Titanium Diffusion Hardening (TDH™)

Titanium Slat Track Improvement Project

KAMATICS
BY KAMAN

TDH™ Development

- **Untreated 6Al-4V Titanium (Age Hardened)**
  - Surface scarring present after testing against a polymer-lined journal bearing at high pressure (33ksi, 228 MPa)

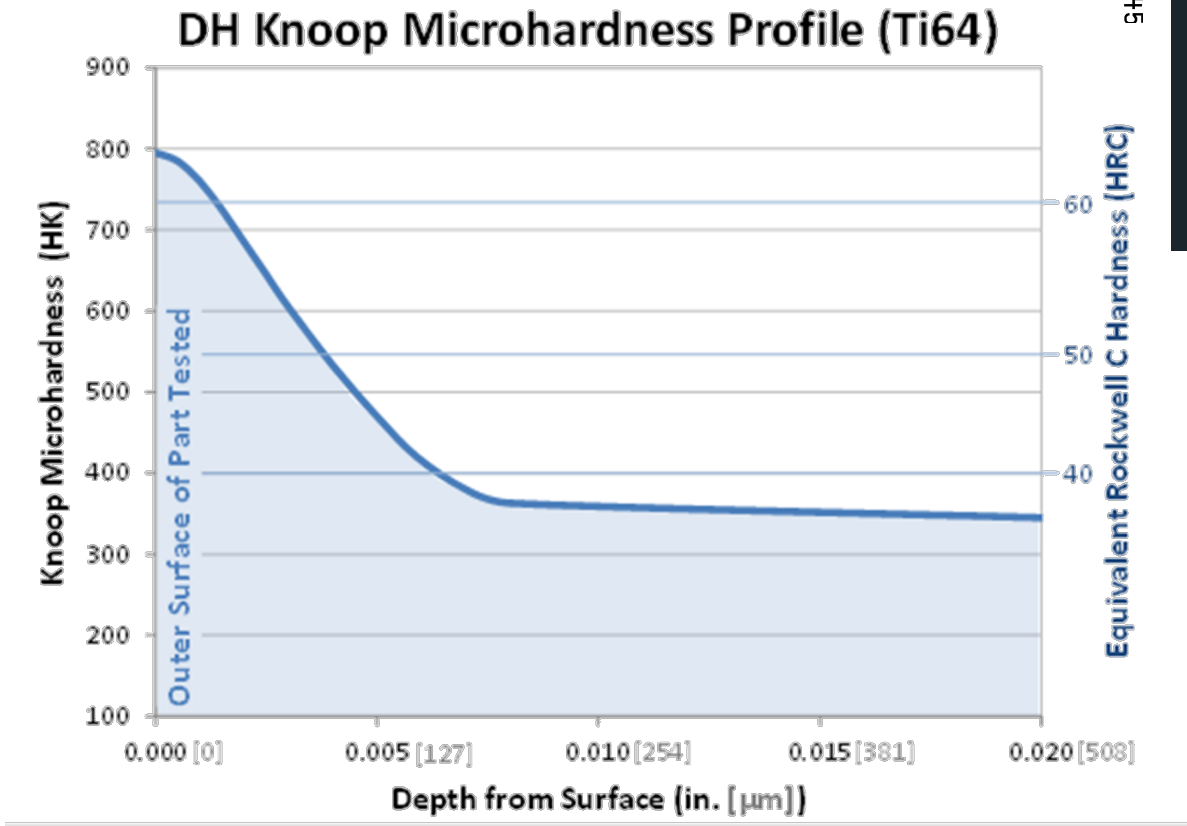
- Developed to improve tribological (wear and friction) properties of titanium alloys in self-lube bearings at high loads.
- Titanium operated under very high dynamic bearing loads experiences:
  - Unstable friction characteristics
  - Surface distress
    - Wear Scarring
    - Galling

Titanium Diffusion Hardening (TDH™)

- TDH™ is a unique diffusion-based case hardening process for titanium alloys
  - Designed to improve the wear & friction properties of titanium alloys in dynamic systems
  - Thermally-effected in a controlled atmosphere
  - Not a superficial coating
  - Hardest at outer surface, gradual hardness transition down to core hardness moving inward
    - R_c 60+ hardness at the surface
- No Line-of-Sight processing constraints
- Significant affected case depth (up to.010”, 250 µm)
- Readily finished to an Ra 4-8 µ·in finish [0.1 – 0.2 µm]

TDH™ Lightweight Titanium Bearing for High Load Applications

- TDH™-treated 6Al-4V serves as an excellent mating surface for all KAron self-lubricating liners
- Optimal for high-load bearing applications
  - High-hardness interface
  - Deep case depth provides foundation to react high bearing loads
  - Fine surface finish readily achieved (central to lined bearing)
- Case-hardened substrate, not a coating

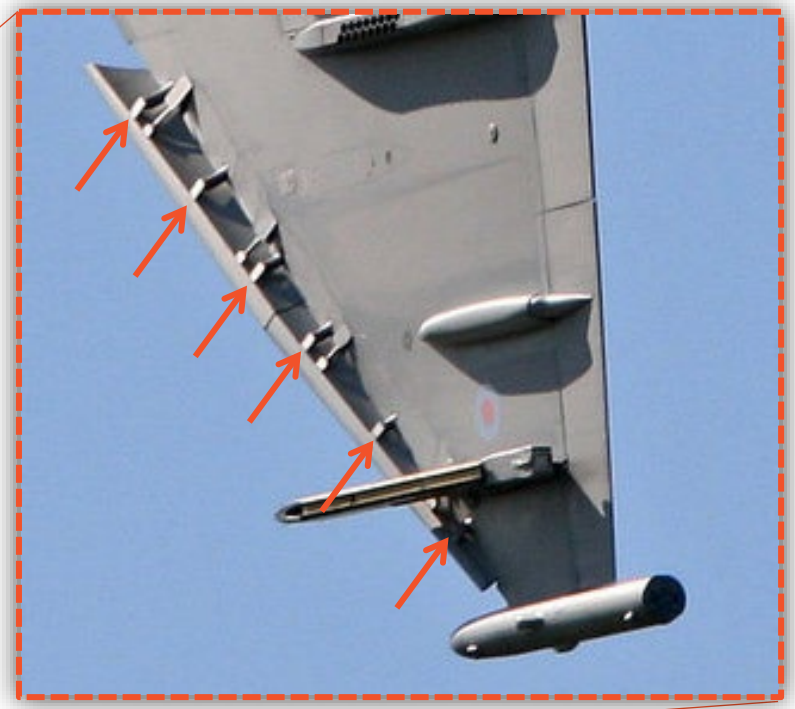


Titanium Slat Track Improvement Project

Information contained herein used under permission

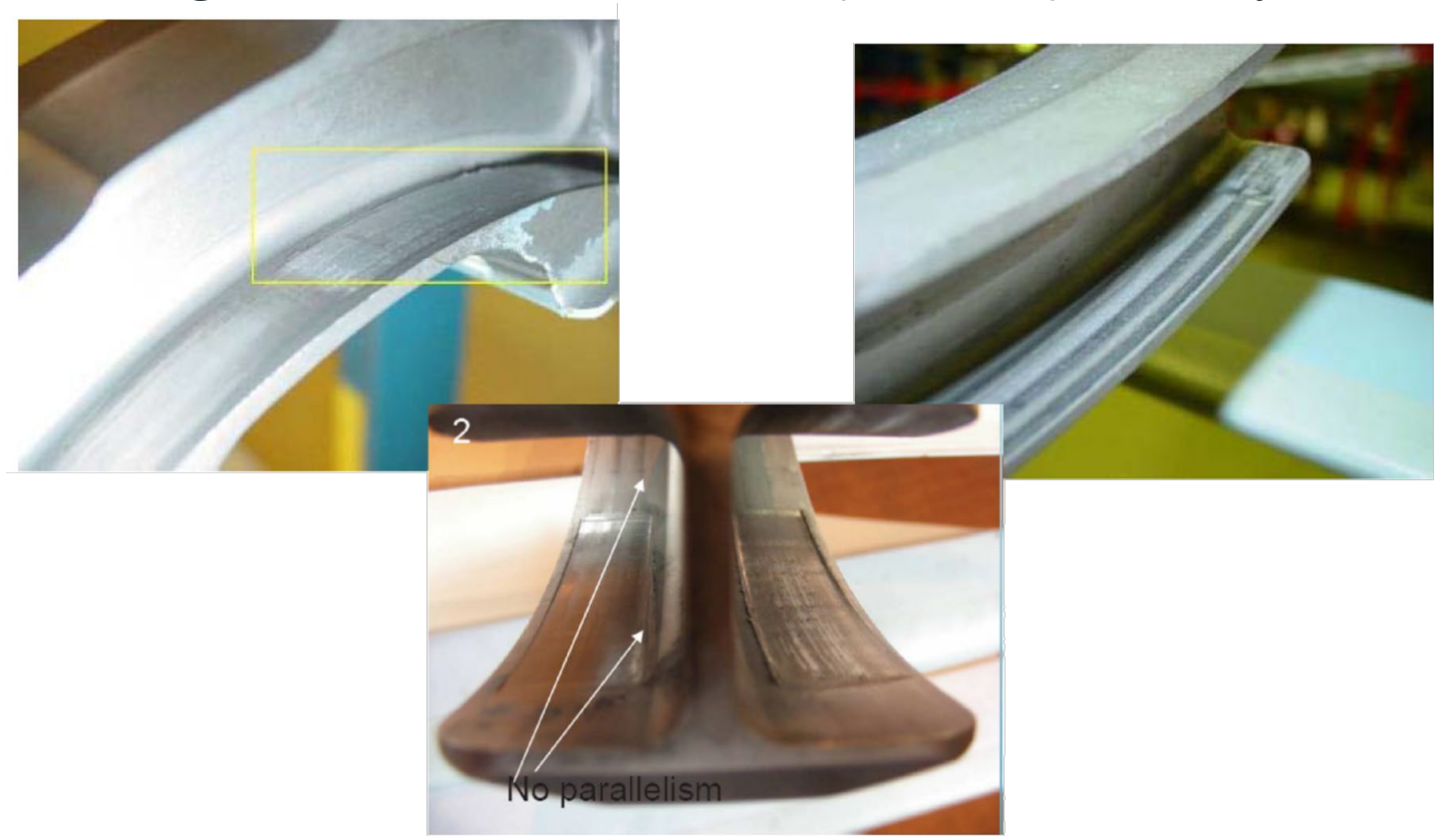
Application Description

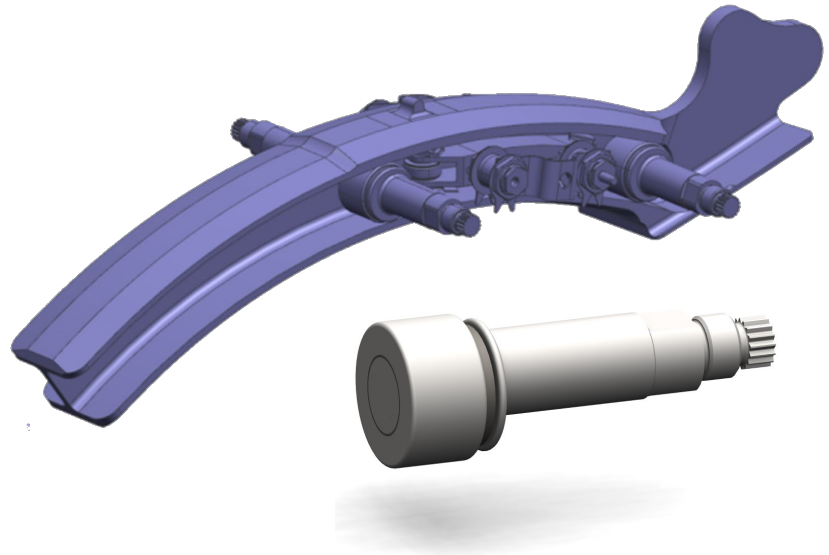
- Military Fixed Wing Aircraft
  - Active slat system
- Slat Actuation – Slat Roller / Track Interface
  - Annealed Titanium (6Al-4V) Track
  - Custom 455 Rollers



Track Wear Description

- Titanium tracks experiencing wear in service
- Running surfaces worn to limits (0.6 mm) as early as 400 flight hours





Track Wear Description

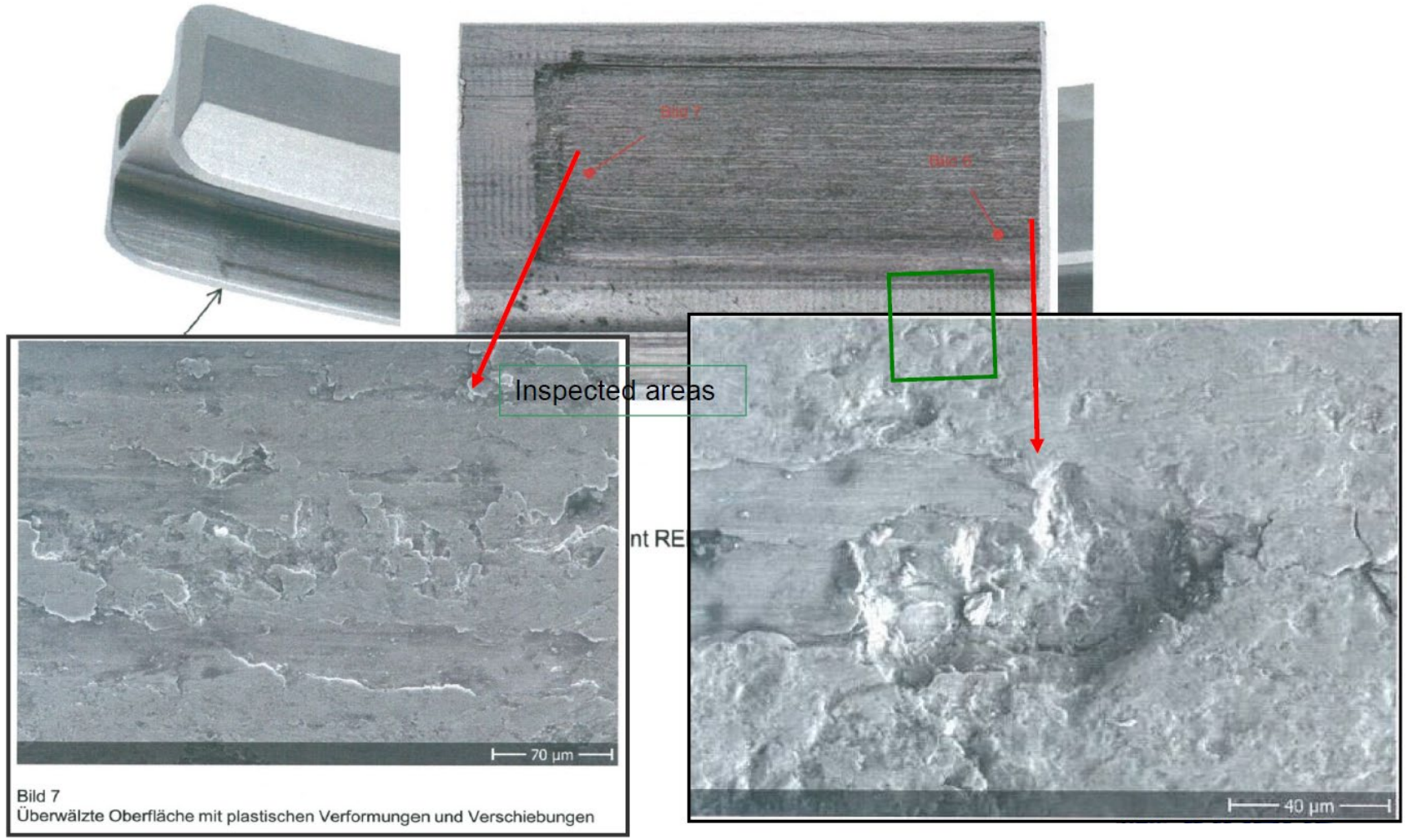
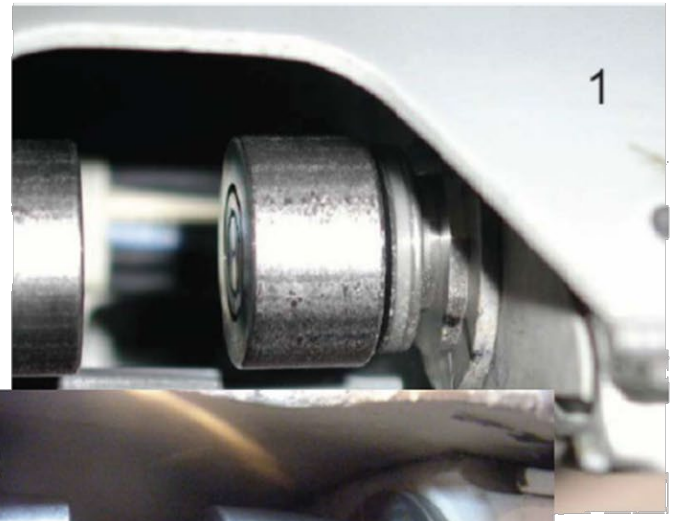
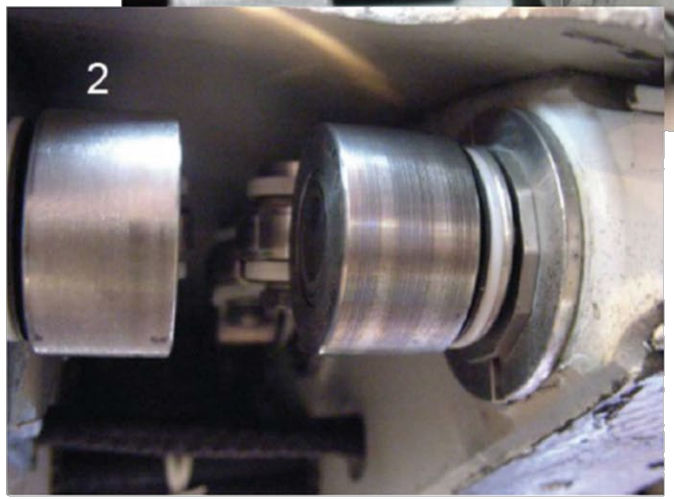


Bild 7
Überwälzte Oberfläche mit plastischen Verformungen und Verschiebungen

Subsequent Roller Wear

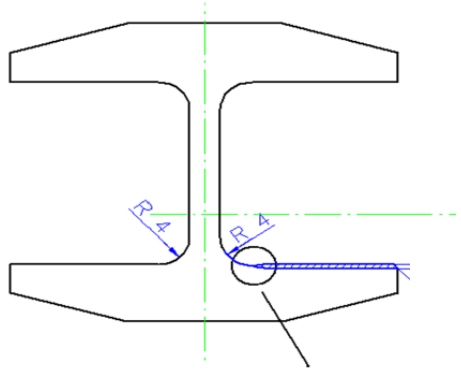
- Adhesive wear condition
- Titanium pickup on roller outer races



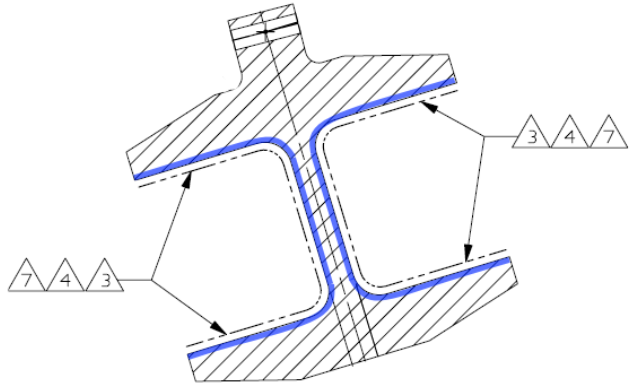


Track Solutions Being Evaluated

1. Ceramic hardcoatings applied to running surfaces
   - 4 Different plasma-spray coatings evaluated
   - 2 different coating vendors, variants of WC-Co
2. Titanium Diffusion-Hardened (TDH) Tracks (Kamatics)
   - TDH case-hardened running surfaces

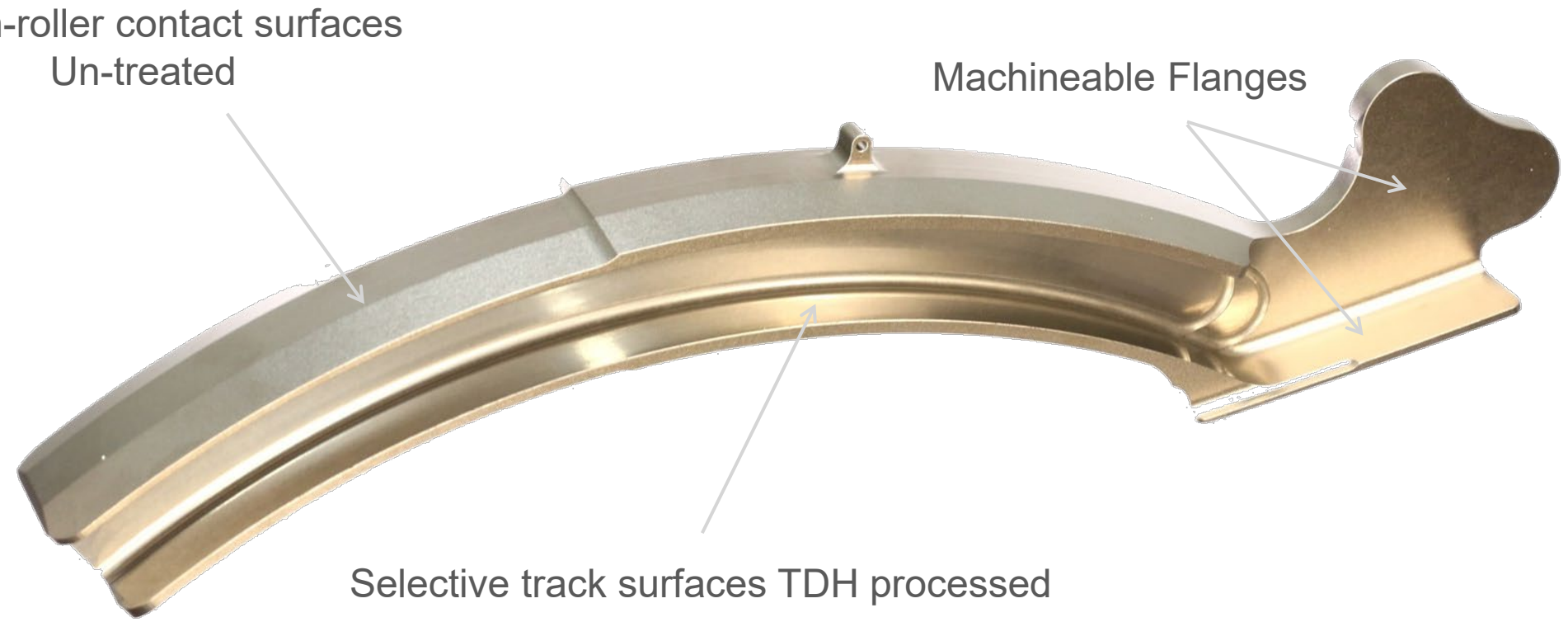


Ceramic Hardcoat Configuration (TYP 4 surfaces)



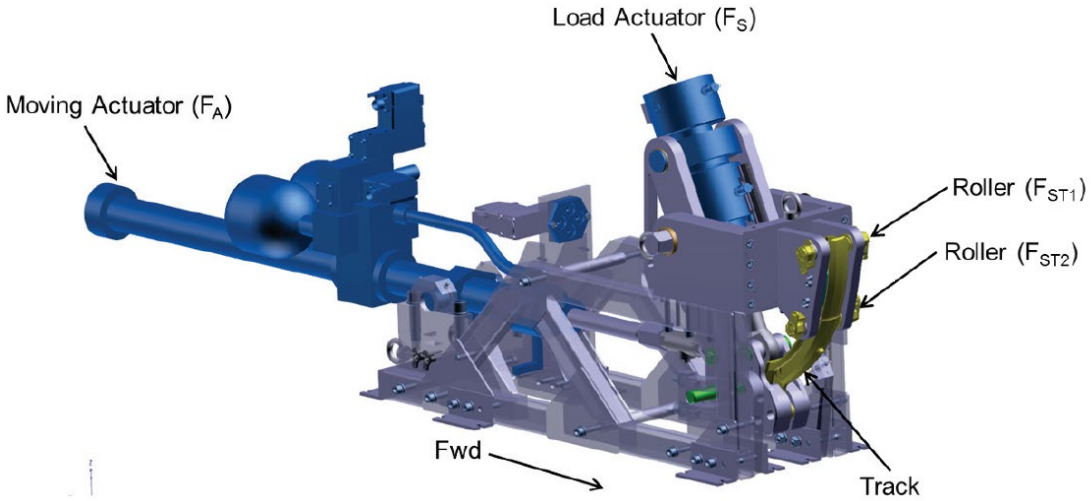
TDH Configuration

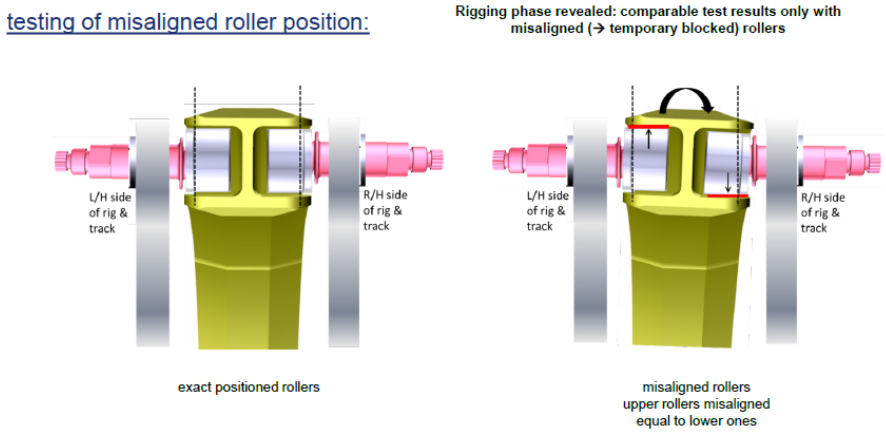
TDH Slat Track Configuration



Test Approach

- Customer testing conducted on dedicated test stand using a simulated flight cycle load profile
- Highly-misaligned rollers and increased loading (F_S) used to generate wear condition representative of service condition under accelerated conditions (conservative)





Test Approach

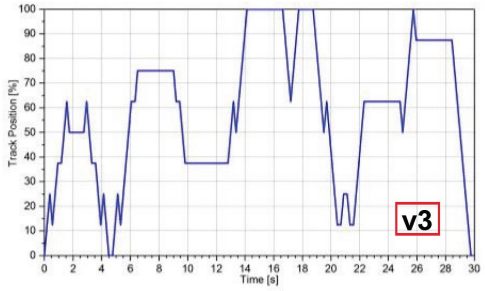
2-Fold Dynamic Test Evaluation:

1. Accelerated Test Program

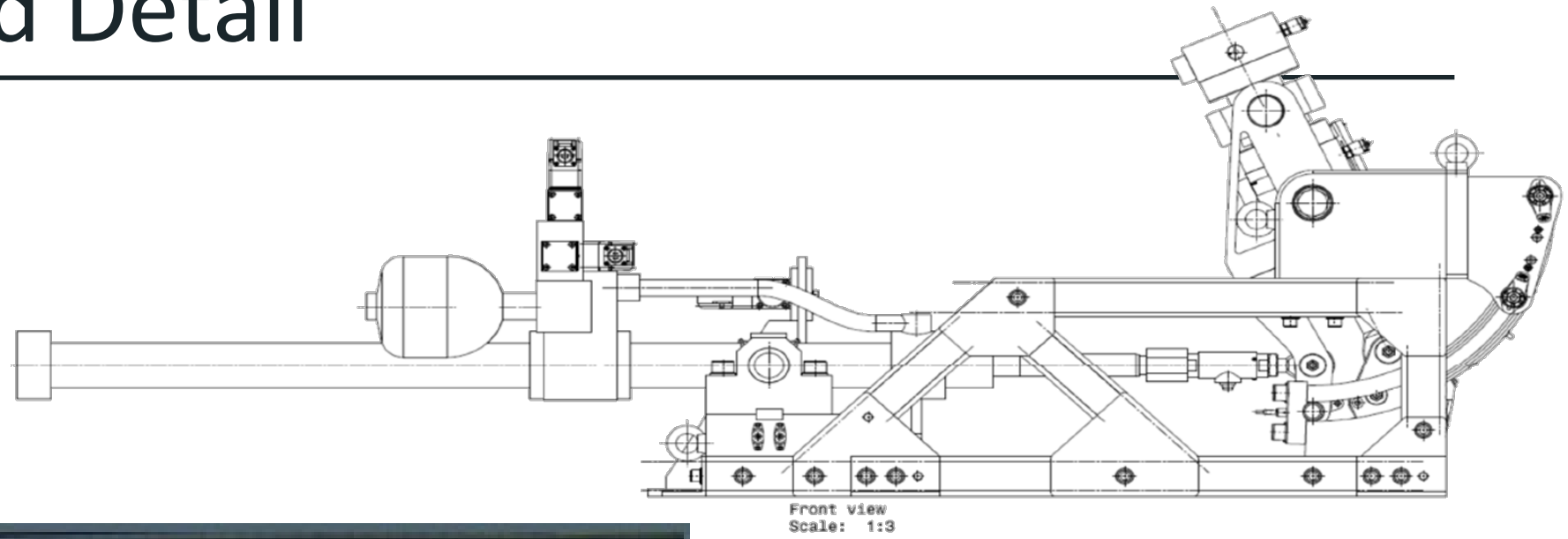
- Initial screening test allows comparison of different solutions for down-selection of technologies
- Load escalation with increasing cycles (up to 150% of service load)

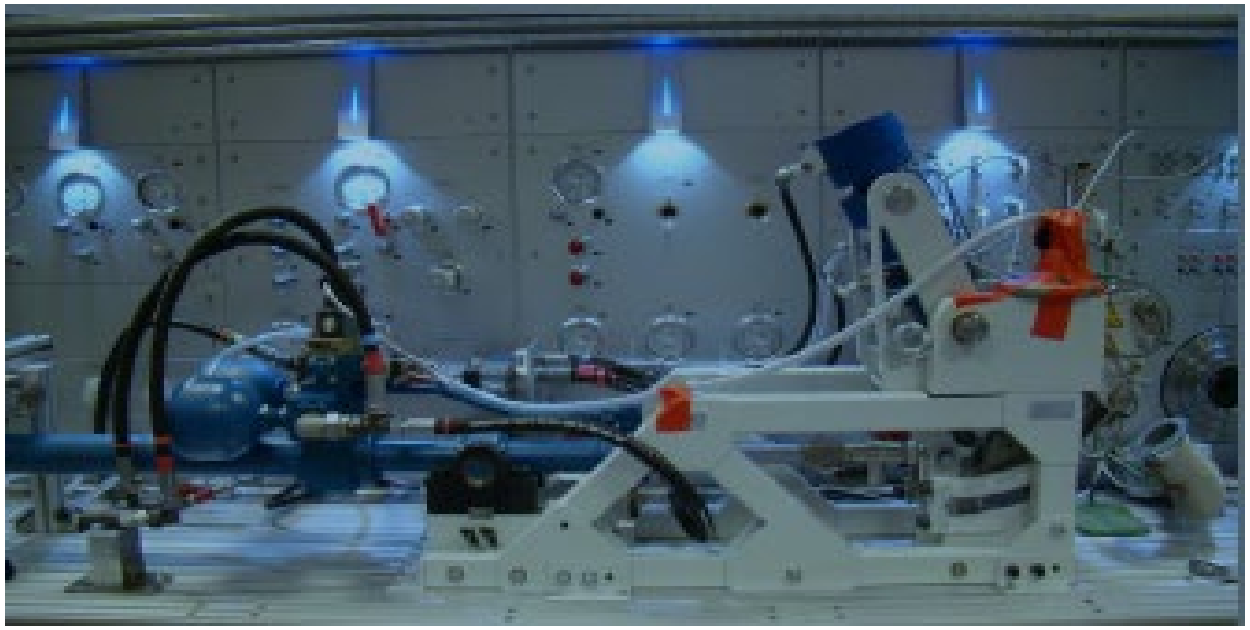
2. Long-Term Endurance Test

- Simulated flight spectrum loading conditions
- 6,000 FH target life (120,000 test cycles)

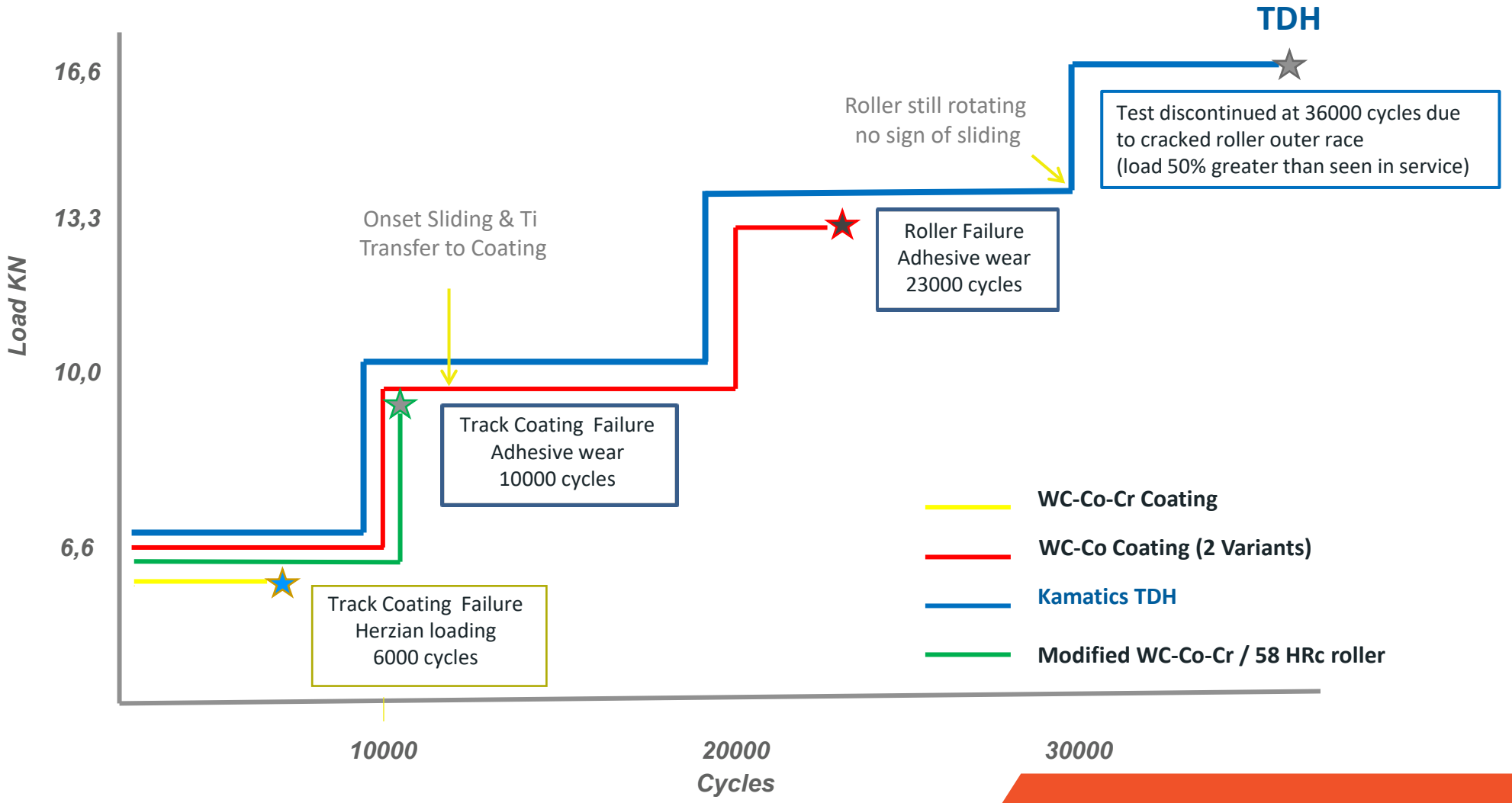


Test Stand Detail





Results of Accelerated Test Program



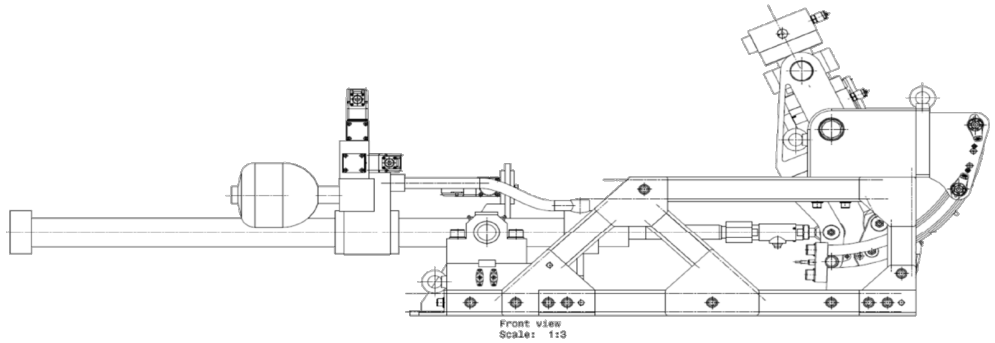
Accelerated Test Results

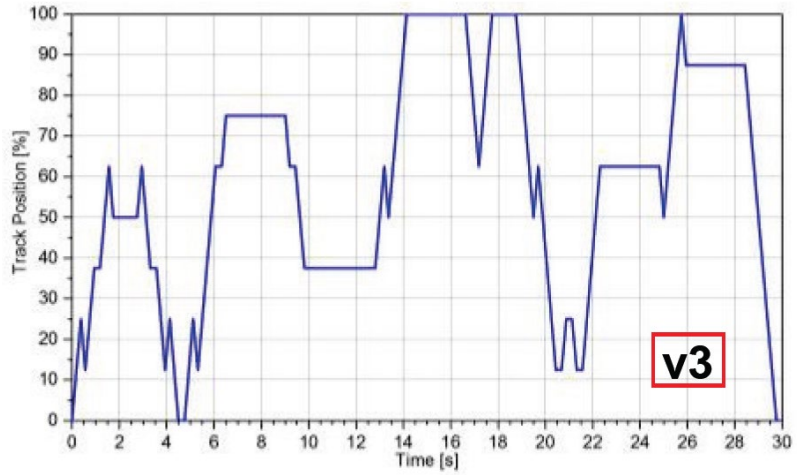
- Accelerated endurance test concluded, evaluating 5 separate solutions
- Early onset ceramic cracking of WC-Co-Cr coatings remedied with process adjustments, however failure mode shifted to roller

- TDH test track exhibited longest endurance of all solutions tested and most favorable material combination (least distress of surface & countersurface)
- Only at 16,6 KN with a cracked roller did the TDH exhibit wear analogue to uncoated Ti.
- **RRBS WC-Co-Cr** and **TDH** selected to progress to full endurance test program

6,000 Hour Endurance Testing

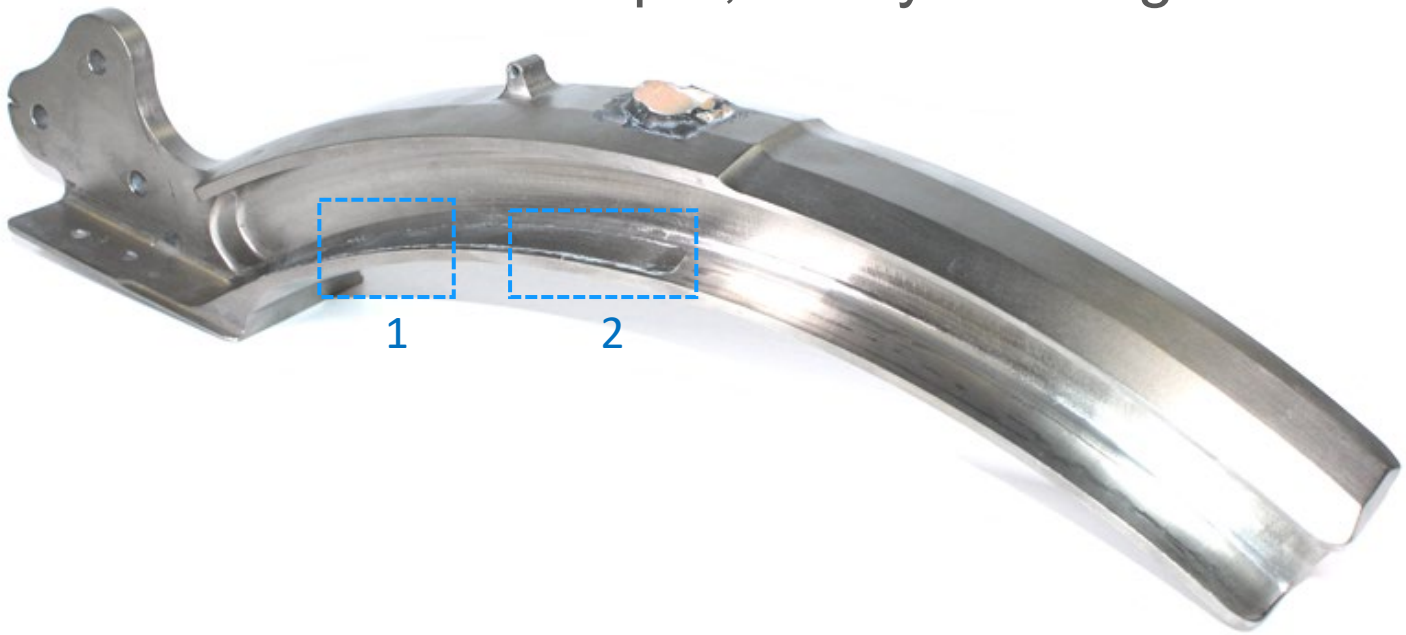
- Simulated flight spectrum loading conditions
- 6,000 FH target life (120,000 test cycles)
- Baseline (annealed Ti64) track tested, wear conditions commensurate with worst-case fielded track wear conditions





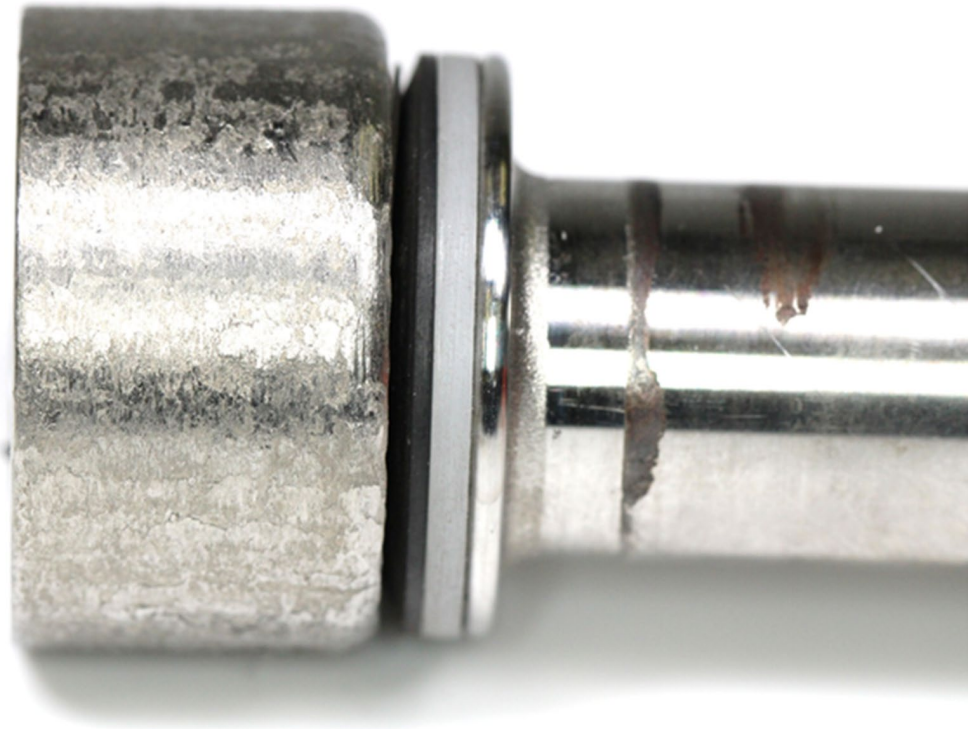
Long-Term Test Rig (Baseline Track)

- Current production hardware (Annealed 6Al-4V Titanium Track)
- Test stopped after **600** test hours, wear limit reached
  - 0.8 mm wear depth, heavy scarring



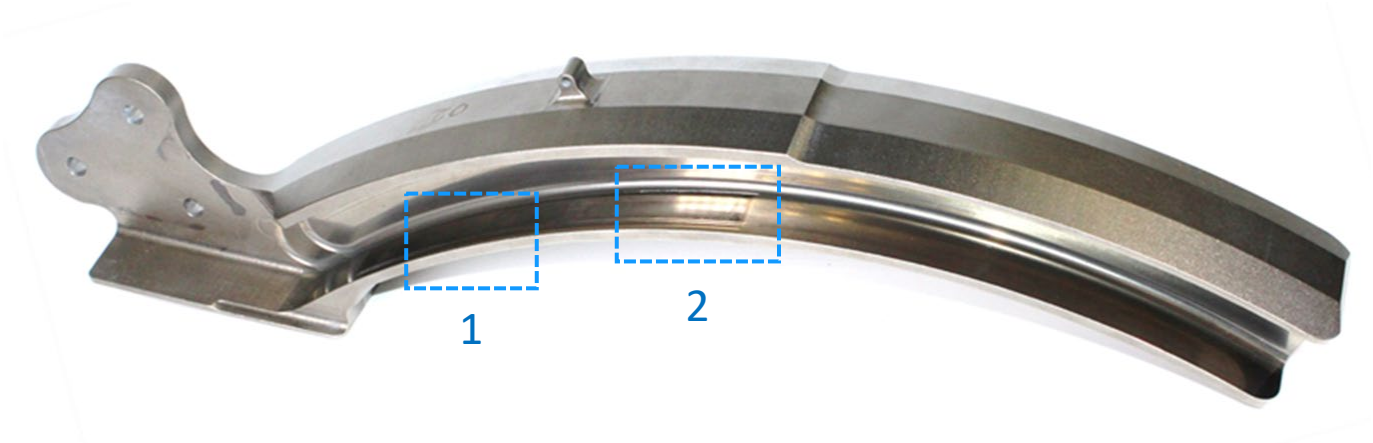
Long-Term Test Rig (Baseline)

- Track roller bearing mated with Annealed Track (600 Hours)
- Heavy distress, adhesive wear (titanium pick-up)



Long-Term Test Rig (TDH Track)

- TDH-treated test track
- Test successfully completed full **6,000** hours
  - Slight surface roughening in one location, no measurable wear to running surfaces



Long-Term Test Rig (TDH Track Test)

- Track roller bearing mated against TDH-treated Track (6000 Hours)
- OD burnishing, no measurable wear

Conclusion

- TDH-treated track successfully demonstrated full endurance life requirement through bench test program
  - **Annealed** baseline track worn to limits at **600 hours**
  - Hardcoat solution discontinued at 5,400 SFH test hours, roller contact wear issues
  - **TDH** track successfully completes **6,000 hours** with no measurable wear

- TDH registers an improvement of more than 30x in specific wear rate when compared with current annealed configuration track and eliminates roller wear