LAT-PR-xxxxx:

TKR-Grid I/F Anomaly Structural Assessment

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Agenda: TKR-Grid I/F Anomaly Structural Assessment

- Loads Assessment
  - Current Loads Assumptions – a look at Grid analysis, TKR analysis and test loads
  - True Loads Experienced at Test – a study in probability density
- Grid Analysis Reprised
  - Margins of Safety Summary for bearing of shoulder bolt on Grid, with expected design dimensions (shoulder/thread engagement)
  - Adjusted margins of safety for as-tested design
- Shoulder Bolt Bending Loads
  - Bolt strength
  - Bolt margins under instantaneous load
  - Bolt margins under cyclic load
  - Unique loading due to 2-thread engagements / Helicoil pullout strength
- System Behavior due to dead band, slippage and impacting
  - Dead band, i.e. TKR alignment and positional uncertainty
  - Slippage, i.e. relative motion between the two mating surfaces after the frictional capacity is exceeded
  - Impacting, i.e. two initially separated surfaces come into contact and exchange momentum
- Conclusions, recommendations and Further Work

Loads Assessment

- **Current Loads Assumptions – a look at Grid analysis, TKR analysis and test loads**
  - **New CLA derived loads are most realistic loads available**
    - **The maximum TKR corner flexure loads from September 2003 CLA**
      - **S max = 691 N**
      - **Fz max = 945 N**

      } **1171 N (1303 N NTE mass)**
    - **With 1.1133 factor applied to achieve max launch mass, Fmax = 1303 N**
  - **Flight loads are significantly more benign than the random vibration test loads.**
    - **The maximum TKR attachment load due to 68 flight load cases**

      2.77x higher than CLA
      - **Fx max = 1642 N**
      - **Fy max = 1615 N**
      - **Fz max = 2280 N**

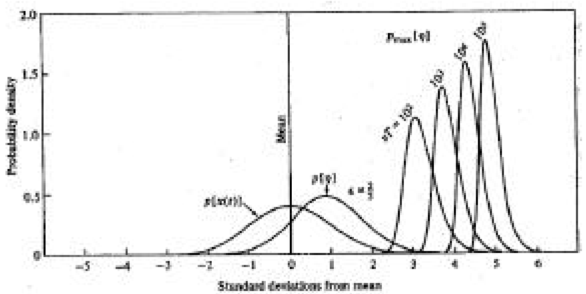
      } **3241 N (3608 N NTE mass)**
    - **With 1.1133 factor applied to achieve max launch mass, Fmax = 3608 N**
  - **Loads induced at a random test are notoriously high due to high amplification above spec levels.**
    - **Hytec design loads were governed by static equivalent loads due to random vibration testing**

      3.21x higher than CLA
      - **3-s design load of 27g lateral, plus shear component added**
      - **4235 N (952 lb$_f$) shear load on fastener**
      - **During test, "notching" was allowed, 3-s load was 24g**

      } **3764 N**
  - **True Loads Experienced at Test – a study in probability density**
    - **For any instantaneous response, 3-s load covers 99.87% of peaks**
    - **As total time of exposure increases, 3-s no longer covers 99.87% of peaks**
    - **From Clough, Dynamics of Structures, the probability wrt number of standard deviations can be observed as**

$$F_e(n_s) = \exp\left[-N \cdot \exp\left(-\frac{n_s^2}{2} \right) \right]$$

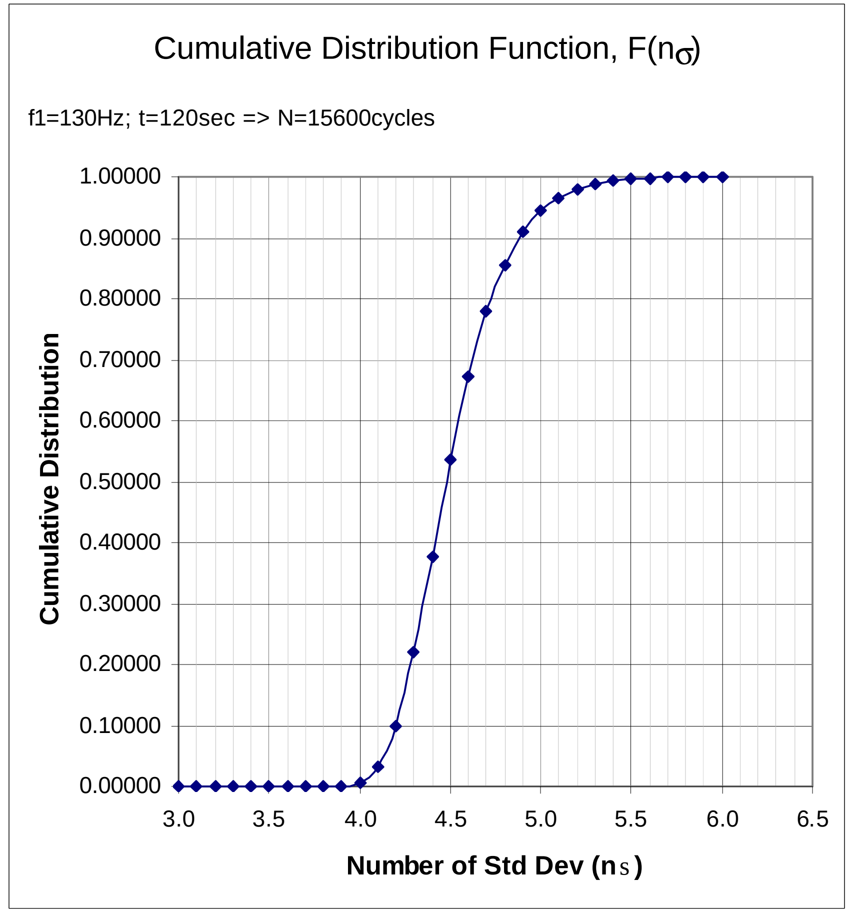
Loads Assessment (cont.)



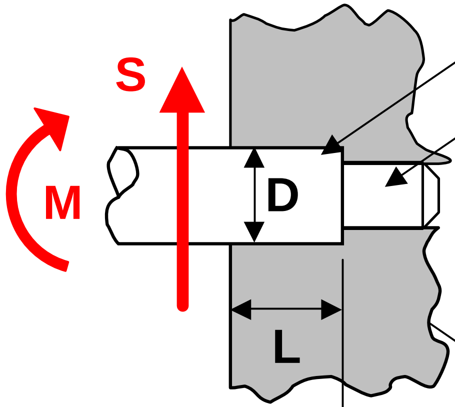
$$F_e(n_s) = \exp\left[-N \cdot \exp\left(-\frac{n_s^2}{2}\right)\right]$$

- The cumulative distribution function depends on
  - f1 = frequency of primary mode
  - t = duration
  - N = number of positive maxima = f1 X t
  - ns = number of standard deviations
- This function is plotted at right based on our observed test parameters
  - f1 = 130 Hz
  - t = 120 s
  - N = f1 X t = 15600 cycles
  - ns = range from 3.0 to 6.0 shown
- The probability of choosing an enveloping load for
  - 3-s is 0.000%, i.e. 100% chance to hit 3-s
  - 4-s is 0.534%, i.e. 99.466% chance to hit 4-s
  - 5.8-s is 99.923%, which meets our goal to envelop 99.87% of all peaks over duration
- If we apply 5.8-s to the Hytec 1-s load (1412 N),
  - Peak design load = 8190 N

7.00x higher than CLA!



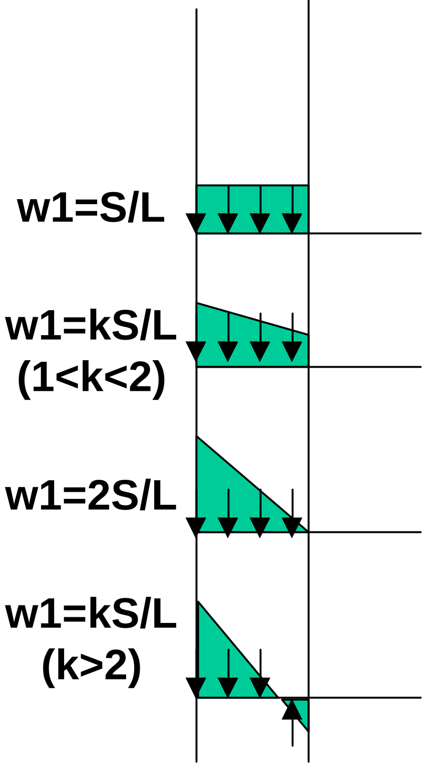
Shoulder Bolt Bearing Calculation Assumptions



AL6061-T6 Bearing Strength
(e/D = 1.5): Fby = 53 ksi; Fbu = 69 ksi
(e/D = 2.0): Fby = 61 ksi; Fbu = 90 ksi

Smax = 811 lbf = 3.61kN
M = 0 N-m
L = 0.197 in = 5 mm
D = 1/4 in = 6.35 mm

Load distributions considered



Distribution 1 – Uniform through depth – UNCONSERVATIVE.
This distribution idealizes the bearing load of the pin on the hole, but is valid for short pins (L/D is a small number). In this case, L/D is 0.89, which is not small.

Distribution 2 – Trapezoidal; Linear varying through depth – REALISTIC.
This distribution is probably the most realistic case. However, there is not a clear method of calculating w1 and w2.

Selected Method

Distribution 3 – Triangular; Linear varying through depth – CONSERVATIVE.
This distribution represents the critical pin depth where less engagement would result in a trapezoidal distribution and more engagement would result in pin bending, i.e. "Distribution 4." This distribution is conservative and easy to calculate.

Distribution 4 – Bending; Linear varying through depth – MOST CONSERVATIVE.
This distribution is well suited for longer pins where pin bending may become a factor. In this case, it is not necessary to be overly conservative.

Grid Analysis Reprised

- **Margins of Safety Summary for bearing of shoulder bolt on Grid, with expected design dimensions (shoulder/thread engagement)**

	Peak Load [N]	Diameter [mm]	Engagement [mm]	Bearing Stress [MPa]	MS y	MS u
CLA	1303	6.35	5	82.08	2.56	3.14
Grid Analysis	3608	6.35	5	227.28	0.28	0.50
Hytec Analysis	3764	6.35	5	237.10	0.23	0.43
Peak Test Load	8190	6.35	5	515.91	-0.43	-0.34

  – **Margins are positive, except for probability extreme loads**

- **Adjusted margins of safety for as-tested design (pin engagement ~0.125” as opposed to expected 0.197”)**

	Peak Load [N]	Diameter [mm]	Engagement [mm]	Bearing Stress [MPa]	MS y	MS u
CLA	1303	6.35	3.175	129.26	1.26	1.63
Grid Analysis	3608	6.35	3.175	357.91	-0.18	-0.05
Hytec Analysis	3764	6.35	3.175	373.39	-0.22	-0.09
Peak Test Load	8190	6.35	3.175	812.45	-0.64	-0.58

  – **Margins are negative, implying some onset of failure during the test**

Shoulder Bolt Bending

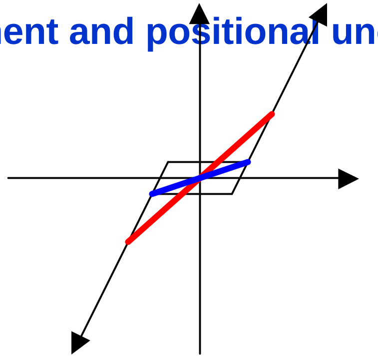
- Bolt strength
  - Catalog item: McMaster-Carr, 18-8 Stainless (70 ksi /482 MPa strength)
- What load is required to deflect the shoulder 0.004”?
  - Based on linear beam theory, the tip load required is 12656 N. This corresponds to a linear stress of 6333 MPa, which has no physical meaning
- What is the max bending stress at the root of the shoulder?

	Peak Load [N]	Diameter [mm]	Ix [m^4]	Length [mm]	Moment [N-m]	Bending Stress [MPa]	MS y
CLA	1303	4.75	2.50E-11	5	6.515	619	-0.44
Grid Analysis	3608	4.75	2.50E-11	5	18.04	1715	-0.80
Hytec Analysis	3764	4.75	2.50E-11	5	18.82	1789	-0.81
Peak Test Load	8190	4.75	2.50E-11	5	40.95	3892	-0.91

  - This shows the bolt cannot carry the bending stress associated with the loads
  - Conclusion: the should must not deform so as to put the threaded portion into bending
- Unique loading due to 2-thread engagements
  - Two thread engagement corresponds roughly to 1 DIA engagement. According to the helicoil strength document, the helicoil can withstand 2300 lbf of pullout.
  - The 70 ksi bolt is good for less than 1500 lbf

System Behavior due to dead band, slippage and impacting

- How does 4 mil diametral clearance affect overall system dynamic behavior?
  - Dead band, i.e. TKR alignment and positional uncertainty – possibility for classic spring stiffening effect



    - Based on test observations, this is not a significant effect
  - Slippage, i.e. relative motion between the two mating surfaces after the frictional capacity is exceeded
    - Clamping energy is released in the form of heat – this increases damping in the joint
  - Impacting, i.e. two initially separated surfaces come into contact and exchange momentum

Conclusions, Recommendations and Further Work

- **Conclusions**

- **Recommendations**
  - Change bolt design so shoulder bottoms out on Grid instead of through the Flexure. This will
  - Random vibration environment commonly induces loads 2X or more higher than flight loads. Is a TKR acoustic test feasible?
- **Further Work**