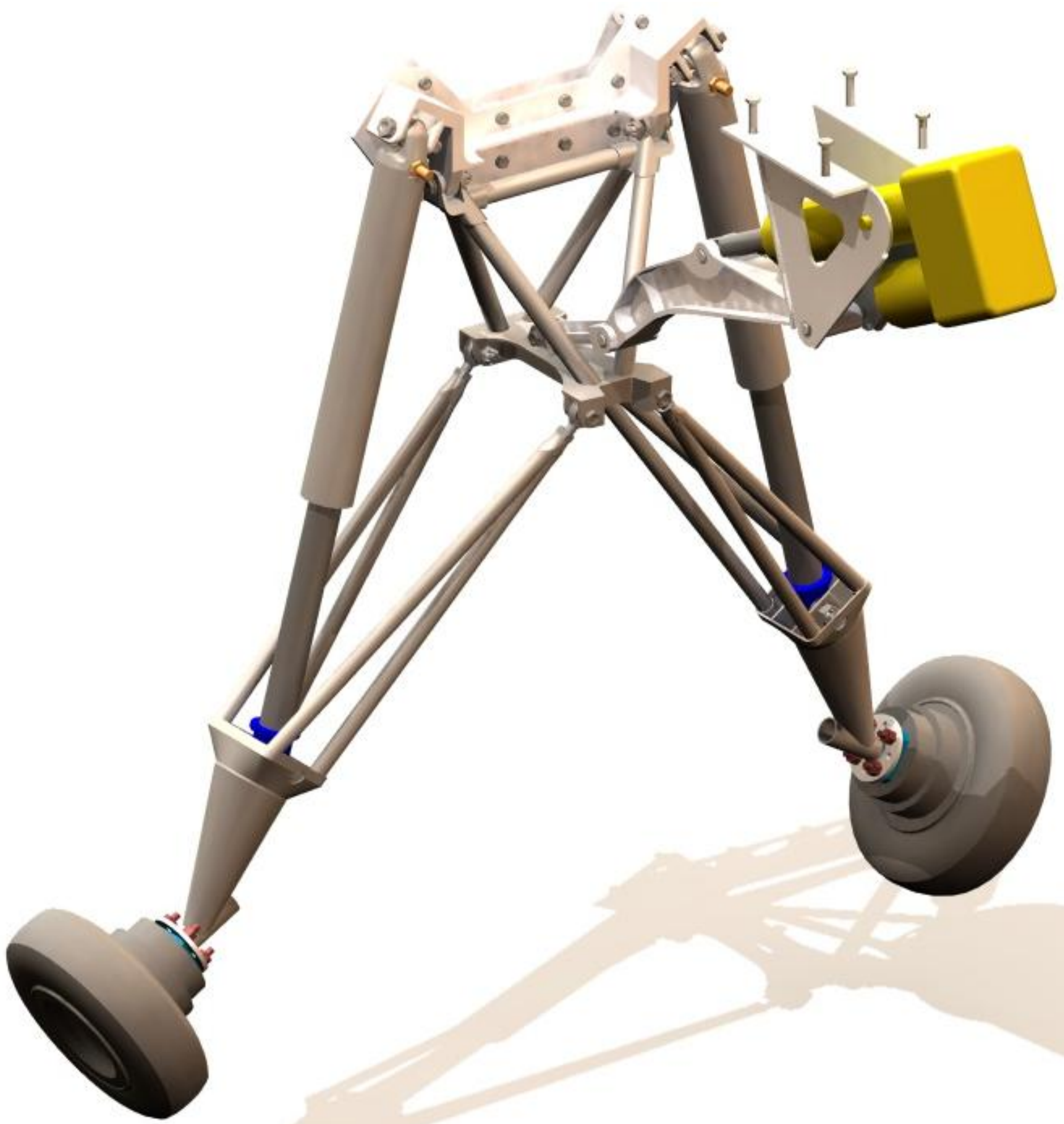
Report, Design, Loads, and Capacity, MLG

for

Kuchera Defense Systems
KnightHawk UAV

by

Ranny Meier – Response Mechanics



1 Contents

2 List of Figures

3 Introduction

We optimized the pivot locations of the links in the assembly to provide the best wheel travel, and minimum weight assembly, within the envelope available. We selected a few critical locations in the assembly where we list the capacity of components. The shocks are 5 way adjustable; oil viscosity, oil level, gas pressure, and compression and rebound side shim stacks.

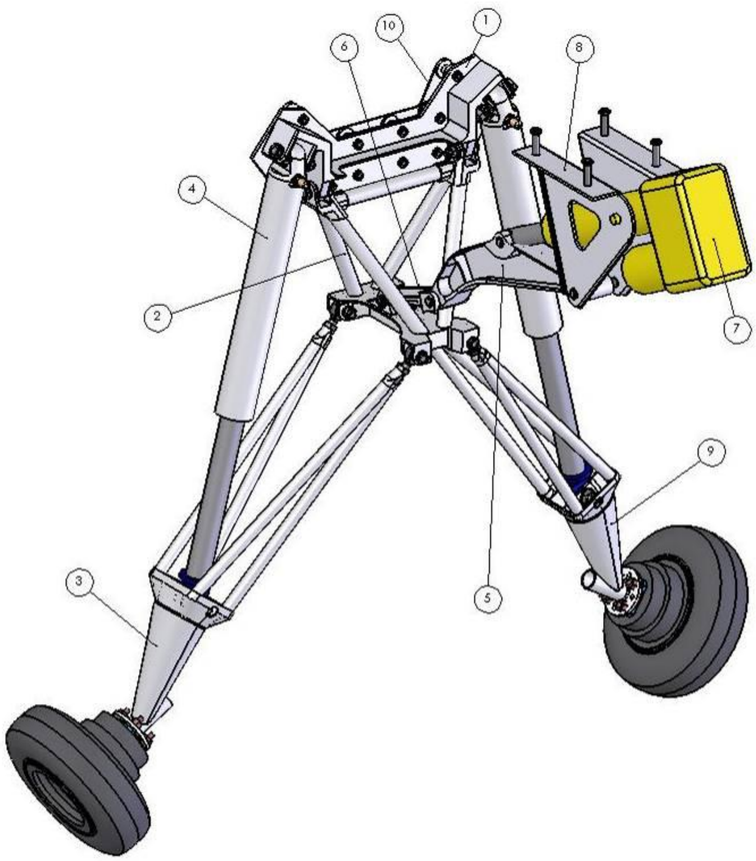


Figure 1 Ten MLG sub-assemblies

ItemNo	AssyNo	Description
1	KA58T321600	Assy, Support, Drive Trunnion
2	KA58T321100	Assy, Drive Trunnion, Main Gear
3	KA58T321200	Assy, Strut, Main Gear, Left Hand
4	KA58T321250	Gas and Oil Shock Absorber
5	KA58T321400	Assy, Brace, Aft, Main Gear
6	KA58T321420	Assy, Brace, Fwd, Main Gear
7	7828568	PPA 24 volt, 4 inch stroke, 1.1 in/sec, limit switch
8	KA58T321500	Assy, Support, Actuator and Brace
9	KA58T321300	Assy, Strut, Main Gear, Right Hand
10	KA58T321030	Assy, Ftg, Insert, Fuselage, Trunnion

Protective boots, not shown in Figure 1, are provided for the shock and actuator shafts (shown in Figure 32 on page 31).

4 References

5 Conclusion

This Main Landing Gear (MLG) system utilizes a pair of adjustable Gas over Oil shock absorbers (OLEO). This allows the necessary setup changes to be done using the same hardware for a wide weight range for the aircraft.

Table 1 Margin of Safety Summary

PartNo	Description	M.S.	Failure Mode	Stress (ksi)	Page
KA58T321215	Tube, Strut, Fwd Lwr	0.08	Tension	116.0	22
KA58T321214	Tube, Strut, Fwd Upr	0.62	Compress	77.0	22
KA58T321214	Tube, Strut, Fwd Upr	0.91	Buckle		22
KA58T321211	Socket, Axle	0.13	Bending	111.0	23
KA58T321116	Tube, Fwd, Trunnion, Right Hand	0.45	Tension	86.0	24
KA58T321117	Tube, Aft, Trunnion, Right Hand	0.62	Compress	77.0	24
KA58T321117	Tube, Aft, Trunnion, Right Hand	4.11	Buckle		24
KA58T321113	Fitting, Clevis, Knee - Lugs	1.37	Tension		25
KA58T321113	Fitting, Clevis, Knee - Bolt	0.42	Bending		25
KA58T321111	Fitting, Clevis, Left Hand - Lugs	2.0	Tension		25
KA58T321111	Fitting, Clevis, Left Hand - Bolt	1.87	Bending		25
KA58T321601	Support, Drive Trunnion - Lugs	1.62	Tension		27
KA58T321601	Support, Drive Trunnion - Bolt	1.04	Bending		27

6 Mass Properties

Mass = 45.1012 pounds at gear down position.
Center of mass: (inches) in aircraft coordinates

X = 178.4327
Y = -0.0039
Z = 80.4355

7 Geometry

7.1 Geometry of swing strut lever

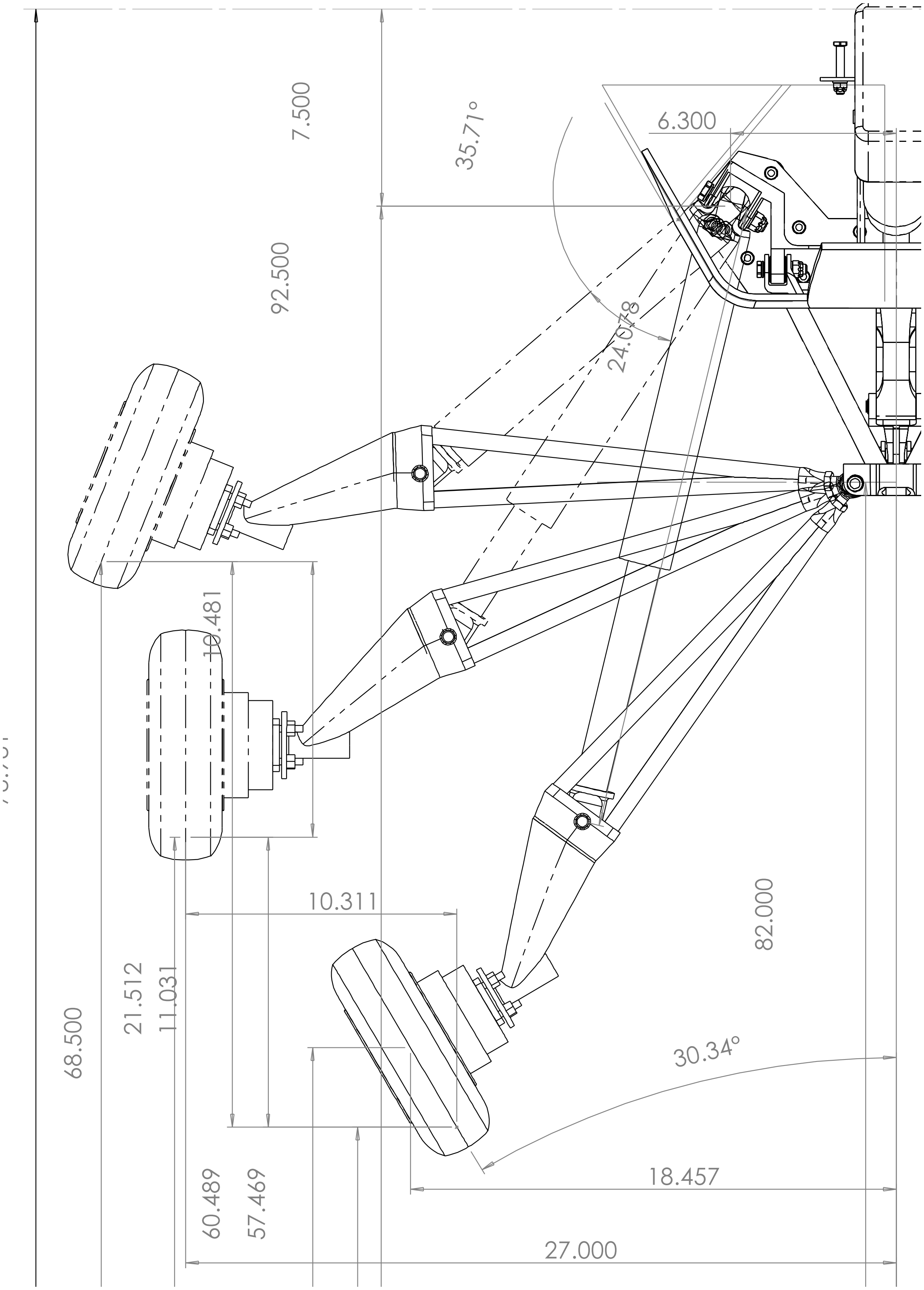


Figure 2 Swing strut lever geometry

The strut leg is made as long as possible to fit in the available retracted position envelope. Then the static ground position of the tire is positioned at 27" out from BL0 to provide a minimum required roll-over angle.

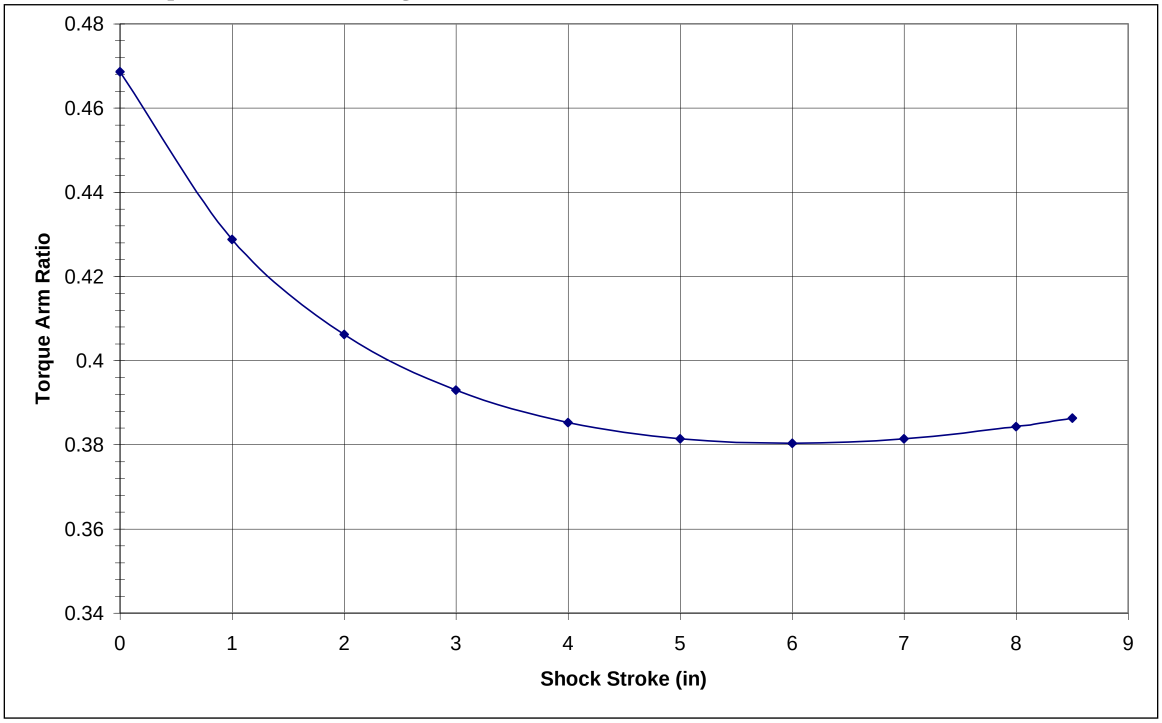


Figure 3 Ratio of Shock Force to vertical ground force at tire contact

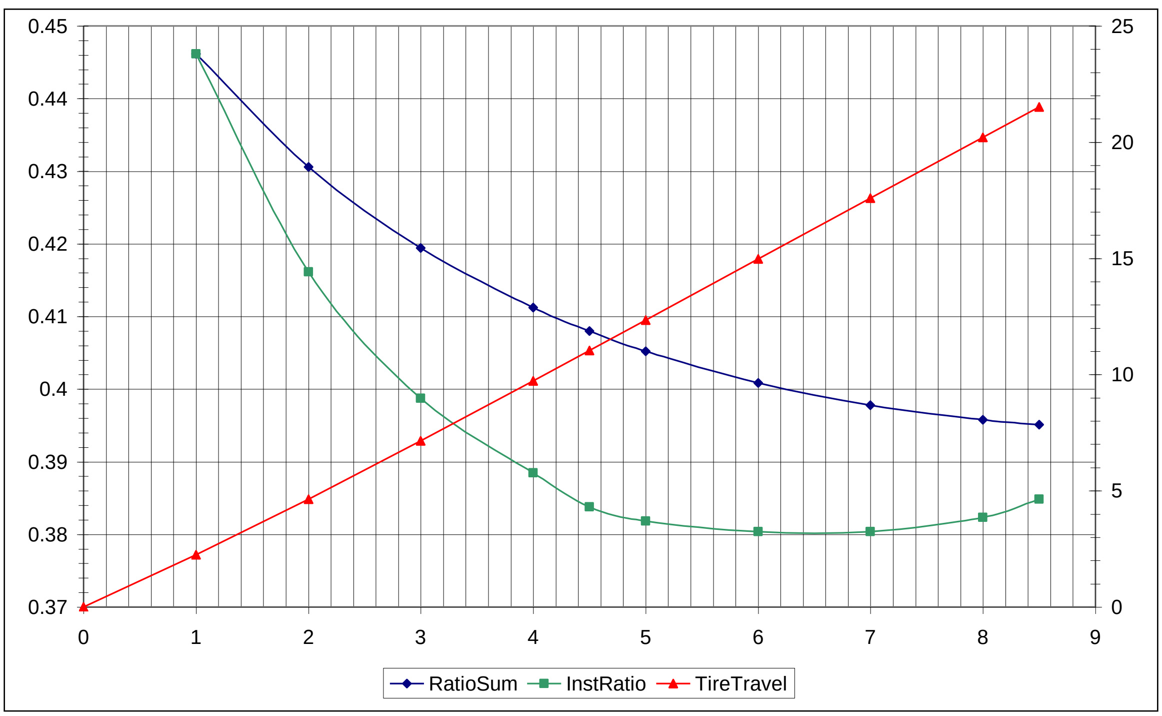


Figure 4 Ratio of shock piston velocity to vehicle sink rate

7.2 Tail Down Clearance

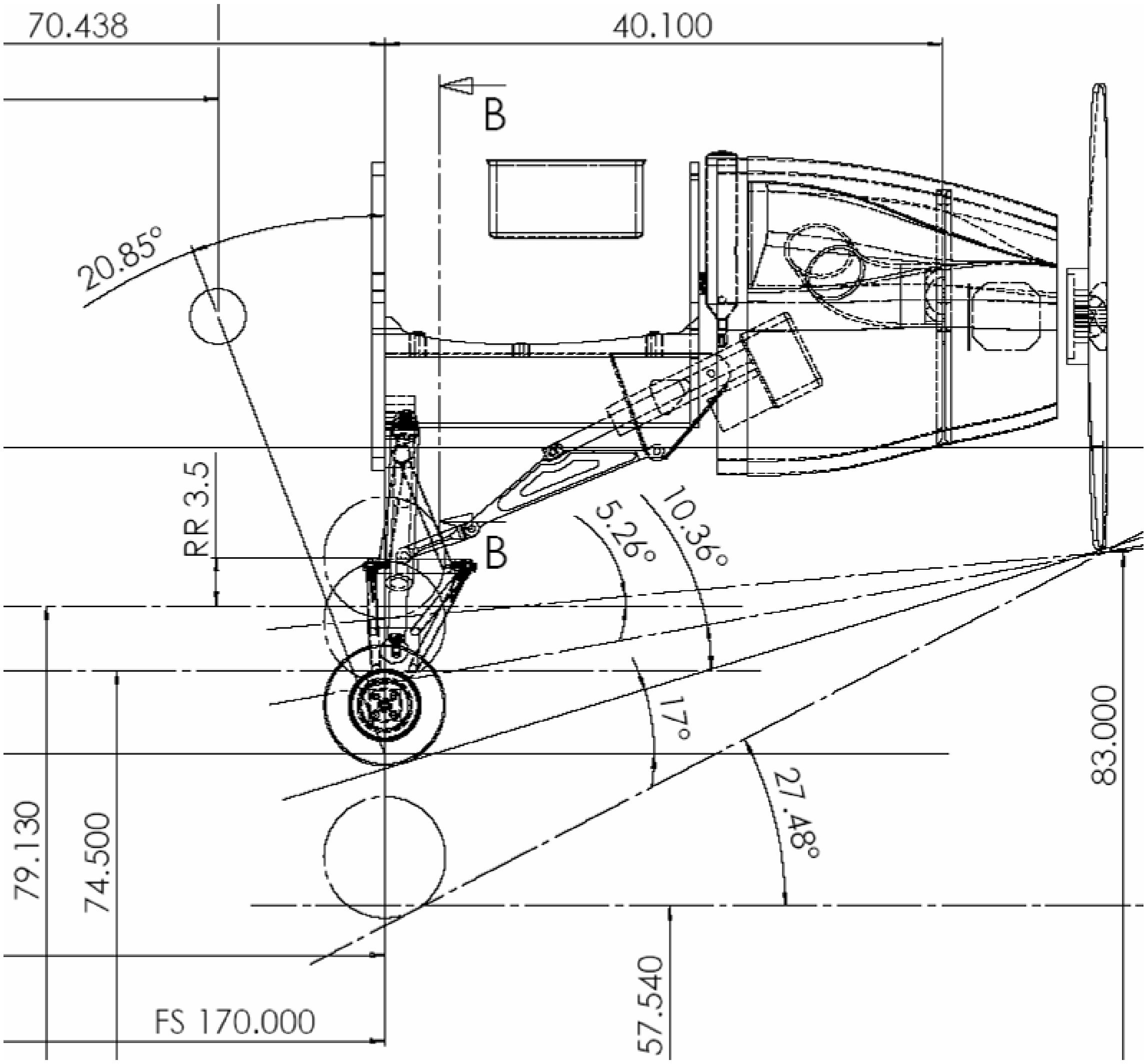


Figure 5 Tail Down Ground Lines

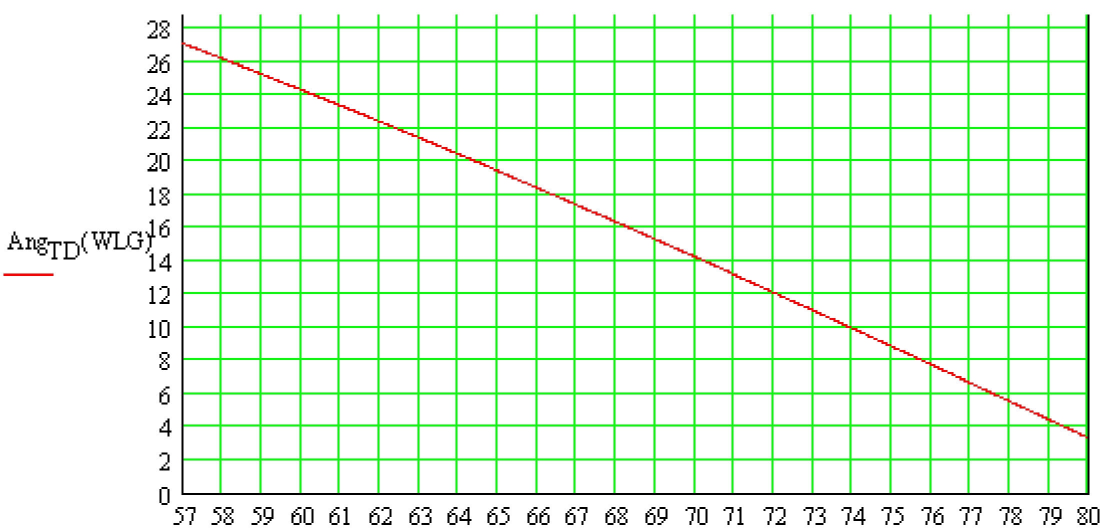


Figure 6 Available Tail Down Angle vs Ground WL

7.3 Wing Tip Clearance

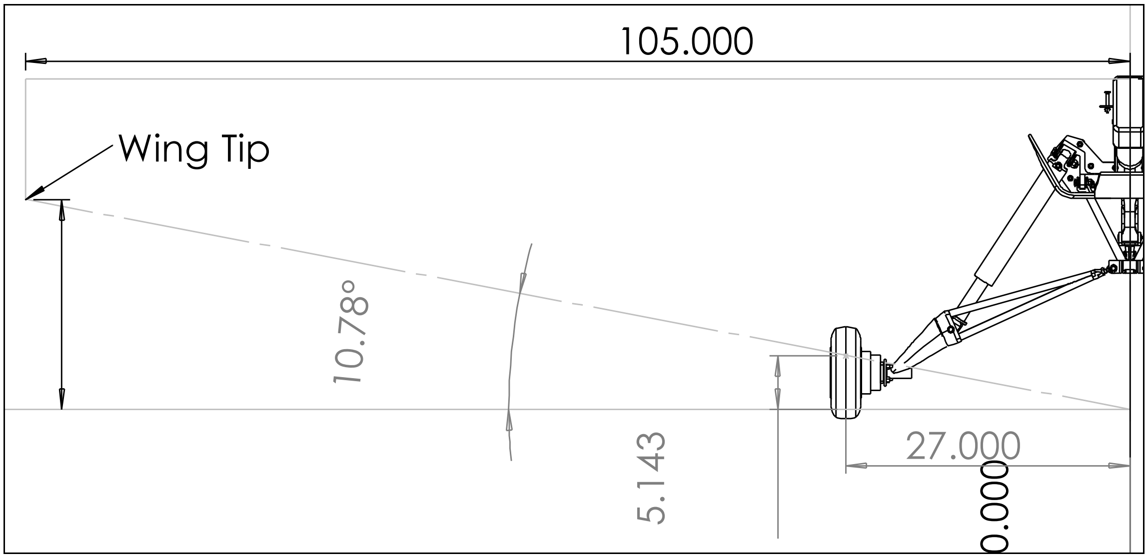


Figure 7 Wing Tip clearance

Referring to Figure 8 on page 10 we see that this 5” of wheel travel that happens before the wing tip touches will increase the ground force at the tire by 125 lbf which ratios to 32 lbf required at the wing tip to hold it down to the ground. This does not happen suddenly due to wind gust because the preloaded digressive shims used in the shock absorber valves (described in §11.4.1 on page 27) keep the gear hydraulically locked in position except for slow static balancing motion that happens as oil moves through slow speed bleed holes in the shock piston.

This plot in Figure 8 shows Tire Ground Force vs Tire Stroke for a family if initial gas pressures; $P_S^T = (170\ \ 190\ \ 210\ \ 230\ \ 250\ \ 270\ \ 290)$. For example an aircraft with weight such that 400 lb is supported by MLG can have the ground line height adjusted from 71.5” to 64.0” by increasing the initial shock gas pressure from 180 psi to 300 psi. We see in Figure 6 on page 8 that this additional 7.5” of ground clearance can amount to an additional 8 deg of tail down angle before touching aft propeller to ground.

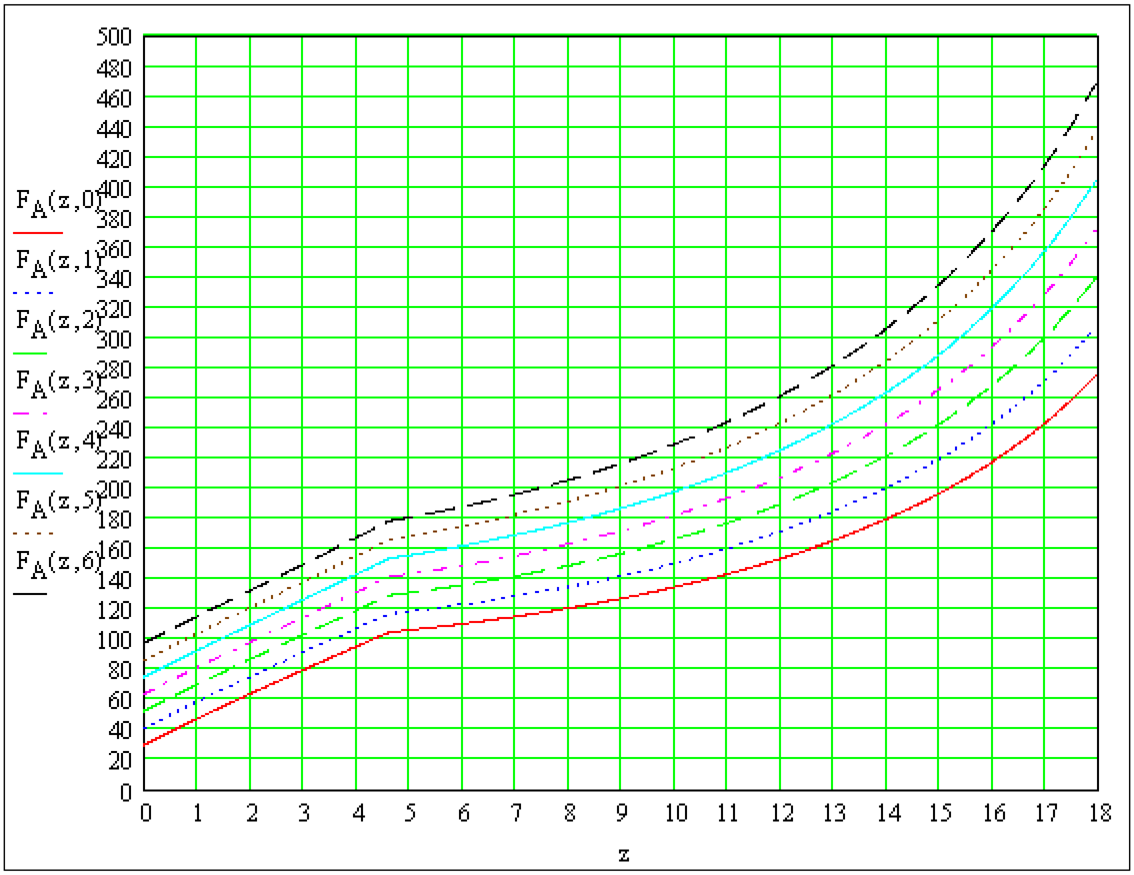


Figure 8 Plot: Force at ground contact vs Tire Stroke for list of initial gas pressures

8 External Loads

The peak load during landing is at the time when the shock is fully compressed and sink rate reaches zero. For a hard landing the force in the shock will be at 2000 lbf. A hypothetical worse case could be having a brake locked up or running over a bump at the same time. To simplify sizing these strut legs we apply a vertical force where the tire meets the ground such that there is 2000 lbf in the shock and then put an aft direction force at the tire patch equal to 0.8 times the vertical force. These are 772.5 lbf +Z vertical and 618.0 lbf +X aft.

8.1 Landing simulation

We use a small time step method to plot the displacement, velocity, acceleration, and force while balancing these non-linear stiffness and dampening forces at each time step.

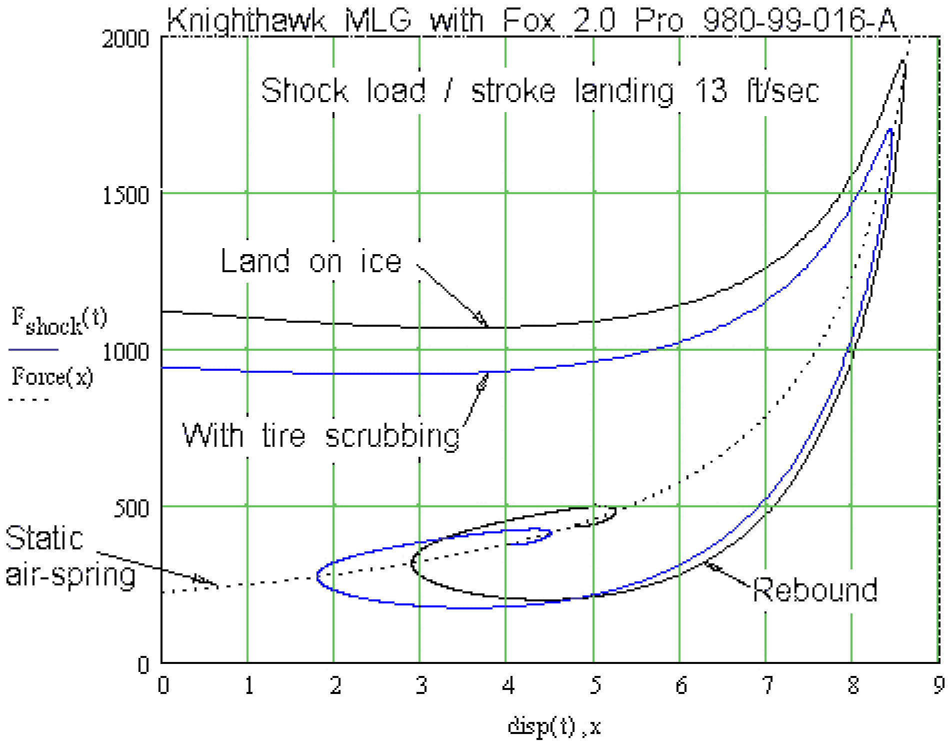


Figure 9 Shock dynamic load / stroke

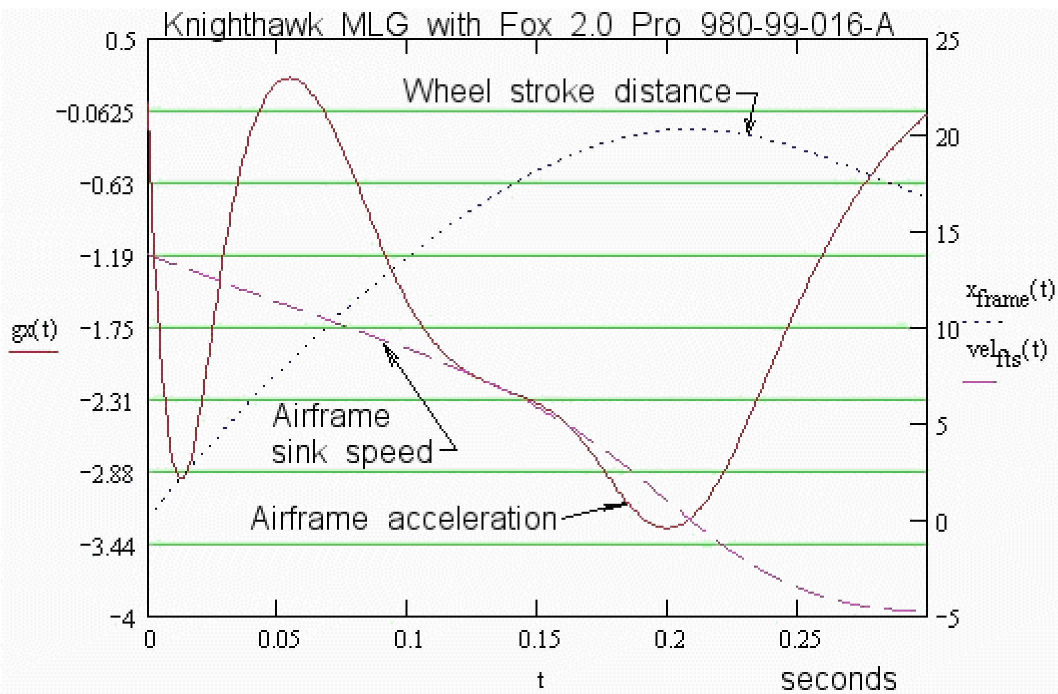


Figure 10 Airframe dynamic landing response

8.2 Bump & Braking simulation

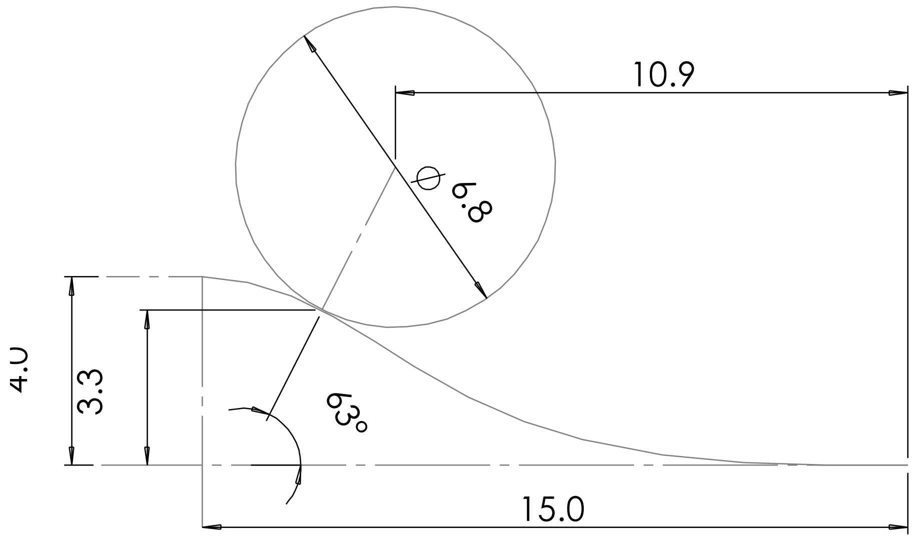


Figure 11 Bump shape

$$V_{fwd} := 60 \cdot \frac{mi}{hr} \qquad Ramp := 10.9\,in \qquad SR := 0.4$$

$$BumpTime = \frac{Ramp}{V_{fwd}} \qquad BumpTime = 0.01\,s$$

$$V_{vert} := \frac{3.3\,in}{BumpTime} \qquad V_{vert} = 319.706\,\frac{in}{s} \qquad V_{shock} := SR \cdot V_{vert} \qquad V_{shock} = 127.883\,\frac{in}{s}$$

$$F_{vert} := 1500\,SR \cdot lbf \qquad F_{horiz} := \frac{F_{vert}}{\tan\left(63 \cdot \frac{\pi}{180}\right)} \qquad F_{horiz} = 305.7\,lbf$$

Figure 12 Aft direction reaction for bump

We are using 0.8 * vertical force in the aft direction for Braking Force.

9 Interface Loads

Table 2 Interface load Node airframe coordinates

ID	FS	BL	WL	
1	170.0	-27.0	68.5	:= Tire / Ground contact - Left Hand
23	170.0	27.0	68.5	:= Tire / Ground contact - Right Hand
400	187.1153	-2.1265	97.3308	:= Actuator mount - Fwd Left Hand
404	187.1153	2.1265	97.3308	:= Actuator mount - Fwd Right Hand
405	191.6893	2.1265	97.3308	:= Actuator mount = Aft Right Hand
408	191.6893	-2.1265	97.3308	:= Actuator mount - Aft Left Hand
412	169.56	0.0	90.1	:= Trunnion Mount interface point

Table 3 Airframe Interface Loads

```
Node 1 := Tire / Ground contact - Left Hand
    Output Vector 1        - Total Translation         = 1.658
    Output Vector 2        - T1 Translation            = 1.6246
    Output Vector 3        - T2 Translation            = -0.25697
    Output Vector 4        - T3 Translation            = 0.20885
    Output Vector 5        - Total Rotation            = 0.17221
    Output Vector 6        - R1 Rotation               = -0.040633
    Output Vector 7        - R2 Rotation               = -0.16698
    Output Vector 8        - R3 Rotation               = 0.011102
    Output Vector 41       - Total Applied Force       = 989.283
    Output Vector 42       - T1 Applied Force          = 618.
    Output Vector 43       - T2 Applied Force          = 0.
    Output Vector 44       - T3 Applied Force          = 772.5

Node 23 := Tire / Ground contact - Right Hand
    Output Vector 1        - Total Translation         = 0.29871
    Output Vector 2        - T1 Translation            = 0.15349
    Output Vector 3        - T2 Translation            = 0.16367
    Output Vector 4        - T3 Translation            = 0.19717
    Output Vector 5        - Total Rotation            = 0.040555
    Output Vector 6        - R1 Rotation               = 0.029554
    Output Vector 7        - R2 Rotation               = -0.020916
    Output Vector 8        - R3 Rotation               = 0.01827
    Output Vector 41       - Total Applied Force       = 772.5
    Output Vector 42       - T1 Applied Force          = 0.
    Output Vector 43       - T2 Applied Force          = 0.
    Output Vector 44       - T3 Applied Force          = 772.5

Node 400 := Actuator mount - Fwd Left Hand
    Output Vector 51       - Total Constraint Force    = 761.726
    Output Vector 52       - T1 Constraint Force       = -600.649
    Output Vector 53       - T2 Constraint Force       = -282.708
    Output Vector 54       - T3 Constraint Force       = 373.527

Node 408 := Actuator mount - Aft Left Hand
    Output Vector 51       - Total Constraint Force    = 1222.15
    Output Vector 52       - T1 Constraint Force       = -406.784
    Output Vector 53       - T2 Constraint Force       = 626.3
    Output Vector 54       - T3 Constraint Force       = -967.435

Node 405 := Actuator mount = Aft Right Hand
    Output Vector 51       - Total Constraint Force    = 827.495
    Output Vector 52       - T1 Constraint Force       = -99.7364
    Output Vector 53       - T2 Constraint Force       = -534.767
    Output Vector 54       - T3 Constraint Force       = -623.558

Node 404 := Actuator mount - Fwd Right Hand
    Output Vector 51       - Total Constraint Force    = 559.235
    Output Vector 52       - T1 Constraint Force       = -405.889
    Output Vector 53       - T2 Constraint Force       = 232.436
    Output Vector 54       - T3 Constraint Force       = 306.547

Node 412 := Trunnion Mount interface point
    Output Vector 51       - Total Constraint Force    = 1097.68
    Output Vector 52       - T1 Constraint Force       = 895.058
    Output Vector 53       - T2 Constraint Force       = -41.2605
    Output Vector 54       - T3 Constraint Force       = -634.081
    Output Vector 55       - Total Constraint Moment   = 16850.2
    Output Vector 56       - R1 Constraint Moment      = -290.474
    Output Vector 57       - R2 Constraint Moment      = 1698.99
    Output Vector 58       - R3 Constraint Moment      = -16761.8
```

Figure 13 KA58T321030 Bulkhead / Trunnion interface fitting

Two facing mirror image plates, with integral cylindrical bosses can be bonded into the bulkhead sandwich structure, one from aft and one from fwd sides, where the MLG trunnion interfaces. The larger diameter portion of these cylindrical bosses will interface with a c-bore of the same diameter cut into the laminate while the smaller diameter portion protrudes through the core.

We should allow for 400 lbf bearing shear force at any one interface boss, until possibly a more refined stress model is done that includes the bulkhead sandwich structure in the model. The expoxy adhesive should provide a minimum 10ksi ultimate bearing stress capacity.

10 Internal Loads

10.1 Configuration

10.2 Strut Leg

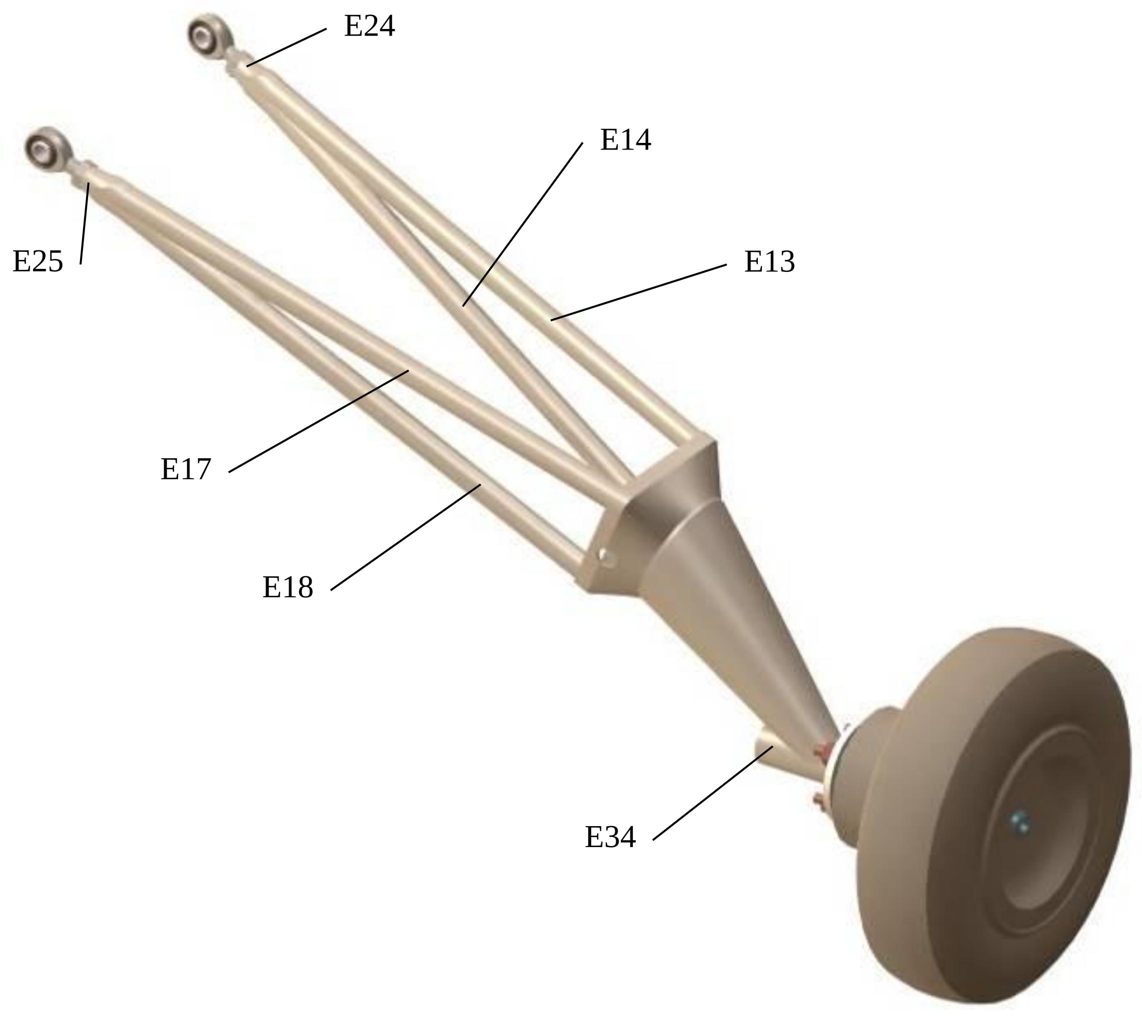


Figure 14 KA58T321200 Strut lever assy element numbers

10.2.1 KA58T321200 Assy, Strut landing event internal load list

The peak forces (lbf) and moments (in-lbf) in these members during the landing event are listed here.

```
List Output Query
Element 13
  Output Set 8 - T1nDspc 772.5Up 618.0Aft
```

```
    Output Vector 3014     - Beam EndA Plane1 Moment   = 133.479
    Output Vector 3015     - Beam EndA Plane2 Moment   = 58.7876
    Output Vector 3016     - Beam EndB Plane1 Moment   = 2.3195
    Output Vector 3017     - Beam EndB Plane2 Moment   = 300.239
    Output Vector 3018     - Beam EndA Pl1 Shear Force = 12.0745
    Output Vector 3019     - Beam EndA Pl2 Shear Force = -22.228
    Output Vector 3022     - Beam EndA Axial Force     = -53.5746
    Output Vector 3024     - Beam EndA Torque Force    = 6.15801

Element 14
  Output Set 8 - T1nDspc 772.5Up 618.0Aft
    Output Vector 3014     - Beam EndA Plane1 Moment   = -148.544
    Output Vector 3015     - Beam EndA Plane2 Moment   = 176.925
    Output Vector 3016     - Beam EndB Plane1 Moment   = -68.7482
    Output Vector 3017     - Beam EndB Plane2 Moment   = 110.182
    Output Vector 3018     - Beam EndA Pl1 Shear Force = -7.42945
    Output Vector 3019     - Beam EndA Pl2 Shear Force = 6.21418
    Output Vector 3022     - Beam EndA Axial Force     = -2057.06
    Output Vector 3024     - Beam EndA Torque Force    = -18.2012

Element 17
  Output Set 8 - T1nDspc 772.5Up 618.0Aft
    Output Vector 3014     - Beam EndA Plane1 Moment   = -192.752
    Output Vector 3015     - Beam EndA Plane2 Moment   = 53.1972
    Output Vector 3016     - Beam EndB Plane1 Moment   = -246.843
    Output Vector 3017     - Beam EndB Plane2 Moment   = 295.988
    Output Vector 3018     - Beam EndA Pl1 Shear Force = 5.14122
    Output Vector 3019     - Beam EndA Pl2 Shear Force = -23.0766
    Output Vector 3022     - Beam EndA Axial Force     = -2244.89
    Output Vector 3024     - Beam EndA Torque Force    = 0.80322

Element 18
  Output Set 8 - T1nDspc 772.5Up 618.0Aft
    Output Vector 3014     - Beam EndA Plane1 Moment   = 241.002
    Output Vector 3015     - Beam EndA Plane2 Moment   = 193.433
    Output Vector 3016     - Beam EndB Plane1 Moment   = 195.879
    Output Vector 3017     - Beam EndB Plane2 Moment   = 92.5936
    Output Vector 3018     - Beam EndA Pl1 Shear Force = 4.3472
    Output Vector 3019     - Beam EndA Pl2 Shear Force = 9.71495
    Output Vector 3022     - Beam EndA Axial Force     = 5299.27
    Output Vector 3024     - Beam EndA Torque Force    = -15.2536

Element 24
  Output Set 8 - T1nDspc 772.5Up 618.0Aft
    Output Vector 3016     - Beam EndB Plane1 Moment   = 202.157
    Output Vector 3017     - Beam EndB Plane2 Moment   = 34.1286
    Output Vector 3020     - Beam EndB Pl1 Shear Force = -168.464
    Output Vector 3021     - Beam EndB Pl2 Shear Force = -28.4405
    Output Vector 3023     - Beam EndB Axial Force     = -2101.46

Element 25
  Output Set 8 - T1nDspc 772.5Up 618.0Aft
    Output Vector 3016     - Beam EndB Plane1 Moment   = -799.533
    Output Vector 3017     - Beam EndB Plane2 Moment   = -23.8799
    Output Vector 3020     - Beam EndB Pl1 Shear Force = 666.276
    Output Vector 3021     - Beam EndB Pl2 Shear Force = 19.8999
    Output Vector 3023     - Beam EndB Axial Force     = 3410.37

Element 34
  Output Set 8 - T1nDspc 772.5Up 618.0Aft
    Output Vector 3014     - Beam EndA Plane1 Moment   = -3324.61
    Output Vector 3015     - Beam EndA Plane2 Moment   = 2659.69
    Output Vector 3016     - Beam EndB Plane1 Moment   = -2758.6
```

```
    Output Vector 3017      - Beam EndB Plane2 Moment   = 2206.88
    Output Vector 3018      - Beam EndA Pl1 Shear Force = -772.5
    Output Vector 3019      - Beam EndA Pl2 Shear Force = 618.
    Output Vector 3024      - Beam EndA Torque Force    = 2162.38
```

10.3 Trunnion

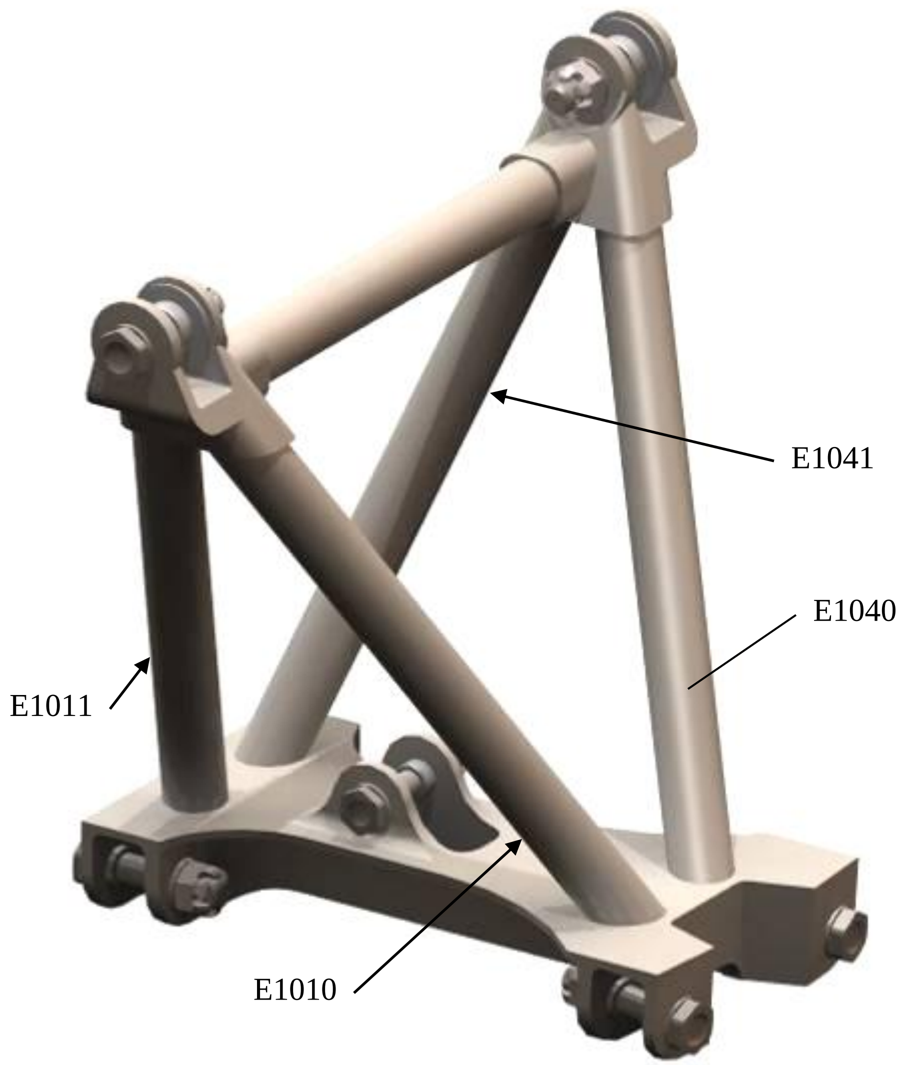


Figure 15 KA58T321100 Trunnion assy element numbers

10.3.1 KA58T321100 Assy, Trunnion landing event internal load list

The peak forces (lbf) and moments (in-lbf) in these members during the landing event are listed here.

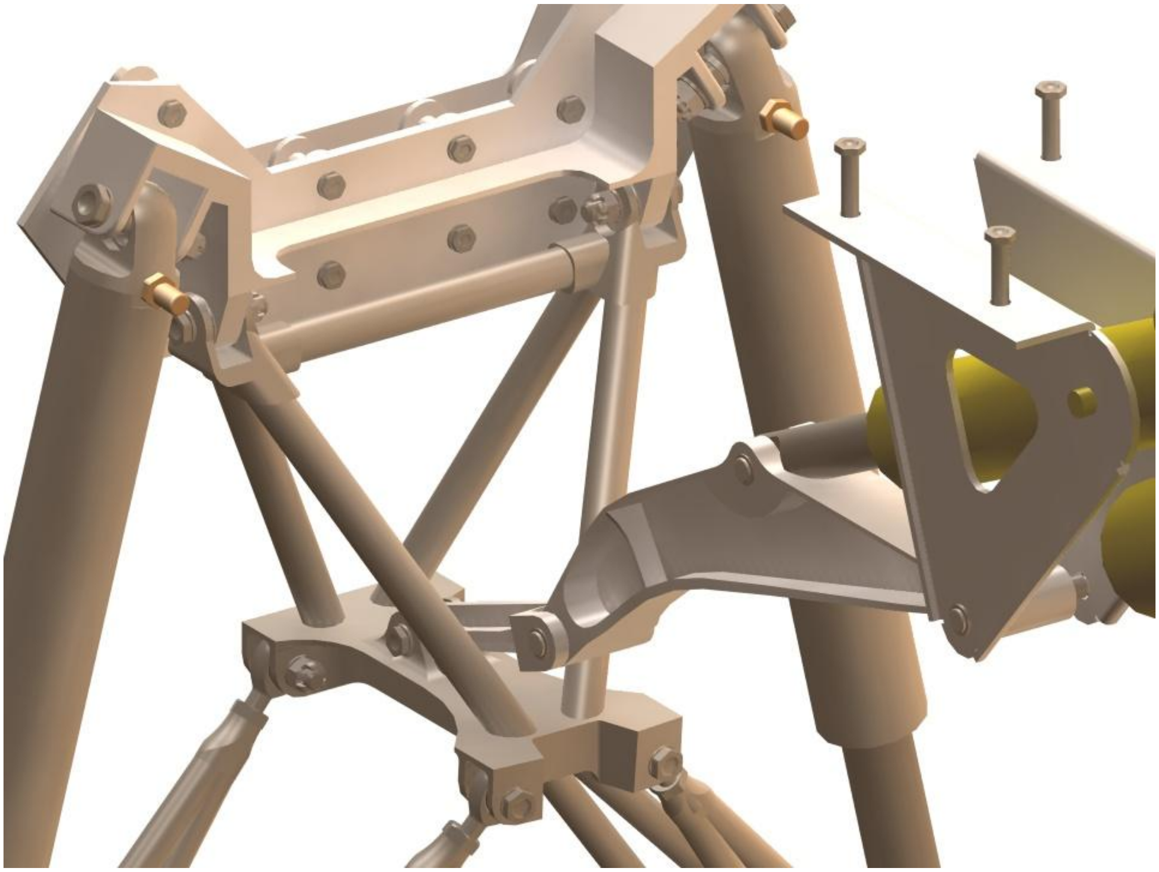
```
List Output Query
Element 1010
  Output Set 8 - T1nDspc 772.5Up 618.0Aft
```

```
    Output Vector 3014     - Beam EndA Plane1 Moment   = 144.319
    Output Vector 3015     - Beam EndA Plane2 Moment   = 286.682
    Output Vector 3016     - Beam EndB Plane1 Moment   = -3.5104
    Output Vector 3017     - Beam EndB Plane2 Moment   = -322.958
    Output Vector 3018     - Beam EndA Pl1 Shear Force = 14.8402
    Output Vector 3019     - Beam EndA Pl2 Shear Force = 61.2001
    Output Vector 3022     - Beam EndA Axial Force     = 2493.56
    Output Vector 3024     - Beam EndA Torque Force    = -147.027

Element 1011
  Output Set 8 - T1nDspc 772.5Up 618.0Aft
    Output Vector 3014     - Beam EndA Plane1 Moment   = 93.3932
    Output Vector 3015     - Beam EndA Plane2 Moment   = 351.37
    Output Vector 3016     - Beam EndB Plane1 Moment   = -274.383
    Output Vector 3017     - Beam EndB Plane2 Moment   = -376.068
    Output Vector 3018     - Beam EndA Pl1 Shear Force = 39.3709
    Output Vector 3019     - Beam EndA Pl2 Shear Force = 77.8733
    Output Vector 3022     - Beam EndA Axial Force     = -725.592
    Output Vector 3024     - Beam EndA Torque Force    = -143.82

Element 1040
  Output Set 8 - T1nDspc 772.5Up 618.0Aft
    Output Vector 3014     - Beam EndA Plane1 Moment   = 71.8801
    Output Vector 3015     - Beam EndA Plane2 Moment   = 322.893
    Output Vector 3016     - Beam EndB Plane1 Moment   = -404.555
    Output Vector 3017     - Beam EndB Plane2 Moment   = -356.142
    Output Vector 3018     - Beam EndA Pl1 Shear Force = 47.828
    Output Vector 3019     - Beam EndA Pl2 Shear Force = 68.1665
    Output Vector 3022     - Beam EndA Axial Force     = -2918.43
    Output Vector 3024     - Beam EndA Torque Force    = -128.392

Element 1041
  Output Set 8 - T1nDspc 772.5Up 618.0Aft
    Output Vector 3014     - Beam EndA Plane1 Moment   = 371.419
    Output Vector 3015     - Beam EndA Plane2 Moment   = 209.486
    Output Vector 3016     - Beam EndB Plane1 Moment   = -56.8338
    Output Vector 3017     - Beam EndB Plane2 Moment   = -245.19
    Output Vector 3018     - Beam EndA Pl1 Shear Force = 45.845
    Output Vector 3019     - Beam EndA Pl2 Shear Force = 48.6738
    Output Vector 3022     - Beam EndA Axial Force     = 4249.25
    Output Vector 3024     - Beam EndA Torque Force    = -122.389
```

10.4 Drag Brace

```
Element 1017
  Output Set 8 - T1nDspc 772.5Up 618.0Aft
    Output Vector 3015     - Beam EndA Plane2 Moment   = 1674.86
    Output Vector 3019     - Beam EndA Pl2 Shear Force = 323.839
    Output Vector 3022     - Beam EndA Axial Force     = -1736.87
```

The peak design compression force in this drag brace is 1737 lbf and the out-of-plane moment at the center hinge clevis joint is 1675 in*lbf.



10.5 Retraction

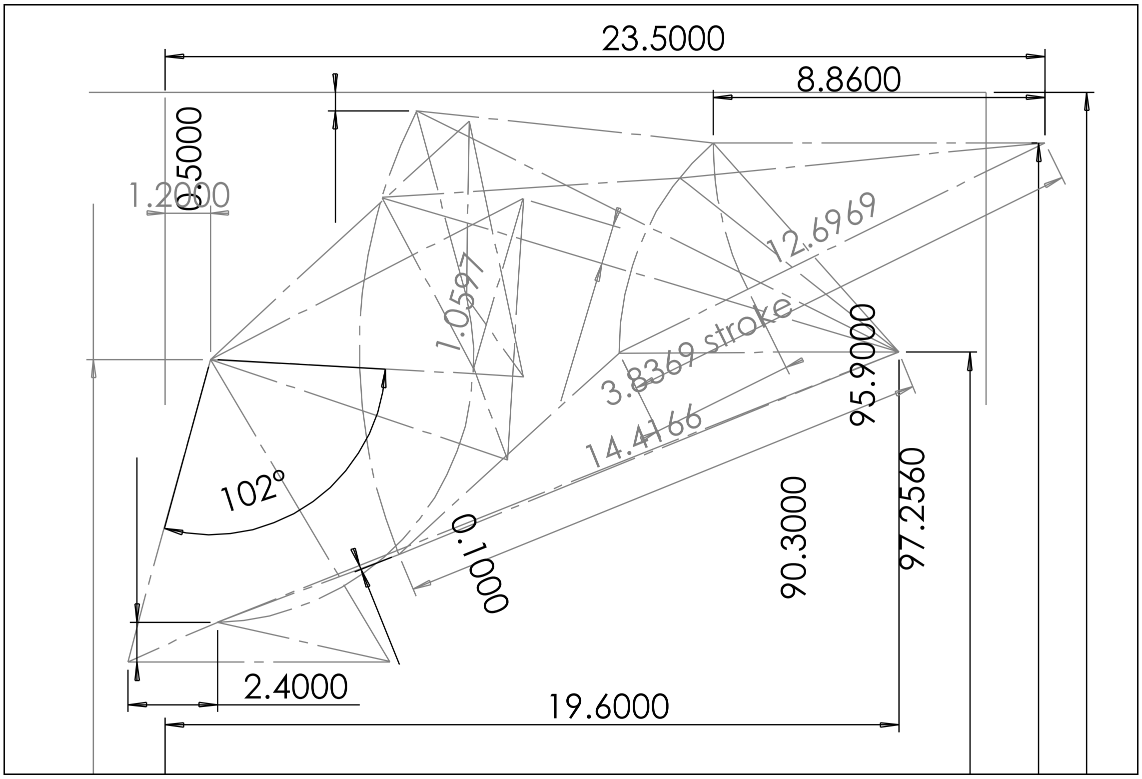


Figure 16 Retract mechanism geometry

This MLG actuator strokes 3.85" during gear retraction (and extension). Actuator speeds are available between 0.4 in/sec and 1.1 in/sec which corresponds to 9.6 sec and 3.5 sec to retract the gear. The slower speed actuator has twice the dynamic load capability; 1500 lbf & 750 lbf respectively.

Figure 17 contains a plot of this actuator load/stroke for 1g down with and without air drag force on the gear. Air drag is conservatively estimated as if a flat plate was attached to the front of the gear legs while they extend and retract. The CD is a constant 1.17 from gear full down until about 45 deg retracted where the CD jumps to about 1.6 because the back side turbulence is shed, and then the CD drops to zero as the gear approaches fully retracted. The F_{act} curve is actuator force due to 1g down only and the FactTotal curve is the 1g down and wind combined.

$$kt := 1.6896 \cdot \frac{ft}{sec} \qquad V_{ge} := 70 \cdot kt \qquad \rho := 0.002378 \cdot \frac{slug}{ft^3} \qquad q := \frac{\rho \cdot V_{ge}^{\,2}}{2} \qquad q = 0.11550034\,psi$$

The actuator force can be anywhere from 450 lbf (tension) to -350 lbf (compression) during gear retract and extend at a 1g down condition. However the wind drag estimate is easily double what it could be and therefore the wind and gravity could easily just cancel out and there be very little actuator force near the middle of the stroke. Possibly a record of the current draw will indicate the actual values during flight test.

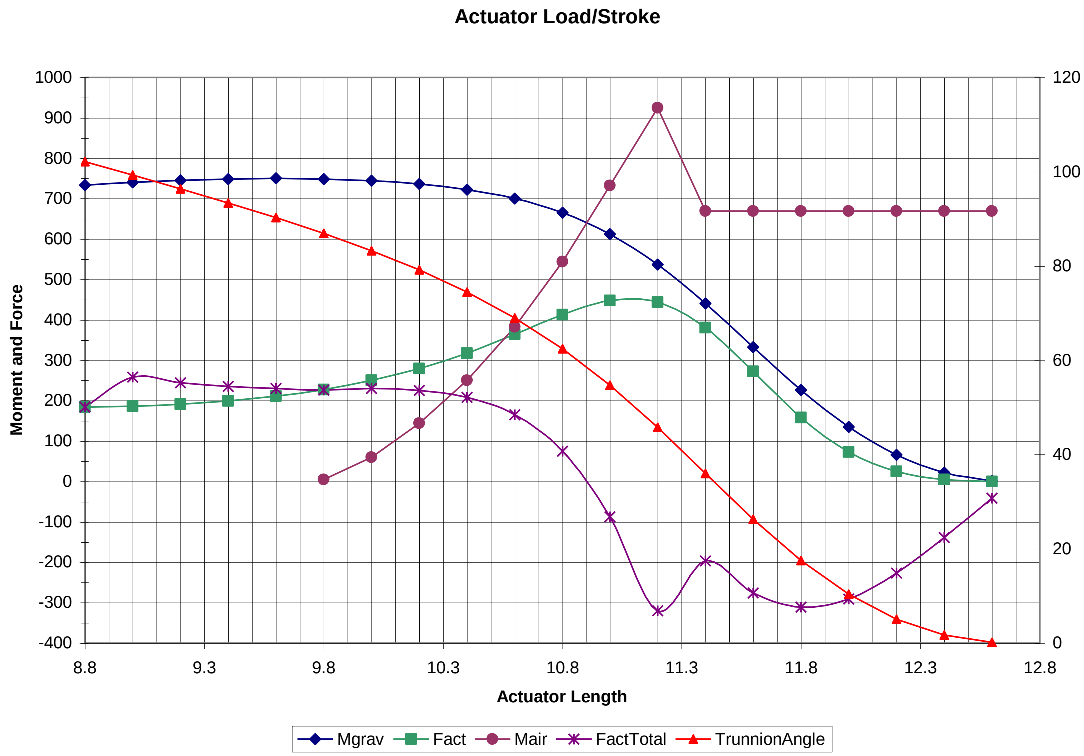


Figure 17 Actuator load / stroke

The M_{grav} curve is the trunnion moment due to 1g down and the M_{air} curve is the negative of the trunnion moment due to wind. The trunnion angle 0 is gear down and trunnion angle 103 is gear up.

11 Component Capacity

11.1 Strut Leg

These stress results are based on loads listed in §10.2.1.

11.1.1 Tension members

$Torque := -15.20 in \cdot lbf$ $F_{axial} := 5299.27 lbf$ $Moment := \sqrt{241^2 + 193^2} \cdot in \cdot lbf$

$OD := 0.625 in$ $t_{wall} := 0.035 in$ $r := \frac{OD}{2}$

$\tau := \frac{Torque}{2 \cdot \pi \cdot r^2 \cdot t_{wall}}$ $\tau = -707.776 \times 10^0 psi$ $\sigma_a := \frac{F_{axial}}{\pi \cdot \left[r^2 - (r - t_{wall})^2\right]}$ $\sigma_a = 81.686 \times 10^3 psi$

$I := \frac{\pi \cdot \left[r^4 - (r - t_{wall})^4\right]}{4}$ $\sigma_b := \frac{Moment \cdot r}{I}$ $\sigma_b = 34.061 \times 10^3 psi$ $\sigma_b + \sigma_a = 115.747 \times 10^3 psi$

Figure 18 Element 18 strut tube strength

11.1.2 Compression members

$Torque := 0.80 in \cdot lbf$ $F_{axial} := -2245 lbf$ $Moment := \sqrt{247^2 + 296^2} \cdot in \cdot lbf$

$OD := 0.625 in$ $t_{wall} := 0.035 in$ $r := \frac{OD}{2}$ $E := 30 \cdot 10^6 \cdot psi$ $Len := 14 \cdot in$

$\tau := \frac{Torque}{2 \cdot \pi \cdot r^2 \cdot t_{wall}}$ $\tau = 37.251 \times 10^0 psi$ $\sigma_a := \frac{F_{axial}}{\pi \cdot \left[r^2 - (r - t_{wall})^2\right]}$ $\sigma_a = -34.606 \times 10^3 psi$

$I := \frac{\pi \cdot \left[r^4 - (r - t_{wall})^4\right]}{4}$ $\sigma_b := \frac{Moment \cdot r}{I}$ $\sigma_b = 42.529 \times 10^3 psi$ $\sigma_b + |\sigma_a| = 77.135 \times 10^3 psi$

$P_{cr} := \frac{\pi^2 \cdot E \cdot I}{Len^2}$ $P_{cr} = 4.279 \times 10^3 lbf$

Figure 19 Element 17 strut tube strength

11.1.3 Rod Ends

11.1.4 Axle fitting

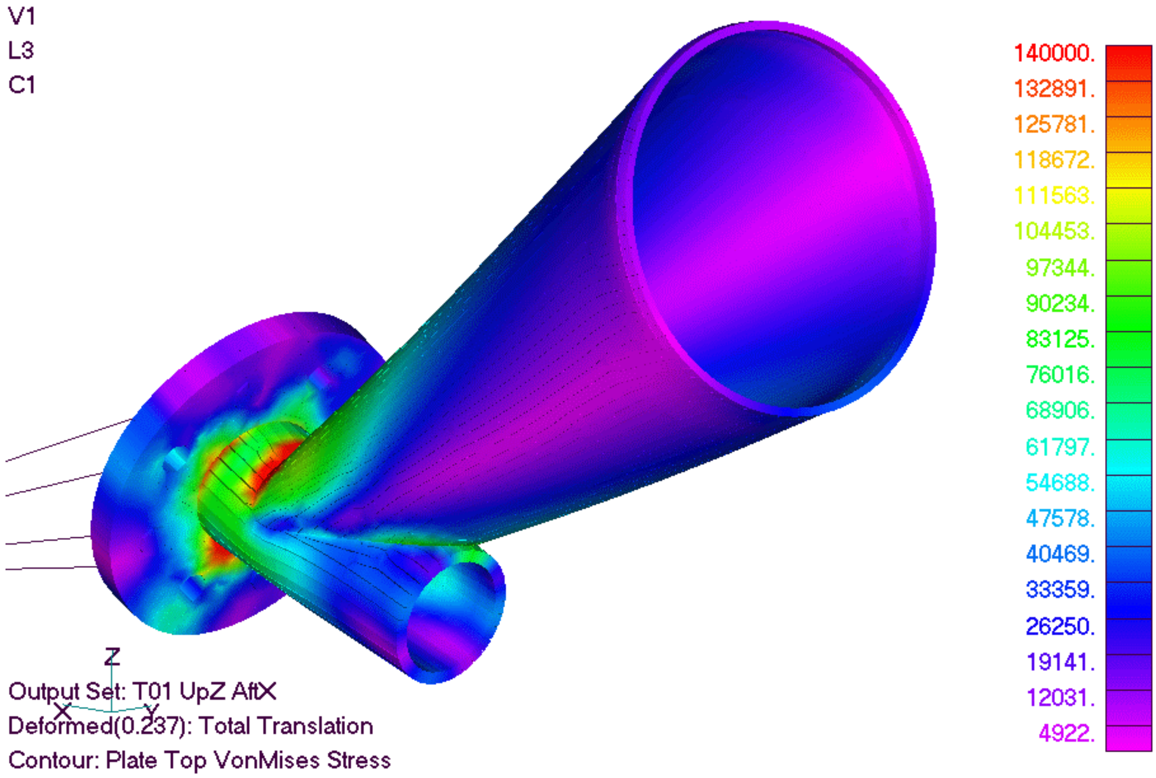


Figure 20 Axle fitting stress result

11.1.5 Clevis Joints

11.2 Trunnion

These stress results are based on loads listed in §10.3.1.

11.2.1 Tension members

$Torque := -122 \cdot in \cdot lbf \qquad F_{axial} := 4249\,lbf \qquad Moment := \sqrt{371^2 + 210^2} \cdot in \cdot lbf$

$OD := 0.75\,in \qquad t_{wall} := 0.035\,in \qquad r := \frac{OD}{2} \qquad E := 30 \cdot 10^6 \cdot psi \qquad Len := 10 \cdot in$

$\tau := \frac{Torque}{2 \cdot \pi \cdot r^2 \cdot t_{wall}} \qquad \tau = -3.945 \times 10^3\,psi \qquad \sigma_a := \frac{F_{axial}}{\pi \cdot \left[r^2 - (r - t_{wall})^2\right]} \qquad \sigma_a = 54.046 \times 10^3\,psi$

$I := \frac{\pi \cdot \left[r^4 - (r - t_{wall})^4\right]}{4} \qquad \sigma_b := \frac{Moment \cdot r}{I} \qquad \sigma_b = 31.745 \times 10^3\,psi$

$\sigma_c := \sigma_b + |\sigma_a| \qquad \sigma_c = 85.791 \times 10^3\,psi$

Figure 21 Element 1041 trunnion fitting tube strength

11.2.2 Compression members

$Torque := -128 \cdot in \cdot lbf \qquad F_{axial} := -2918\,lbf \qquad Moment := \sqrt{405^2 + 356^2} \cdot in \cdot lbf$

$OD := 0.75\,in \qquad t_{wall} := 0.035\,in \qquad r := \frac{OD}{2} \qquad E := 30 \cdot 10^6 \cdot psi \qquad Len := 10 \cdot in$

$\tau := \frac{Torque}{2 \cdot \pi \cdot r^2 \cdot t_{wall}} \qquad \tau = -4.139 \times 10^3\,psi \qquad \sigma_a := \frac{F_{axial}}{\pi \cdot \left[r^2 - (r - t_{wall})^2\right]} \qquad \sigma_a = -37.116 \times 10^3\,psi$

$I := \frac{\pi \cdot \left[r^4 - (r - t_{wall})^4\right]}{4} \qquad \sigma_b := \frac{Moment \cdot r}{I} \qquad \sigma_b = 40.153 \times 10^3\,psi$

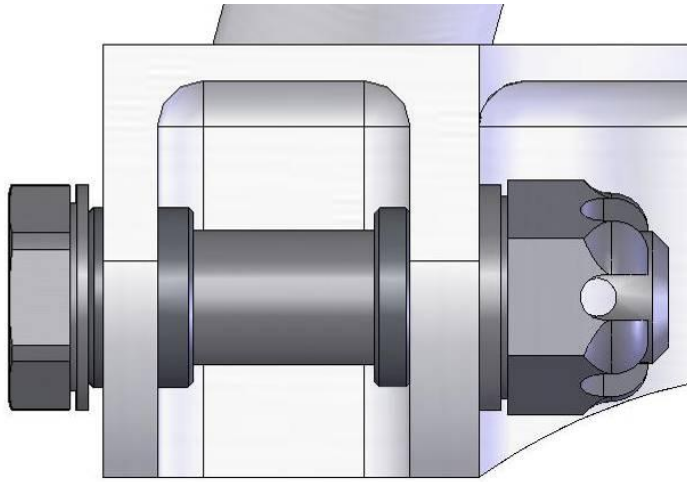
$\sigma_c := \sigma_b + |\sigma_a| \qquad \sigma_c = 77.269 \times 10^3\,psi$

$P_{cr} := \frac{\pi^2 \cdot E \cdot I}{Len^2} \qquad P_{cr} = 14.911 \times 10^3\,lbf$

Figure 22 Element 1040 trunnion fitting tube strength

11.2.3 Clevis Joints

11.2.3.1 KA58T321113 Knee Fitting



$F_{tu} := 125000\,psi$ $D := 0.375\,in$ $R := .60\,in$ $P_{axial} := 3410\cdot 1.5\,lbf$

$F_{br} := 4\cdot F_{tu}\cdot\frac{2\cdot R - D}{2\cdot R + 3\cdot D}$ $F_{br} = 1.774\times 10^{5}\,psi$ $g := 0.110\,in$ $t_{il} := 0.5\,in$

$t_{lb} := \frac{P_{axial}}{F_{br}\cdot D}$ $t_{lb} = 0.077\,in$ $t_{lb} := 0.120\,in$ $M_{bending} := P_{axial}\cdot\left(\frac{t_{lb}}{4} + \frac{g}{2} + \frac{t_{il}}{8}\right)$

$M_{bending} = 754.462\,in\cdot lbf$ $MS := \frac{1070\,in\cdot lbf}{M_{bending}} - 1$ $MS = 0.418$

11.2.3.2 KA58T321111 Clevis Fitting

```
List Output Query
Element 1008 - Trunnion / Trunnion mount clevis ftg
  Output Set 8 - T1nDspc 772.5Up 618.0Aft
    Output Vector 3018     - Beam EndA Pl1 Shear Force = -1301.83
    Output Vector 3019     - Beam EndA Pl2 Shear Force = -1403.62
    Output Vector 3022     - Beam EndA Axial Force     = -1727.1
```

$F_{tu} := 125000\,psi$ $D := 0.375\,in$ $R := .560\,in$ $P_{axial} := \sqrt{1302^2 + 1404^2}\cdot 1.5\,lbf$

$F_{br} := 4\cdot F_{tu}\cdot\frac{2\cdot R - D}{2\cdot R + 3\cdot D}$ $F_{br} = 1.659\times 10^{5}\,psi$ $g := 0.10\,in$ $t_{il} := 0.5\,in$

$t_{lb} := \frac{P_{axial}}{F_{br}\cdot D}$ $t_{lb} = 0.046\,in$ $t_{lb} := 0.070\,in$ $M_{bending} := P_{axial}\cdot\left(\frac{t_{lb}}{4} + \frac{g}{2} + \frac{t_{il}}{8}\right)$

$M_{bending} = 373.384\,in\cdot lbf$ $MS := \frac{1070\,in\cdot lbf}{M_{bending}} - 1$ $MS = 1.866$

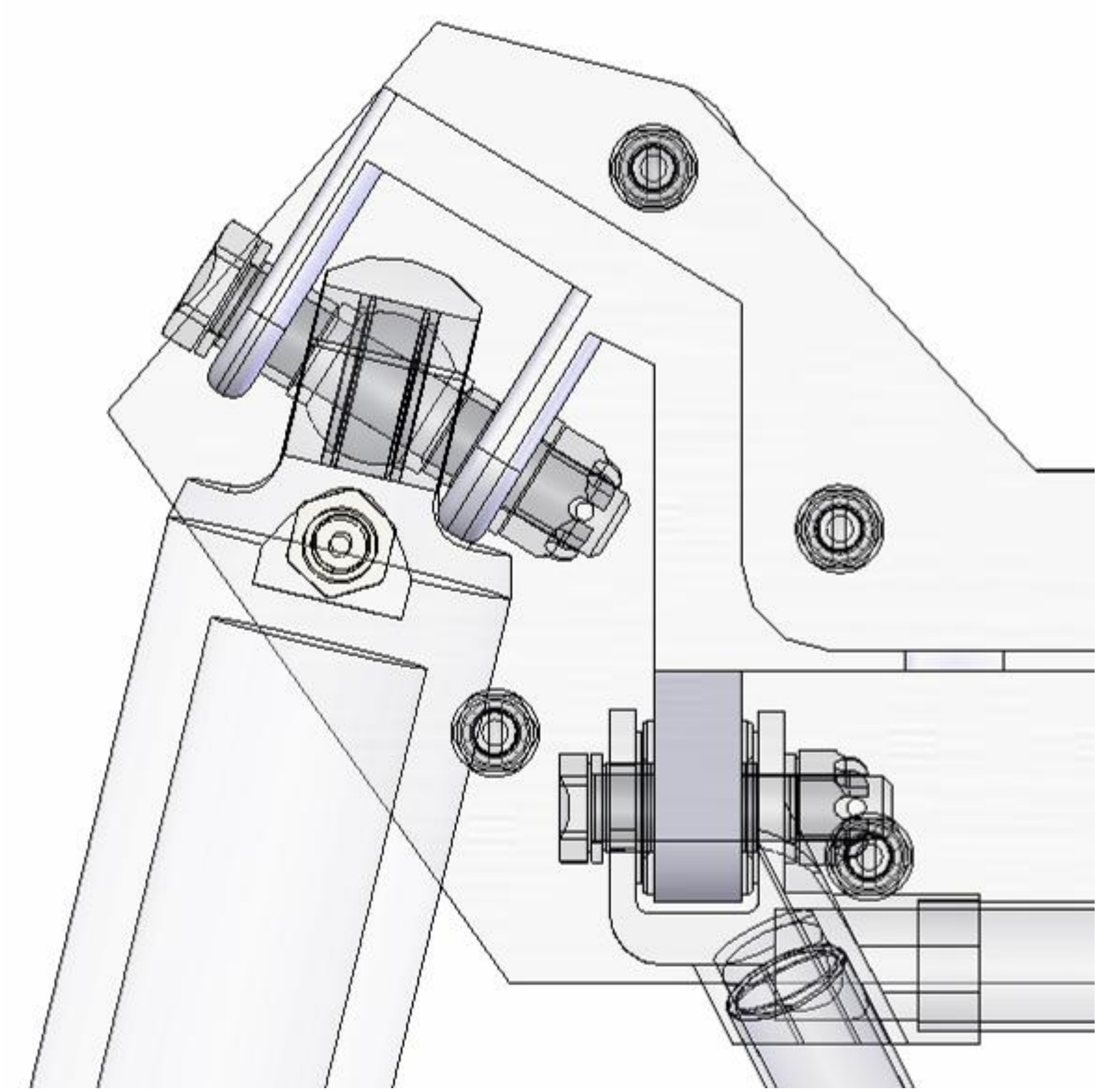


Figure 23 Trunnion and Shock mount clevis joints

11.3 KA58T321600 Trunnion Support Assy

11.3.1 Shock mount clevis joint

This clevis joint is also pictured in Figure 23. A peak design load for the shock absorber is 2000 lbf.

$F_{tu} := 62000\,psi \quad D := 0.4375\,in \quad R := .50\,in \quad P_{axial} := 2000 \cdot 1.5\,lbf$

$F_{br} := 4 \cdot F_{tu} \cdot \frac{2 \cdot R - D}{2 \cdot R + 3 \cdot D} \quad F_{br} = 6.032 \times 10^{4}\,psi \quad g := 0.3250\,in \quad t_{il} := 0.619\,in$

$t_{lb} := \frac{P_{axial}}{F_{br} \cdot D} \quad t_{lb} = 0.114\,in \quad t_{lb} := 0.150\,in \quad M_{bending} := P_{axial} \cdot \left(\frac{t_{lb}}{4} + \frac{g}{2} + \frac{t_{il}}{8} \right)$

$M_{bending} = 832.125\,in \cdot lbf \quad MS := \frac{1700\,in \cdot lbf}{M_{bending}} - 1 \quad MS = 1.043$

Figure 24 Shock upper clevis joint strength

11.4 KA58T321250 Shock Absorber

11.4.1 Shim stack and bleed hole adjustments

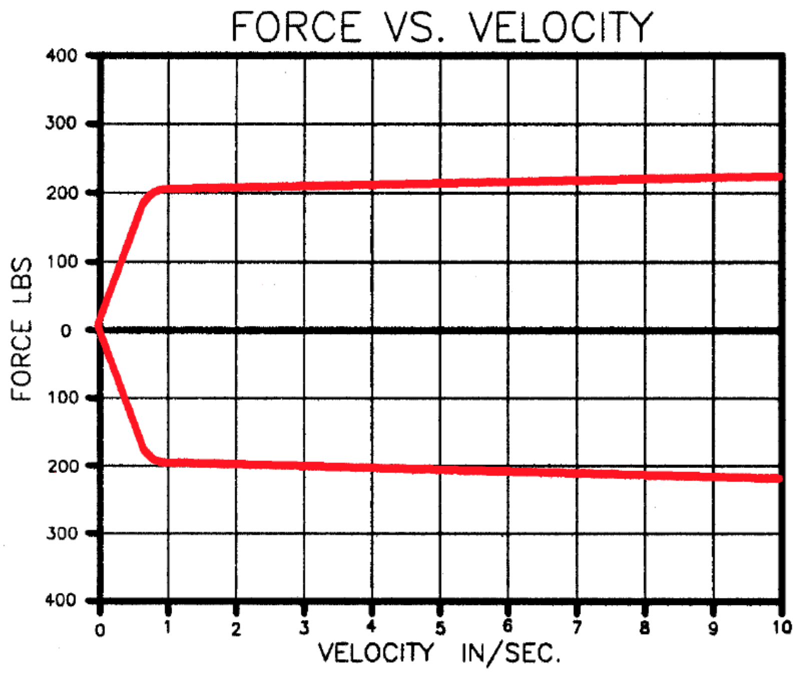


Figure 25 Digressive preloaded valve shim force / velocity plot

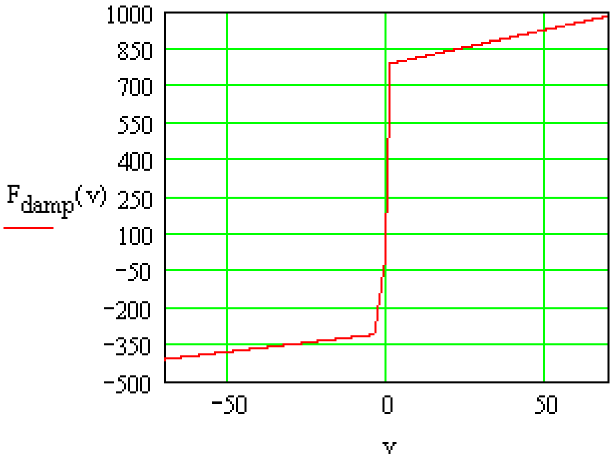


Figure 26 Digressive (compression) / Linear (rebound) shim stack

We see in Figure 27 that using digressive shims (Figure 26) can spread out the deceleration resulting in a lower peak, as compared to linear dampening without any preload threshold (as in Figure 10 on page 11). Using preloaded shims can let the bounce nearly stop at a position other than the normal static position and then over a period of several seconds it settles at the static position.

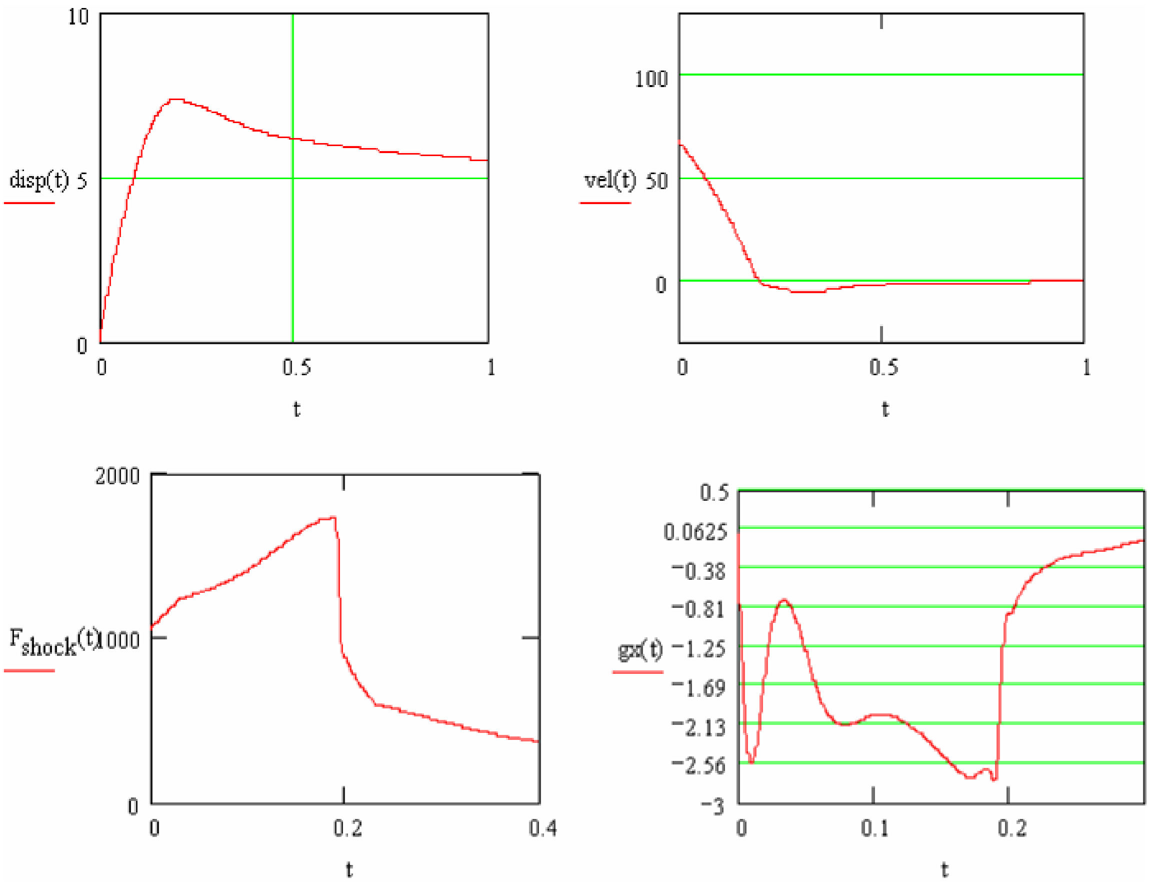


Figure 27 Landing response with preloaded shims

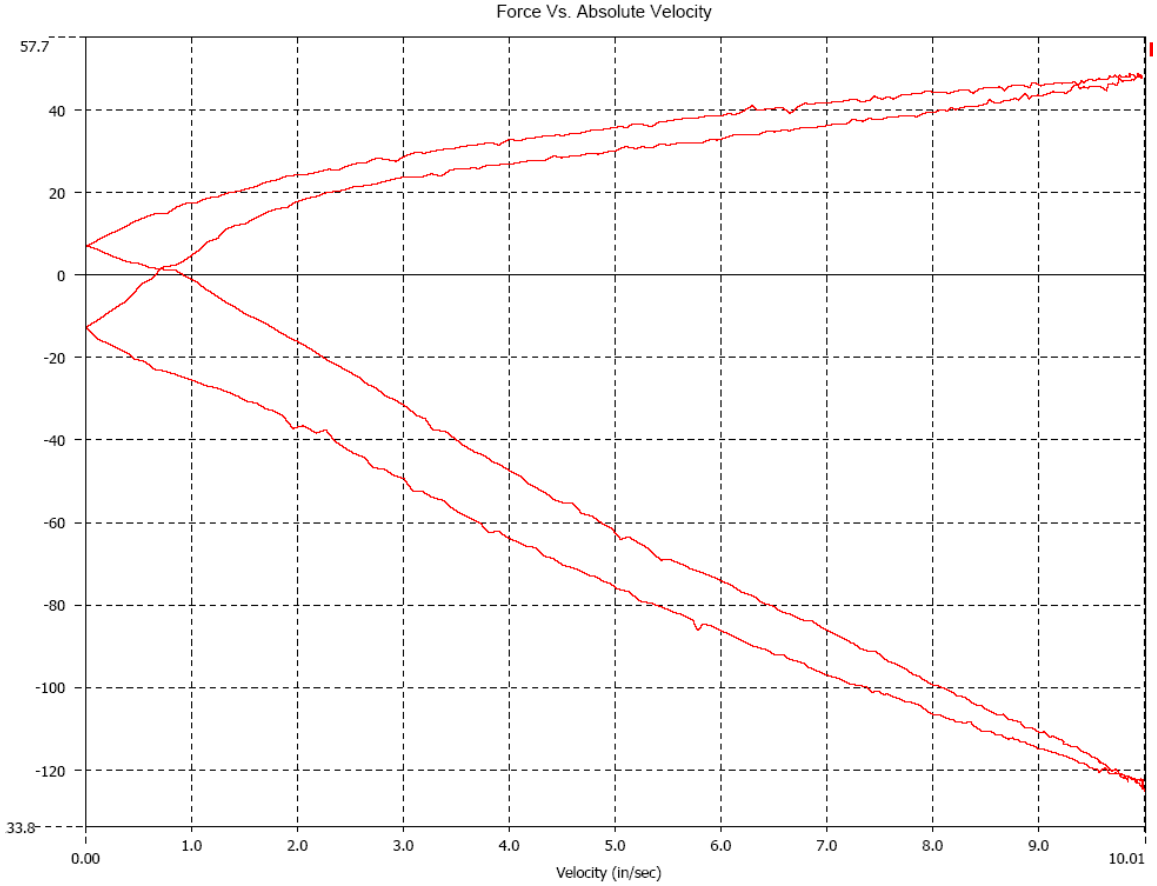


Figure 28 Air Shock 2.0 (1.24 shaft) dyno result

11.4.2 Oil level and initial gas pressure adjustments

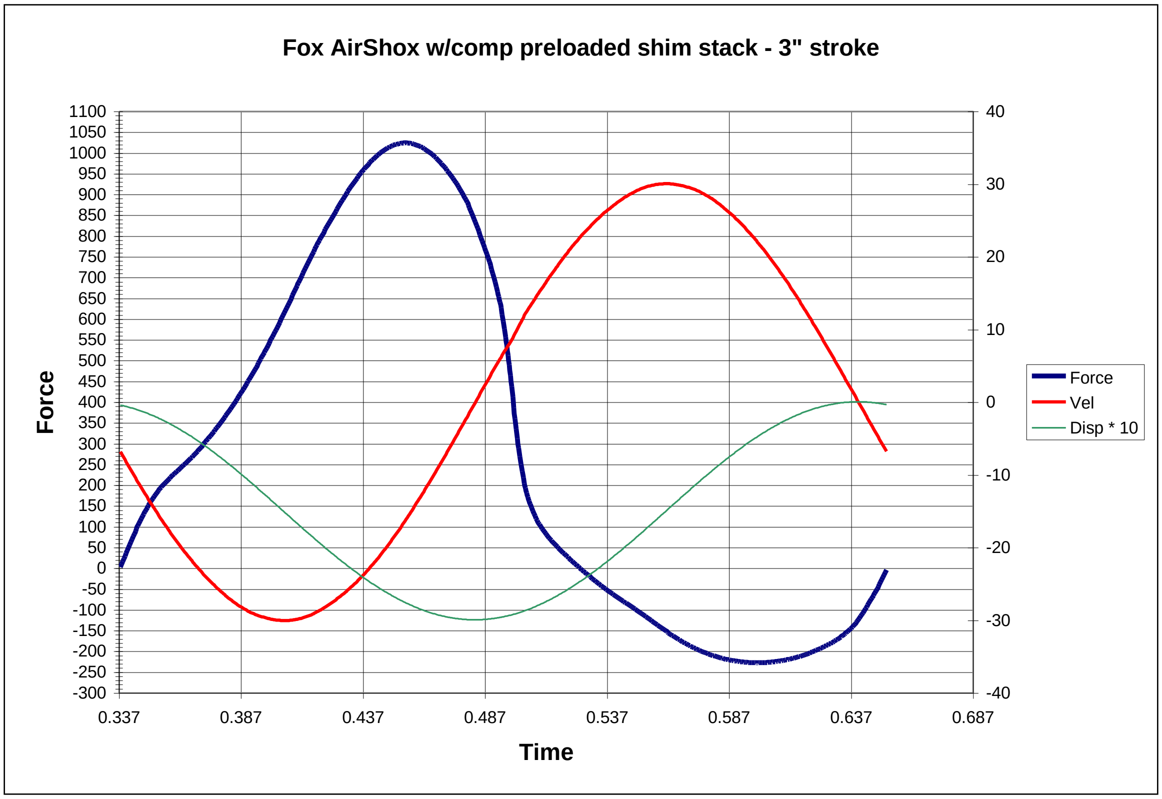


Figure 29 Dyno result for 2.0 Fox Shox w/ preloaded comp shim stack

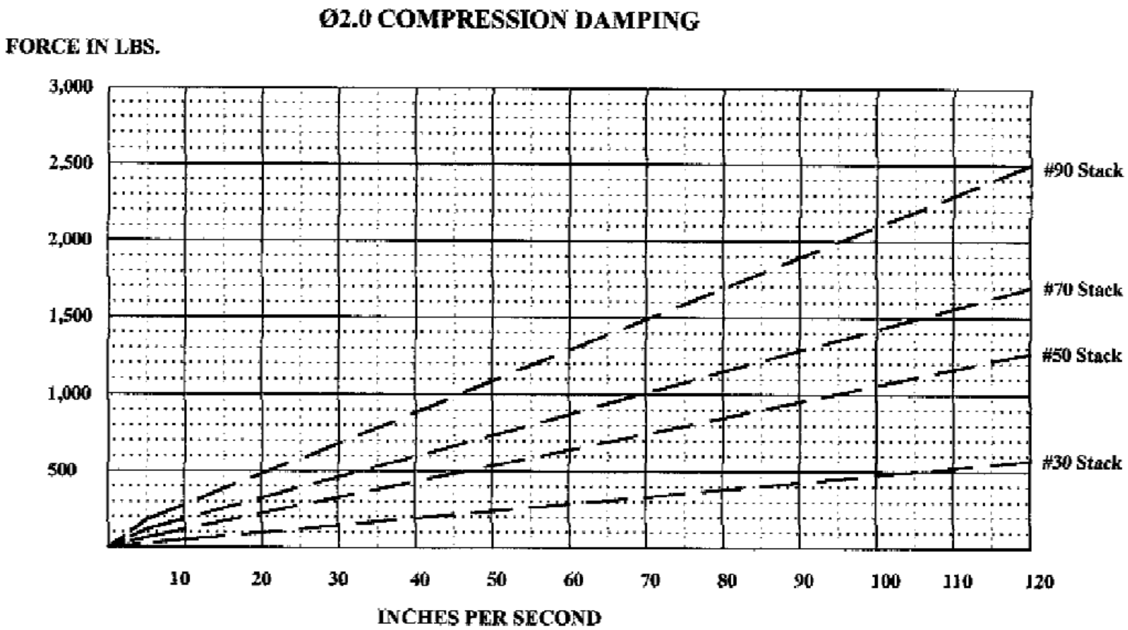


Figure 30 Fox 2.0 (0.625 dia shaft) compression dyno results

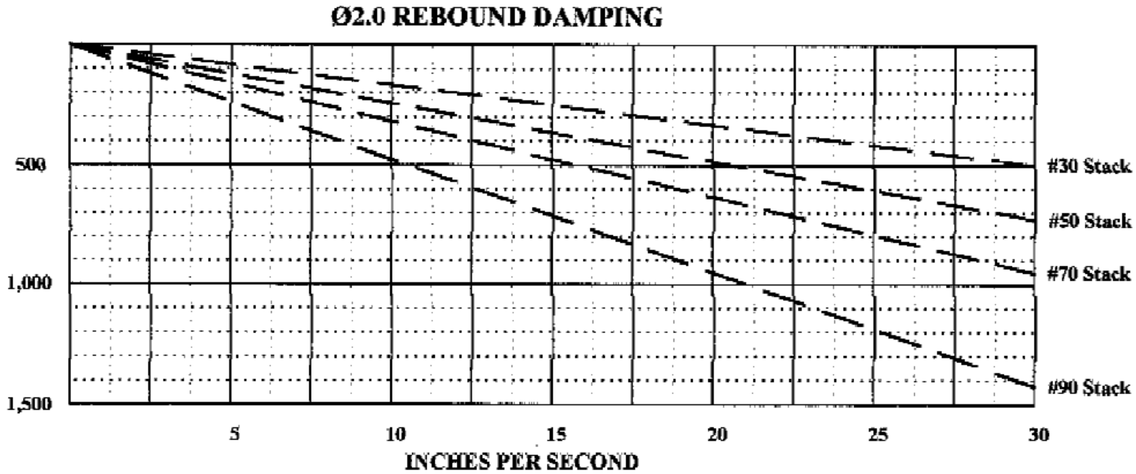


Figure 31 Fox 2.0 (0.625 dia shaft) rebound dyno results

11.4.3 Dust and sand protection

The shafts on the shocks and actuator are protected from dirt and sand with rubber boots.

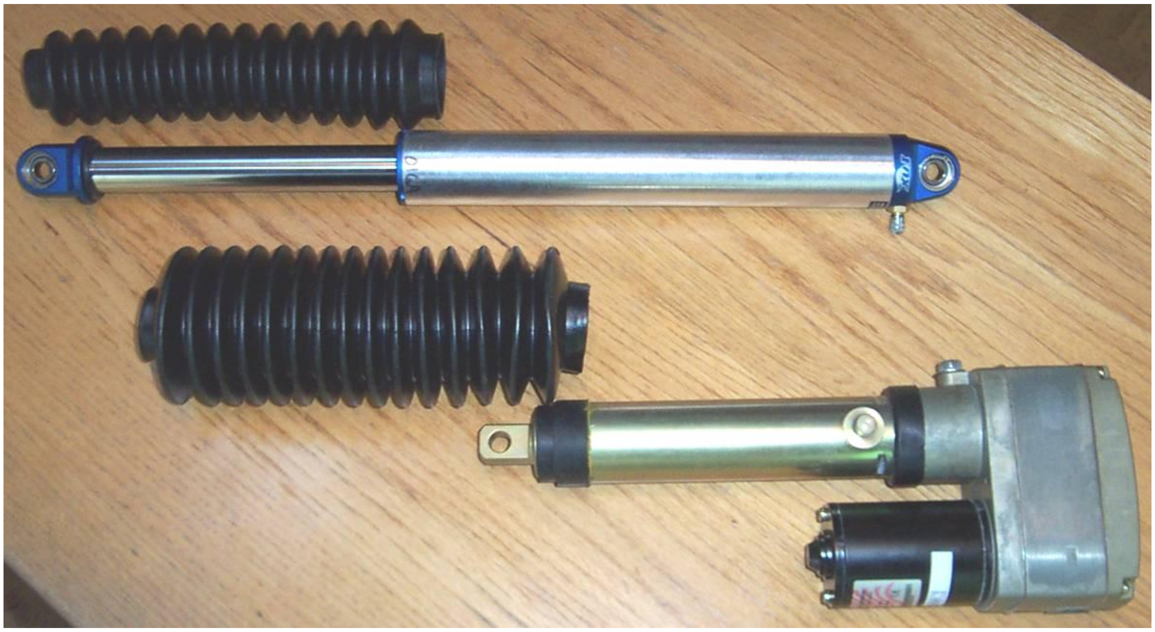


Figure 32 Protective accordion boots for shock and actuator

Spherical rod end type bearings are used on each end of the shock absorber and also at the strut lever hinge (Figure 14 on page 15). These type bearings have the outer TFE lined race preloaded tight around the inner steel ball. This tight fit helps to exclude dirt and sand from the bearing in dirty environments.

11.5 Drag Brace

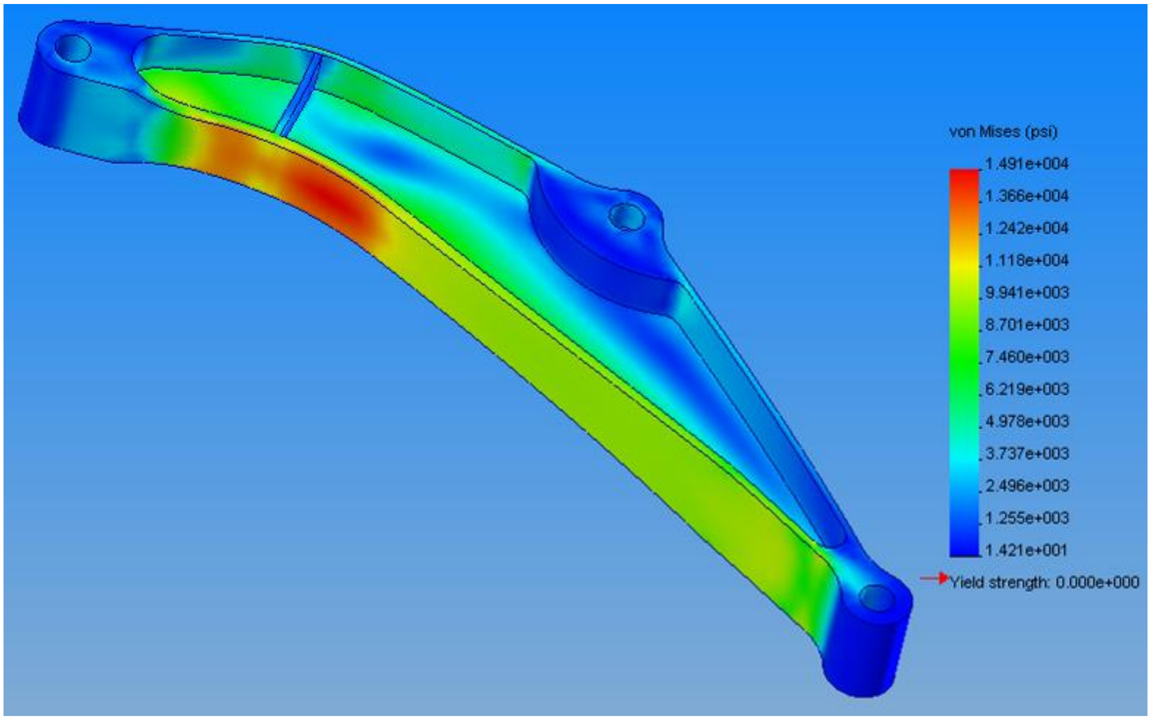


Figure 33 Peak design stress in Aft Drag Brace

11.6 Retraction Actuator

Both actuator models, described in §10.5 on page 19, have the same 3000 lbf static hold capability, which is sufficient to hold the gear in the retracted position during flight.. Either speed actuator has sufficient force to move the MLG for the 1g load conditions. Now if we need to retract the gear during a 2g pullup then the slower actuator (lower gearing) would be needed, unless the higher speed actuator was allowed to stall until the vertical acceleration subsided, and then the retraction would continue. I guess a wind gust could occasionally create a 2g pullup condition.

11.7 Material Properties

11.7.1 AISI 4130 Properties

Alloy [For specification see Tables 2.3.1.0(a) and (b)] . .	AISI 4130, 4135, 8630, and 8735		See steels listed in Table 2.3.0.2 for the applicable strength levels					
Form	Sheet, strip, plate, tubing		All wrought forms					
Condition	N		Quenched and tempered[a]					
Thickness or diameter, in. . .	≤0.187	>0.187	See Table 2.3.0.2					
Basis	S	S	S	S	S	S	S	S
Mechanical Properties:								
F_{tu}, ksi	95	90	125	140	150	160	180	200
F_{ty}, ksi	75	70	100	120	132	142	163	176
F_{cy}, ksi	75	70	109	131	145	154	173	181
F_{su}, ksi	57	54	75	84	90	96	108	120
F_{bru}, ksi:								
(e/D = 1.5)	...	...	194	209	219	230	250	272
(e/D = 2.0)	200	190	251	273	287	300	326	355
F_{bry}, ksi:								
(e/D = 1.5)	...	...	146	173	189	202	230	255
(e/D = 2.0)	129	120	175	203	218	231	256	280
e, percent	See Table 2.3.1.0(d)		See Table 2.3.1.0(e)					
E, 10^3, ksi	29.0							
E_c, 10^3 ksi	29.0							
G, 10^3, ksi	11.0							
μ	0.32							
Physical Properties:								
ω, lb/in.^{3}	0.283							
C, K, and α	See Figure 2.3.1.0							

[a]Values in these columns are applicable only to steels for which the indicated F_{tu} has been substantiated through adequate quality-control inspection testing.

Figure 34 AISI 4130 Properties

11.7.2 Aluminum 7075-T7351 Properties

Temper	T73	T7351												
Thickness, in.	0.040-0.249	0.250-0.499	0.500-1.000		1.001-1.500		1.501-2.000		2.001-2.500		2.501-3.000		3.001-3.500	3.501-4.000
Basis	S	S	A	B	A	B	A	B	A	B	A	B	S	S
Mechanical Properties:														
F_{tu}, ksi:														
L	67	68	68	70	67	69	66	68	65	67	63	65	62	60
LT	67	69	69	71	68	70	67	69	66	68	64[c]	66	63	61
ST	...	...	...	...	...	...	63	65	62	64	60	62	59	57
F_{ty}, ksi:														
L	56	57	57	59	57	59	55	57	52	55	49	53	49	48
LT	56	57	57	59	57	59	55	57	52[b]	55	49[c]	53	49	48
ST	...	...	...	...	...	...	52	54	49	52	47	50	47	46
F_{cy}, ksi:														
L	55	56	56	58	56	58	53	55	50	53	47	51	47	45
LT	58	59	59	61	59	61	57	59	54	57	51	55	51	50
ST	...	...	...	...	...	...	59	61	55	58	51	55	50	48
F_{su}, ksi	38	38	38	39	38	40	39	40	39	40	38	39	38	37
F_{bru}[a], ksi:														
(e/D=1.5)	105	102	103	106	103	106	102	106	102	105	100	103	99	96
(e/D=2.0)	134	131	132	136	132	136	132	136	131	135	128	132	127	124
F_{bry}[a], ksi:														
(e/D=1.5)	84	79	81	83	83	86	82	85	79	83	76	81	76	76
(e/D=2.0)	102	95	97	100	99	102	97	101	93	99	89	96	89	88
e, percent (S-basis):														
LT	8	7	7	...	6	...	6	...	6	...	6	...	6	6
E, 10^3 ksi	10.3	10.3												
E_c, 10^3 ksi	10.5	10.6												
G, 10^3 ksi	3.9	3.9												
μ	0.33	0.33												
Physical Properties:														
ω, lb/in.^{3}	0.101													

Figure 35 Aluminum 7075-T7351 Properties