Investigation of Bolt Preload Relaxation for JWST Thermal Heat Strap Assembly Joints with Aluminum-1100 and Indium Gaskets

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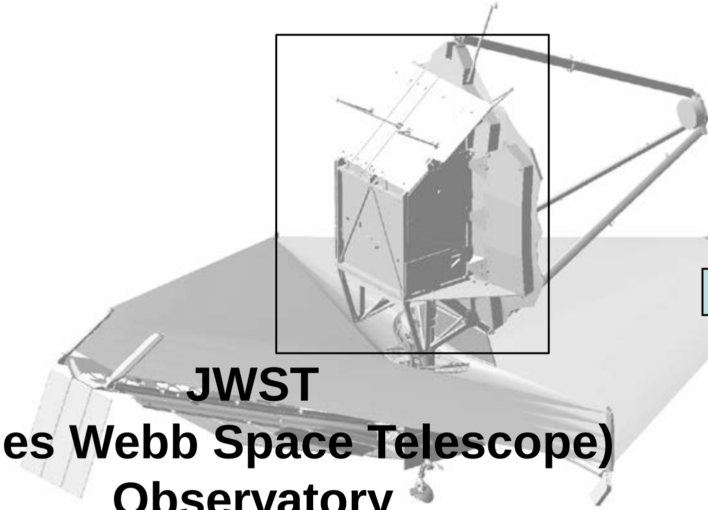
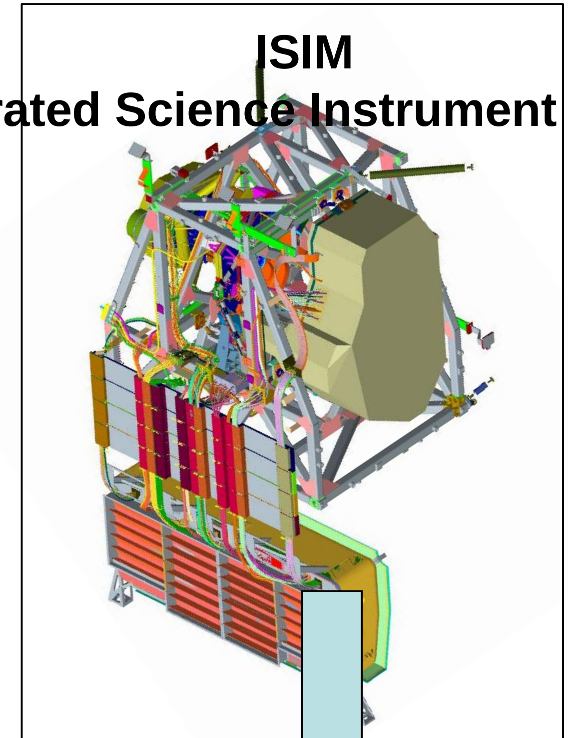
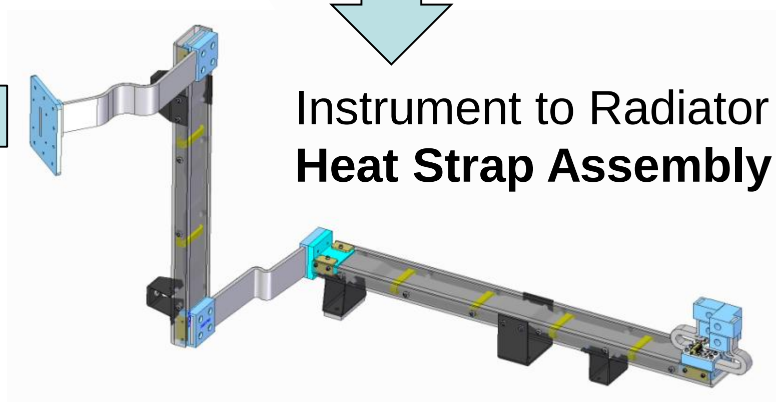
JWST and Heat Strap Bolted Joint Overview



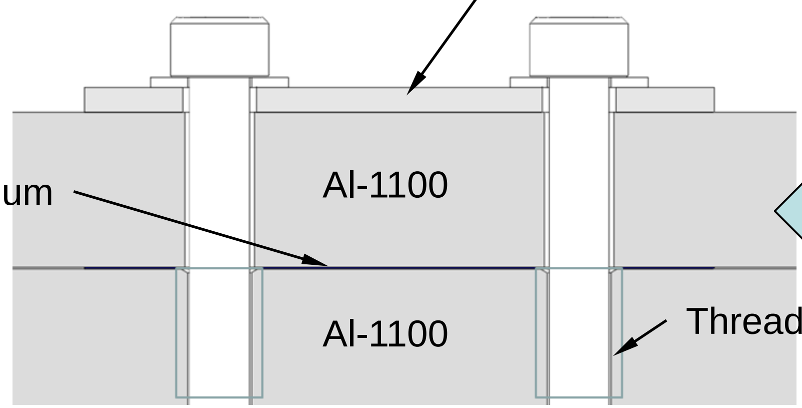
JWST
(James Webb Space Telescope)
Observatory



ISIM
(Integrated Science Instrument Module)



Instrument to Radiator
Heat Strap Assembly



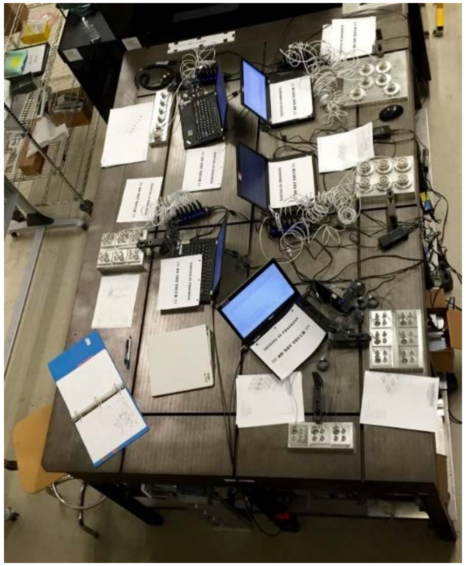
Heat Strap Bolted Joint

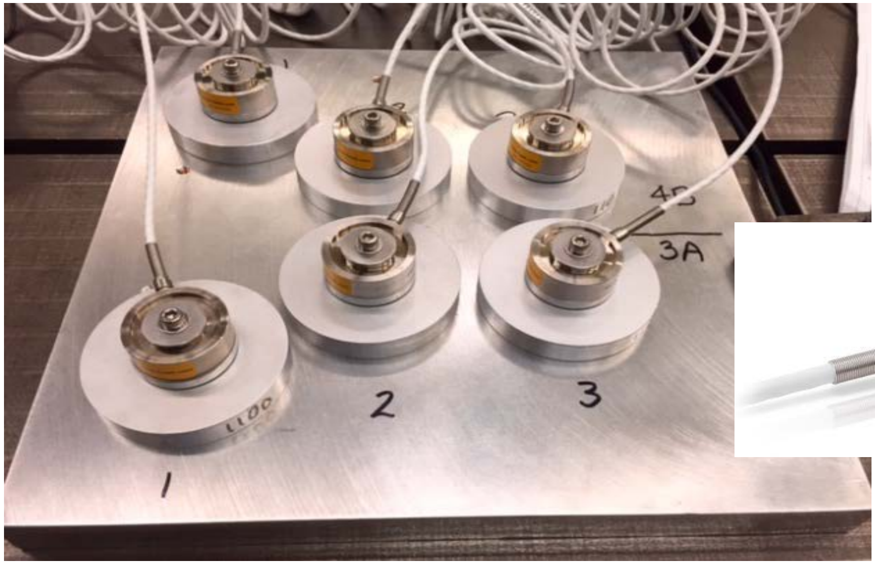
Heat Strap Bolted Joint Design Challenge

- Heat strap joints must meet minimum preload requirements on-orbit 5 years after initial torque application.
- Al-1100 joint members prohibit large preloads, drastically reducing the design space for the initial torque spec.
- Joint preload decreases under cool down and must be compensated for by temperature compensation washers.
- Several mechanisms for preload relaxation exists:
  - **Al-1100 Creep at RT**
  - **Indium Flow-out**
  - Joint Interface Embedment
- Difficult to mathematically model joint preload relaxation. A preload relaxation test and curve fitting of test data is required for predicting preload during mission life.

Preload Relaxation Test Overview

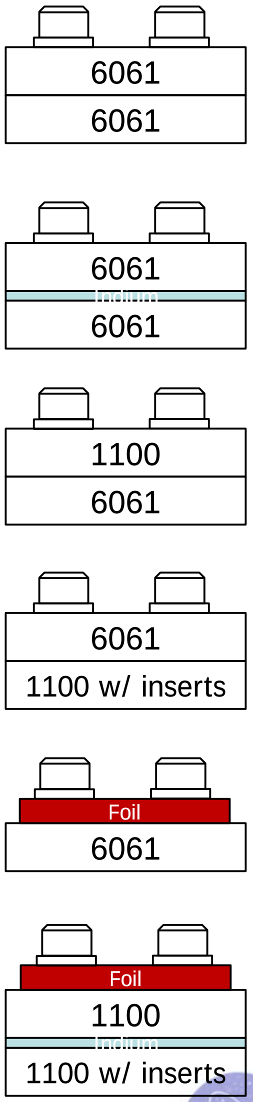
- Six coupon configurations were tested in order to isolate different drivers for preload relaxation.
- Each configuration consisted of 6 coupons (3 re-torqued after 24 hours and 3 without re-torque).
- Bolted coupons were torqued to design specs and included in-line load cells for preload monitoring.
- Preloads were sampled every 10 minutes for ~8 months.





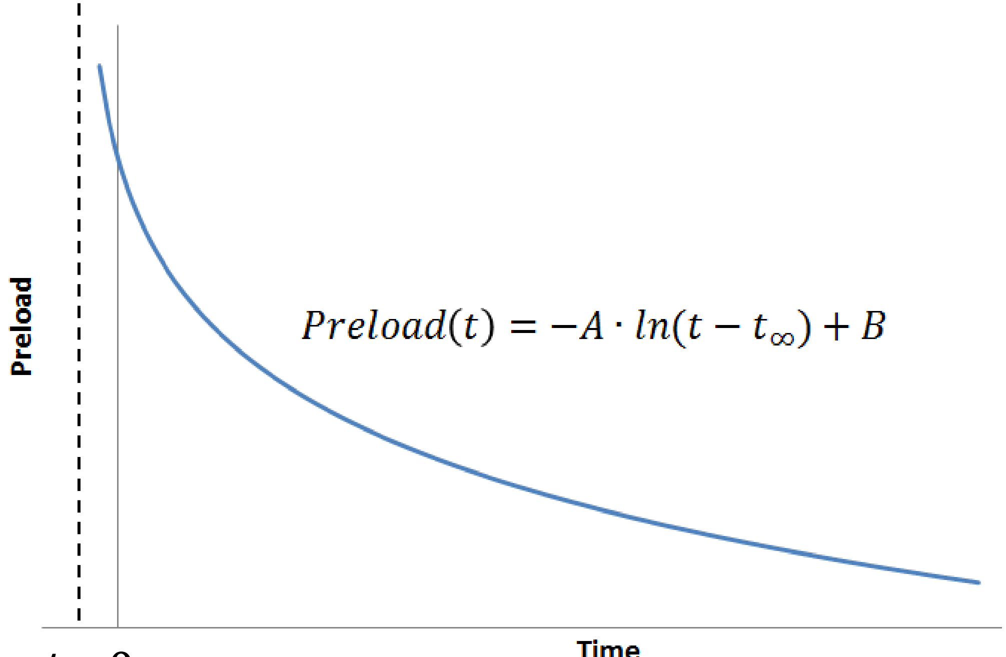
Preload Relaxation Test Configurations

- Coupons included six different configurations:
  1. **Control**: 6061 plate bolted into 6061 plate
  2. **Indium in Compression**: 0.005” Indium between 6061 plates
  3. **1100 Series Aluminum in Compression**: 1100 plate bolted into 6061 bottom plate
  4. **1100 Series Aluminum in Tension**: 6061 plate bolted into 1100 plate (threads in tension)
  5. **Aluminum Foil in Compression**: High purity Aluminum (0.040” total stack-up) in direct compression against 6061 bottom plate.
  6. **Flight**: Combines Aluminum foil in compression, 1100 plate in compression, Indium in compression, 1100 plate in tension.



Test Data Curve Fit

- The natural logarithm function proved to be the most successful function for fitting the data across the various test configurations:

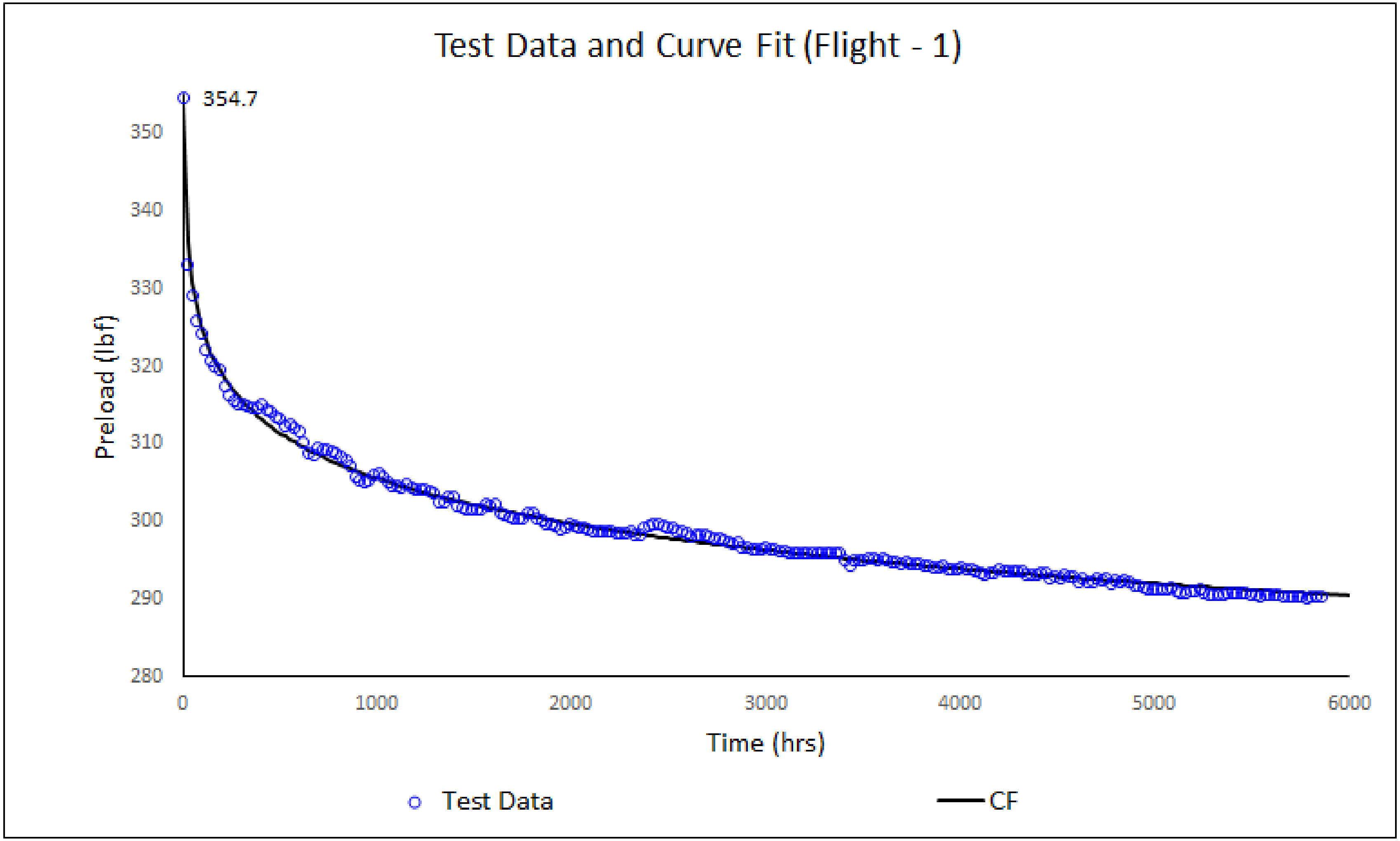


$$Preload(t) = -A \cdot ln(t - t_{\infty}) + B$$

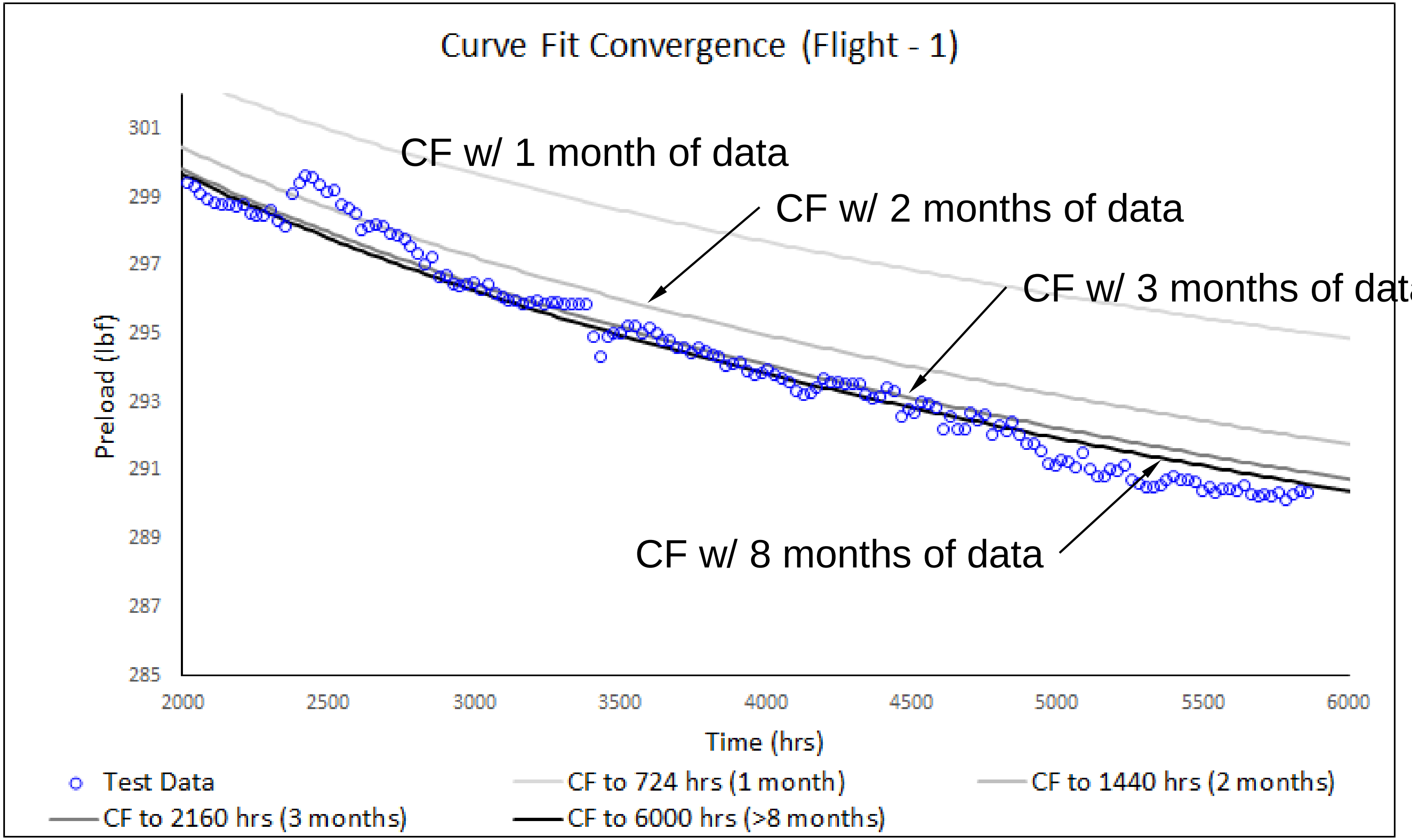
t_{∞} 0

  - Test data was processed in Excel and the software's Solver Tool was run for minimizing the chi square values.
  - Coefficient of determination (R^2) was calculated for each curve fit.
  - Curve fit drift was also monitored throughout test progression.

Curve Fit Example – Flight 1 Coupon

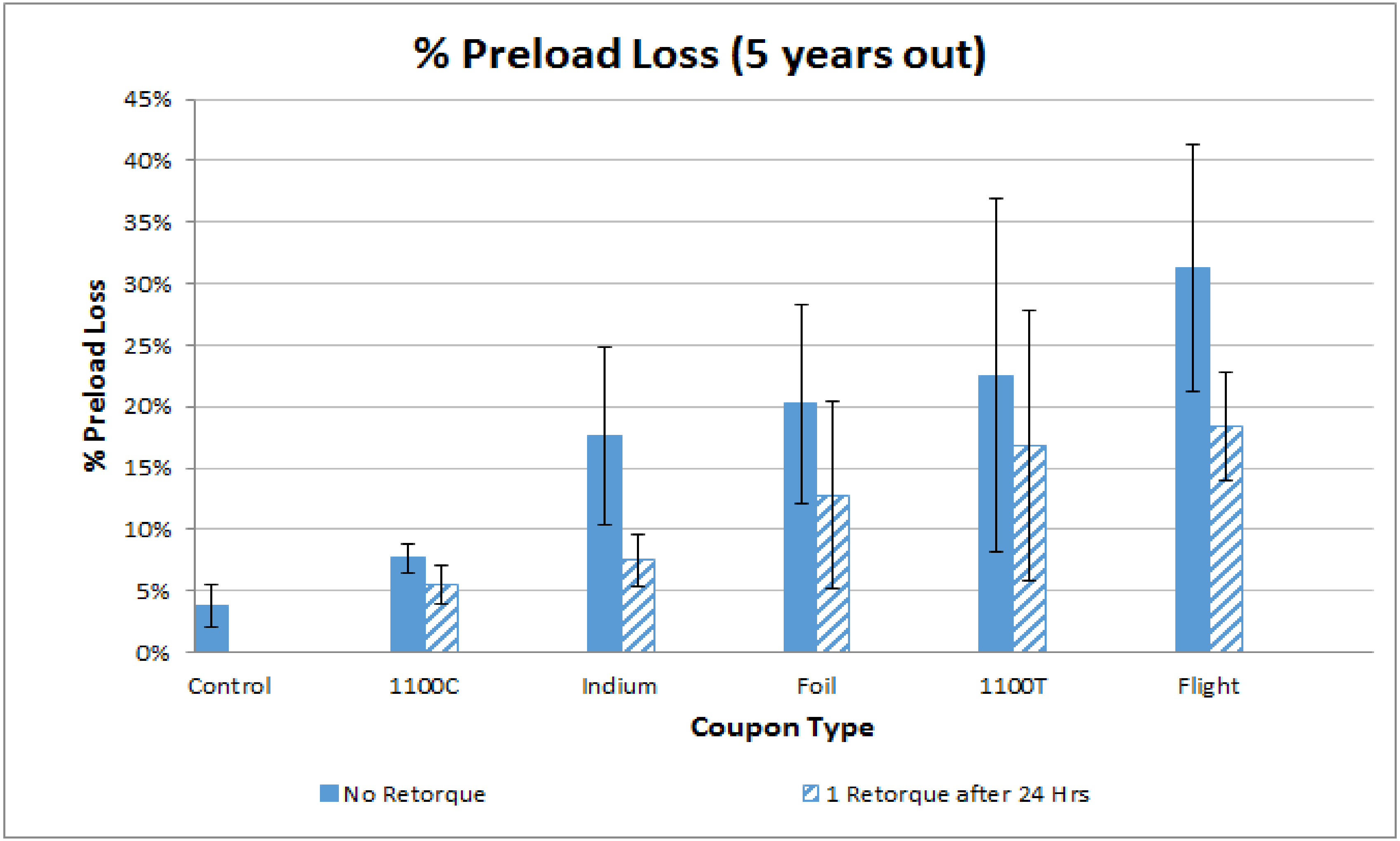


Curve Fit Drift Example – Flight 1 Coupon



- Curve fit drift slowed down considerably near the end of testing.

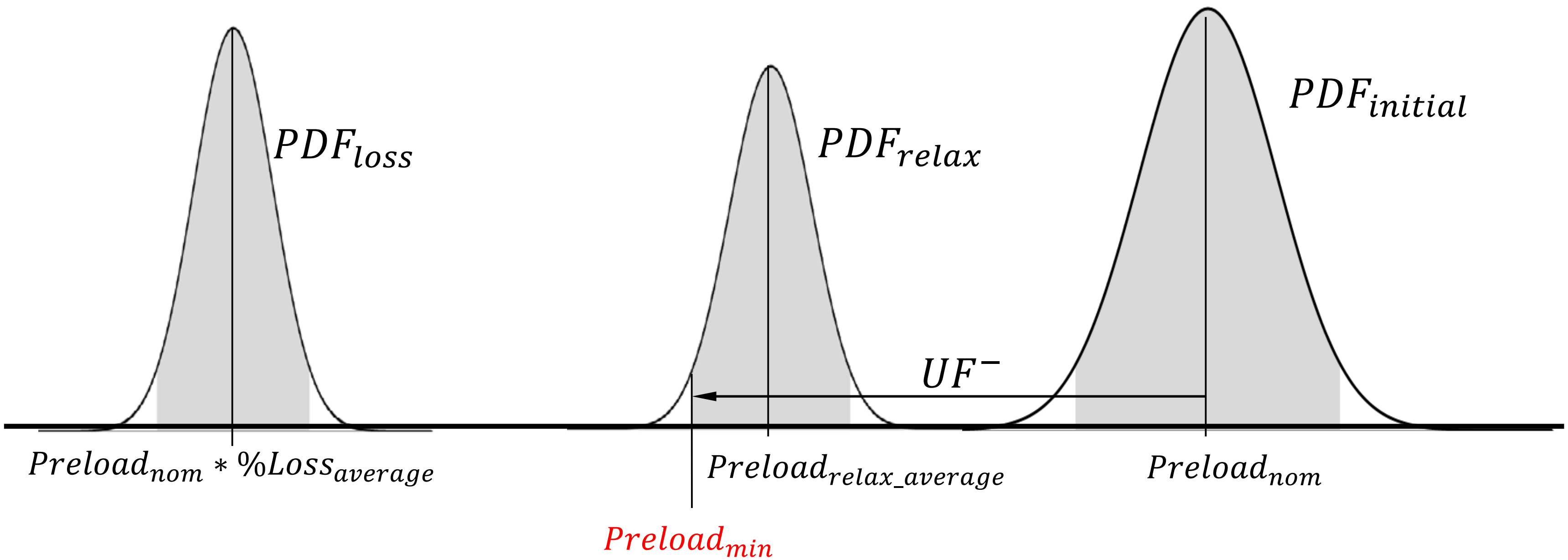
Test Data Curve Fit Results Summary



- Error bars shown are 2-sigma errors.
- Al-1100 in tension (insert pull-out in 1100) is the biggest driver for relaxation.
- Indium flow-out benefits the most from a re-torque.
- Flight joints can lose up to ~25% of preload (+2-sigma) 5 years after re-torque.

Test Results Application

- Expansion of preload uncertainty factor to include both torque/preload scatter and preload relaxation



$$Preload_{min} = Preload_{nom}\left(1 - \%Loss_{average}\right)\left(1 - UF_{relax}\right)$$

$$Preload_{min} = Preload_{nom}\left(1 - \%Loss_{average} - UF_{relax} + \%Loss_{average}UF_{relax}\right)$$

$$Preload_{min} = Preload_{nom}\left(1 - UF^{-}\right)$$

$$UF^{-} = \%Loss_{average} + UF_{relax} - \%Loss_{average}UF_{relax}$$

Test Results Application

- Calculated 0.52 uncertainty factor that is applied to the nominal preload accounting for both initial preload scatter and preload relaxation 5 years after initial torque and re-torque application.

Coupon	Retorque	Max Preload (lbf)	% Preload Loss from CF		
			after 24 hrs	after 5 years	after 13 years
Flight-1	Y	354.7	4.9%	22.9%	25.1%
Flight-2	Y	344.5	3.1%	20.1%	22.3%
Flight-3	Y	341.4	1.6%	19.1%	21.3%
		Average	3.2%	20.7%	22.9%
		Sigma	1.7%	2.0%	2.0%
		B-basis Prealod UF (Torque/Preload)	0.36	0.36	0.36
		B-basis Preload UF (Loss)	0.14	0.16	0.17
		Preload UF (Relax)	0.39	0.40	0.40
		UF(+)	0.36	0.36	0.36
		UF(-)	0.41	0.52	0.54

Summary and Lessons Learned

- Largest driver for preload relaxation in the JWST/ISIM heat straps is Al-1100 in tension (insert pull-out in 1100).
  - **Nuts or nut-plates is preferred over inserts for reducing relaxation.**
- Indium flow-out benefits the most from re-torqueing.
- The B-basis preload uncertainty factor for the JWST/ISIM heat strap joints is 52% (5 years after initial torque and re-torque application).
- The results from this test apply directly to the JWST/ISIM heat strap joint design (materials, size, bolt, torque spec, etc.). **The results from this test should not be applied directly to other joint configurations, but may be used for guidance and insight when designing other joints with similar configuration.**