



“That’s Why We Carry Backup Hardware!”

## Thruster B-Branch Swap

Julie L. Webster  
Cassini Spacecraft Operations Manager





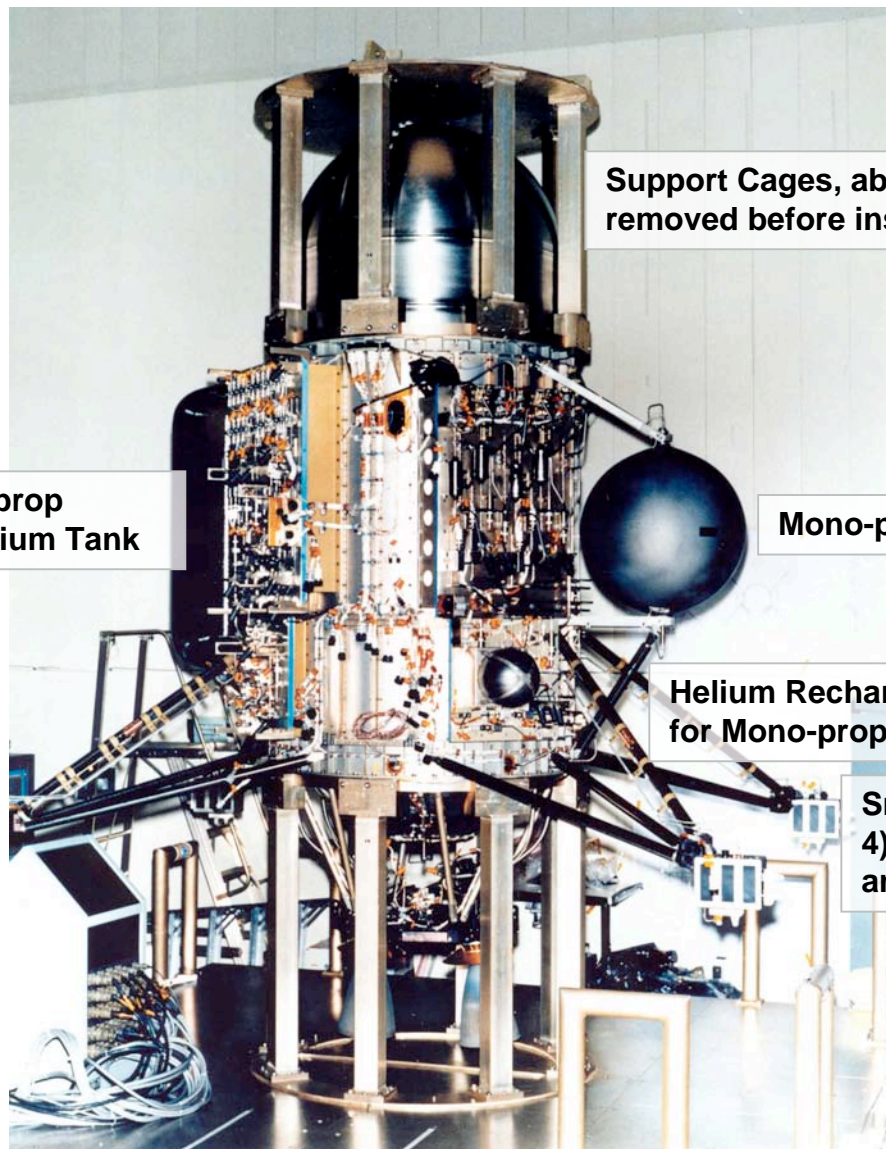
## Engineers must plan for “what if..”

- **Cassini has redundant hardware in all engineering subsystems**
  - Redundant hardware is very expensive
    - Hardware cost
    - Fault protection logic software associated with redundancy (main cost driver)
  - But the alternative is unthinkable on a Flagship mission!
- **Two ways to switch to redundant hardware**
  - 1) Fault Protection does it for you (“fast” failure)
  - 2) Switch after observing degradation and impending failure
  - The second method is ALWAYS preferred!
- **Cassini used single Reaction Wheel Assembly (RWA) redundancy in 2003**
  - Replaced RWA-3 with articulatable RWA-4
  - Created software program to predict and prevent problems with remaining RWAs
- **Now Cassini has switched to the redundant thruster set in 2009**



## Mono-Propellant Design

- **Cassini has 4 Z-facing thrusters and 4 Y-facing thrusters with redundant set**
  - Used for small ( $<0.3$  m/sec) maneuvers, Reaction Wheel momentum changes (biases), “fast” turns for Science
  - Thrusters are Aerojet heritage (1 Newton, 0.2 lbf)
    - Same (similar) to Voyager, Magellan, MRO, Stardust, New Horizons
    - Only Voyager and Cassini A-branch Z-facing thrusters have Chamber Pressure transducers (to measure Pc roughness)



Support Cages, above and below removed before installation

Bi-prop Helium Tank

Mono-prop Hydrazine Tank

Helium Recharge Tank for Mono-prop

Small Thruster Cluster (1 of 4) with nozzles facing down and out

Main Engine (2)





A picture is worth a thousand words!

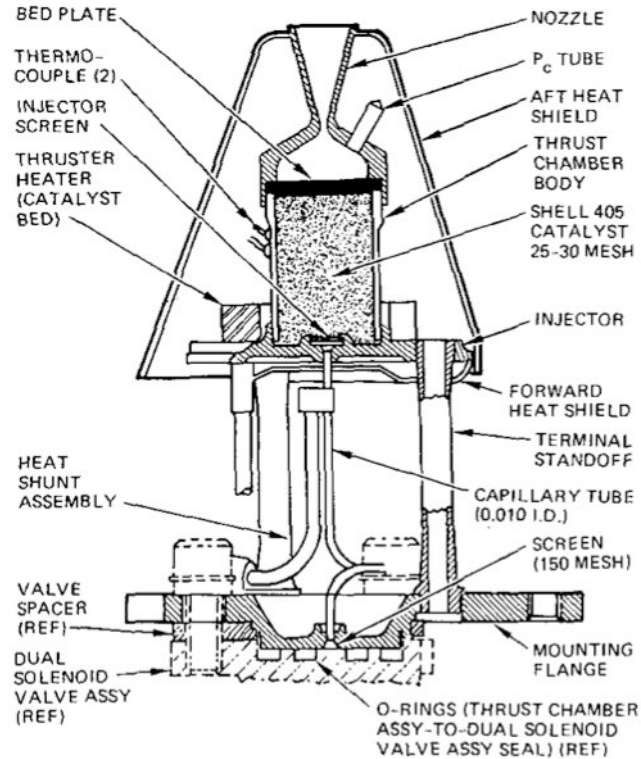


Fig. 2. 0.2-lbf Thruster Thrust Chamber Assembly  
(Rocket Research Corp.)

Ref: Van Camp, V. V., "Characterization Testing of a 0.20 lbf Hydrazine Thruster," AIAA 79-1306, 1979



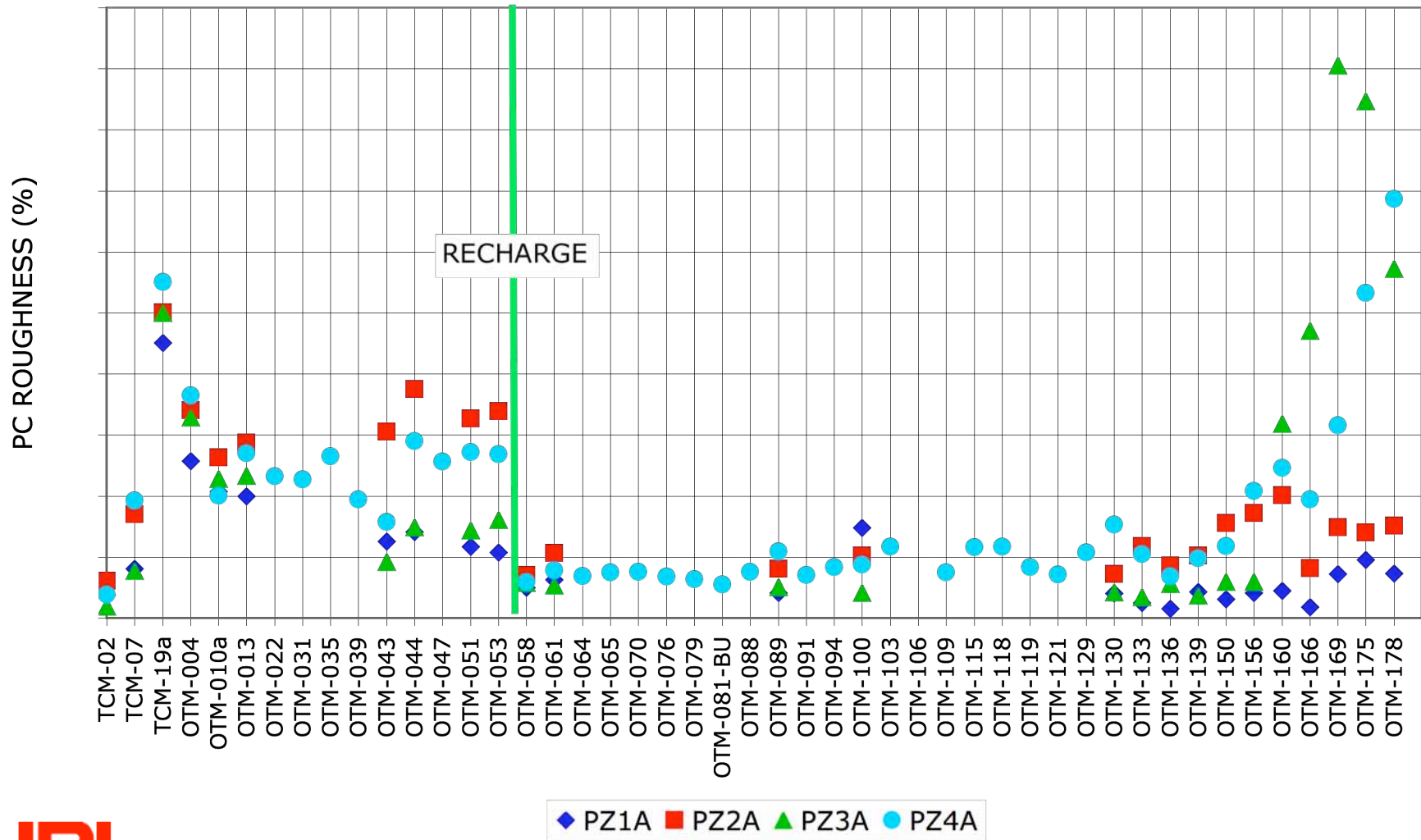
## What happened?

- **On Orbit Trim Maneuver 169 (10/29/08), RCS Thruster Z3A performance degraded dramatically**
  - Significant underburn
  - Extreme Pc roughness on thruster Z3A
  - Increasing Pc roughness on thruster Z4A
  - Significant future delta-V penalty incurred
- **Subsequent OTMs (175, 178) and momentum biases showed continued degradation**
- **Voyager experienced similar, but smaller variations in Chamber pressure roughness**
  - Did not see significantly lowered thrust
- **Cassini also saw increased Pc roughness in early cruise**
  - Mono-prop recharge on 4/10/06 cleared up early Pc roughness



# RCS CHAMBER PRESSURE ROUGHNESS DURING OTM

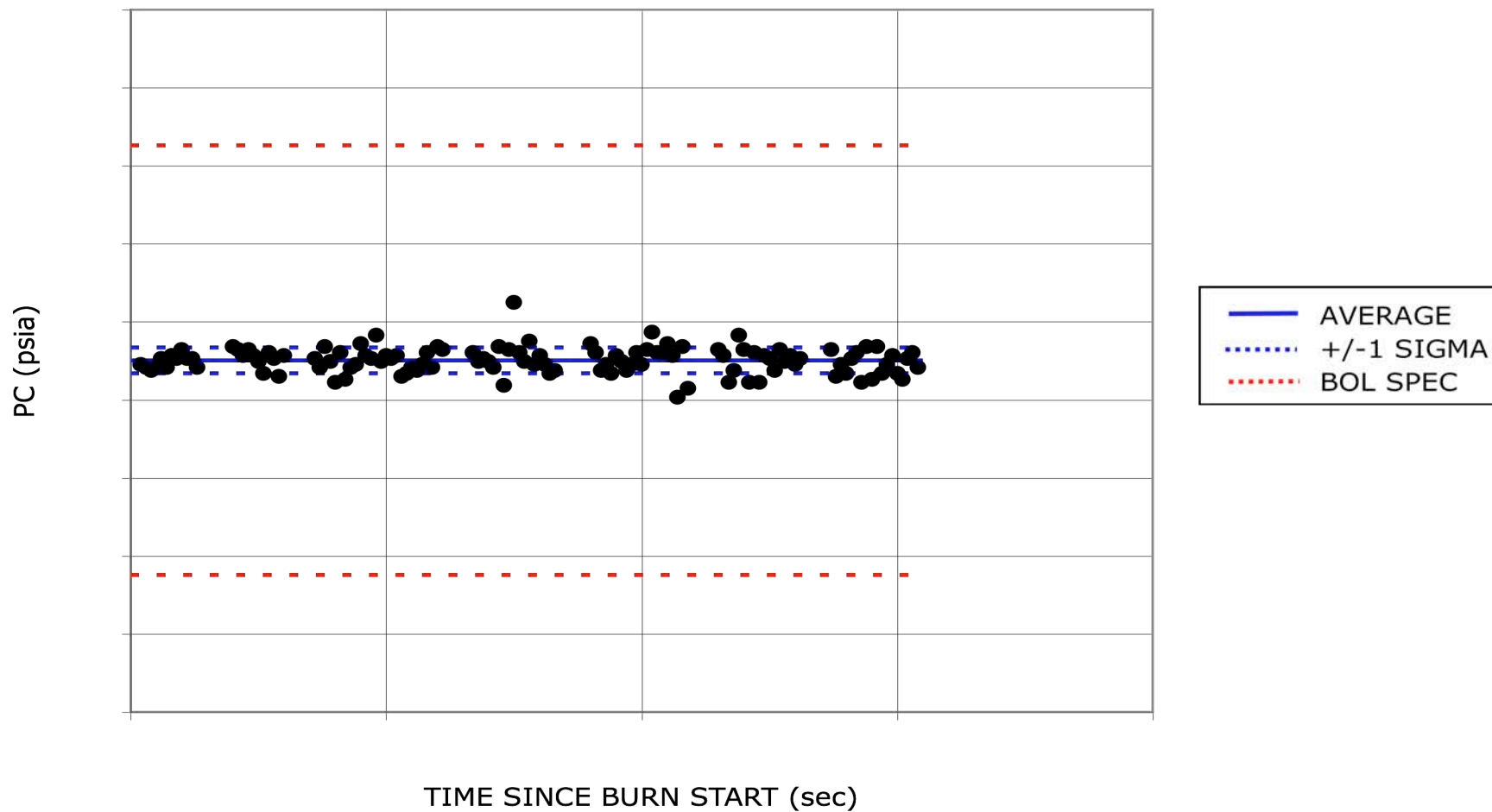
( standard deviation / mean )





# OTM-156

PZ3A CHAMBER PRESSURE, OFF PULSES FILTERED OUT

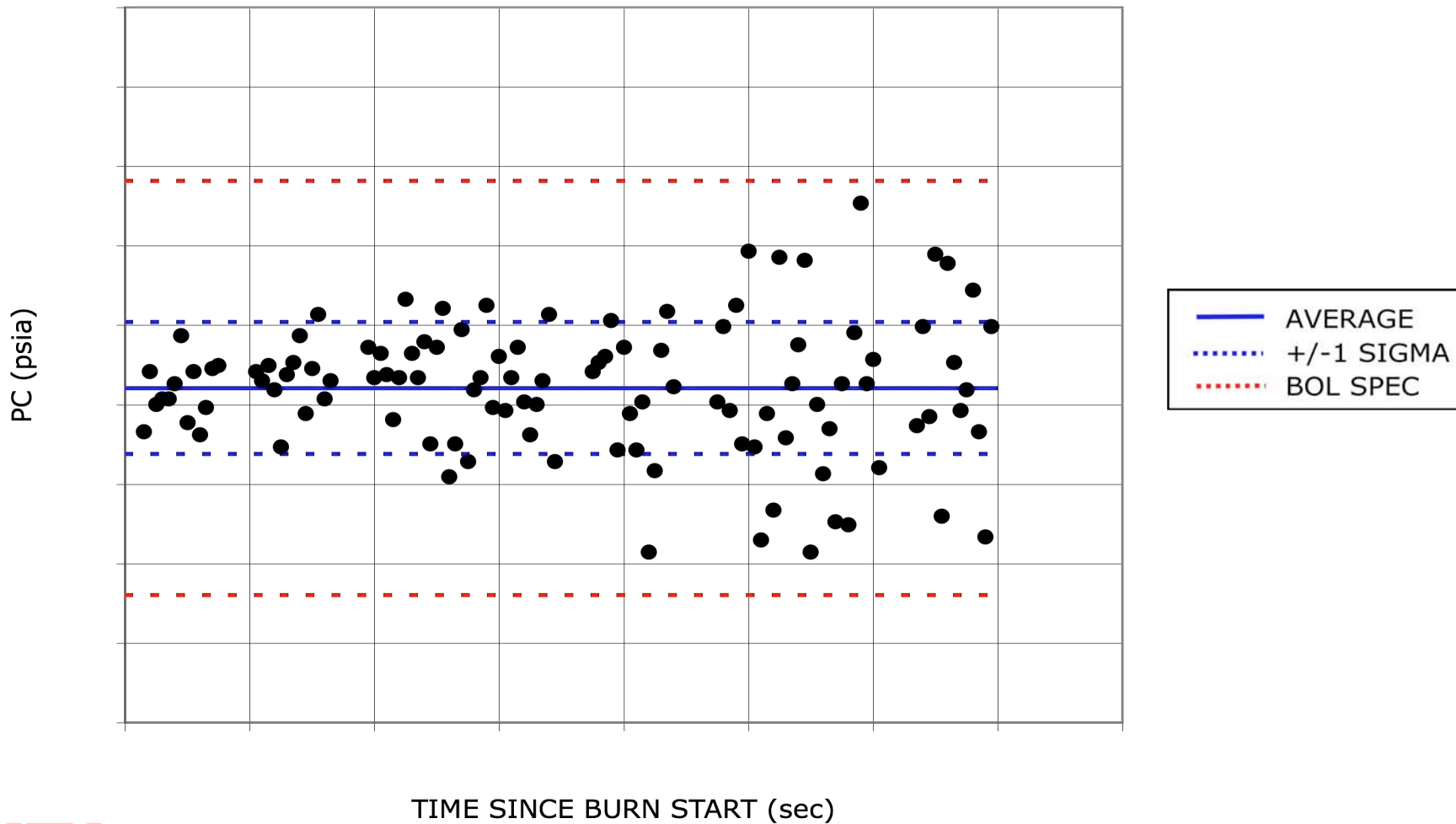






# OTM-160

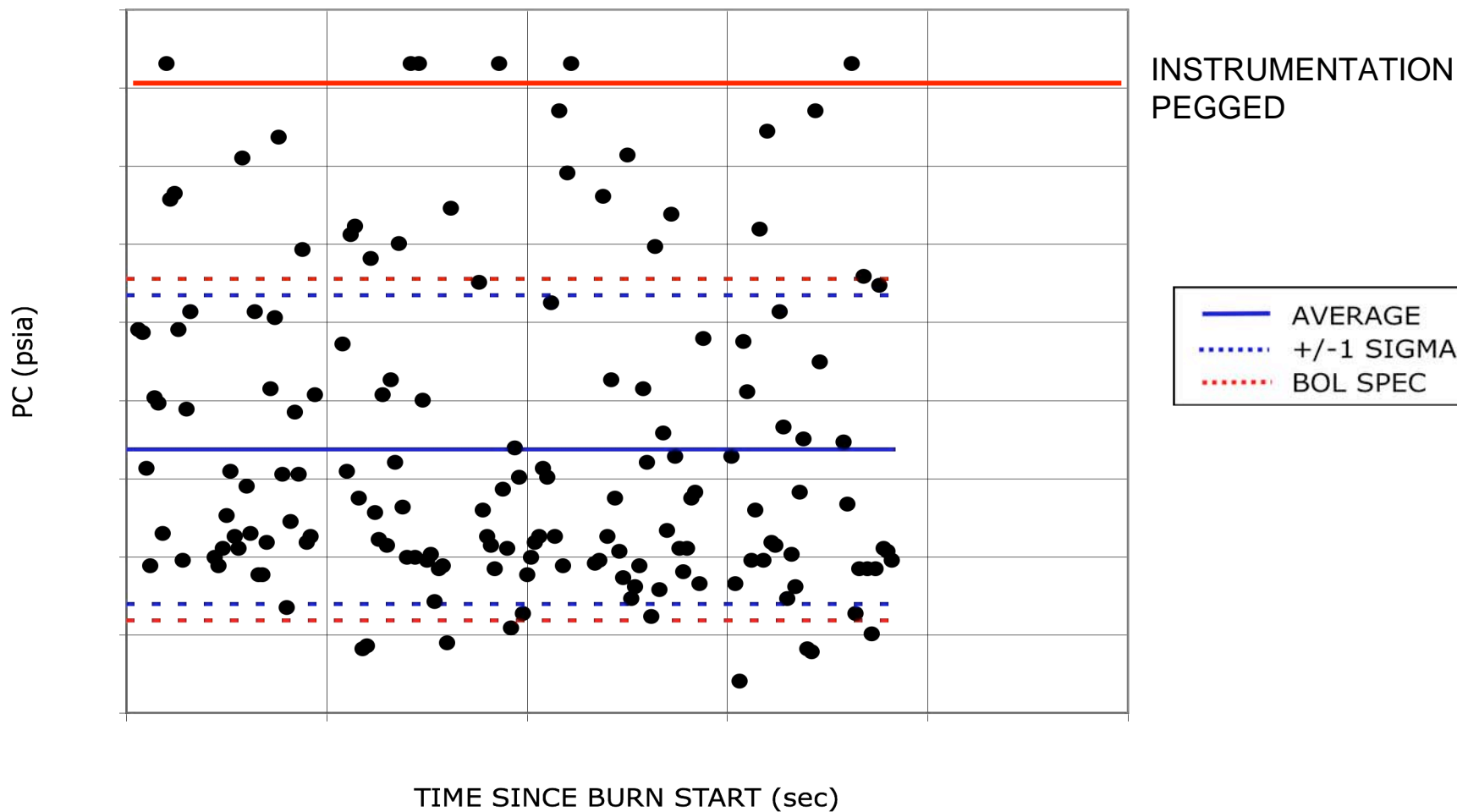
PZ3A CHAMBER PRESSURE, OFF PULSES FILTERED OUT





# OTM-169

PZ3A CHAMBER PRESSURE, OFF PULSES FILTERED OUT





## Meetings

- **Technical Interchange Meeting with thruster manufacturer, propulsion teams on 01/22/09**
  - Conclusion reached that Thruster Z3A is exhibiting end-of-life properties
  - Recommendation made to switch to B-Branch thrusters
- **Meeting with JPL management 01/26/09**
  - Okay to continue plans for thruster swap
- **Cassini internal weekly meetings to develop plan and procedures**



## High Level Plan

- **Identify timeframe for Thruster B Branch swap and Checkout**
  - To be completed in a “timely” fashion, avoiding any chances of missing an OTM and falling off tour design
    - Each targeted encounter has 3 OTMs to pinpoint time and altitude
- **Use Thruster B Checkout plan, procedure developed in 2003 (pre-SOI)**
  - Update and re-test for current spacecraft status, background sequence
  - Run Fault Protection regression tests in Attitude Control Flight Software Simulator, test beds
  - Dry-run all commands through Integrated Test Laboratory



## Why does it take so long from decision to thruster swap?

- **In spacecraft business, take the time available to do it right**
  - First, do no harm
    - Test to make sure all commands are recoverable
  - Find the right place and time for all parties
    - Testers preferred six months
    - Propulsion preferred six days
    - Science preferred “quiet time” without Priority Science
    - Spacecraft team and Navigation preferred maximum time between OTMs
    - Best time for Spacecraft Team, Navigation, and Science was 3/12-18/09
      - Six weeks from decision to spacecraft



## Conclusion

- **Swap to Thruster B set was entirely NOMINAL!**