1 /_{in} = \frac{2Q}{(I.D._1)^4} \quad K_2$$

Where 2Q is the flow rate in tube L_1 and K_2 is some constant. The line loss of pressure in tube L_2 is given as

$$\Delta P_2 /_{in} = \frac{Q}{(I.D._2)^4} \quad K_2$$

From these two equations a function is easily formed stating the pressure drop from point A to point B as shown in Figure 2.

$$(\Delta P)_{A \text{ to } B} = K_2 \left[L_1 \frac{2Q}{(I.D._1)^4} + L_2 \frac{Q}{(I.D._2)^4} \right]$$

It has been found (Ref. Study of Criteria for Hydraulic and Pneumatic Systems for Space Vehicles, Charles H. Cannon) that the average efficiency of transmission tubes is approximately 80% of the system operating pressure. Thus, figuring half of this loss in the high pressure side, and half in the low pressure side, we have a maximum allowable drop from point A to point B equal to .1 times the system pressure. Therefore:

$$(2) \quad (\Delta P)_{A \text{ to } B} = K_2 \left[L_1 \frac{2Q}{(I.D._1)^4} + L_2 \frac{Q}{(I.D._2)^4} \right] = .1 \text{ (PRES)}$$

The relationship that relates the O.D. of a tube as a function of the I.D. is shown below

$$(O.D.)^2 = (I.D.)^2 \left(\frac{1 + K_3 P}{1 - K_3 P} \right)$$

Where

P = System pressure

K_3 = Constant

Substituting the above relationship in the weight equation (Equation 1)

$$(3) \quad W = K_1 \left[\left(\frac{1 + K_3 P}{1 - K_3 P} \right) - 1 \right] \left[L_1 \, (I.D._1)^2 + 2L_2 \, (I.D._2)^2 \right]$$

The next step will be to minimize the weight equation subject to the following single constrant.

$$(4) \quad K_2 \left[\frac{2Q}{(I.D._1)^4} L_1 + \frac{Q}{(I.D._2)^4} L_2 \right] - .1 \text{ PRES}) = 0$$

The minimizing of the weight equation will be carried out making use of Lagrangean's equation for minimizing a function that is subject to a single constant.

Lagrangean's equation will be formed by adding the constant equation (Equation 4) that has been mutliplied by some variable λ, to the weight equation (Equation(3)). Minimizing will then be accomplished by partial differentiating with respect to each of the variables and setting them equal to zero. The equations can then be solved for the constants and a solution will have been found. This work is shown below.

$$L\,(L_1,L_2) = K_1\left[\left(\frac{1+K_3P}{1-K_3P}\right)-1\right]\left[L_1\,(I.D._1)^2 + 2L_2\,(I.D._2)^2\right]$$

$$+\lambda\left\{K_2\left[\frac{2Q}{(I.D._1)^4}\,L_1 + \frac{Q}{(I.D._2)^4}\,L_2\right] -.1\,(\text{PRES})\right\}$$

(5) $$\frac{\partial\, L\,(L_1,L_2)}{\partial\,(I.D._1)} = K_1\left[\left(\frac{1+K_3P}{1-K_3P}\right)-1\right]\left[2L_1\,(I.D._1)\right] +$$

$$\lambda K_2\left[\frac{-8Q}{(I.D._1)^5}\,L_1\right] = 0$$

(6) $$\frac{\partial\, L\,(L_1,L_2)}{\partial\,(I.D._2)} = K_1\left[\left(\frac{1+K_3P}{1-K_3P}\right)-1\right]\left[4L_2\,(I.D._2)\right] +$$

$$\lambda K_2\left[\frac{-4Q}{(I.D._2)^5}\,L_2\right] = 0$$

(7) $$\frac{\partial\, L\,(L_1,L_2)}{\partial\,(\lambda)} = K_2\left[\frac{2Q}{(I.D._1)^4}\,L_1 + \frac{Q}{(I.D._2)^4}\,L_2\right] -.1\,(\text{PRES} = 0$$

Working with equations (5) and (6) to eliminate .

$$K_1 \left[\left(\frac{1 + K_3 P}{1 - K_3 P} \right) -1 \right] \left[2L_1 \ (I.D._1) \right] = \lambda K_2 Q \left[\frac{8}{(I.D._1)^5} \ L_1 \right]$$

$$K_1 \left[\left(\frac{1 + K_3 P}{1 - K_3 P} \right) -1 \right] \left[4L_2 \ (I.D._2) \right] = K_2 Q \left[\frac{4}{(I.D._2)^5} \ L_2 \right]$$

$$\frac{2L_1 \ (I.D._1)}{\frac{8L_1}{(I.D._1)^5}} = \frac{\lambda K_2 \ Q}{K_1 \left[\left(\frac{1 + K_3 P}{1 - K_3 P} \right) -1 \right]}$$

$$\frac{4L_2 \ (I.D._2)}{\frac{4L_2}{(I.D._2)^5}} = \frac{K_2 \ Q}{K_1 \left[\left(\frac{1 + K_3 P}{1 - K_3 P} \right) -1 \right]}$$

Substracting the second from the first we have,

$$\frac{2L_1 \ (I.D._1)}{\frac{8L_1}{(I.D._1)^5}} - \frac{4L_2 \ (I.D._2)}{\frac{4L_2}{(I.D._2)^5}} = 0$$

Which further reduces to

$$(I.D._1)^6 - 4 \ (I.D._2)^6 = 0$$

Therefore:

$$(I.D._1) = (I.D._2) \ (1.26)$$

Substituting this relationship back into equation (7) we have

$$K_2 \left\{ \frac{2Q}{\left[(I.D._2)\ 1.26\right]^4} L_1 + \frac{Q}{(I.D._2)^4} L_2 \right\} = .1\ (PRES)$$

This then reduces to

$$(I.D._2) = \sqrt[4]{\frac{K_2 Q\ (.794L_1 + L_2)}{.1\ (PRES)}}$$

We now have three equations for our solution. They are as follows:

$$(I.D._2) = \sqrt[4]{\frac{K_2\ Q\ (.794L_1 + L_2)}{.1\ (PRES)}}$$

$$(I.D._1) = (I.D._2)\ (1.26)$$

$$\text{Weight} = K_1 \left[\left(\frac{1 + K_3 P}{1 - K_3 P} \right) -1 \right] \left[L_1\ (I.D._1)^2 + 2L_2\ (I.D._2)^2 \right]$$

<u>Solving for Constants K_1, K_2, and K_3 Constant K_1</u>

In determining K_1 it was found that for a typical system (Stainless Steel Tubing) the weight was 2.83211. With the other following values

L_1 = 120 in	L_2 = 36.3 in.
$(O.D._1)$ = .5 in.	$(O.D._2)$ = .375 in.
$(I.D._1)$ = .416 in.	$(I.D._2)$ = .305 in.

Then:

$$\text{Weight:} = K_1 \left\{ L_1 \left[(O.D._1)^2 - (I.D._1)^2 \right] + 2L_2 \left[(O.D._2)^2 - (I.D._2)^2 \right] \right\}$$

$$2.832 = K_1 \left\{ 120 \left[(.5)^2 - (.416)^2 \right] + 2\,(36.3) \left[(.375)^2 - (.305)^2 \right] \right\}$$

$$2.832 = K_1 \,(12.72)$$

$$K_1 = \frac{2.832}{12.72}$$

$$\therefore K_1 = .222$$

Constant K_2

K_2 will be determined by again considering a typical system.

$$\Delta P/_{in} = \frac{Q}{(I.D.)^4} \quad K_2$$

Considering a typical system of $Q = 11.55\ in^3/sec$, $P = 0.625\ psi/_{in}$, and $(I.D.) = 0.370$ in.

$$K_2 = 0.625 \left[\frac{(.370)^4}{11.55} \right]$$

$$K_2 = 1.02 \times 10^{-3}$$

Constant K_3

It was found that for a typical system using stainless steel tubing and operating at a system pressure of 3000 psi, that the I.D. was 0.305 in. with an O.D. of 0.375 in.

$$(O.D.)^2 = (I.D.)^2 \left(\frac{1 + K_3 P}{1 - K_3 P} \right)$$

$$K_3 = \frac{(O.D.)^2 - (I.D.)^2}{P \left[(O.D.)^2 + (I.D.)^2 \right]}$$

$$K_3 = \frac{(.375)^2 - (.305)^2}{3000 \left[(.375)^2 + (.305)^2 \right]}$$

$$\therefore K_3 = 6.83 \times 10^{-5}$$

Substituting these values for the constants K_1, K_2, and K_3 into the final equations, results in the expressions for minimizing the weight of the tube system.

$$(I.D._2) = \sqrt[4]{\frac{1.02 \times 10^{-2} \; (Q) \; (.794 L_1 + L_2)}{(PRES)}}$$

Which may be expressed in computer language as

```
TMT2J = ((1.02E-2*FLOW*(.794*TMTL1+TMTI2))/PRES)**.25
```

$$(I.D._1) = (I.D._2)\,(1.26)$$

which may be expressed as

```
TMT1J = TMT2J * 1.26
```

and finally, the weight equation of

$$\text{Weight} = .222 \left[\left(\frac{1 + 6.83 \times 10^{-5}P}{1 - 6.83 \times 10^{-5}P}\right) - 1\right]\left[L_1 \,(I.D._1)^2 + 2L_2(I.D._2)^2\right]$$

may be expressed in computer language as

```
TMTSW  =  (.222)*((13.66E-5*PRES)/(1.0-6.83E-5 *PRES))

          *((TMTL1)*(TMT1J**2.0)+2.0*(TMTL2)*(TMT2J**2.0))

TMTSW  =  (.222)*((13.66E-5*PRES)/1.0-6.83E-5*PRES))

          *((TMTL1)*(TMT1J**2.0))+2.0*(TMTL2)*(TMT2J*2.0))
```

RELIABILITY

The failure rate of a tube may be contributed to two primary failure modes. The first is due to tube surface damage which is caused by scratches, dents, and nicks. The second failure mode is due to accidental bending of the tube by steping on it or setting heavy objects upon it. The failures due to nicks, scratches, and/or dents are functions of the tube outside area, and the tube wall thickness. As the tube O.D. and length are increased, more surface area is available for damage to be inflicted. Thus the failure rate varies directly as the outside surface area. As the tube wall thickness becomes thinner, a nick, scratch, or dent increases the possibility of a failure. Thus, the failure rate varies inversely as the wall thickness therefore

$$FR_1 = K_1 \frac{(\text{tube outside surface area})}{(\text{wall thickness})}$$

$$FR_1 = K_2 \frac{(\text{tube length})\ (\text{tube O.D.})}{(\text{wall thickness})}$$

The second failure mode is a function of tube length, tube diameter, and tube wall thickness. As the tube length increases it will increase its susceptibility to accidently bending failures, thus, failure rate varies directly as tube length. As wall thickness becomes thinner, and as the O.D. of the tube decreases, accidental bending will increase. Thus, failure rate varies inversely as the tube O.D. and tube wall thickness.

Then:

$$FR_2 = K_3 \frac{\text{(tube length)}}{\text{(wall thickness) (tube O.D.)}}$$

The total failure rate will be a sum of the two failure rates or,

$$FR = FR_1 + FR_2$$

It has been found that for a tube with length = 120 inches, wall thickness = .042 inches, and O.D. = 0.5 inch, the total failure rate was .01 with FR_1 contributing 40% and FR_2 contributing 60%.

Then:

$$.004 = K_2 \frac{(120)\ (0.5)}{(.042)}$$

$$K_2 = \frac{(.004)\ (.042)}{(120)\ (0.5)}$$

$$K_2 = 2.8 \times 10^{-6}$$

and:

$$.006 = K_3 \frac{(120)}{(.042)\ (0.5)}$$

$$K_3 = \frac{(.042)\ (0.5)\ (.006)}{(120)}$$

$$K_3 = 1.05 \times 10^{-6}$$

Therefore, the total failure rate is,

$$FR = 2.8 \times 10^{-6} \left[\frac{(\text{tube length})\ (\text{tube O.D.})}{(\text{wall thickness})} \right] + 1.05 \times 10^{-6} \left[\frac{\text{Tube length}}{(\text{wall thickness})\ (\text{tube O.D.})} \right]$$

Or

$$TMTSR = 2.8 \times 10^{-6} \left[\frac{(TMTLN)\ (TMTNI)}{TMTNT} \right] + 1.05 \times 10^{-6} \left[\frac{TMTLN}{(TMTNT)\ (TMTNI)} \right]$$

TD-04-296-01 (8-64)

EQUATIONS

ITEM NAME: Metal Tube Fittings

SYMBOL: T M T F

REQUIRED INPUTS: T M T N J

REQUIRED OUTPUTS:

OUTPUTS:

STANDARD

Weight	T	M	T	F	W	=	M*(A(I,J))
Reliability $^{-1}$	T	M	T	F	R	=	.06*TMTNI+1.47E-3/(TMTNI*TMTNI)
Life					L	=	
Response					S	=	
Cont. Oper. Time					O	=	
Devel. Time					T	=	
Devel. Cost					D	=	
Unit Cost					U	=	

OTHER

	T	M	T	N	I	=	TMTNJ*(((1+6.83E-5PRES)/1-6.83E-5*PRES)) **.5
						=	
						=	
						=	

NOTES: TMTNJ is the I.D. of tube number N that is under consideration.

T-14

ANALYSIS BY: D. A. Teamster   CHECKED BY: D. R. Moody

DERIVATION OF EQUATIONS

ITEM NAME: Metal Tube Fittings SYMBOL T M T F

WEIGHT

The weight of a fitting may be expressed as a function of the fitting size, which in turn is a function of the tube O.D. The tube O.D. can be expressed as a function of the tube I.D. and system pressure.

Therefore:

$$\text{O.D.} = \text{I.D.} \sqrt{\frac{1 + 6.83 \times 10^{-5} P}{1 - 6.83 \times 10^{-5} P}}$$

which may be expressed in FORTRAN Language as

```
TMTNI  =  TMTNJ*(((1 + 6.83E-5*PRES)/1 - 6.83E-5*PRES))**.5)
```

The thickness of the tube can then be calculated from.

$$\text{Thickness} = \frac{\text{O.D.} - \text{I.D.}}{2}$$

The calculated O.D. and thickness will then be changed to the next Standard O.D. and thickness above the calculated values and these values will be used in further calculations.

The derivation of a representative curve for the weight of a fitting versus the tube O.D. is based on the assumption that MS fittings will be used in the system. If a different type of fittings are used, the basic shape of the curve will be unchanged, shifting either up or down with respect to the weight.

The weight of a fitting has been broken down into parts according to the number of ports in the fittings. As an example, a cross was divided into four equal parts, a tee divided into three equal parts, etc. It was found that the divided portions of the fittings were

ANALYSIS BY: D. A. Trommater

CHECKED BY: D. R. Moody

approximately the same weight for all fittings of a particular standard size. It was thus concluded that the weight of a fitting could be determined by multiplying the number of ports times a weight number which varies according to the tube O.D. The weight number is a total of the part of the weight of the fitting, plus the weight of the nut, plus the weight of the sleeve.

The weight number has been calculated from actual weights of standard fittings. After an O.D. has been selected for a tube the corresponding weight number will be determined by the computer for the Standard O.D. This weight number will be designated A (I.J), where A(I,J) will be the number in the standard fitting array. Then the weight of a fitting will be

$$W_{fitting} = M\ (A(I,J))$$

Where

M = number of ports in fitting

$A(I,J)$ = weight number for Standard tube O.D.

this may be expressed in FORTRAN as:

```
TMTFW = M*(A(I,J))
```

RELIABILITY

The failure rate of a tube fitting may be considered to be a function of two failure modes. The first of these modes is improper seating of the sleeve. As the O.D. of the tube increases there will be more linear distance around the tube circumference for the sleeve to seal. Therefore, the failure rate will vary directly as the tube

O.D. The second failure mode is due to over torqueing of the nut. As the tube O.D. and/or wall thickness decrease, the fitting is more likely to fail due to this failure mode. Also, any cracking of the nut due to over torquing would be worse on a smaller nut than on a larger one. Therefore, the failure rate will vary inversely as the tube O.D. and wall thickness.

Then,

$$F.R. = F.R._1 + F.R._2$$

Where

$$F.R._1 = K_1 \text{ (Tube O.D.)}$$

$$F.R._2 = \frac{K_2}{\text{(Tube O.D.) (Wall Thickness)}}$$

$$F.R. = K_1 \text{ (Tube O.D.)} + \frac{K_2}{\text{(Tube O.D.) (Wall Thickness)}}$$

It has been found that for a tube with O.D. = 0.5 inch, and wall thickness = .042 inch. That the total failure rate was 0.10 with $F.R._1$ contributing 30% and $F.R._2$ contributing 70% of the total failure rate.

Then

$$.03 = K_1 (0.5)$$

$$K_1 = \frac{.03}{0.5}$$

$$K_1 = .06$$

and

$$.07 = \frac{K_2}{(.05)\ (.042)}$$

$$K_2 = (0.5)\ (.042)\ (.07)$$

$$K_2 = 1.47 \times 10^{-3}$$

Therefore, the total failure rate of a tube fitting is

$$\text{F.R.} = .06\ (\text{Tube O.D.}) + \frac{1.47 \times 10^{-3}}{(\text{Tube O.D.})\ (\text{Tube wall thickness})}$$

or

$$\text{TMTFR} = .06\ (\text{TMTNI}) + \frac{1.47 \times 10^{-3}}{(\text{TMTNI})\ (\text{TMTNT})}$$

H

O-RINGS

O-RINGS

Due to the large number of "O" rings in the system and the complex failure modes for "O" rings, the equations for their weight and reliability were derived as separate items. These equations were used in a computer program subroutine. The weight and reliability for a particular "O" ring is found by (1) determining the operating pressure and either the O.D. or I.D. of the "O" ring and (2) referring these values to the "O" ring subroutine and having the subroutine determine the weight and reliability. This made it possible to maintain consistancy in the O-ring equations in all portions of the computer program.

The derivation of the O-ring equations is contained on the following pages.

CONTENTS OF "O"-RINGS EQUATIONS

TD-04-296-01 (8-64)

EQUATIONS

ITEM NAME: O-Ring Failure Rate Subroutine

SYMBOL O S F R

REQUIRED INPUTS:

REQUIRED OUTPUTS:

OUTPUTS:

STANDARD

WEIGHT	W	=
RELIABILITY $^{-1}$	R	=
LIFE	L	=
RESPONSE	S	=
CONT. OPER. TIME	O	=
DEVEL. TIME	T	=
DEVEL. COST	D	=
UNIT COST	U	=

OTHER

=

=

=

=

NOTES:

ANALYSIS BY: R. A. Tcommater

O-1

CHECKED BY: D. R. Moody

TD-04-296-02(8-64)

DERIVATION OF EQUATIONS

ITEM NAME: O-Ring Failure Rate Subroutine

SYMBOL O S F R

The failure rate of "O" rings is a function of the two dependent variables, pressure and size, or:

$$F.R. = f(\text{pressure, size})$$

For the analysis, it was assumed that separation of variables could be employed, the total failure rate being some function of pressure times some function of size, or:

$$F.R. = \left[f(\text{pressure}) \right] \left[f(\text{size}) \right]$$

With this approach, each parameter can be analyzed separately, and the variation of the failure rate for each parameter determined.

In these derivations, $(F.R.)_p$ will be used in place of $f(\text{pressure})$ and $(F.R.)_s$ will be used in place of $f(\text{size})$. Also, each parameter will be composed of a number of sub factors, each sub factor representing a different type of failure "generator". (i.e., the pressure function will consist of a function representing the failure "generators" (flaws) that result in low pressure failures and a function representing the failure "generator" (extrusion) that result in high pressure failures. Since these "generators" act independently, the failure generator functions will be summed. For the example given:

$$(F.R.)_p = (F.R.)_{(\text{Low Pressure})} + (F.R.)_{(\text{High Pressure})}$$

ANALYSIS BY: D. A. Twommater CHECKED BY: D. R. Moody

O-2

"O" Ring Reliability Variation with Size

There are four major contributing factors associated with the "O" ring size that contribute to the failures. These factors are:

1. Damage or improper procedures during manufacturing.
2. Damage to and stretching of the "O" ring during installation into a piston grove. (Not applicable to shaft and face seals).
3. Damage during assembly of piston or shaft into body (not applicable to face seals).
4. Damage resulting from "O" ring roll during cycling (not applicable to static seals and dynamic seals with cap strips).

These four factors leading to failures of "O" rings each attribute a certain proportionate amount towards the total failure rate of an "O" ring. The following is a qualitative analysis of each failure mode and a final derivation of the "O" ring representative equation.

1. Damage During Manufacturing

Manufacturing damage to "O" rings will lead to flaws in the "O" ring surface which can lead to eventual leakage past the seal when installed in a system. Since these flaws occur on a random basis, with the larger flaws having a smaller probability of occurrence, the distribution of the total number of flaws of a given size on a given surface area can be approximated to be the normal logarithmic distribution for a characteristic of this type of:

$$\frac{\text{Total number of flaws of a given size}}{\text{Unit area}} = K_1 \ln\left[\frac{K_2}{\text{flaw size}}\right]$$

Note that as the flaw size approaches zero, the total number of flaws of that size approaches infinity as would be expected from microscopic considerations.

Since the largest flaw size that can occur on a given "O" ring would be a flaw completely around the "O" ring cross sectional circumference, and since the probability of such a flaw occurring is close to zero, K_2 can be evaluated to be equal to π W where W is the diameter of the "O" ring cross sectional area. This reduces the above equation to

$$N_S = K_1 \ln \frac{\pi W}{S}$$

Where N_S is the total number of flaws of size "S" per unit area.

The smallest flaw that can result in a leak would be one which just bridges the sealing surface of the seal. The sealing surface for the ranges of squeeze considered effective is approximately equal to:

$$\frac{\pi\,(W)}{2} \quad \frac{(\%\ \text{squeeze})}{100}$$

The total number of flaws per unit of surface area that can result in a leak path is therefore

(Number of flaws of smallest size that can cause leakage)

$$\int S\, d(N_s)$$

(Number of flaws of largest size considered).

$$= \int_0^{K_1 \ln\left(\frac{2}{\alpha}\right)} \pi W e^{-N_s/K_1}\, d(N_s)$$

Where α = (percent squeeze/100)

$$= \pi W \left[-K_1 e^{-N_s/K_1} \right]_0^{K_1 \ln\left(\frac{2}{\alpha}\right)}$$

Or:

$$\frac{\text{Total number of flaws that can cause a leak}}{\text{Unit Area}} = K_2 \left[1 - \frac{\alpha}{2} \right]$$

Since the surface area of the "O" ring is approximately equal to:

$$\text{Surface area} \approx \frac{(\text{I.D.} + \text{O.D.})\pi}{2} \left[\pi W \right]$$

the total number of flaws that can result in a leak for a given "O" ring is:

$$K_3 \left[I.D. + O.D. \right] \left[W \right] \left[1 - \frac{\alpha}{2} \right]$$

The proportion of these flaws that are on the sealing surface of the "O" ring is:

$$\frac{(\text{Sealing Surface Width}) \ \frac{(I.D. + O.D.)}{2}}{(\text{"O" Ring Cross Sectional Circumference}) \ \frac{(I.D. + O.D.)}{2}}$$

$$= \frac{\frac{\pi W}{2} \alpha}{\pi W} = \frac{\alpha}{2}$$

The number of flaws that will effect sealing is therefore:

$$K_4 \left[I.D. + O.D. \right] \left[W \right] \left[1 - \frac{\alpha}{2} \right] \alpha$$

Since the total number of flaws which can result in a leak is proportional to the failure rate of this failure mode,

$$F.R._1 = K_5 \left[I.D. + O.D. \right] \left[W \right] \left[1 - \frac{\alpha}{2} \right] \alpha$$

where $F.R._1$ is the failure rate of the "O" ring due to manufacturing errors.

2. Damage to the "O" Ring During Installation on a Shaft

When an "O" ring is installed on a shaft, the "O" ring must be stretched by some force which can result in damage to the "O" ring. The amount of damage can be approximated to be proportional to the force/unit area during installation. Also, since the damage will occur at one point, the effect of any damage will be independent of the seal circumferential length but will be inversely proportional to the effective sealing width. Therefore:

$$(F.R.)_2 = \frac{K_6 \text{ (Force/unit area)}}{(W)}$$

Considering the "O" ring as a spring with k proportional to the cross sectional area and inversely proportional to the circumference, the force can be approximated to be:

$$(\text{Force}) = K_7 \left[\frac{(\Delta X) \quad (W)^2}{(I.D. + O.D.)} \right]$$

where Δ X is the total required stretch to install the "O" ring.

Δ X can be approximated to be equivalent to the difference between the deformed "O" ring I.D. during installation and the undeformed "O" ring I.D., but the "O" ring I.D. during installation is approximately equivalent to the undeformed "O" ring O.D.

Therefore:

$$\Delta X = \pi (O.D. - I.D.)$$
$$= 2 W \pi$$

This reduces the force equation to:

$$\text{Force} = K_7 \left[\frac{(W^3) \quad 2\pi}{(\text{I.D.} + \text{O.D.})} \right]$$

The total area where this force is applied can be approximated to be a percentage of the total seal length times the cross sectional area or:

$$(\text{Length})\,(\text{Area}) = \frac{\pi W^2}{4} \; \frac{(\text{I.D.} + \text{O.D.})\,\pi}{2}$$

The force per unit area will therefore be:

$$\frac{\text{Force}}{\text{Unit area}} = K_8 \frac{\dfrac{W^3}{(\text{I.D.} + \text{O.D.})}}{(W^2)\,(\text{I.D.} + \text{O.D.})}$$

$$= K_8 \frac{W}{(\text{I.D.} + \text{O.D.})^2}$$

Leading to:

$$(\text{F.R.})_2 = K_9 \frac{\dfrac{W}{(\text{I.D.} + \text{O.D.})^2}}{W\,\alpha}$$

$$= \frac{K_9}{(\text{I.D.} + \text{O.D.})^2\,(\,\alpha\,)}$$

3. Damage During Assembly

When the "O" ring is installed, damage can occur to the "O" ring as a result of chipping during assembly of the shaft into the housing. Chipping can result from two causes, cocking of the shaft during assembly in the bore, or a poor chamfer in the bore or on the shaft. Since less damage is done with a large chamfer and since the chamfer length can be approximated to the "O" ring (O.D. + L.D.)/2, the damage per unit length of seal can be approximately to be inversely proportional to the "O" ring (O.D. + I.D.). The amount of damage per unit length can also be approximated to increase with the squeeze on the "O" ring and to also decrease as the clearance is increased. A third consideration is the probability of having sharp edges on the chamfer. The probability of sharp edge passing through Quality Control inspection without detection will decrease as the O.D. is increased but also the probability of having a sharp edge will increase with the O.D. Therefore, these two factors were considered to be self compensating and not included in the representative equation. The total amount of damage per unit length to the "O" ring during assembly is therefore approximated to be:

$$\frac{\text{Total damage}}{\text{Unit length}} = \frac{K_{10}\,(\text{Total equeeze})}{(\text{O.D.} + \text{I.D.})\,(\text{Clearance})} =$$

$$K_{10}\,\frac{(\alpha)\,(W)}{(\text{O.D.} + \text{I.D.})\,(C)}$$

(C = diametral clearance)

which leads to the conclusion that the total damage to an "O" ring during assembly is

$$\text{Total damage} = \frac{K_{11}\,(\alpha)\,(W)}{(C)}$$

As previously noted, the effects of any seal damage will be decreased as the sealing width is increased.

This leads to the conclusions that

$$(F.R.)_3 = \frac{\left[\frac{K_{11}\ (\alpha)\ (W)}{C}\right]}{\text{Sealing width}}$$

$$= \frac{\left[\frac{K_{12}\ (\alpha)\ (W)}{C}\right]}{(\alpha)\ (W)}$$

$$= \frac{K_{12}}{C}$$

4. <u>Dynamic "O" Ring Roll During Usage</u>

One predominant failure mode of large dynamic "O" rings is the tendency of the "O" ring to roll during cycling, resulting in a spiral failure. The tendency of the "O" ring to roll in proportional to the torque applied to the "O" ring cross sectional area. This torque in turn is proportional to the "O" ring squeeze force times $\frac{W}{2}$, leading to:

$$\text{Tendency to roll} = K_{12}\ (\text{squeeze force})\ \frac{(W)}{2}$$

The squeeze force can be approximated to be proportional to total squeeze or $(\alpha)\ (W)$. Therefore:

$$\text{Tendency to roll} = K_{13}\ (\alpha)\ (W)^2$$

For constant torque, the effects of rolling can be approximated to be inversely proportional to W since an "O" ring with a larger cross sectional diameter will have a smaller angle of roll. This leads to:

$$(F.R.)_4 = K_{14} \frac{(\alpha)(W)^2}{W}$$

$$= K_{14} (\alpha) (W)$$

These four failure mode factors can be directly added to arrive at the representation of the failure rate as a function of the "O" ring dimensions for various "O" ring configurations. The result is:

a. For a dynamic piston seal without cap strip

$$(F.R.)_s = (F.R.)_1 = (F.R.)_2 + (F.R.)_3 + (F.R.)_4$$

b. For a static piston type seal

$$(F.R.)_s = (F.R.)_1 + (F.R.)_2 = (F.R.)_3$$

c. For a static shaft seal

$$(F.R.)_s = (F.R.)_1 + (F.R.)_3$$

d. For a face seal

$$(F.R.)_s = (F.R.)_1$$

Where:

Manufacturing Damage, $(F.R.)_1$:

$$(F.R.)_1 = K_5 \left[I.D. + O.D. \right] \left[W \right] \left[1 - \frac{\alpha}{2} \right] \alpha$$

Installation Damage, $(F.R.)_2$

$$(F.R.)_2 = \frac{K_9}{(I.D. + O.D.)^2 \, (\alpha)}$$

Assembly Damage, $(F.R.)_3$

$$(F.R.)_3 = \frac{K_{12}}{C}$$

Roll Damage, $(F.R.)_4$

$$(F.R.)_4 = K_{14} \, (\alpha) \, (W)$$

"O" Ring Reliability Variation with Pressure

There are two difference failure modes of "O" rings with regard to pressure; 1) low pressure leakage and 2) high pressure leakage and extrusion.

The first type, failure resulting from low pressure, is primarily caused by the reduction in sealing effectiveness as the pressure is reduced. This reduction in sealing effectiveness is a result of the reduction in the compressive force which forces the seal to conform to the groove configuration. The failure rate for this mode can therefore be approximated to be inversely proportional to the seal compressive force or:

$$(F.R.)_5 = \frac{K_{15}}{\text{Compressive Force}}$$

The compressive force is proportional to $(K_2 + PRES)$ where K_2 is the force due to the initial squeeze. The above equation can therefore be reduced to:

$$(F.R.)_5 = \frac{K_{16}}{(K_{17} + \text{Pressure})}$$

The second type of failure mode, high pressure leakage and extrusion, results from damage to the "O" ring due to high pressure, normally in the form of extrusion of the seal between the shaft and the housing. The failure rate for the mode can be approximated to be:

$$(F.R.)_6 = K_{18}\,(\text{Extrusion Force})\,(\text{Clearance between shaft and housing})$$

The compressive force tending to extrude the "O" ring will be proportional to the pressure plus a constant. The clearance between the shaft and housing can be approximated to be inversely proportional to $(K_{20} - PRES)$ or:

$$\text{Clearance} = \frac{K_{19}}{(K_{20} - PRES)}$$

This expression was used since, when the pressure is equal to the yield strength of the groove material, the clearance approaches infinity.

The resulting failure rate equation for the high pressure mode is:

$$(F.R.)_6 = K_{21}\,\frac{\text{Pressure} + K_{22}}{K_{20} - \text{Pressure}}$$

$$= \frac{K_{23}\,(\text{Pressure})}{(K_{20} - \text{Pressure})} + K_{24}$$

The complete failure rate expression for pressure is therefore:

$$(F.R.)_p = \frac{K_{16}}{(K_{17} + \text{Pressure})} + \frac{K_{23}\ (\text{Pressure})}{(K_{20} - \text{Pressure})} + K_{24}$$

Note that in the derivation of the above equation, no consideration was made between dynamic and static seals. Although the form of the equation for dynamic seals will be the same as that for static seals, the value of the constants will be different. Therefore the above equation will be used for evaluation of static seals and the following equations for dynamic seals:

$$(F.R.)_{p(Dyn)} = \frac{K_{25}}{(K_{26} + \text{Pressure})} + \frac{(K_{27})\ (\text{Pressure})}{(K_{28} - \text{Pressure})} + K_{29}$$

<u>Complete Failure Rate Equations for "O" Rings</u>

The failure rate expressions for the various failure modes are:

1. <u>Size</u>

Mfg. $= (F.R.)_1 = K_5 \left[I.D. + O.D. \right] \left[W \right] \left[1 - \frac{\alpha}{2} \right] \alpha$

Installation $= (F.R.)_2 = \dfrac{K_9}{\left[I.D. + O.D. \right]^2 \left[\alpha \right]}$

Assembly $= (F.R.)_3 = \dfrac{K_{12}}{6}$

"O" Ring Roll $= (F.R.)_4 = K_{14}\ (\alpha)\ (W)$

2. Pressure

$$\text{Low Pressure Static} = (\text{F.R.})_5 = \frac{K_{16}}{(K_{17} + \text{Pressure})}$$

$$\text{High Pressure Static} = (\text{F.R.})_6 = K_{23}\left[\frac{\text{Pressure}}{K_{20} - \text{Pressure}}\right] + K_{24}$$

$$\text{Low Pressure Dynamic} = (\text{F.R.})_7 = \frac{K_{25}}{(K_{26} + \text{Pressure})}$$

$$\text{High Pressure Dynamic} = (\text{F.R.})_8 = K_{27}\left[\frac{\text{Pressure}}{(K_{28} - \text{Pressure})}\right] + K_{29}$$

The resulting representative failure rate equations for various "O" ring configurations are:

a. Dynamic Piston (Without Cap Strip) - Linear

$$\text{F.R.} = \left[(\text{F.R.})_1 + (\text{F.R.})_2 + (\text{F.R.})_3 + (\text{F.R.})_4\right]\left[(\text{F.R.}_7 + (\text{F.R.})_8\right] = \underline{\text{DPLI}} \text{ or } \underline{\text{DPLO}}$$

b. Static Piston Seal

$$\text{F.R.} = \left[(\text{F.R.})_1 + (\text{F.R.})_2 + (\text{F.R.})_3\right]\left[(\text{F.R.})_5 + (\text{F.R.})_6\right] = \underline{\text{SPSI}} \text{ or } \underline{\text{SPSO}}$$

c. Dynamic Shaft Seal (Without Cap Strip) - Linear

$$\text{F.R.} = \left[(\text{F.R.})_1 + (\text{F.R.})_3 + (\text{F.R.})_4\right]\left[(\text{F.R.})_7 + (\text{F.R.})_8\right] = \underline{\text{DSLI}} \text{ or } \underline{\text{DSLO}}$$

d. Dynamic Shaft Seal (Without Cap Strip) - Rotary

$$F.R. = \left[(F.R.)_1 + (F.R.)_3 \right] \left[(F.R.)_7 + (F.R.)_8 \right]$$

= <u>DSRI</u> or <u>DSRO</u>

e. Static Shaft Seal

$$(F.R.) = \left[(F.R.)_1 + (F.R.)_3 \right] \left[(F.R.)_5 + (F.R.)_6 \right]$$

= <u>SSSI</u> or <u>SSSO</u>

f. Dynamic Face Seal - (Rotary)

$$(F.R.) = \left[(F.R.)_1 \right] \left[(F.R.)_7 + (F.R.)_8 \right]$$

= <u>DFRI</u> or <u>DFRO</u>

g. Static Face Seal

$$(F.R.) = \left[(F.R.)_1 \right] \left[(F.R.)_5 + (F.R.)_6 \right]$$

= <u>SFSI</u> or <u>SFSO</u>

h. Dynamic Piston Seal with Cap Strip

$$(F.R.) = \left[(F.R.)_1 + (F.R.)_2 \right] \left[(F.R.)_5 + (F.R.)_6 \right]$$

= <u>DPCI</u> or <u>DPCO</u>

NOTE: The four character symbol following each of the above equations is the name of the respective equation for the computer program. The "I" or "O" in the last place indicates that the given dimension is the I.D. or O.D. respectively, all other dimensions being determined from the given dimension.

The various constants for the equations have been determined from the past failure history of various seals in the representative system. Two of the constants can be initially eliminated by noting that only fourteen of the fifteen constants are independent. (i.e. the equations will remain unchanged if the size terms are divided by K_5 and the pressure terms are multiplied by K_5). Therefore, K_5 was initially set at unity.

K_{20} and K_{28} were set at 40,000 since "O" rings have been known to withstand 30,000 psi but will fail in many housing after one cycle of 40,000 psi since a majority of housing are aluminum and since the yield point of aluminum (T-6) is near 40,000 psi.

The other constants were determined from the following considerations:

1. Since the standard pressure used for "O" ring <u>design</u> is 1500 psi, (although these "O" rings are used at other pressures) the minimum failure rate for static seals should occur near 1500 psi.
2. The generic failure rate for a 1.5 inch I.D. static piston type "O" ring seal at 3000 psi is .0186.
3. The generic failure rate for a 1.5 inch I.D. static piston type "O" ring seal at 1500 psi is .0165.
4. The generic failure rate for a 1.5 inch I.D. static piston type "O" ring seal at 0 psi is .020.

5. The generic failure rate for a 1.5 inch I.D. dynamic piston (rotary) seal at 3000 psi is .0247.

6. The general failure rate for a 1.5 inch I.D. dynamic piston (rotary) seal at 1500 psi is .0232.

7. The generic failure rate for a 1.5 inch I.D. dynamic piston (rotary) seal at 0 psi is .030.

8. The generic failure rate for a 0.1 inch I.D. static piston type "O" ring seal at 3000 psi is .180.

9. The generic failure rate for a .75 inch I.D. static piston type "O" ring seal at 3000 psi is .0254.

10. The generic failure rate for a 6.0 inch I.D. dynamic (linear) piston type "O" ring seal at 3000 psi is .0545.

These data points were determined from a review of the past failure history of various "O" rings used on the Titan I and II hydraulic systems and extrapolation to standard sizes and pressures.

Solution of the equations using the above points yields the following values for the constants:

$$K_5 = 1.00$$
$$K_9 = .1512$$
$$K_{12} = .0046$$
$$K_{14} = 29.1$$
$$K_{16} = 46.9$$

K_{17} = 2000

K_{20} = 40,000

K_{23} = .1529

K_{24} = 0 (Negligible)

K_{25} = 70.4

K_{26} = 2000

K_{27} = .1835

K_{28} = 40,000

K_{29} = 0 (Negligible)

The failure rate equations are used as subroutines in the computer program with the standard Fortran Subroutine instructions. Given a diameter (either I.D. or O.D.) and pressure, the other size parameters (cross sectional with, other diameter, clearance, squeeze, etc.) being a function of the diameter are determined by the subroutine (Ref.: Parker "O" Ring Handbook #5700). After the other size parameters are determined, the subroutine then calculates the failure rate for the "O" Ring, taking into account the type of seal that the "O" Ring is being used. As an example, the reliability of the actuator valve 1st stage flex sleeve "O" ring (AV1JR) can be determined for a given I.D. and pressure. The "O" Ring I.D. is equal to two times the flapper O.D. (AV1MI), and the average pressure is equal to 1/2 the system pressure. The seal is a static face seal and therefore:

```
AV1JR = SFSI (2.0*AV1MI, PRES/2.0)
```

This type of equation will appear on the Equation Derivation Forms.

It will then be converted to the form

CALL OSFR (DIAM, SPRE, A, B, RINGFR)

in the actual computer program.

OSFR - Identifying name of the "O"-Ring Failure Rate Subroutine.

DIAM - "O" Ring Diameter (Either I.D. or O.D.)

SPRE - Associated pressure on the "O" Ring

B - Identifying diameter number which may take on one of two values.

1 - If the diameter is an I.D. or

2 - If the diameter is an O.D.

A - Identifying number which defines one of seven different seal types that the "O" Ring may be used for.

1 - DPL, Linear Dynamic Piston Seal (Without a cap strip).

2 - SPS; Static Piston Seal

3 - DSL; Linear Dynamic Shaft Seal (without a cap strip)

4 - DSR; Rotary Dynamic Shaft Seal (without a cap strip)

5 - SSS; Static Shaft Seal

6 - SFS: Static Face Seal

7 - DPC: Dynamic Piston Seal (<u>With</u> a cap strip)

Therefore, the equation for the above example will be

CALL OSFR (2.0*AV1MI, PRES/2.0, 6, 1, RINGFR)

This computer command will cause the computer to automatically calculate the reliability for the "O" ring with the I.D. equal to two times the flapper O.D. and operating at a pressure equal to 1/2 the system pressure. The actual numerical value of the "O" Ring failure rate will be identified as RINGFR and may be used as such in further calculations

The "O" Ring Failure Rate Subroutine will be placed in permanent storage in the computer and will be available anytime that it is called by code command as described above.

TD-04-296-01 (8-64)

EQUATIONS

ITEM NAME: "O" Ring Weight Subroutine

SYMBOL O S W E

REQUIRED INPUTS:

REQUIRED OUTPUTS:

OUTPUTS:

STANDARD

WEIGHT	W	=
RELIABILITY $^{-1}$	R	=
LIFE	L	=
RESPONSE	S	=
CONT. OPER. TIME	O	=
DEVEL. TIME	T	=
DEVEL. COST	D	=
UNIT COST	U	=

OTHER

=

=

=

=

NOTES:

ANALYSIS BY: D. A. Trammater 0-22 CHECKED BY: D. R. Moody

TD-04-296-02 (8-64)

DERIVATION OF EQUATIONS

ITEM NAME: "O" Ring Weight Subroutine

SYMBOL O S W E

VOLUME

The volume of an "O" Ring may be approximated as the Cross sectional area times the mean ring circumference.

$$\text{Cross Sectional Area} = \pi/4 \; (\text{Cross Sectional Dia.})^2$$

$$\text{Cross Sectional Area} = \pi/4 \; (\text{Width})^2$$

$$\text{Mean Circumference} = \pi/2 \; (\text{I.D.} + \text{O.D.})$$

then:

$$\text{Volume} = \pi/2 \; (\text{I.D.} + \text{O.D.}) \quad \pi/4 \; (\text{Width})^2$$

$$\text{Volume} = K_1 \; (\text{I.D.} + \text{O.D.}) \; (\text{Width})^2$$

WEIGHT

The weight of the "O" Ring will be proportional to the Volume.

$$\text{Wt} = K_2 \; (\text{Volume})$$

$$\text{Wt} = K_3 \; (\text{I.D.} + \text{O.D.}) \; (\text{Width})^2$$

For

$$\text{I.D.} = 1.5, \quad \text{O.D.} = 1.92, \quad \text{Width} = .21$$

$$\text{Wt} = .00866$$

$$K_3 = \frac{.00866}{(1.5 + 1.92)\,(.21)^2}$$

$$K_3 = .0574$$

Therefore:

$$\text{Wt} = .0574 \; (\text{I.D.} + \text{O.D.}) \; (\text{Width})^2$$

ANALYSIS BY: R. A. Lommatto O-23 CHECKED BY: D. R. Moody

Derivation of Equations

In order to calculate the weight of an "O" Ring, a subroutine called OSWE will be placed in permanent storage in the computer using the Standard Fortran Subroutine form. Given a diameter (either I.D. or O.D.), the other size parameters (cross sectional width and the other diameter) being a function of the diameter are determined by the subroutine. After determining the other two size parameters the subroutine then calculates the weight of the "O" Ring. Using as an example the actuator valve 1st Stage Flex Sleeve "O" Ring weight (AV1JW), the "O" Ring I.D. is equal to two times the flapper O.D. (AV1MI). This will appear on the Equation Derivation Forms as;

AV1JW = SSWI (2.0*AV1MI)

This equation will then be converted into the actual computer form as;

```
CALL OSWE (DIAM, A, RINGWT)
```

Where

OSWE - Identifying name of the "O" Ring Weight Subroutine.

DIAM - "O" Ring Diameter

A - Identifying diameter number which may take on one of two values

1 - If the diameter is an I.D. or

2 - If the diameter is an O.D.

therefore the computer equation for the above example will be

```
CALL OSWE (2.0*AV1MI, 1, RINGWT)
```

This command will cause the computer to automatically calculate the weight for the "O" Ring with I.D. equal to two times the flapper O.D. The actual numerical value of the "O" Ring Weight will be identified as RINGWT and may be used as such in further calculations.

With the "O" Ring Weight Subroutine in permanent storage in the computer, it will be available anytime that it is called by coded Command as described above.

I

COST AND DEVELOPMENT TIME

DERIVATION OF COST EQUATIONS

UNIT COST:

In the derivation of unit cost and development cost equations for applicable components in this study program, data was obtained from various suppliers of commercial and qualified airborne hardware, including corresponding unit prices.

The initial step was to establish the relationship between off-the-shelf unit price or percent change in price with respect to applicable independent parameters being considered (i.e. port size, rated pressure, rated flow, unit weight, etc.).

Simultaneous equations were then solved to determine the equation constants. This was done by using the acquired costs to establish a cost relationship with respect to the selected independent parameter. With these constants, it was then possible to write an equation which represented cost as a function of the specific parameter being considered.

In every instance where the price of commercial hardware was used to establish cost curves, current prices of qualified airborne hardware were used to adjust the constants of the derived cost equations.

The derived cost equations for all components except the actuators, includes a fixed cost for acceptance testing, paper work and cleaning. For the actuators, the costs are listed as fixed values for each actuator subassemblies.

DEVELOPMENT COST:

Values for the development cost, in dollars, were obtained from previous contracts and divided into two sections, A) Design Costs and B) Qualification Costs. The Design Cost section includes costs for engineering design drawing, tool drawings, and tool fabrication. The Qualification Cost Section includes costs for flight certification, qualification testing, reliability analysis, and writing test procedures.

Tool fabrication costs in the design cost section for the applicable component was determined by multiplying a constant by the unit cost. The value for the constant varied for each component and was determined to be a function of the part complexity.

In programming these equations, each term was multiplied by an appropriate constant. This constant will automatically set the respective design and/or qualification cost to zero (0) if the respective unit has been designed and/or qualified.

The input costs used for the derivation of the cost equations was generally confidential information. They are therefore not presented on the equation derivation forms.

DEVELOPMENT TIME:

Values for development time, in weeks, were obtained from previous contracts and divided into two sections, A) Design Time and B) Qualification Time. The Design Time section includes the duration for engineering design drawings, total drawings, and tool fabrication. The Qualification Time includes the duration for flight certification, qualification testing, reliability analysis, and writing test procedures.

In programming these equations, each term was multiplied by an appropriate constant. This constant will automatically set the design and/or qualification time to zero if the respective unit has been designed and/or qualified.

CONTENTS OF COST EQUATIONS

Contents of Cost Equations - (Continued)
Page 2

TD-04-296-01 (8-64)

EQUATIONS

ITEM NAME: Actuator Base Cost

SYMBOL A B C S T

REQUIRED INPUTS:

A P P P K
A P P P I
P R E S
T R A L
A A A A 8
A I P A 1
A I P A 2
A I P A 3
A I P A 4

REQUIRED OUTPUTS: A B C S T

A A A A 2
A A A A 6
A A A A 1
A A A A 7
A A A A 4

OUTPUTS:

STANDARD

Weight				W	=	
Reliability $^{-1}$				R	=	
Life				L	=	
Response				S	=	
Cont. Oper. Time				O	=	
Devel. Time				T	=	
Devel. Cost				D	=	
Unit Cost				U	=	

OTHER

Actuator Base Cost	A	B	C	S	T	=	See Last Page
						=	
						=	
						=	

NOTES:

C-1

ANALYSIS BY: Russell S. Harris CHECKED BY: J. J. Harrington

DERIVATION OF EQUATIONS

ITEM NAME: Actuator Base Cost (Unit)   SYMBOL A B C S T

The base cost of the actuator was determined by collecting cost figures on off-the-shelf hydraulic cylinder, determining which factors influence the cost and then using the previously collected figures to determine the constants for each factor on a simultaneous equation solution computer library program. The factors used for the cylinders were:

Shaft O.D. (APPPK)

Piston O.D. (APPPI)

Stroke (TRAL)

Pressure (PRES)

The results from the program for an aircraft type cylinder were:

$$5.20 \Big\{ (71.82)\,(APPPK) - 9.77\,(APPPK)^{2.0} + 2.014\,(APPPK)^{3.0} + (APPPI)^{3.0} \left[.875758 - \frac{200.9068}{PRES} - \frac{79711.07}{(PRES)^{2.0}} \right] + \frac{66628232.}{(PRES)^{2.0}} - \frac{117434.89}{PRES} + 105.55801 - (.034223256)\,(PRES) + 1.0761896 \times 10^{-5}\,(PRES)^{2.0} \Big\} \left[1.0 + .0188\,(TRAL) \right]$$

The cost for the Δ P transducer was a constant at \$367.00. The cost for a valve is constant at \$497.07 until the flow rate exceeds 20 CIS, in which case the cost of the valve include the additional factor:

ANALYSIS BY: Russell L. Hanish   C-2   CHECKED BY: J. J. Harrington

$$\left\{ 556.78 + 2.293\,(\text{FLOR}) - \frac{4.875 \times 10^{+14}}{\left[(\text{FLOR})\,(.25975 + 133.3)\right]^{5.5629}} \right\}$$

Where FLOR is the valve rated flow at 3000 PSI supply or:

$$\text{FLOR} = \text{FLOW}\,\left(\frac{3000.0}{\text{PRES}}\right)^{0.5}$$

The cost of snubbers (AAAA8 = 1.0) was similarly determined to be:

$$51.41 + .0008176\,(\text{PRES}) + .00646\,(\text{PRES})\,(\text{APPPI}) - 20.285\,(10^{-5})\,(\text{APPPI})^{2.0}\,(\text{PRES}) - .6927\,(\text{APPPI}) + 1.1711\,(\text{APPPI})^{2.0}$$

The cost of a potentiometer (AIPA4 = 1.0) was determined to be 261.30 + 27.30 (number of switch elements) + 35.10 (number of pot. elements) + 31.20 (Travel) (Total number of elements)

Or

$$261.30 + 27.30\,(\text{AIPA3}) + 35.10\,(\text{AIPA1} + \text{AIPA2}) + 31.20\,(\text{TRAL})\,(\text{AIPA1} + \text{AIPA2} + \text{AIPA3})$$

For mechanical F/B (AAAA2 = 1.0), the cost was determined to be a function of cam O.D. (AFCCI) and total travel (TRAL), resulting in a cost of

$$\left[100.0\,(\text{AFCCI}) + 250.0\right]\;\left[1.0 + .0188\,(\text{TRAL})\right]$$

The cost of SLEW (AAAA6 = 1.0) was similarly determined to be:

$$.333\left[100.0\,(\text{AFCCI}) + 250.0\right]\left[1.0 + .0188\,(\text{TRAL})\right]$$

The cost of the flow limiter was determined to be a function of the rate flow (FLOR) or:

$$167.49 + .3822\,(\mathrm{FLOR}) - \frac{.8125\mathrm{X}10^{+14}}{\left[(\mathrm{FLOR})\,(.25974) + 133.3\right]^{5.5629}}$$

The cost of adding P.Q. to a valve (AAAA1 = 1.0) was determined to be essentially equal of adding the cost of a flow limiter. Also the cost of adding DPF to a P.Q. valve was determined to be 1/2 of this cost. Therefore:

```
ABCST  =  5.20*(71.82*APPPK-9.77*APPPK**2.0+2.014*APPPK**3.0
          +APPPI**3.0*(.875758-200.9068/PRES-79711.07/PRES**2.0)
          +66628232./PRES**2.-117434.89/PRES+105.55801-
          .034223256*PRES+1.0761896E-5*PRES**2.0)*
          (1.0+.0188*TRAL)+864.07+(556.78+2.293*FLOR-
          4.875E+14/(FLOR*.25974+133.3)**5.5629)*AAA15+
          (51.41+.0008176*PRES+.00646*PRES*APPPI-20.285E-5*
          APPPI**2.0*PRES-.6927*APPPI+1.1711*APPPI**2.0)*
          AAAA8+AIPA4*(261.30+27.30*AIPA3+35.10*(AIPA1+AIPA2)+
          31.20*TRAL*(AIPA1+AIPA2+AIPA3))+(100.0* AFCCI+250.0)*
          (1.0+.0188*TRAL)*(AAAA2+.333*AAAA6)+(167.49+.3822*FLOR
          -.8125E+14/(FLOR*.25974+133.3)**5.5629)*(AAAA7+
          AAAA1+0.5*AAAA4)
```

Where

$$\mathrm{FLOR} = \mathrm{FLOW}\left(\frac{3000.0}{\mathrm{PRES}}\right)^{0.5}$$

and

$$\text{AAA15} = \begin{cases} 1.0 \text{ if FLOR} > 20.0 \text{ CIS} \\ 0.0 \text{ if FLOR} \leqslant 20.0 \text{ CIS} \end{cases}$$

TD-04-296-01 (8-64)

EQUATIONS

ITEM NAME: Actuator Test, Paper Work and Cleaning Costs (Per Unit)

SYMBOL A T C S T

REQUIRED INPUTS: A I P A 1
A I P A 2
A I P A 3
A I P A 4
A A A A 8
A A A A 2
A A A A 7

REQUIRED OUTPUTS: A T C S T
A A A A 6

OUTPUTS:

STANDARD

Weight	W	=
Reliability^{-1}	R	=
Life	L	=
Response	S	=
Cont. Oper. Time	O	=
Devel. Time	T	=
Devel. Cost	D	=
Unit Cost	U	=

OTHER

Test Cost A T C S T = 910.0+10.0*AAAA8+AIPA4*(20.0+5.0*(AIPA1+
= AIPA2+AIPA3))+AAAA2*10.0+AAAA7*20.0+
= AAAA6*20.0
=

NOTES:

ANALYSIS BY: Russell S. Hanish CHECKED BY: J. J. Harrington

TD-04-296-02 (8-64)

DERIVATION OF EQUATIONS

ITEM NAME: Actuator Test, Paper Work, and Cleaning Costs (Per Unit)

SYMBOL A T C S T

From previous contract it was determined that this cost for a basic actuator was \$910.00. Also, the additional cost for snubbers is \$10.00 (If AAAA8 = 1.0), the additional cost for a basic single element pot is \$25.00 (if AIPA4 = 1.0), plus \$5.00 for each element over and above a single element (if AIPA1 + AIPA2 + AIPA3 - 1.0); the additional cost for mechanical F/B (AAAA2 = 1.0), is \$10.00, for a flow limiter (AAAA7 = 1.0) is \$20.00 and for S.L.E.W. (AAAA6 = 1.0) is \$20.00. Therefore

$$\begin{aligned} ATCST = {} & 910.0 + 10.0\,(AAAA8) + AIPA4\,[20.0 + 5.0 \\ & (AIPA1 + AIPA2 + AIPA3)] + (AAAA2)\,(10.0) \\ & + AAAA7\,(20.0) + AAAA6\,(20.0) \end{aligned}$$

ANALYSIS BY: Russell G. Hanish

CHECKED BY: J. J. Harrington

TD-04-296-01 (8-64)

EQUATIONS

ITEM NAME: Actuator Unit Cost

SYMBOL A U C S T

REQUIRED INPUTS: A B C S T

A T C S T

REQUIRED OUTPUTS: A U C S T

OUTPUTS:

STANDARD

WEIGHT	W	=
RELIABILITY^{-1}	R	=
LIFE	L	=
RESPONSE	S	=
CONT. OPER. TIME	O	=
DEVEL. TIME	T	=
DEVEL. COST	D	=
UNIT COST	U	=

OTHER

A U C S T = ABCST+ATCST

=

=

=

NOTES:

ANALYSIS BY: Russell G. Hanish CHECKED BY: J. J. Harrington

DERIVATION OF EQUATIONS

ITEM NAME: Actuator Unit Cost SYMBOL A U C S T

The actuator unit cost will be equal to the base cost (ABCST) plus the cost of testing, paper work and cleaning (ATCST).

Therefore:

$$AUCST = ABCST + ATCST$$

ANALYSIS BY: Russell G. Hanish

CHECKED BY: J. J. Harrington

TD-04-296-01 (8-64)

EQUATIONS

ITEM NAME: Actuator Development Cost

SYMBOL A D C S T

REQUIRED INPUTS: A A A A 8
A I P A 4
A A A A 2
A A A A 7
A A A A 6
A A A A 1

REQUIRED OUTPUTS: A D C S T
A A A A 4
A A A A 9
A A A 1 0
A B C S T

OUTPUTS:

STANDARD

WEIGHT	W	=
RELIABILITY^{-1}	R	=
LIFE	L	=
RESPONSE	S	=
CONT. OPER. TIME	O	=
DEVEL. TIME	T	=
DEVEL. COST	D	=
UNIT COST	U	=

OTHER

A D C S T = (138000. + 1.0E + 4*AAAA8 + 8000.0*
= AIPA4 + 2.0E+4*AAAA2 + 14000.0*AAAA7
= +1.0E+4*AAAA6 + 1.0E+4* (AAAA1 + AAAA4)
= + 18.0*ABCST)*AAAA9 + AAA10* 154000.0

NOTES:

C-10

ANALYSIS BY: Russell L. Hanish CHECKED BY: J. J. Harrington

DERIVATION OF EQUATIONS

ITEM NAME: Actuator Development Cost　　　**SYMBOL** A D C S T

The basic cost of design for a new actuator (AAAA9 = 1.0) is $138,000. The additional design cost for extras on the basic actuator is:

Snubbers	(AAAA8 = 1.0)	$10,000
Potentiometer	(AIPA4 = 1.0)	$ 8,000
Mechanical F/B	(AAAA2 = 1.0)	$20,000
Flow Limiter	(AAAA7 = 1.0)	$14,000
S.L.E.W.	(AAAA6 = 1.0)	$10,000
P.Q. Valve	(AAAA1 = 1.0)	$10,000
D.P.F. Valve	(AAAA1 = 1.0	
and	AAAA4 = 1.0)	$20,000

+ 18.0 times the actuator unit cost (ABCST) (for tooling).

The cost of qualification of a unit was determined to be $154,000.00. Therefore:

ADCST = (138,000. + 1.0E+4*AAAA8 + 8000.0* AIPA4 +
2.0E+4*AAAA2 + 14000.0*AAAA7 + 1.0E+4*AAAA6 +
2.0E+4*(AAAA1 + AAAA4) + 18.0*ABCST)*AAAA9 +
AAA10*154000.0

ANALYSIS BY: [signature]　CHECKED BY: [signature]

EQUATIONS

ITEM NAME: Actuator Development Time

SYMBOL A D T I M

REQUIRED INPUTS: A A A A 9
A A A 1 0

REQUIRED OUTPUTS: A D T I M

OUTPUTS:

STANDARD

WEIGHT W =

RELIABILITY[-1] R =

LIFE L =

RESPONSE S =

CONT. OPER. TIME O =

DEVEL. TIME T =

DEVEL. COST D =

UNIT COST U =

OTHER

A D T I M = AAAA9*62.0 + AAA10*21.0

=

=

=

NOTES:

ANALYSIS BY: Russell G. Hanish

C-12

CHECKED BY: J. J. Harrington

TD-04-296-02 (8-64)

DERIVATION OF EQUATIONS

ITEM NAME: Actuator Development Time **SYMBOL** A D T I M

The design time for a new actuator (AAAA9 = 1.0) is 62 weeks and the time for qualification (AAA10 = 1.0) is 21 weeks. Therefore:

ADTIM = AAAA9*62.0 + AAA10*21.0

ANALYSIS BY: Russell A. Hanish **CHECKED BY:** J. J. Harrington

TD-04-296-01 (8-64)

EQUATIONS

ITEM NAME: Truss - Unit Cost

SYMBOL X R U S U

REQUIRED INPUTS: X M R A X

X T H I X

X M T L X

X M T U X

A P P P J

REQUIRED OUTPUTS: X R U S U

OUTPUTS:

STANDARD

Weight					W	=	
Reliability $^{-1}$					R	=	
Life					L	=	
Response					S	=	
Cont. Oper. Time					O	=	
Devel. Time					T	=	
Devel. Cost					D	=	
Unit Cost	X	R	U	S	U	=	See attached pages.

OTHER

NOTES:

C-14

ANALYSIS BY: Russell R. Harris CHECKED BY: J. J. Harrington

TD-04-296-02(8-64)

DERIVATION OF EQUATIONS

ITEM NAME: Truss-Unit Cost **SYMBOL** X R U S U

The truss unit cost was determined similarly to the tubing unit cost in that it is dependent on the wall thickness, O.D. and length of tubing selected for the truss. Where:

Tubing Wall Thickness	=	XTHIX
Tubing Outside Dia. O.D.	=	(XMRAX)(2.0)+XTHIX
Tubing Total Length	=	XMTLX+2.0(XMTUX)

The resulting unit cost equation is:

```
XRUSU1 = (.8992*(2.0*XMRAX+XTHIX)**1.09885+.482)*
                (XMTLX+2.0*XMTUX)*(XCON1)
```

Where:

$$
XCON1 = \left\{ \begin{array}{l} 19.61 \\ 17.30 \\ 15.20 \\ 14.23 \\ 13.44 \\ 12.87 \\ 12.10 \\ 11.60 \\ 11.00 \\ 10.50 \\ 10.15 \end{array} \right. \quad \text{If} \quad XTHIX = \left\{ \begin{array}{l} \geq .120 \\ .109 \\ .095 \\ .083 \\ .072 \\ .065 \\ .058 \\ .049 \\ .042 \\ .035 \\ \leq .028 \end{array} \right.
$$

ANALYSIS BY: Russell B. Hanish CHECKED BY: J. J. Harrington

Unit cost for each clevis was determined to be a function of actuator bearing I.D. designated as (APPPJ).

XRUSU2 = 37.75*APPPJ**1.5962+78.0

Where:

XRUSU2 = Unit cost of clevis

APPPJ = Actuator Bearing I.D.

NOTE: The unit cost equation for each clevis was derived using total time to machine and weld the chevis at $10.00/hour overhead plus cost of raw material (Stainless Steel #302, #304, #410, #416) at an average price of .75/pound.

For overhead rates other than $10.00/hour, designated in the above equation, multiply the constant 78.0 by a ratio of overhead rates to determine a new constant.

Truss Unit Cost (Assembly)

Combining costs for truss tubing and all clevises (four (4) clevises per truss) the resulting unit cost equation for each truss assembly is.

XRUSU = (.8992*(2.0*XMRAX+XTHIX)**1.09885+.482)*
(XMTLX+2.0*XMTUX)*(XCON1)+(37.75*APPPJ**
1.5962+78.0)*4.0

Where:

Unit Cost of Truss Assembly	=	XRUXU
Tubing Wall Thickness	=	XTHIX
Tubing Outside Dia. O.D.	=	(XMRAX)(2.0)+(XTHIX)
Tubing Total Length	=	(XMTLX)+(2.0)(XMTUX)
Actuator Bearing I.D.	=	APPPJ

Derivation of Equations

and

$$\text{XCON1} = \left\{ \begin{array}{l} 19.61 \\ 17.30 \\ 15.20 \\ 14.23 \\ 13.44 \\ 12.87 \\ 12.10 \\ 11.60 \\ 11.00 \\ 10.50 \\ 10.15 \end{array} \right. \quad \text{If} \quad \text{XTHIX} = \left\{ \begin{array}{r} \geq .120 \\ .109 \\ .095 \\ .083 \\ .072 \\ .065 \\ .058 \\ .049 \\ .042 \\ .035 \\ \leq .028 \end{array} \right.$$

TD-04-296-01 (8-64)

EQUATIONS

ITEM NAME: Truss Development Cost

SYMBOL X R U S D

REQUIRED INPUTS:

X	M	T	L	X
X	M	T	U	X
X	R	U	S	U
X	X	X	X	1

REQUIRED OUTPUTS: X R U S D

OUTPUTS:

STANDARD

Weight					W	=	
Reliability^{-1}					R	=	
Life					L	=	
Response					S	=	
Cont. Oper. Time					O	=	
Devel. Time					T	=	
Devel. Cost	X	R	U	S	D	=	See next page
Unit Cost					U	=	

OTHER

NOTES: In determining development cost for the truss, the truss unit costs must be calculated prior to evaluating development costs.

ANALYSIS BY: Russell S. Hansel C-18 CHECKED BY: J. J. Harrington

TD-04-296-02(8-64)

DERIVATION OF EQUATIONS

ITEM NAME: Truss Development Cost

SYMBOL X R U S D

Development costs of the truss and installation drawings were determined by the following evaluation: A fixed cost of $900.00 was assigned to clevises for complete drawings. Development of the truss tubing and installation drawings was determined to be approximately $12.50 per inch of tubing, plus 10 times the truss unit cost for tooling and tool building. Assuming that, if any part is qualified or if the truss tubing is developed, the approximate cost is zero (i.e. is already drawn).

The resulting development cost equation is.

XRUSD = (900.+12.50*(XMTLX*2.0*XMTUX)+10*XRUSU)*XXXX1

ANALYSIS BY: Russell G. Hannah

CHECKED BY: J. J. Harrington

TD-04-296-01 (8-64)

EQUATIONS

ITEM NAME: Installation and Tubing Cost Per Hydraulic System

SYMBOL T U C S

REQUIRED INPUTS: A C T W T / P U W T 1 / P U W T 2 / F W G H T

REQUIRED OUTPUTS: T U C S U / T U C S D

	R	A	W	G	T	F	F	F	F	1	T	M	T	1	I
	A	N	U	M	B	S	S	S	I		T	M	T	2	I
	S	7				T	M	T	1	T	T	M	T	L	1
	S	8				T	M	T	2	T	T	M	T	L	2
OUTPUTS:	X	X	X	X	2	A	A	A	1	O	T	C	O	N	1
	R	R	R	R	4	P	P	P	P	3	T	C	O	N	2
	F	F	F	F	4	P	P	P	P	4					

STANDARD

WEIGHT					W	=	
RELIABILITY^{-1}					R	=	
LIFE					L	=	
RESPONSE					S	=	
CONT. OPER. TIME					O	=	
DEVEL. TIME					T	=	
DEVEL. COST	T	U	C	S	D	=	See corresponding pages
UNIT COST	T	U	C	S	U	=	See corresponding pages

OTHER

=

=

=

=

NOTES:

ANALYSIS BY: Russell S. Hanish

CHECKED BY: J. J. Harrington

TD-04-296-02(8-64)

DERIVATION OF EQUATIONS

ITEM NAME: Installation and Tubing Cost Per Hydraulic System

SYMBOL T I C S

The cost for installation of a typical component was determined to be:

$$\text{Cost/component} = (100.0 + K_1 (10) + 1.15\, K_1 \sqrt{\text{Component Weight}})$$

Where K_1 is a complexity factor and depends only on the component to be installed and not on the size. The following complexity factors were determined for standard components.

Actuator $K_1 = 2$

Pump $K_1 = 4$

Reservoir only $K_1 = 4$

Addition of accum. $K_1 = 1$

Filter $K_1 = 1$

Therefore, the cost of installing the components in a single system is:

$\text{Cost} = (120.0 + 2.3\sqrt{\text{ACTWT}})\ (\text{ANUMB})$	Actuator
$+ (140.0 + 4.6\sqrt{\text{PUWT1}})\ (\text{S7})$	Fixed angle Pump
$+ (140.0 + 4.6\sqrt{\text{PUWT2}})\ (\text{S3})$	In Line Pump
$+ (110.0 + 1.15\sqrt{\text{FWGHT}})\ (\text{FFFF1})$	Filter
$+ (140.0 + 4.6\sqrt{\text{RAWGT}})\ \left[1.0 + .25\ (\text{SSSI})\right]$	Res-Accum.

ANALYSIS BY: Russell G. Hanish C-21 CHECKED BY: J. J. Harrington

Derivation of Equations

The cost of tubing and tubing installation was determined to be a function of the O.D., wall thickness and length. Due to the complexity of the equations, a separate equation was used for each wall thickness or:

$$C = \left[.8992\ (O.D.)^{1.09885} + .482\right] \left[\text{Length}\right] \left[K_1\right]$$

Where

$$K_1 = \begin{cases} 19.61 \\ 17.30 \\ 15.20 \\ 14.23 \\ 13.44 \\ 12.87 \\ 12.1 \\ 11.6 \\ 11.0 \\ 10.5 \\ 10.15 \end{cases} \quad \text{For a wall thickness of} \quad \begin{cases} .120 \\ .109 \\ .095 \\ .083 \\ .072 \\ .065 \\ .058 \\ .049 \\ .042 \\ .035 \\ .028 \end{cases}$$

For the two sizes of tubes in the system, the following table gives the respective dimension names.

Tube System	O.D.	Wall Thickness	Length
1	TMT1I	TMT1T	TMTL1
2	TMT2I	TMT2T	TMTL2

```
TUCSU  =  (120.0 + 2.3*ACTWT**0.5)*ANUMB
       +  (140.0  +  4.6*PUWT1**0.5)*S7
       +  (140.0  +  4.6*PUWT2**0.5)*S8
       +  (110.0  +  1.15*FWGHT**0.5)*FFFF1
       +  (.8992*(TMT1I)**1.09885 + .482)*(TMTL1)
       *(TCON1), +  (.8992*(TMT2I)**1.09885 + .482)
       *(TMTL2) * (TCON2)) * (ANUMB /2.0)
       +  (140.0 + 4.6*RAWGT**0.5)*(1.0+.25*SSSI)
```

Where:

$$\left.\begin{matrix} TCON1 \\ TCON2 \end{matrix}\right\} = \left\{\begin{matrix} 19.61 \\ 17.30 \\ 15.20 \\ 14.23 \\ 13.44 \\ 12.87 \\ 12.1 \\ 11.6 \\ 11.0 \\ 10.5 \\ 10.15 \end{matrix}\right. \quad \text{If} \quad \left\{\begin{matrix} TMT1T \\ TMT2T \end{matrix}\right\} = \left\{\begin{matrix} .120 \\ .109 \\ .095 \\ .083 \\ .072 \\ .065 \\ .058 \\ .049 \\ .042 \\ .035 \\ .028 \end{matrix}\right.$$

NOTE: The $\left(\frac{\text{AMUMB}}{2.0}\right)$ factor was added to the tube equations since the equations are for a two actuator system. Also the last term in the total cost equation (that associated with the accumulator-reservoir) cannot be added in until the reservoir calculation has been made.

For development of the tubing and installation drawings, the cost for each foot of tube was determined to be approximately \$150.00 per foot, the installation drawing of each major component (reservoir, actuator and pump) is \$460.00, installation drawing cost of the filter is \$230.00, installation drawing cost of an accumulator added to the reservoir is \$120.00 and a fixed cost of \$450.00. Assuming that, if any part is qualified or if the tubes are developed, the appropriate cost is zero (i.e. is already drawn), the tube development cost and installation drawing cost is:

```
TUCSD  =  (450. + 12.50*(ANUMB/2.0)*(TMTL1 + TMTL2)*(XXXX2)
        + (460.0)*ANUMB*AAA10
        + 460.0 *S7*PPPP3
        + 460.0 *S8*PPPP4
        + 460.0*RRRR4
        + 120.0*RRRR4*SSSI
        + 230.0*FFFF1*FFFF4
```

TD-04-296-01 (8-64)

EQUATIONS

ITEM NAME: Pump Fixed Angle

SYMBOL P F A V

REQUIRED INPUTS: P P P P 2 / P P P P 3 / P A D S / S 5

REQUIRED OUTPUTS: P F A V T / P F A V D / P F A V U

OUTPUTS:

STANDARD

Weight					W	=	
Reliability $^{-1}$					R	=	
Life					L	=	
Response					S	=	
Cont. Oper. Time					O	=	
Devel. Time	P	F	A	V	T	=	
Devel. Cost	P	F	A	V	D	=	
Unit Cost	P	F	A	V	U	=	

OTHER

NOTES: See next page

ANALYSIS BY: Russell B. Hanish C-25 CHECKED BY: J. J. Harrington

NOTES: I. In determining development costs for the variable flow and/or fixed flow, fixed angle pump, the unit costs for pump or pumps must be calculated prior to evaluating development costs.

II. Prior to unit cost evaluation, perform the following:

(Equations valid only for displacement above .065 in^3/revolution)

Solve: (PADS - 1.4)

If the above equation is greater or equal to 0, set

S10 = 1.0

If the above equation is less than 0, set

S10 = 0.0

TD-04-296-02(8-64)

DERIVATION OF EQUATIONS

ITEM NAME: Pump - Fixed Angle Variable Q   SYMBOL P F A V

DEVELOPMENT TIME:

The development time for a variable flow, fixed angle pump is 54 weeks from engineering go-ahead to delivery of 1st unit plus 23 weeks for qualification tests.

Therefore:

PFAVT1 = (54.0) (PPPP2) + (23.0) (PPPP3)

DEVELOPMENT COSTS:

The development cost of a fixed angle, variable flow (PFAVD1), when applicable, includes cost for a new design plus cost for a qualified unit.

A new design, when applicable, includes costs for design drawings, tool design, and tool fabrication when (PPPP2 = 1.0). Qualification costs include flight certification, qualification tests, ATP, reliability analysis, with (PPPP3 = 1.0) when applicable.

PFAVD1 = (85,000. + 18.*PFAVU1) *PPPP2 + 93,000.*PPPP3

UNIT COSTS:

Unit costs of an airborne quality, variable flow, pump were determined to be a function of pump displacement in in.^{3}/rev. plus additional costs for acceptance testing, paper work, and cleaning.

PFAVU1 = 160.85*(PADS + .054)**1.5812 + 1094.44 + 400.0

if $.065 \leq$ PADS ≤ 1.4 in.^{3}/rev.

PFAVU1 = 471.38 + 612.51*PADS + 154.43*PADS**-3.0 + 400.0

if PADS $>$ 1.4 in.^{3}/rev.

ANALYSIS BY: Russell B. Hanish   CHECKED BY: J. J. Harrington

DERIVATION OF EQUATIONS

ITEM NAME: Pump - Fixed Angle
Fixed Q

SYMBOL P F A V

DEVELOPMENT TIME:

The development time for a pump is 48 weeks from engineering go-ahead to delivery of 1st unit plus 19 weeks for qualification tests. Therefore:

PFAVT2 = (48.0) (PPPP2) + (19.0) (PPPP3)

DEVELOPMENT COSTS:

The development costs of a fixed angle pump, fixed flow, (PFAVD2) were determined in the same method as previously described in fixed angle, variable flow section.

PFAVD2 = (65,000. + 18.* PFAVU2) *PPPP2 + 74,000.* PPPP3

UNIT COSTS:

Unit costs of an airborne quality, fixed flow, fixed angle pump were determined to be a function of pump displacement in $in.^3$/rev. plus additional costs for acceptance testing, paper work, and cleaning.

PFAVU2 = 128.68*(PADS + .054)** 1.5812 + 875.55 + 380.

if $.065 \leq$ PADS ≤ 1.4 $in.^3$/rev.

PFAVU2 = 377.10 + 490.10* PADS + 123.54/PADS**3.0 + 380.

if PADS $>$ 1.4 in^3/rev.

ANALYSIS BY: Russell R. Hanish

CHECKED BY: J. J. Harrington

DERIVATION OF EQUATIONS

ITEM NAME: Pump - Fixed Angle

SYMBOL P F A V

DEVELOPMENT TIME:

Since S5 is 1.0 if the pump has compensator and 0.0. if not, the equations for the two types of pumps can be combined as follows:

PFAVT = (48.0) (PPPP2) + (19.0) (PPPP3) + S5 ((6.0) (PPPP2)
+ (4.0) (PPPP3))

DEVELOPMENT COST:

PFAVD = S5*((85.000.0 + 18.*PFAVU)*PPPP2 + 93.000.00*
PPPP3) + (1.0 - S5)*((65,000.0 + 18.0* PFAVU)*
PPPP2 + 74,000.0*PPPP3)

UNIT COSTS:

PFAVU = S5 *(1.0 - S10.)*((PADS + .054)**1.582 + 1094.44
+ 400.) + S5* S10.* (471.38 + 612.51*PADS+154.43
*PADS**-3.0+400.) + (1.0 - S5)*(1.0 - S10)*128.68
*((PADS + .054)**1.582 + 875.55 + 380.0) + (1.0 - S5)*
S10.* (377.10 + 490.10*PADS + 123.54*PADS**
- 3.0 + 380.0)

ANALYSIS BY: Russell A. Hanish

CHECKED BY: J. J. Harrington

TD-04-296-01 (8-64)

EQUATIONS

ITEM NAME: Pump - Inline

SYMBOL P I N F

REQUIRED INPUTS: P P P P 4 / P P P P 5 / P W D S / S 6

REQUIRED OUTPUTS: P I N F T / P I N F D / P I N F U

OUTPUTS:

STANDARD

WEIGHT					W	=	
RELIABILITY $^{-1}$					R	=	
LIFE					L	=	
RESPONSE					S	=	
CONT. OPER. TIME					O	=	
DEVEL. TIME	P	I	N	F	T	=	See corresponding pages
DEVEL. COST	P	I	N	F	D	=	See corresponding pages
UNIT COST	P	I	N	F	U	=	See corresponding pages

OTHER

NOTES: In determining development costs for the variable flow and/or fixed flow inline pump, the unit costs for applicable pump or pumps must be calculated prior to evaluating development costs.

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ANALYSIS BY: Russell B. Harris CHECKED BY: J. J. Harrington

TD-04-296-02(8-64)

DERIVATION OF EQUATIONS

ITEM NAME: Pump - Inline Variable Q

SYMBOL P I N F

Development Time:

The development time for a variable flow pump is 54 weeks from engineering go-ahead to delivery of 1st unit plus 23 weeks for qualification tests: Therefore

PINFT1 = (54.0) (PPPP4) + (23.0) (PPPP5)

Development Costs:

The development cost of a inline pump, variable flow (PINFD1), when applicable, includes cost for a new design plus cost for a qualified unit.

A new design, when applicable, includes costs for design drawings, tool design, and tool fabrication when (PPPP4 = 1.0). Qualification costs include flight certification, qualification tests, ATP, Reliability Analysis, with (PPPP5 = 1.0) when applicable.

PINFD1 = (66,000. + 18* PINFU 1)*PPPP4 + 88,500.*PPPP5

Unit Costs:

Unit costs of an airborne quality, variable flow, pump were determined to be a function of pump displacement in $in.^3$/rev. plus additional cost for acceptance testing, paper work and cleaning.

PINFU1 = 911.84 + 207.95*PWDS**.50 - 515.22*PWDS +

445.03*PWDS**1.5+400.0

ANALYSIS BY: Russell G. Hanish

CHECKED BY: J. J. Harrington

DERIVATION OF EQUATIONS

ITEM NAME: Pump - Inline

Fixed Q

SYMBOL P I N F

Development Time:

The development time for a fixed flow pump is 48 weeks from engineering go-ahead to delivery of 1st unit plus 19 weeks for qualification tests. Therefore:

PINFT2 = (48.0) (PPPP4) + (19.0) (PPPP5)

Development Costs:

The development costs of an inline pump, - fixed flow, (PINFD2) were determined in the same method as previously described in the inline pump, variable flow section.

PINFD2 = (30000. + 18* PINFU2) *PPPP4 + 69,000.* PPPP5

Unit Costs:

Unit costs of an airborne quality, fixed flow, pump were determined to be a function of pump displacement in $in.^3$/rev. plus additional costs for acceptance testing, paper work, and cleaning.

PINFU2 = 710.28 + 161.98* PWDS**.50 - 401.33*PWDS +

346.66*PWDS**1.50 + 380.0

ANALYSIS BY: Russell D. Harish CHECKED BY: J. J. Harrington

DERIVATION OF EQUATIONS

ITEM NAME: Pump - Inline SYMBOL P I N F

Development Time:

Since S6 is 1.0 if the pump has a compensator, and 0.0 if not, the equations for the two types of pumps can be combined as follows:

PINFT = (48.0) (PPPP4) + (19.0) (PPPP5) + S6 ((6.0) (PPPP4) + (4.0) (PPPP5))

Development Cost:

PINFD = S6* ((66000.0 + 18.* PINFU)* PPPP4 + 88500.0* PPPP5) + (1.0 - S6)*((30000.0 + 18.0*PINFU)* PPPP4 + 69000.0* PPPP5)

Unit Cost:

PINFU = S6* (911.84 + 207.95* PWDS**0.5 - 515.22*PWDS + 445.03*PWDS** 1.5 + 400.00) + (1.0 - S6)* (710.28 + 161.98* PWDS** 0.5 - 401.33* PWDS + 346.66* PWDS**1.5 + 380.0)

Intensifier Equations:

Because the Inline-pumps, without a compensator, and a intensifier are similar in function, all derived Inline-Pump equations were used to establish similar equations for the Intensifier. In the Intensifier equations, the designated changes are I) Development Time (PFRFT), II) Development Cost (PTPFD), III) Unit Cost (PTFRU), and IV) Displacement in^3/rev. (PIDS).

ANALYSIS BY: Russell D. Hanish CHECKED BY: J. J. Harrington

In using the above stated Development Time and cost equations of the Inline-Pump to obtain development time and costs for the Intensifier, the value of S6 will always be zero (0).

TD-04-296-01 (8-64)

EQUATIONS

ITEM NAME: Filter-Hydraulic

Unit Cost

SYMBOL F U C S U

REQUIRED INPUTS:

A	N	U	M	B
F	F	F	F	2
T	M	T	1	I
F	F	F	F	1

REQUIRED OUTPUTS:

OUTPUTS:

STANDARD

Weight					W	=	
Reliability $^{-1}$					R	=	
Life					L	=	
Response					S	=	
Cont. Oper. Time					O	=	
Devel. Time					T	=	
Devel. Cost					D	=	
Unit Cost	F	U	C	S	U	=	See Next Page

OTHER

	F	P	O	R	T	=	TMT1I*(FFFF2*ANUMB/2.)**0.5
						=	
						=	
						=	

NOTES:

ANALYSIS BY: Russell L. ... **CHECKED BY:** J. J. Harrington

TD-04-296-02 (8-64)

DERIVATION OF EQUATIONS

ITEM NAME: Filter Hydraulic Unit Cost

SYMBOL F U C S U

The unit cost of each hydrualic filter was determined from data in previous contracts, and data from suppliers of airborne qualified units, with costs established as a function of port size.

Included in the price of each filter are costs for acceptance testing, paperwork, cleaning, and $26.00 for the pressure drop indicator on each filter.

A ratio of required filter flow/maximum system flow rate was used to establish the filter port size for the system under consideration.

$$\text{FPORT} = \text{TMT1I} \times \sqrt{\text{FFFF2} \times \frac{\text{ANUMB}}{2.0}}$$

Where:

ANUMB = Number of actuators.

FFFF2 = Ratio of $\frac{\text{Required Filter Flow}}{\text{Maximum System Flow Rate}}$

TMT1I = Outside diameter of tubing leading to airborne pump in a hydraulic system including (2) actuators.

FFFF1 = Number of filters per hydraulic system.

FUCSU = (56. + 280.* FPORT + 9.1/FPORT**2.0)* FFFF1

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ANALYSIS BY: Russell S. Hanish CHECKED BY: J. J. Harrington

TD-04-296-01 (8-64)

EQUATIONS

ITEM NAME: Filter-Hydraulic

Development Cost

SYMBOL F U C S D

REQUIRED INPUTS:

F	U	C	S	U
F	F	F	F	3
F	F	F	F	4

REQUIRED OUTPUTS:

OUTPUTS:

STANDARD

WEIGHT					W	=	
RELIABILITY $^{-1}$					R	=	
LIFE					L	=	
RESPONSE					S	=	
CONT. OPER. TIME					O	=	
DEVEL. TIME					T	=	
DEVEL. COST	F	U	C	S	D	=	~~See next page~~
UNIT COST					U	=	

OTHER

NOTES:

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ANALYSIS BY: Russell E. Hanish CHECKED BY: J. J. Harrington

DERIVATION OF EQUATIONS

ITEM NAME: Filter Hydraulic Development Costs

SYMBOL F U C S D

Development costs of the hydraulic filter (FUCSU) includes costs for a new design plus qualification of the new design when applicable.

A new design, when applicable, includes costs for Design Drawings, Tool Design, and Tool Fabrication when (FFFF3 = 1.0). Qualification costs include Flight Certification, Qualification Tests, ATP, Reliability analysis, with (FFFF4 = 1.0) when applicable.

FUCSD = (15,000. + 10.*FUCSU)*FFFF3 + 42,000*FFFF4

ANALYSIS BY: Russell A. Hanish

CHECKED BY: J. J. Harrington

TD-04-296-01 (8-64)

EQUATIONS

ITEM NAME: Accumulator Unit Cost

SYMBOL S A C S U

REQUIRED INPUTS:

S	P	A	G	I
S	P	A	P	I
R	P	A	R	I
R	H	P	P	I
P	R	E	S	.
R	P	A	P	I
S	S	S	I	

REQUIRED OUTPUTS:

OUTPUTS:

STANDARD

WEIGHT					W	=	
RELIABILITY $^{-1}$					R	=	
LIFE					L	=	
RESPONSE					S	=	
CONT. OPER. TIME					O	=	
DEVEL. TIME					T	=	
DEVEL. COST					D	=	
UNIT COST	S	A	C	S	U	=	See next page

OTHER

NOTES:

ANALYSIS BY Russell S. Hanish CHECKED BY: J. J. Harrington

DERIVATION OF EQUATIONS

ITEM NAME: Accumulator Unit Cost SYMBOL S A C S U

(Includes base price, test, paper work and cleaning costs.) (Per unit)

The method used to determine unit cost equations for the reservoir was also used in determining unit cost equations for the accumulator. Factors determined for the accumulator are.

Accumulator Piston Guide O.D. = SPAGI

Accumulator Piston O.D. = SPAPI

Reservoir Piston Rod O.D. = RPARI

Reservoir High Pressure Piston O.D. = RHPPI

System Pressure = PRES

Reservoir Piston O.D. = RPAPI

$$\text{SACSU} = (2.7492(71.82*\text{SPAGI}-9.77\ \text{SPAGI}**2.0 + 2.014*\ \text{SPAGI}**3.0 + \text{SPAPI}**3.0*\left(.875758 - \frac{200.9068}{\text{PRES}} - \frac{79711.07}{\text{PRES}**2.0}\right) + \frac{66628232.0}{\text{PRES}**2.0} - \frac{117434.89}{\text{PRES}} + 105.55801 - .034223256*\text{PRES} + 1.0761896\text{E-}5*\text{PRES}**2.0)* (1.0 + .0188*\left(\frac{\text{SPAGI}}{5}\right)) + 50.)*\ \text{SSSI}$$

Where

SSSI = 1.0 If accumulator is used in system

= 0.0 If accumulator is not used in system.

ANALYSIS BY: Russell B. Hanish CHECKED BY: J. J. Harrington

TD-04-296-01 (8-64)

EQUATIONS

ITEM NAME: Potentiometer Assembly Unit Cost Reservoir-Accumulator

SYMBOL R S P A U

REQUIRED INPUTS: R S P A 1
R S P A 2
R S P A 3
R P A P I

REQUIRED OUTPUTS:

OUTPUTS:

STANDARD

Weight					W	=	
Reliability^{-1}					R	=	
Life					L	=	
Response					S	=	
Cont. Oper. Time					O	=	
Devel. Time					T	=	
Devel. Cost					D	=	
Unit Cost	R	S	P	A	U	=	See next page

OTHER

NOTES:

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ANALYSIS BY: Russell G. Hanish CHECKED BY: J. J. Harrington

DERIVATION OF EQUATIONS

ITEM NAME: Reservoir-Accumulator Potentiometer Assembly Unit Cost Includes ATP SYMBOL R S P A U

From previous contracts the cost of a potentiometer was determined to be a function of number of switch elements, number of potentiometer elements and total stroke.

The unit cost of a potentiometer, when RSPA3 = 1.0 is therefore

RSPAU = RSPA3 (281.30 + 32.30)(Number of switch elements) + 40.10 (Number of potentiometer elements) + 15.60 (Travel) (Total number elements)

or

RSPAU = RSPA3* (281.30 + 32.30* RSPA2 + 40.10* RSPA1 + 15.60* RPAPI* (RSPA1 + RSPA2))

ANALYSIS BY: Russell B. Hanish CHECKED BY: J. J. Harrington

TD-04-296-01 (8-64)

EQUATIONS

ITEM NAME: Reservoir Unit Cost

SYMBOL R E C S U

REQUIRED INPUTS:

R P A P I
R P R E
R P A R I
P R E S
R H P P I

REQUIRED OUTPUTS:

OUTPUTS:

STANDARD

WEIGHT					W	=	
RELIABILITY^{-1}					R	=	
LIFE					L	=	
RESPONSE					S	=	
CONT. OPER. TIME					O	=	
DEVEL. TIME					T	=	
DEVEL. COST					D	=	
UNIT COST	R	E	C	S	U	=	See Next Page

OTHER

=

=

=

=

NOTES:

ANALYSIS BY: Russell G. Hanish

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CHECKED BY: J. J. Harrington

TD-04-296-02(8-64)

DERIVATION OF EQUATIONS

ITEM NAME: Reservoir Unit Cost SYMBOL R E C S U

Includes base price, test, paper work and cleaning costs (per Unit).

In determining unit cost of the reservoir, cost data on off-the-shelf hydraulic cylinders was collected. The factors influencing the costs were determined by solving simultaneous equations. The factors used for the cylinder were.

Reservoir Piston O.D. = RPAPI

Return Pressure = RPRE

Reservoir Piston Rod O.D. = RPARI

System Pressure = PRES

Reservoir High Pressure Piston O.D. = RHPPI

$$
\begin{aligned}
\text{RECSU} = {} & 2.7492 * \Big[22.3786 + \text{RPAPI}^{**} 3.0 * \Big(.875758 \\
& - \frac{200.9068}{(\text{RPRE} + 500.)} - \frac{79711.07}{(\text{RPRE} + 500.)^{**}2.0} \Big) + \frac{66628232.0}{(\text{RPRE} + 500.)^{**}2.0} \\
& - \frac{117434.89}{(\text{RPRE} + 500.)} + 105.55801 - .034223256 * (\text{RPRE} + 500.) \\
& + 1.0761896\text{E}{-5} * (\text{RPRE} + 500.)^{**}2.0 \Big] * \Big(1.0 + .0188 * \\
& \Big(\frac{\text{RPAPI}}{2}\Big)\Big) + 2.7492 \Big[71.82 * \text{RPARI} - 9.77 * \text{RPARI}^{**}2.0 \\
& + 2.014 * \text{RPARI}^{**}3.0 + \text{RHPPI}^{**}3.0 * \Big(.875758 - \frac{200.9068}{\text{PRES}} \\
& - \frac{79711.07}{\text{PRES}^{**}2.0} \Big) + \frac{66628232.0}{\text{PRES}^{**}2.0} - \frac{117434.89}{\text{PRES}} + 105.55801 - .034223256 \\
& * \text{PRES} + 1.0761896\text{E}{-5} * \text{PRES}^{**}2.0 \Big] * \Big(1.0 + .0188 * \Big(\frac{\text{RPAPI}}{2}\Big)\Big) + 520.
\end{aligned}
$$

ANALYSIS BY: Russell [signature] CHECKED BY: J. J. Harrington

TD-04-296-01 (8-64)

EQUATIONS

ITEM NAME: Reservoir-Accumulator Assembly Unit Cost

SYMBOL R A P C U

REQUIRED INPUTS:
R E C S U
S A C S U
R S P A U

REQUIRED OUTPUTS:

OUTPUTS:

STANDARD

WEIGHT					W	=	
RELIABILITY $^{-1}$					R	=	
LIFE					L	=	
RESPONSE					S	=	
CONT. OPER. TIME					O	=	
DEVEL. TIME					T	=	
DEVEL. COST					D	=	
UNIT COST	R	A	P	C	U	=	RECSU + SACSU + RSPAU

OTHER

NOTES:

ANALYSIS BY: Russell A. Hanish CHECKED BY: J. J. Harrington

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TD-04-296-02(8-64)

DERIVATION OF EQUATIONS

ITEM NAME: Reservoir-Accumulator Assembly Unit Cost (Per Unit)

SYMBOL R A P C U

The reservoir-accumulator assembly unit cost (RAPCU) will be equal to the unit cost of the reservoir (RECSU) plus unit cost of accumulator (SACSU) plus unit cost of potentiometer (RSPAU). Included in the unit cost of the Reservoir-Accumulator Assembly is the cost of acceptance testing, paperwork and cleaning. Therefore:

$$RAPCU = RECSU + SACSU + RSPAU$$

ANALYSIS BY: Russell J. Hanish C-45 CHECKED BY: J. J. Harrington

TD-04-296-01 (8-64)

EQUATIONS

ITEM NAME: Reservoir-Accumulator Development Cost

SYMBOL R A P C D

REQUIRED INPUTS:

S S S I
R R R R 3
R R R R 4
R A P C D

REQUIRED OUTPUTS:

OUTPUTS:

STANDARD

WEIGHT					W	=	
RELIABILITY $^{-1}$					R	=	
LIFE					L	=	
RESPONSE					S	=	
CONT. OPER. TIME					O	=	
DEVEL. TIME					T	=	
DEVEL. COST	R	A	P	C	D	=	See next page
UNIT COST					U	=	

OTHER

NOTES:

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ANALYSIS BY: Russell G. Hanish CHECKED BY: J. J. Harrington

TD-04-296-02(8-64)

DERIVATION OF EQUATIONS

ITEM NAME: Reservoir-Accumulator Development Cost

SYMBOL R A P C D

Development costs (RAPCD) of the Reservoir-Accumulator was determined from previous contracts and includes new design plus qualification where applicable.

A new design includes costs for Design Drawings, Tool Design and Tool Fabrication with (RRRR3 = 1.0)when applicable. Qualification costs include Flight Certification, Qualification Tests, ATP, Reliability Analysis with (RRRR4 = 1.0) when applicable.

RAPCD = (74000. + 20000.* SSSI + RAPCU*10)

*RRRR3 + (69000. + 5700.*SSSI)*RRRR4

ANALYSIS BY: Russell [illegible] Hanish C-47 CHECKED BY: J. J. Harrington

TD-04-296-01 (8-64)

EQUATIONS

ITEM NAME: Quick Disconnect Unit Cost

SYMBOL Q D C S U

REQUIRED INPUTS: T M T 1 I
Q Q Q Q 3
A N U M B

REQUIRED OUTPUTS:

OUTPUTS:

STANDARD

Weight					W	=	
Reliability^{-1}					R	=	
Life					L	=	
Response					S	=	
Cont. Oper. Time					O	=	
Devel. Time					T	=	
Devel. Cost					D	=	
Unit Cost	Q	D	C	S	U	=	See next page

OTHER

NOTES:

C-48

ANALYSIS BY: Russell R. Hanish CHECKED BY: J. J. Harrington

DERIVATION OF EQUATIONS

ITEM NAME: Quick-Disconnect Unit Cost SYMBOL Q D C S U

The unit cost of the hydraulic Quick Disconnect is for complete assembly, ground and airborne half, and was determined to be a function of the center or high pressure port. Size of the high pressure port was established to be $TMT1I \times \sqrt{QQQQ3 \times \frac{ANUMB}{2.0}}$.

Included in the price are costs for Acceptance testing, paperwork and cleaning

ANUMB = Number of actuators

TMT1I = Outside diameter of tubing leading to airborne pump. System includes two (2) actuators

QQQQ3 = $\frac{\text{Ratio of Q.D. Rated Flow}}{\text{Max. Sys. Flow Rate}}$

QDCSU = 68.55* (TMT1I* (QQQQ3* ANUMB/2.0)**.5)**2.26286 + 532.53 + 300.

ANALYSIS BY: Russell J. Hanish C-49 CHECKED BY: J. J. Harrington

EQUATIONS

ITEM NAME: Quick Disconnect Development Cost

SYMBOL Q D C S D

REQUIRED INPUTS: Q D C S U
Q Q Q Q 1
Q Q Q Q 2

REQUIRED OUTPUTS:

OUTPUTS:

STANDARD

Weight					W	=	
Reliability $^{-1}$					R	=	
Life					L	=	
Response					S	=	
Cont. Oper. Time					O	=	
Devel. Time					T	=	
Devel. Cost	Q	D	C	S	D	=	See next page
Unit Cost					U	=	

OTHER

NOTES:

C-50

ANALYSIS BY: Russell S. Hanish CHECKED BY: J. J. Harrington

DERIVATION OF EQUATIONS

ITEM NAME: Quick Disconnect Development Cost

SYMBOL Q D C S D

The development cost of the hydraulic Quick-Disconnect (QDCSD) includes costs for new design plus qualification when applicable.

A new design, when applicable, includes costs for Design Drawing, Tool Design, and Tool Fabrication and (QQQQ1 = 1.0). Qualification Costs include Flight Certification, Qualification Tests, ATP, Reliability Analysis, with (QQQQ2 = 1.0) when applicable.

QDCSD = (20,000. + 10.* QDCSU)* QQQQ1 + 42,000.* QQQQ2.

ANALYSIS BY: Russell Harish

CHECKED BY: J. J. Harrington

J

OVERALL VEHICLE

SYSTEM "COST" FOR THE LAUNCH VEHICLE PROGRAM

This portion of the analysis is concerned with converting the following pertinant hydraulic system characteristics to a theoretical "dollar cost."

a. Weight

b. Reliability

c. Actuator Response

d. Component Life

e. Maximum Life

f. Maximum System Operating Time

g. System Development Cost

h. System Unit Cost

i. System Development Time

The hydraulic system "cost" determined herein is the "cost" of the above characteristics of a particular stage being investigated for the total launch vehicle program.

1. Weight "Cost":

The "cost" of the hydraulic system weight is determined from the system weight and the cost per pound of the stage being investigated. Since the cost per pound (coded as VWCST) varies widely from one program to another, it is left as a required "input" to the analysis program.

2. Reliability "Cost":

The reliability "cost" is a measure of the "unreliability" of the system. The reliability of the system is given by a generic failure rate or the number of failures per million hours of operating time. The "cost" of these failures can be determined if the actual cost due to the failed component with respect to the particular operation is known. From past experience on the Titan ICBM programs, the operating time of the system on component reduces from hours during receiving inspection to seconds during actual launch vehicle flight, and the cost of a component failure increase from a few thousand dollars during receiving inspection to hundreds of thousands of dollars for a failure during flight. It was assumed for a good approximation that the product of the operating time and the cost of failure for any particular operation was about the same. The cost and operating time during flight was selected for the analyses since these two parameters are known early in the launch vehicle design phase.

3. <u>Actuator Response "Cost"</u>:

The actuator response "cost" is the cost of any required weight increase to stiffen the actuator structural spring to meet the required system resonant frequency. The analysis is presented in the truss portion of this report.

4. <u>Component Life "Cost"</u>:

The component life "cost" is the cost of repairing those components whose designed "life" is less than the required "life" of the launch vehicle. From the Titan ICBM program, two items which came the closest to fitting this catagory were the actuators and pumps and are the only components considered for this analysis.

5. Maximum System Operating Time "Cost":

The maximum system operating time "cost" is the cost of having to shutdown or delay a test on the vehicle due to the limited system continuous operating time of the hydraulic system. Again the average cost of the test (coded as VTCST) varies widely from one program to another and therefore must be a required "input" by the user of the analysis program.

6. System Development "Cost":

The development "cost" of the system was determined by the sum of the development cost of developing the system and components to the point where they are flight worthy. This cost is independent of the number of vehicles used in the launch vehicle program.

7. System Unit "Cost":

The system unit cost is the actual unit cost of the components and system installation for the entire launch vehicle program.

8. System Development Time "Cost":

The system development time "cost" is a measure of insufficient development time required to develop a system or component resulting in a delay in delivery of a launch vehicle for flight. The "cost" is a function of the time delay and the "penalty cost". The "penalty cost" varies from one program to another and therefore is a required input to the computer program.

SYSTEM "COST" FOR LAUNCH VEHICLE INDEX

TD-04-296-01 (8-64)

EQUATIONS

ITEM NAME: Total Cost of Hyd. Sys. of Stage Being Investigated for the Launch Vehicle Program.

SYMBOL V P C S T

REQUIRED INPUTS:
V H S R C
V H S W C
V H S L C
V P H D U
V H D T C
V H O T C

REQUIRED OUTPUTS: V P C S T

OUTPUTS:

STANDARD

Weight					W	=	
Reliability^{-1}					R	=	
Life					L	=	
Response					S	=	
Cont. Oper. Time					O	=	
Devel. Time					T	=	
Devel. Cost					D	=	
Unit Cost					U	=	

OTHER

V P C S T = VHSRC + VHSWC + VHSLC + VPHDU + VHDTC + VHOTC

NOTES:

ANALYSIS BY: M. Nakai

V-1

CHECKED BY: J. J. Harrington

TD-04-296-02 (8-64)

DERIVATION OF EQUATIONS

ITEM NAME: Total Cost of Hyd. Sys. of Stage Being Investigated for the Launch Vehicle Program. SYMBOL V P C S T

Launch Vehicle Program.

VPCST = Total cost of the hydraulic systems of the particular stage being investigated for the launch vehicle program.

VPCST = VHSRC + VHSWC + VHSLC + VPHDU + VHDTC + VHOTC

Where:

VHSRC = Cost of hydraulic system failures

VHSWC = Cost of hydraulic system weight

VHSLC = Cost of hydraulic system maximum life

VPHDU = Hydraulic system unit and development cost

VHDTC = Cost of hydraulic system development time

VHOTC = Cost of hydraulic system operating time

The above costs are total costs for the launch vehicle program.

ANALYSIS BY: M. Nakai CHECKED BY: J. J. Harrington

TD-04-296-01(8-64)

EQUATIONS

ITEM NAME: Total Cost of Hyd. Sys. Failures of Stage Investigated per Launch Vehicle Program

SYMBOL V H S R C

REQUIRED INPUTS: V H Y S R
V H Y S B
V H S F O
V F L R C

REQUIRED OUTPUTS: H H S R C

OUTPUTS:

STANDARD

WEIGHT					W	=	
RELIABILITY^{-1}					R	=	
LIFE					L	=	
RESPONSE					S	=	
CONT. OPER. TIME					O	=	
DEVEL. TIME					T	=	
DEVEL. COST					D	=	
UNIT COST					U	=	

OTHER

V H S R C = .99*VHYSR*VHYSB*VHSFO*VFLRC X10^{-6}

NOTES:

ANALYSIS BY: M. Nakai CHECKED BY: J. J. Harrington

DERIVATION OF EQUATIONS

ITEM NAME: Total Cost of Hyd. Sys. Failures of Stage Investigated per Launch Vehicle Program **SYMBOL** V H S R C

CONVERSION FACTOR FOR FAILURE RATE TO DOLLARS

The cost of a failure in the missile system is dependent upon the number of failure occurring during any operation and the cost of the failure during the particular operation.

The cost of the hydraulic system failure for a particular stage in a launch vehicle

$$\frac{\text{Cost of Failure}}{\text{Stage (x)}} = (F.R._{sys}) \; (A_x) \quad \sum K_n T_n C_n$$

Where

$F.R._{(Sys)}$ = Generic failure rate for the idependent hydraulic system for missile stage x

A_x = Number of independent hydraulic system per stage x

K_n = % of failures during operation(n)

T_n = Time of operation (on time) of system during operation(n)

C_n = The cost of failures during operation(n)

Where n = operation

n = 1 = Receiving and Inspection

n = 2 = Missile stage fill, and bleed

n = 3 = System test

n = 4 = Static firing test

n = 5 = Countdown

n = 6 = Flight

ANALYSIS BY: M. Nakai CHECKED BY: J. J. Harrington

The cost of the hydraulic system failures of stage (x) for the launch vehicle program is,

VHYRC = Total cost of the hydraulic failures of Stage X launch vehicle program.

$$= (F.R._{sys})\ (A_x)\ (\sum K_n\ T_n\ C_n)\ \ B$$

Where B = The total number of stage (X) for the launch vehicle flight program.

$$= (F.R._{sys})\ (A_x)\ (B)\ (K_1\ T_1\ C_1 + K_2\ T_2\ C_2 + K_4\ T_4\ C_4 + K_4\ T_4\ C_4 + K_5\ T_5\ C_5 + K_6\ T_6\ C_6)$$

From past experiences it is known that the cost of failures is far more costly than failure occurring during the component receiving and inspection however the time of operation during receiving and inspection is far longer than the actual flight time.

$$C_1 < C_2 < C_3 < C_4 < C_5 \ll C_6$$

and

$$T_1 > T_2 > T_3 > T_4 > T_5 \gg T_6$$

or for a simplified approximation

$$C_1\ T_1 \approx C_2\ T_2 \approx C_3\ T_3 \approx C_4\ T_4 \approx C_5\ T_5 \approx C_6\ T_6$$

$$\text{VHYRC} = (F.R._{sys})\ (A_x)\ T_6\ C_6\ \ (K_1 + K_2 + K_3 + K_4 + K_5 + K_6)\ B$$

It can be assumed that

$$K_1 + K_2 + K_3 + K_4 + K_5 + K_6 = .99$$

$$VHYRC = (F.R._{sys}) (A_x)(T_6\ C_6) (.99) \times 10^{-6}$$

T_6 = VHSFO = Vehicle hydraulic system operating time during flight hours.

C_6 = VFLRC = Cost of failure of launch vehicle during flight.

B = VPNUB = Number of stages being investigated per launch vehicle program.

FR_{sys} = VHYSR = Generic failure rate of the independent hydraulic system of the stage being investigated.

A_x = VHYSB = Number of independent hydraulic systems per stage being investigated.

The above equation transfers into

$$VHYRC = (.99) (VHYSR) (VHYSB) (VHSFO) (VFLRC)\ 10^{-6}$$

TD-04-296-01 (8-64)

EQUATIONS

ITEM NAME: Cost of the Hyd. Sys. Weight of the Stage Being Investigated for the Launch Vehicle Program

SYMBOL V H S W C

REQUIRED INPUTS:

V	H	Y	S	W
V	H	Y	S	B
V	P	N	U	B
V	W	C	S	T

REQUIRED OUTPUTS: V H S W C

OUTPUTS:

STANDARD

Weight	W	=
Reliability^{-1}	R	=
Life	L	=
Response	S	=
Cont. Oper. Time	O	=
Devel. Time	T	=
Devel. Cost	D	=
Unit Cost	U	=

OTHER

V H S W C = VHYSW*VHYSB*VPNUB*VWCST

NOTES:

ANALYSIS BY: M. Nakai CHECKED BY: J. J. Harrington

DERIVATION OF EQUATIONS

ITEM NAME: Cost of the Hyd. Sys. Weight of the Stage Being Investigated for the Launch Vehicle Program

SYMBOL V H S W C

Conversion of weight to cost. The total cost of the hydraulic system weight of the particular stage under investigation for the entire launch vehicle program is

VHSWC = (VHYSW) (VHYSB) (VPNUB) (VWCST)

Where

VHSWC = The total cost of the hydraulic system weight of the stage being investigated for the entire launch vehicle program.

VHYSW = The weight of the independent hydraulic system of the stage being investigated.

VHYSB = The number of independent hydraulic systems per stage being investigated.

VPNUB = Number of stages being investigated per launch vehicle program

VWCST = Cost per pound of weight, dollars/pound.

ANALYSIS BY: M. Nakai

CHECKED BY: J. J. Harrington

TD-04-296-01 (8-64)

EQUATIONS

ITEM NAME: Cost of Maximum Life of Hyd. Sys. for the Launch Vehicle Program

SYMBOL: V H S L C

REQUIRED INPUTS: A N U M B

V H Y S B

V P N U B

A U C S T

V R E P R

A L I F E

V L I F P

A C Y C L

V C Y C A

P F A F U

F I N F U

P A L F

P W L F

V P U C

REQUIRED OUTPUTS: V H S L C

OUTPUTS:

STANDARD

Weight					W	=	
Reliability $^{-1}$					R	=	
Life					L	=	
Response					S	=	
Cont. Oper. Time					O	=	
Devel. Time					T	=	
Devel. Cost					D	=	
Unit Cost					U	=	

OTHER

	V	H	S	L	C	=	See next page.
						=	
						=	
						=	

NOTES:

ANALYSIS BY: M. Nakai **CHECKED BY:** J. J. Harrington

Equations

$$\text{VHSLC} = \text{ANUMB*VHYSB*VPNUB*AUCST*VREPR*(VQUAM-1.0)} + \text{VHYSB* VPNUB*VPUC*}$$

$$\text{VREPR*(VLIFP/}_{\text{VPMLC}}\text{-1.0) *S10}$$

$$\text{If } \left(\frac{\text{ALIFE}}{\text{VLIFA}} - \frac{\text{ACYCL}}{\text{VCYCA}}\right) = \begin{Bmatrix} 0 \\ 1 \\ 2 \end{Bmatrix} \text{ then VQUAM } = \begin{cases} \text{ACYCL/}_{\text{VCYCA}} \\ \text{ALIFE/}_{\text{VLIFP}} \\ \text{ALIFE/}_{\text{VLIFP}} \end{cases}$$

$$\text{If (VQUAM -1)} = \begin{Bmatrix} 0 \\ 1 \\ 2 \end{Bmatrix} \text{ Then (VQUAM - 1)} = \begin{Bmatrix} 0 \\ 0 \\ \text{(VQUAM -1)} \end{Bmatrix}$$

$$\text{If PPPP 8} = \begin{Bmatrix} 0 \\ 1 \\ 2 \end{Bmatrix} \text{ then VPMLC} = \begin{Bmatrix} 10^6 \\ \text{PALF} \\ \text{PWLF} \end{Bmatrix} \quad \text{VPUC} = \begin{Bmatrix} 0 \\ \text{PFAFU} \\ \text{PINFU} \end{Bmatrix}$$

$$\text{and S10} = \begin{matrix} 0 \\ \text{S7} \\ \text{S8} \end{matrix}$$

DERIVATION OF EQUATIONS

ITEM NAME: Cost of Maximum Life of Hyd. Sys. for the Launch Vehicle Program **SYMBOL** V H S L C

The cost of maximum life of the hydraulic system component for the launch vehicle program is dependent upon the number of components required for spares in order for the system to operate for its required time and the cost of repairing the components. From past experience on the Titan II program the controlling items of maximum life are the actuators and pumps.

$$\text{VHSLC} = \frac{\text{Cost of maximum system life}}{\text{Launch vehicle program}}$$

$$= (\text{ANUMB})(\text{VHYSB})(\text{VPNUB})(\text{AUCST})(\text{VREPR})(\text{VQUAM}-1)$$

$$+ (\text{VHYSB})(\text{VPNUB})(\text{VPUC})\left(\frac{\text{VLIFP}}{\text{VPMLC}} - 1\right)(\text{VREPR})*\text{S10}$$

If $\text{PPPP8} = \begin{Bmatrix} 0 \\ 1 \\ 2 \end{Bmatrix}$ then $\text{VPMLC} = \begin{Bmatrix} 10^6 \\ \text{PALF} \\ \text{PWLF} \end{Bmatrix}$ $\text{VPUC} = \begin{Bmatrix} 0 \\ \text{PFAFU} \\ \text{PINFU} \end{Bmatrix}$ and $\text{S10} = \begin{matrix} 0 \\ \text{S7} \\ \text{S8} \end{matrix}$

If $\left(\frac{\text{ALIFE}}{\text{VLIFA}} - \frac{\text{ACYCL}}{\text{VCYCA}}\right) = \begin{Bmatrix} 0 \\ 1 \\ 2 \end{Bmatrix}$ then $\text{VQUAM} = \begin{Bmatrix} \frac{\text{ACYCL}}{\text{VCYCA}} \\ \frac{\text{ALIFE}}{\text{VLIFP}} \\ \frac{\text{ALIFE}}{\text{VLIFP}} \end{Bmatrix}$

If (VQUAM - 1) __-__, __0__, __+__

(VQUAM -1) = 0,

(VQUAM -1) = 0,

(VQUAM -1) = (VQUAM-1)

ANALYSIS BY: M. Nakai **CHECKED BY:** J. J. Harrington

Where:

ANUMB = Number of actuators per independent hydraulic system

VHYSB = Number of independent hydraulic systems per stage.

VPNUB = Number of vehicle per launch program.

AUCST = Actuator unit cost.

VREPR = Ratio of component repair cost to the unit cost.

VLIFP = Required life in on time for pump.

PWLF = In line pump life.

PALF = Fixed angle pump life.

ACYCL = Actuator life in (cycles)

ALIFE = Actuator life in (on time)

VCYCA = Required life in cycles for actuators.

VLIFA = Required life in (on-Time) for actuator.

PFAFU = Fixed angle pump unit cost.

PINFU = In line pump unit cost.

TD-04-296-01 (8-64)

EQUATIONS

ITEM NAME: Development & Unit Cost The Particular Stage Hydraulic System for the Launch Vehicle Program

SYMBOL V P H D U

REQUIRED INPUTS: SEE BELOW

REQUIRED OUTPUTS:

OUTPUTS:

STANDARD

WEIGHT					W	=	
RELIABILITY $^{-1}$					R	=	
LIFE					L	=	
RESPONSE					S	=	
CONT. OPER. TIME					O	=	
DEVEL. TIME					T	=	
DEVEL. COST					D	=	
UNIT COST					U	=	

OTHER

V P H D U = ADCST+PFAFD+PINFD+TUCSD+QDCSD+XRUSD+RAPCD+

= ((AUCST+XRUSU)(ANUMB)+(PFAFU)(S7)+

= (PINFU)(S8)+FUCSU+TUCSU+QDCSU+

= RAPCU+VTPRU) (VHYSB)(VPNUB)+FUCSD

NOTES:

ANALYSIS BY: M. Nakai CHECKED BY: J. J. Harrington

DERIVATION OF EQUATIONS

ITEM NAME: Development & Unit Cost The Particular Stage Hydraulic System for the Launch Vehicle Program

SYMBOL V P H D U

The total development and unit cost of the hydraulic systems of the particular stage being investigated for the launch vehicle program.

VPHDU = Development And Unit Cost / Launch Vehicle Program = System Devel. Cost + System unit cost (VHYSB)(VPNUB)

System Development Cost = ADCST+PFAFD+PINFD FUCSD TUCSD+QDCSD+RAPCD

System Unit Cost = (AUCST)(ANUMB)+(PFAFU)(S7) + (PINFU) (S8)

+ FUCSU+TUCSU+QDCSU+RAPCU

+ VTPRU

VPHDU = ADCST+PFAFD+PINFD+FUCSD+TUCSD+QDCSD +

XRUSD +RAPCD+ [(AUCST+XRUSU)(ANUMB)+(PFAFU)(S7) + (PINFU) (S8)

+FUCSU+TUCSU+QDCSU+RAPCU+VTPRU]

(VHYSB)(VPNUB)

Where

ANUMB = Number of actuators per independent hydraulic system

VHYSB = The number of independent hydraulic systems/stage

VPNUB = The number of particular stages per launch vehicle program

S7 = The number of fixed angle pumps/hyd. system.

S8 = The number of inline pumps/hyd. system.

ANALYSIS BY: M. Nakai CHECKED BY: Y. Y. Harrington

Derivation of Equations

	DEVELOPMENT COST	UNIT COST
Actuator	ADCST	AUCST
Fixed Angle Pump	PFAFD	PFAFU
In-Line Pump	PINFD	PINFU
Filter	FUCSD	FUCSU
Tubing	TUCSD	TUCSU
Q.D.	QDCSD	QDCSU
Reservoir	RAPCD	RAPCU
Temperature Probe	———	VTPRU
Turss	XRUSD	XRUSU

EQUATIONS

ITEM NAME: Cost of Development Time

SYMBOL V H D T C

REQUIRED INPUTS:

V	D	E	V	L
P	F	A	F	T
A	D	T	I	M
V	D	E	V	L
V	P	E	N	D

REQUIRED OUTPUTS: V H D T C

OUTPUTS:

STANDARD

WEIGHT					W	=	
RELIABILITY $^{-1}$					R	=	
LIFE					L	=	
RESPONSE					S	=	
CONT. OPER. TIME					O	=	
DEVEL. TIME					T	=	
DEVEL. COST					D	=	
UNIT COST					U	=	

OTHER

	V	H	D	T	C	=	See Next Page
						=	
						=	
						=	

NOTES:

ANALYSIS BY: M. Nakai CHECKED BY: J. J. Harrington

DERIVATION OF EQUATIONS

ITEM NAME: Cost of Development Time SYMBOL V H D T C

VHDTC = (Required Devel. Time - Development Time) (Penalty Payment).

VHDTC = (VDEVL - VHCDT) VPEND

VHCDT = Maximum development time

Of the following PFAFT, PINFT, ADTIM

Set the largest quantity equal to VHCDT

Where:

PFAFT = Development time, fixed angle pump

PINFT = Development time, in-line pump

ADTIM = Development time, actuator

VDEVL = Required development time

VPEND = The penalty cost per week delay in development

If VDEVL - VHCDT is negative or 0. Set VHDTC = 0

ANALYSIS BY: M. Nakai CHECKED BY: J. J. Harrington

TD-04-296-01 (8-64)

EQUATIONS

ITEM NAME: Cost of Maximum Operating Time

SYMBOL V H O T C

REQUIRED INPUTS: V T E S T / V H Y S B / V P N U B / V P E R / V T C S T / P O W P / P A O P

REQUIRED OUTPUTS: V H O T C

OUTPUTS:

STANDARD

WEIGHT					W	=	
RELIABILITY $^{-1}$					R	=	
LIFE					L	=	
RESPONSE					S	=	
CONT. OPER. TIME					O	=	
DEVEL. TIME					T	=	
DEVEL. COST					D	=	
UNIT COST					U	=	

OTHER

	V	H	O	T	C	=	See Below
						=	
						=	
						=	

NOTES:

VHOTC = VTEST*VHYSB*VPNUB*(VOPER/PMOP-1.0)*VTCST

PMOP = PWOP or PAOP Whichever is greater

If (VOPER/PMOP - 1.0) = 0, - Set VHOTC = 0

V-18

ANALYSIS BY: M. Nakai CHECKED BY: J. J. Harrington

DERIVATION OF EQUATIONS

ITEM NAME: Cost of Maximum Operating Time

SYMBOL V H O T C

The cost of limited pump operating time is the cost of having to interrupt or delay missile test due to the limited operating of the hydraulic system. From past experience the limiting operating time is dependent upon the pump.

VHOTC = (VTEST)(VHYSB)(VPNUB)(VOPER/PMOP-1.0)(VTCST)

PMOP = PWOP or PAOP whichever is larger if (VOPER/PWOP -1.0) is negative or 0, set VHOTC = 0

VTEST = Number of tests required for each independent hydraulic system per stage.

VHYSB = Number of independent hydraulic systems per stage.

VPNUB = Number of launch vehicles per program.

VTCST = Cost of single hydraulic system test.

VOPER = Required time for average system test.

PMOP = Maximum pump operating time

ANALYSIS BY: M. Nakai **CHECKED BY:** J. J. Harrington

TD-04-296-01 (8-64)

EQUATIONS

ITEM NAME: Hydraulic System (Independent) SYMBOL V H Y S

REQUIRED INPUTS: See next page

REQUIRED OUTPUTS: V H Y S W

V H Y S R

OUTPUTS:

STANDARD

WEIGHT	V	H	Y	S	W	=	See next page
RELIABILITY $^{-1}$	V	H	Y	S	R	=	See next page
LIFE					L	=	
RESPONSE					S	=	
CONT. OPER. TIME					O	=	
DEVEL. TIME					T	=	
DEVEL. COST					D	=	
UNIT COST					U	=	

OTHER

NOTES:

ANALYSIS BY: M. Nakai CHECKED BY: J. J. Harrington

The total hydraulic system weight for the stage under investigation is the sum of the component weight of each independent hydraulic system.

```
VHYSW  =  (ACTWT+XRUWT)ANUMB+TWGHT*ANUMB/2.0+PUWT1*S7+
          PUWT2*S8+RAWGT+FWGHT+FFFF1+YTPRW+QWGHT

VHYSR  =  (ACTRB+XRURB)ANUMB+TFAIL*ANUMB/2.0+PREL1*S7+
          PREL2*S8+RAFAL+FFAIL*FFFF1+YTPRF+QFAIL
```

TD-04-296-01 (8-64)

EQUATIONS

ITEM NAME: Quick Disconnect Failure Rate

SYMBOL Q F A I L

REQUIRED INPUTS: P R E S / T M T 1 I / A N U M B / Q Q Q Q 3 / D S L I / S S S I / D P C I

REQUIRED OUTPUTS: Q F A I L

OUTPUTS:

STANDARD

WEIGHT	W	=
RELIABILITY^{-1}	R	=
LIFE	L	=
RESPONSE	S	=
CONT. OPER. TIME	O	=
DEVEL. TIME	T	=
DEVEL. COST	D	=
UNIT COST	U	=

OTHER

QFAIL = 0.020+DSLI(QPORT,PRES)+SSSI(1.1*QPORT,PRES)+DPCI(1.1*QPORT,40.0)+DSLI(1.35*QPORT,40.0)+SSSI(1.35*QPORT,40.0)

QPORT = TMT1I*(ANUMB*QQQQ3/2.0)**0.5

NOTES:

ANALYSIS BY: D. R. Moody CHECKED BY: J. J. Harrington

DERIVATION OF EQUATIONS

ITEM NAME: Quick Disconnect Failure Rate

SYMBOL Q F A I L

The predominant failure mode for the quick disconnects (coaxial type) is failure of the O-rings. The body failure rate of the quick disconnect can be assumed to be approximately equal to .020 and constant. The quick disconnect contains five O-rings (airborne half only) as follows:

	PRESSURE	I.D. RELATION TO PORT DIAM.	TYPE
1	PRES	X 1.0.	DSLI
2	PRES	X 1.1	SSSI
3	40.0	X 1.1	DPCI
4	40.0	1.35	DSLI
5	40.0	1.35	SSSI

Since the Port Diam = (REF: QWGHT)

$$QPORT = TMT1I * \sqrt{\frac{ANUMB * QQQQ3}{2.0}}$$

$$QFAIL = 0.020 + DSLI\ (QPORT, PRES) + SSSI\ (1.1*QPORT, PRES) + DPCI\ (1.1*QPORT, 40.0) + DSLI\ (1.35*QPORT, 40.0) + SSSI\ (1.35*QPORT, 40.0)$$

ANALYSIS BY: D. R. Moody CHECKED BY: J. J. Harrington

TD-04-296-01 (8-64)

EQUATIONS

ITEM NAME: Quick Disconnect Total Weight SYMBOL Q W G H T

REQUIRED INPUTS: T M T 1 I
P R E S
A N U M B
Q Q Q Q 3

REQUIRED OUTPUTS: Q W G H T

OUTPUTS:

STANDARD

WEIGHT	W =	
RELIABILITY $^{-1}$	R =	
LIFE	L =	
RESPONSE	S =	
CONT. OPER. TIME	O =	
DEVEL. TIME	T =	
DEVEL. COST	D =	
UNIT COST	U =	

OTHER

QWGHT = 1.84E-6*PRES**2.0*TMT1I**3.0*(ANUMB*QQQQ3/2.0)**1.5

NOTES:

ANALYSIS BY: Russell S. Hanish CHECKED BY: J. J. Harrington

TD-04-296-02 (8-64)

DERIVATION OF EQUATIONS

ITEM NAME: Quick Disconnect Total Weight

SYMBOL Q W G H T

The weight of the quick disconnect was determined to follow an equation of the following type:

$$QWGHT = K_1 \, (PRES)^2 \, (PORT\ DIA.)^3$$

This equation was determined from data for off-the-shelf quick disconnects. For an airborne half of a coaxial quick disconnect for a 3000 psi system and 3/8 in. port diameter, the weight is 14 oz. or .875#.

Therefore:

$$K_1 = \frac{.875}{(3000)^2 \, (.375)^3} = 1.84 \times 10^{-6}$$

and

$$QWGHT = 1.84 \times 10^{-6} \, (PRES)^2 \, (Port\ Dia.)^3$$

The port diameter will be determined from the main tube diameter (TMT1I). Since TMT1I is determined for two actuators and since QQQQ3 is the rating of required Q.D. flow rate to max. system flow rate.

$$DIAM = TMT1I * \sqrt{\frac{ANUMB}{2.0} * QQQQ3}$$

and

$$QWGHT = 1.84 \times 10^{-6} \, (PRES)^2 \, (TMT1I)^3 * \left[\frac{(ANUMB)}{2.0} \, (QQQQ3) \right]^{3/2}$$

ANALYSIS BY: Russell G. Hanish CHECKED BY: J. J. Harrington

TD-04-296-01 (8-64)

EQUATIONS

ITEM NAME: Temperature Probe

SYMBOL Y T P R

REQUIRED INPUTS:

REQUIRED OUTPUTS: Y T P R U

OUTPUTS:

STANDARD

WEIGHT	Y	T	P	R	W	=	.0431
RELIABILITY $^{-1}$	Y	T	P	R	R	=	.0628
LIFE					L	=	
RESPONSE					S	=	
CONT. OPER. TIME					O	=	
DEVEL. TIME					T	=	
DEVEL. COST					D	=	
UNIT COST	Y	T	P	R	U	=	250.0

OTHER

=

=

=

=

NOTES:

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ANALYSIS BY: Russell A. Hanish CHECKED BY: J. J. Harrington

TD-04-296-02(8-64)

DERIVATION OF EQUATIONS

ITEM NAME: Temperature Probe SYMBOL Y T P R

Since the body of the temperature probe has been included in the tubing calculations, the remaining part of the probe (element, wire and connector) is constant.

Therefore

$$YTPRW = K_1$$

$$YTPRR = K_2$$

and

$$YTPRU = K_3$$

The weight of the connector, element and wire was determined to be .0431 pounds with an assembly failure rate of .0628. The combined basic cost, test cost and cleaning cost was determined to be $250.00.

Therefore:

$$K_1 = .0431$$

$$K_2 = .0628$$

$$K_3 = 250.0$$

ANALYSIS BY: Russell G. Hanish CHECKED BY: J. J. Harrington