Thales Tactical Pulse Tube Cryocooler Testing Status

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December 10, 2012
Jet Propulsion Laboratory
California Institute of Technology

Presented for Thales Cryogenics

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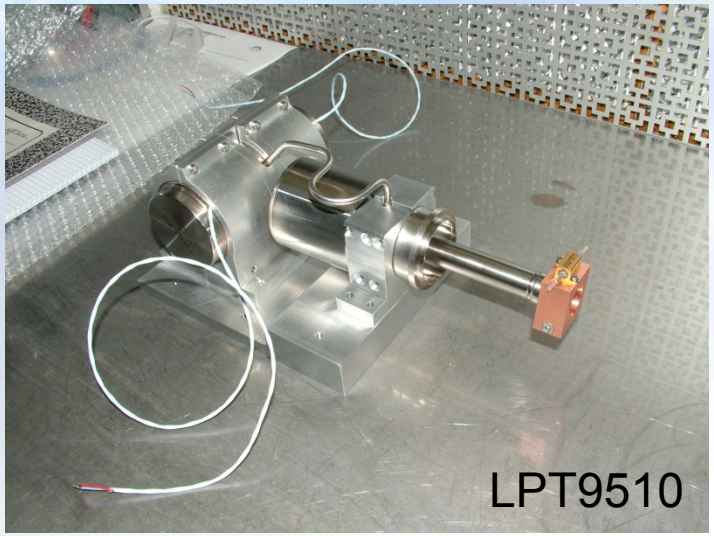
Outline

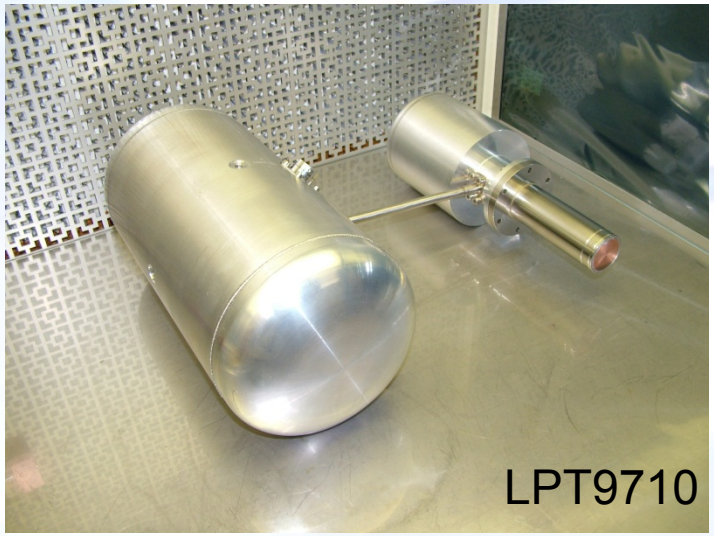
- Objectives
- Thales cryocooler hardware at JPL
- Testing facilities
- Top level test plans
- Test data obtained to date
- Path to needed improvements
- Summary

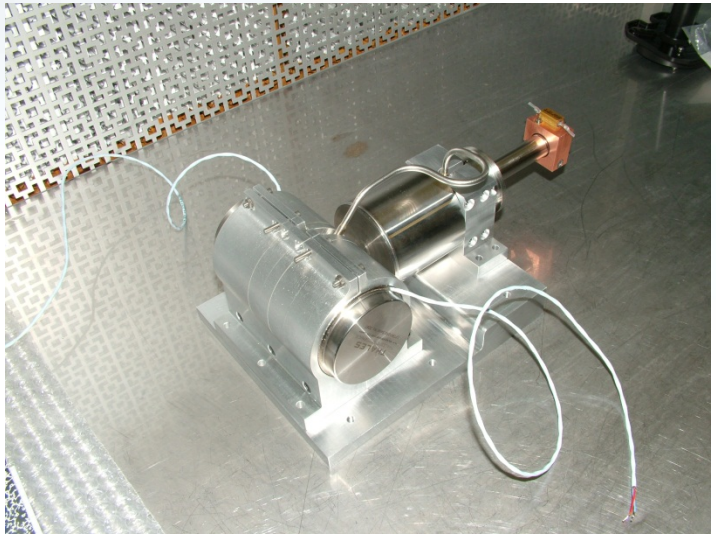
Overall Objectives

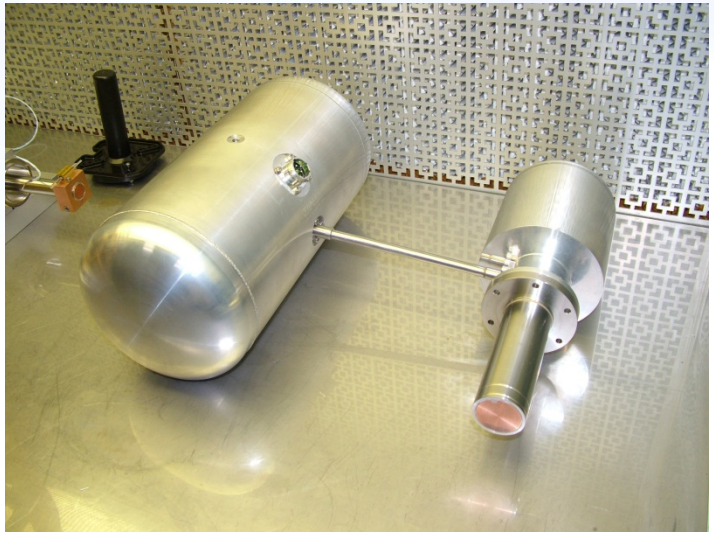
- Flight qualify LPT9510 as is with Iris Technology Low Cost Cooler Electronics (LCCE) by end of FY2013 (Sept 2013)
  - TRL 6 is required for Earth Ventures and other science instrument Announcement of Opportunities (AOs)
  - 2nd generation flight LPT9510 with improved performance targeted for CY14
    - Thermodynamic performance testing early CY14
    - Complete flight qualification testing by end of CY14
  - 2nd generation Iris Technology LCCE with vibration suppression and input power filtering targeted for CY14
  - Complete 2nd generation LPT9510 cooler system with drive electronics will be at TRL 6 by end of CY14
- In close succession proceed with similar flight cooler development approach for LPT9310 and LPT9710

Thales Cryocoolers at JPL





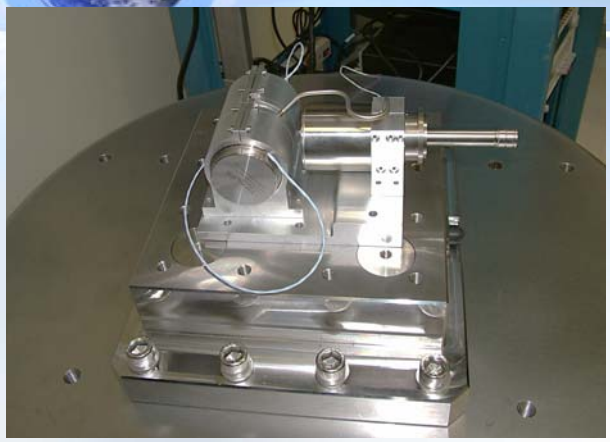


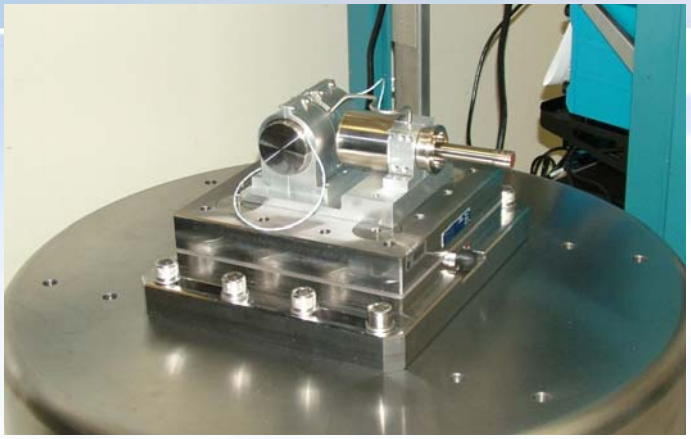


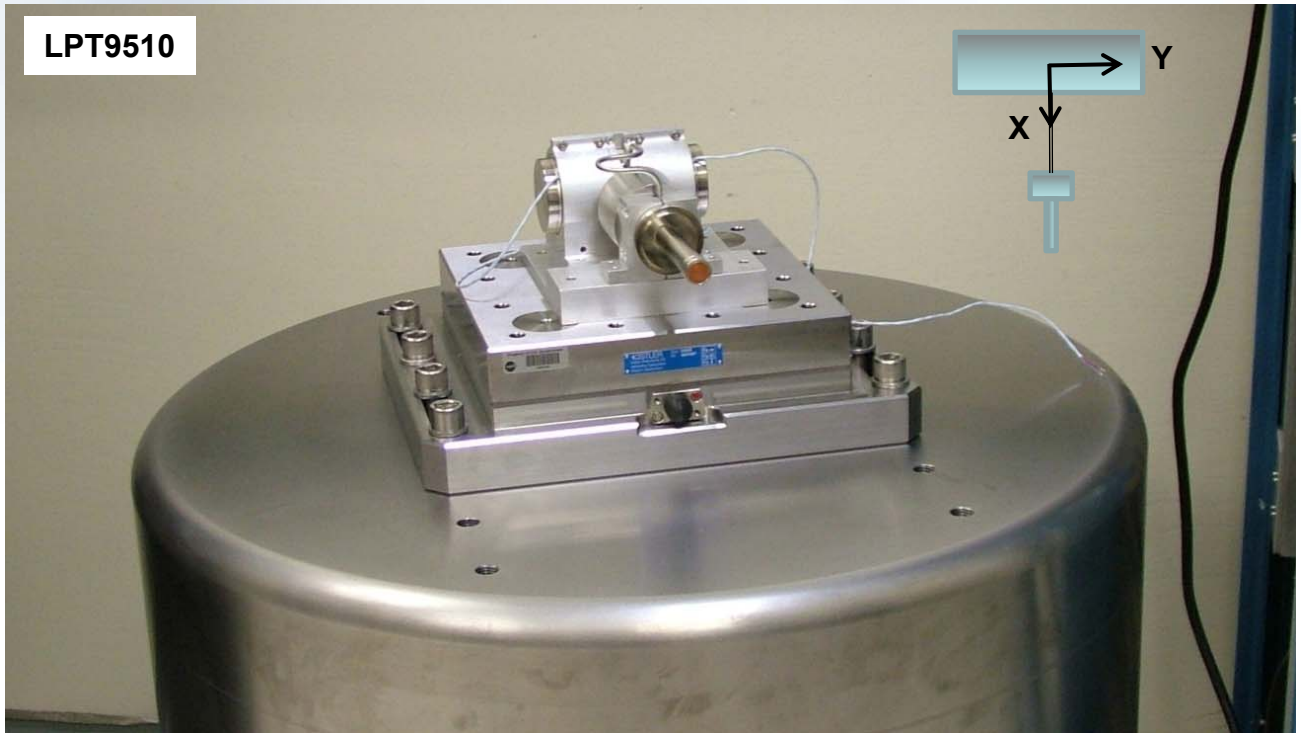
Testing Facilities

Dedicated 24in Thermal Vacuum chamber for tactical cooler testing

Exported Vibration Test Facility



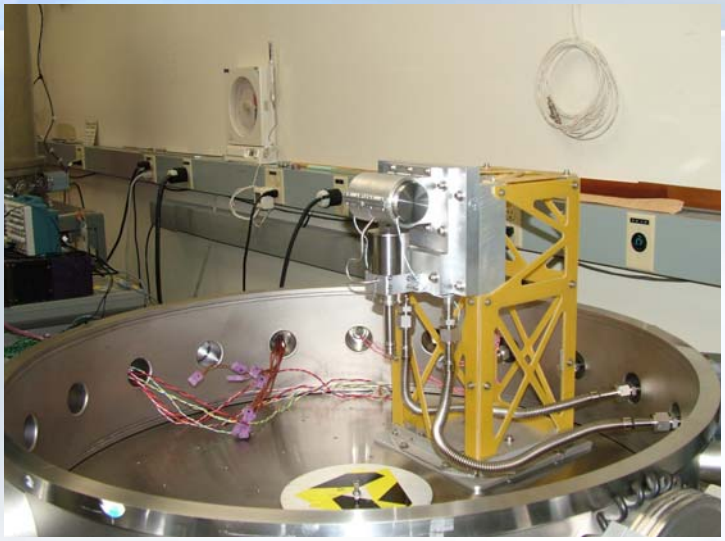


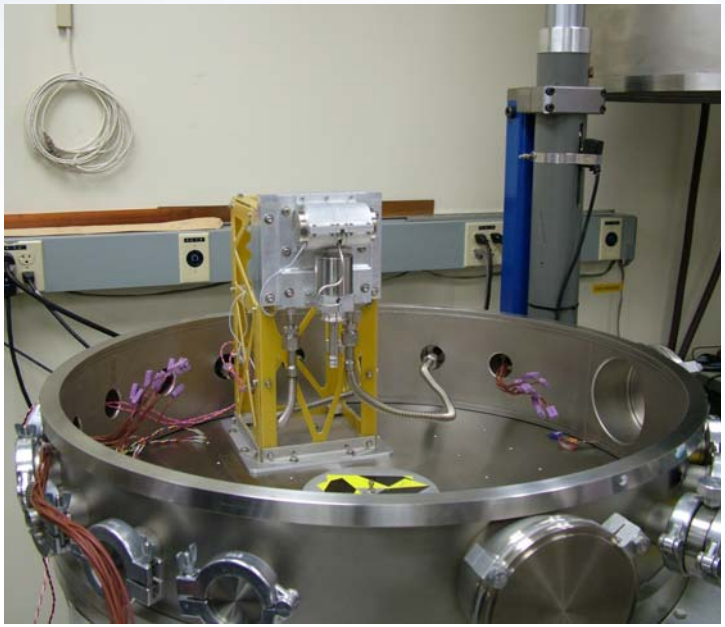


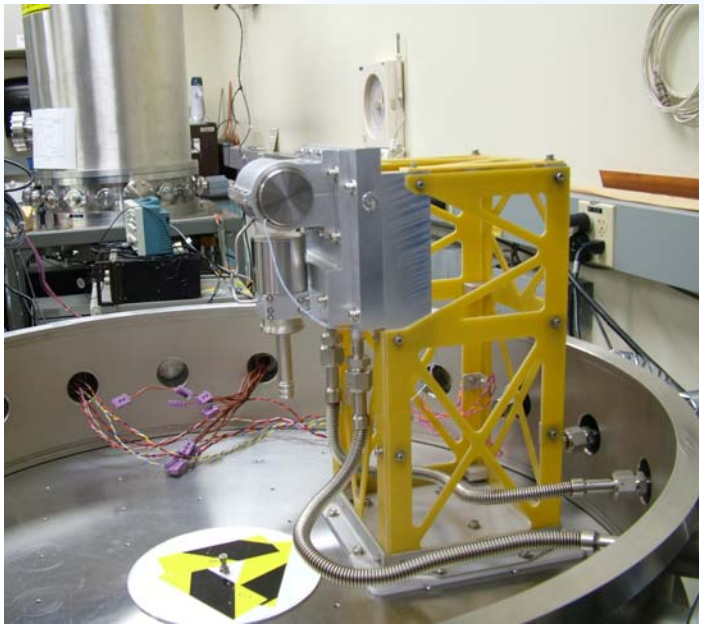
3-Axis Kistler dynometer table for measuring cryocooler exported vibration

- Measures Fx, Fy, Fz and Mx, My, Mz
- Dynamic force measurement accuracy to 10mN

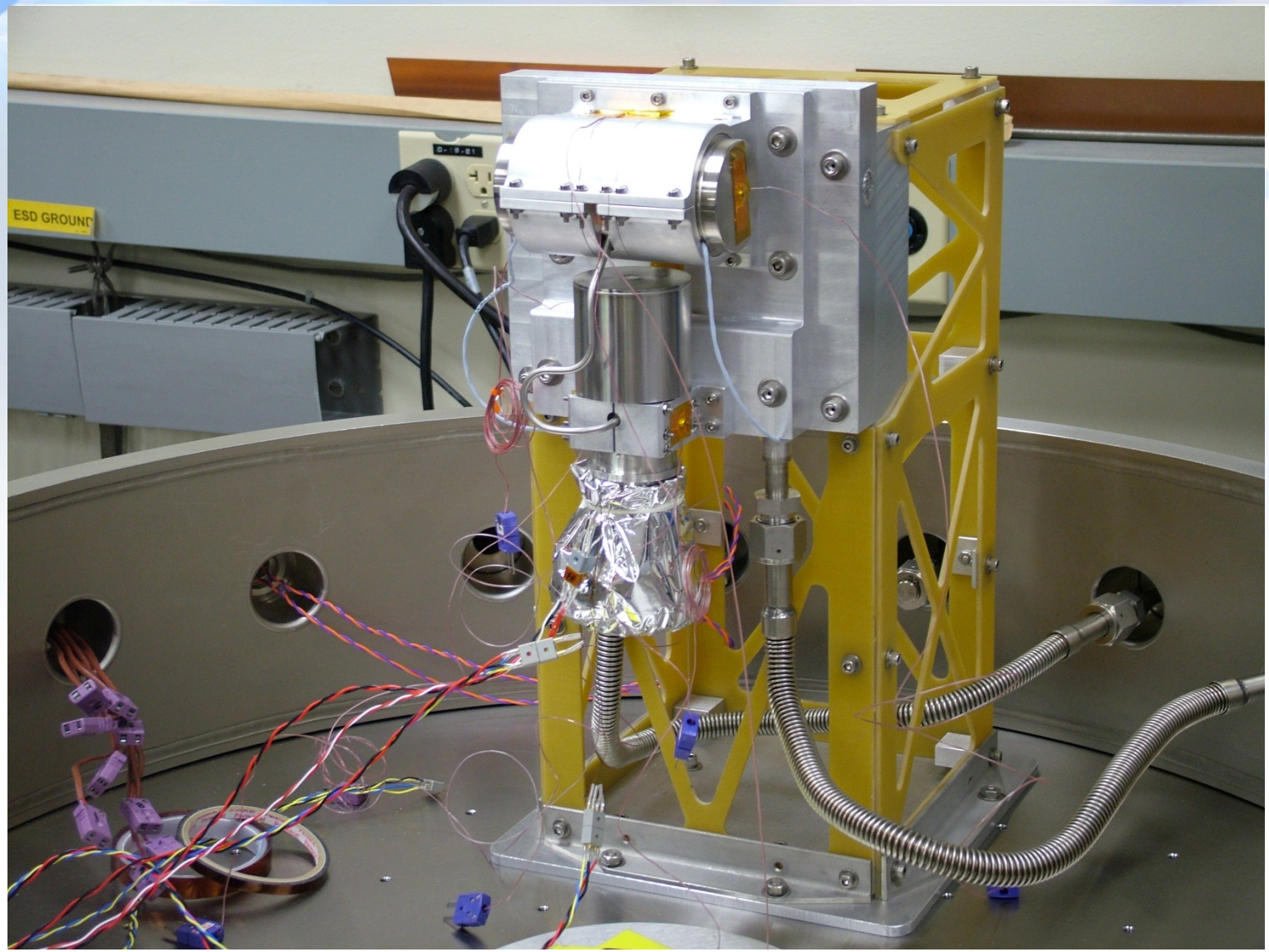
Thales LPT9510
Preparation for Thermal Performance Testing



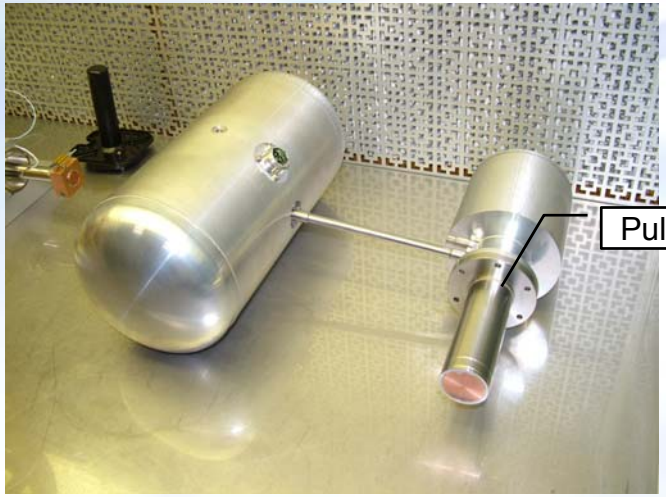


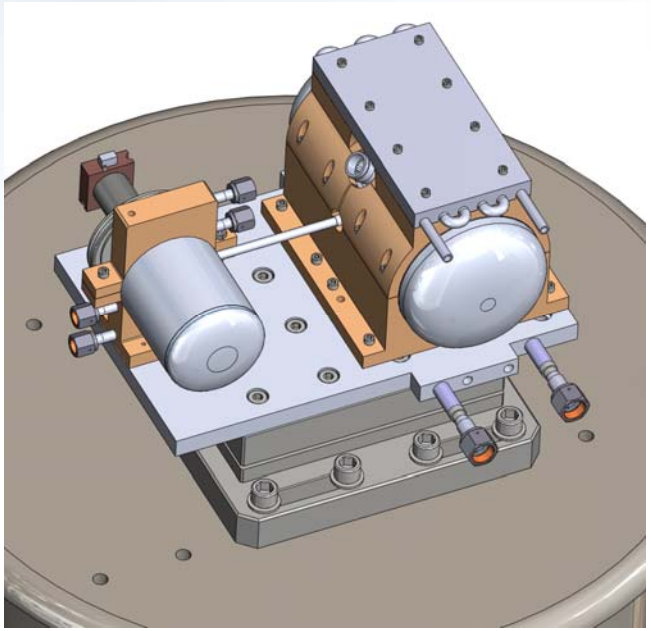


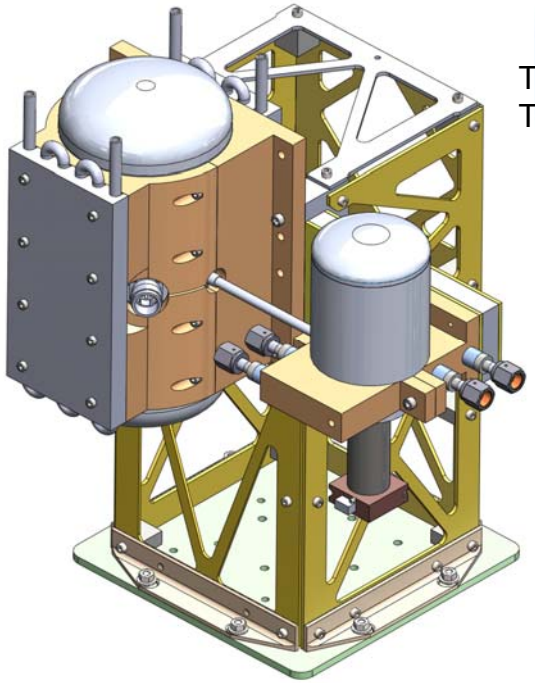
Thermal-Vacuum Test Setup with Instrumentation and MLI on Coldfinger



Thales LPT9710



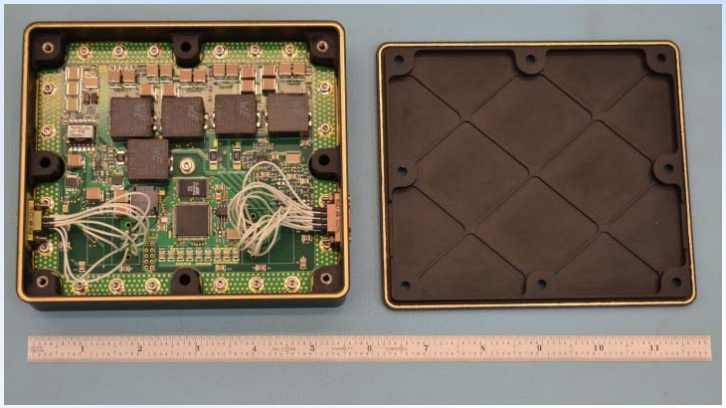


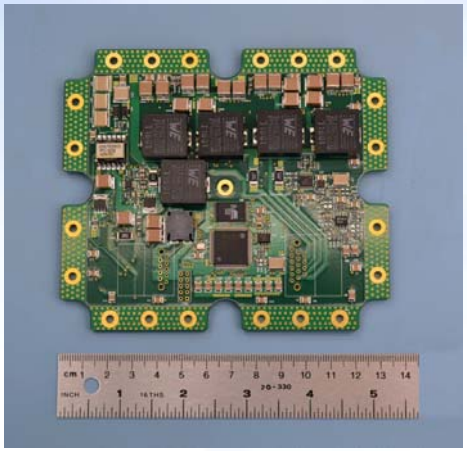


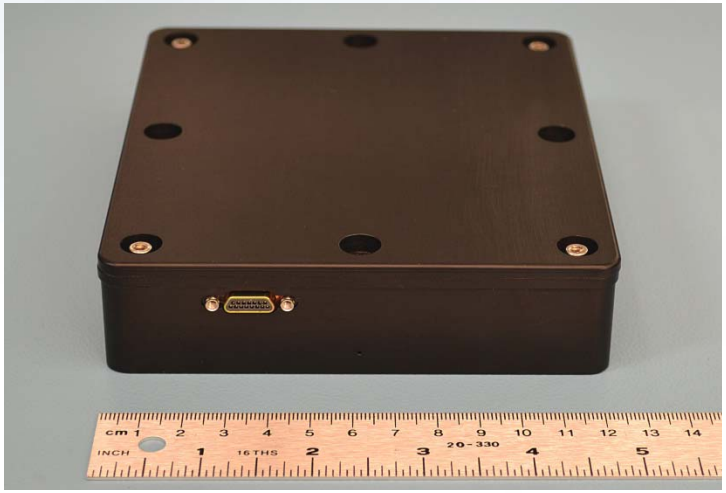
Tvac Performance Characterization Testing Setup

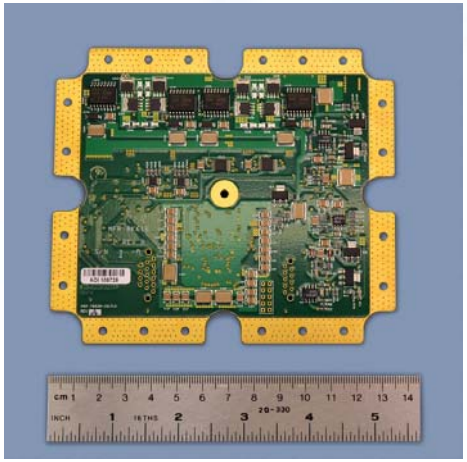
Iris Technology LCCE

Electronics developed and under test at JPL





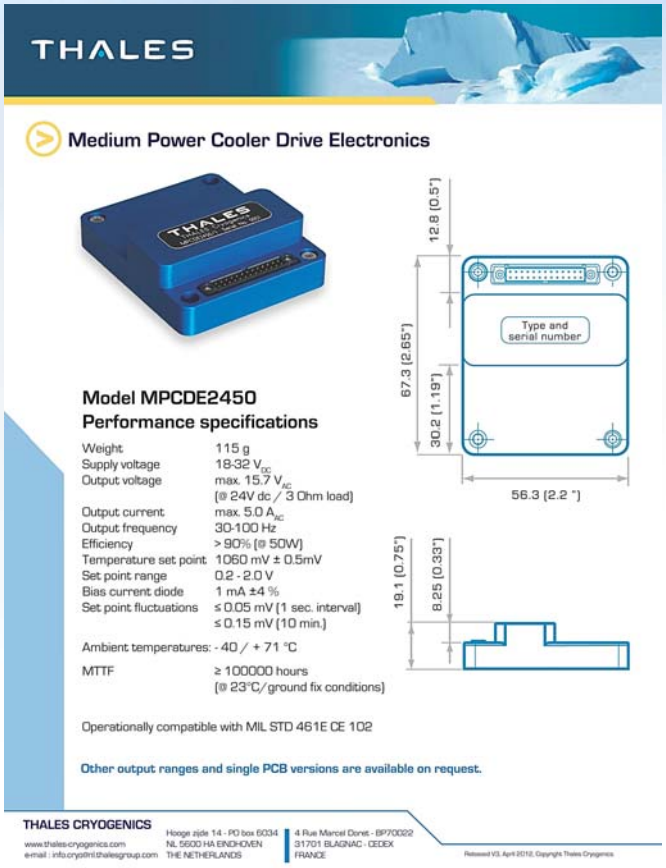




Iris Technology LCCE	
Input Voltage	22 - 37 V_{dc}
Max Output Current	6 A_{ac}
Max Output Voltage	15.2 V_{ac}
Mass	725 gr Total (<225 gr PCB)
Operating Temperature	-50 to 65°C
Non-operating Temperature	-60 to 75°C
Efficiency	>90% @ 40W >85% @ 70W
Output Frequency	50-150 Hz

Thales COTS Cooler Drive Electronics

Thales COTS electronics available for LPT9510 and LPT9310 coolers



THALES

Medium Power Cooler Drive Electronics

Model MPCDE2450
Performance specifications

Weight	115 g
Supply voltage	18-32 V_{DC}
Output voltage	max. 15.7 V_{AC} (@ 24V dc / 3 Ohm load)
Output current	max. 5.0 A_{AC}
Output frequency	30-100 Hz
Efficiency	> 90% (@ 50W)
Temperature set point	1060 mV ± 0.5mV
Set point range	0.2 - 2.0 V
Bias current diode	1 mA ±4 %
Set point fluctuations	≤ 0.05 mV (1 sec. interval) ≤ 0.15 mV (10 min.)
Ambient temperatures:	- 40 / + 71 °C
MTTF	≥ 100000 hours (@ 23°C/ground fix conditions)

Operationally compatible with MIL STD 461E CE 102

Other output ranges and single PCB versions are available on request.

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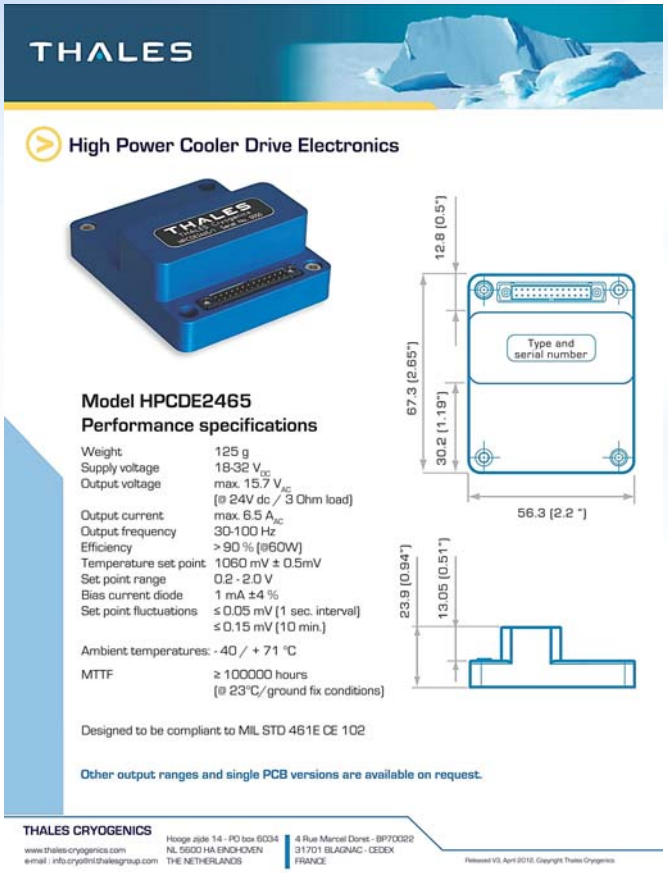
31701 BLAGNAC - CEDEX
FRANCE



THALES

High Power Cooler Drive Electronics

Model HPCDE2465
Performance specifications

Weight	125 g
Supply voltage	18-32 V_{DC}
Output voltage	max. 15.7 V_{AC} (@ 24V dc / 3 Ohm load)
Output current	max. 6.5 A_{AC}
Output frequency	30-100 Hz
Efficiency	> 90 % (@60W)
Temperature set point	1060 mV ± 0.5mV
Set point range	0.2 - 2.0 V
Bias current diode	1 mA ±4 %
Set point fluctuations	≤ 0.05 mV (1 sec. interval) ≤ 0.15 mV (10 min.)
Ambient temperatures:	- 40 / + 71 °C
MTTF	≥ 100000 hours (@ 23°C/ground fix conditions)

Designed to be compliant to MIL STD 461E CE 102

Other output ranges and single PCB versions are available on request.

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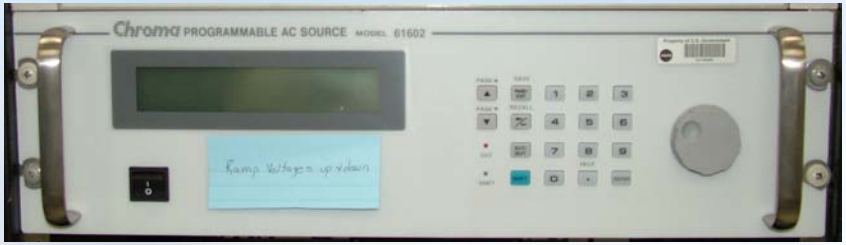
THALES CDE	
Input Voltage	18 - 32 V_{dc}
Max Output Current	5 - 6.5 A_{ac}
Max Output Voltage	15.7 V_{ac}
Mass	115 - 125 grams
Operating Temperature	-40 to 71°C
Efficiency	> 90% @ 50W
Output Frequency	30 - 100 Hz

Laboratory Drive Electronics and Power Measurement Electronics for Performance Testing

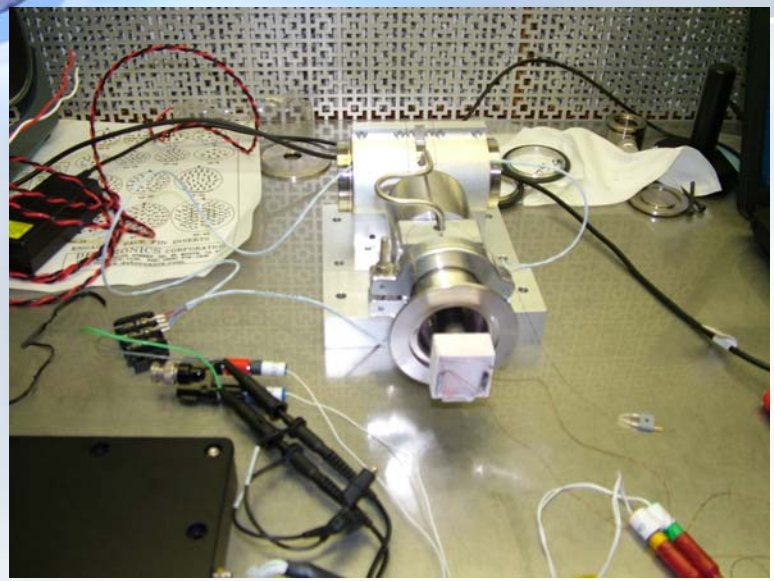


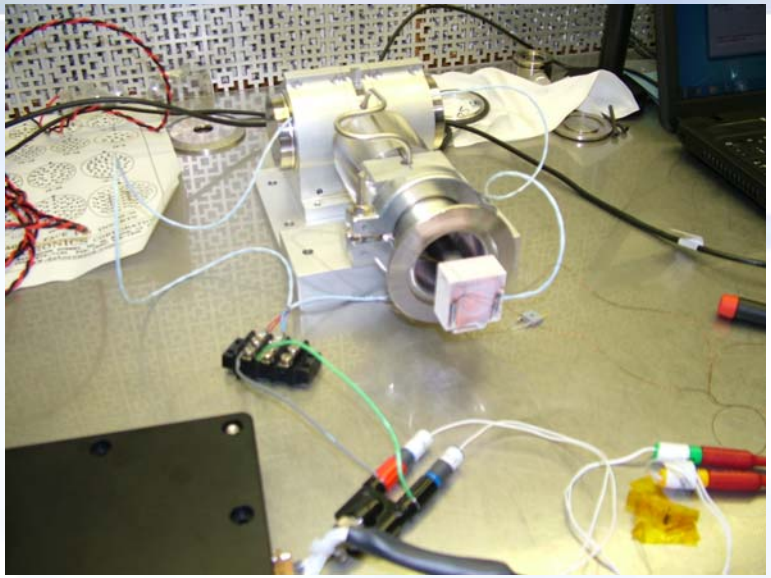
Chroma AC Power Supply
Model 61602

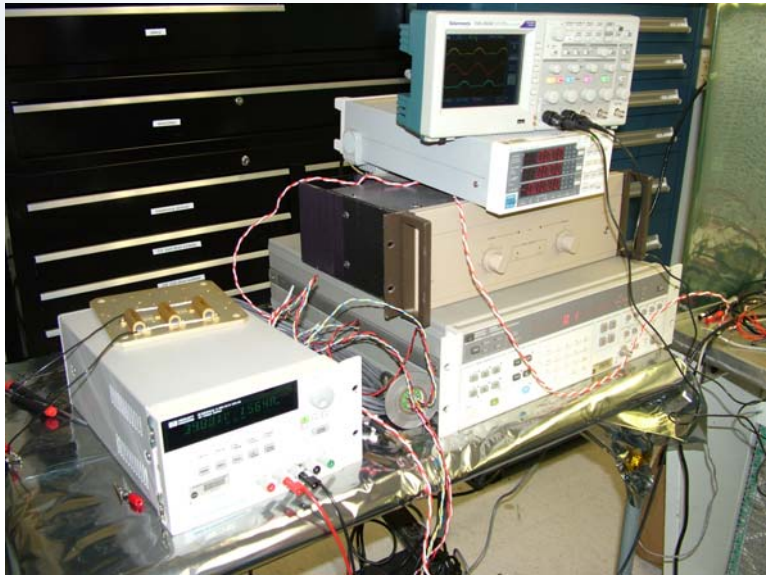
Tektronix Oscilloscope to view AC cooler drive waveforms
Model TDS 2024C

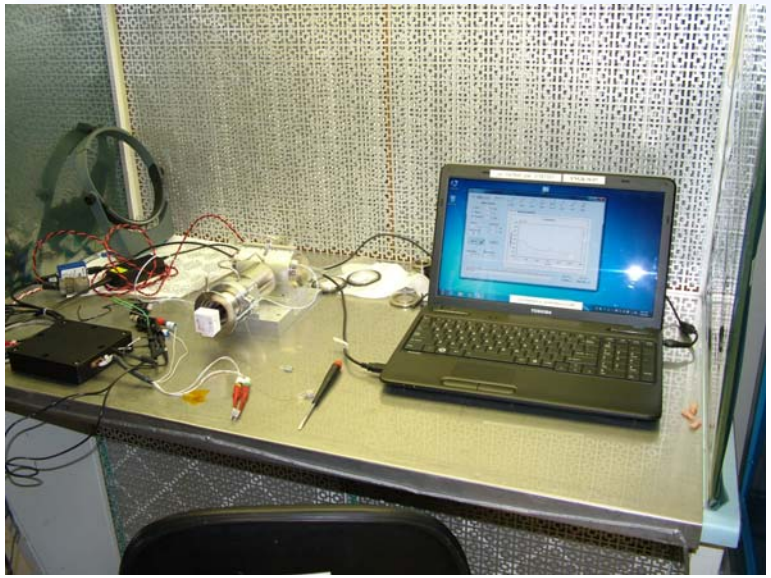
YOKOGAWA Power Meters
Model WT210

1st Cooldown at JPL with LCCE









Near-Term Plans

- Obtain baseline performance of LPT9510
  - Thermodynamic performance as a function of key parameters
  - Exported vibration as a function of power input levels
  - Thermodynamic performance as a function of pulse tube orientation
  - Develop experience running cooler with laboratory drive electronics and Iris Technology LCCE
- Proceed to flight qualification testing of LPT9510 with LCCE
  - Thermal vacuum qualification testing (temp cycling, cold/hot non-op soaks, cold/hot operational temp start-ups)
  - Launch vibration
  - EMI/EMC, current ripple, in-rush
- Complete flight qualification testing of LPT9510 with LCCE by end FY13 (Sept 2013)

Long-Term Plans

- Develop plans in 1st quarter CY13 for LPT9510 performance improvements and other modifications needed to simplify/improve integration on instruments
- Work with Iris Technology to add vibration suppression and input power filtering to 2nd generation LCCE
- In parallel begin baseline testing of LPT9710 and LPT9310 coolers in 2nd quarter CY13
- Proceed to flight qualification of LPT9310 and LPT9710
- Develop plans for performance improvements and other mods needed for 2nd generation flight LPT9310 and LPT9710 coolers

Baseline Performance Characterization
Cooler Subsystem Testing

THALES LPT9510

Lab Power Amplifier/FWG
Iris Technology LCCE
Thales COTS CDE

THALES LPT9310

Lab Power Amplifier/FWG
Thales COTS CDE

THALES LPT9710

Lab Power Amplifier/FWG

THERMAL PERFORMANCE

Measures cooler thermodynamic performance to determine specific power

- Cooler with CDE test
- 24in bell-jar vacuum chamber
- Coldtip temperature control for short and long-term stability
- Variables:
  - ✓ heat sink temperature
  - ✓ Coldtip temperature
  - ✓ Coldtip temperature control
  - ✓ Coldtip heat lift
  - ✓ Input power (drive level)

COOLER DRIVE ELECTRONICS PERFORMANCE

Measures CDE efficiency and tare power

- Variables:
  - ✓ Input power (drive level)
  - ✓ Drive frequency
  - ✓ Coldtip temperature control

EXPORTED VIBRATION

Measures residual exported vibration and moments using 3-axis dynamometer

- Cooler is bagged and purged or uses vacuum bonnet to operate in ambient conditions
- Variables:
  - ✓ Input power (drive level)
  - ✓ Drive frequency
  - ✓ Vibe suppression
  - ✓ Coldtip temperature control

VARIABLE TILT ANGLE THERMAL PERFORMANCE

Measures cooler thermodynamic performance as a function of tilt angle

- Cooler with CDE test
- Small bell-jar vacuum chamber on Flotron rotation device
- Variables:
  - ✓ Heat sink temperature
  - ✓ Coldtip temperature
  - ✓ Coldtip heat lift
  - ✓ Input power (drive level)
  - ✓ Coldtip temperature control

Cryocooler Flight Qualification Testing

THALES LPT9510

Iris Technology LCCE

THALES LPT9310

Thales COTS CDE

THALES LPT9710

Need to develop CDE

THERMAL CYCLE

Burn-in thermal stress test to evaluate product reliability and detect workmanship defects and robustness to thermal fatigue

- X cycles (acceptance)
- Y cycles (protoflight)
- Functional test after 1st and last cycles
- Variables:
- ✓ Input power (drive level)
- ✓ Drive frequency
- ✓ Coldtip temperature control

THERMAL VACUUM

Demonstrates ability of product to perform in thermal vacuum environment subjected to the maximum and minimum predicted temperatures

- 1 cycle (acceptance level)
- 3 cycles (protoflight level)
- Functional test after 1st and last cycle
- Variables:
- ✓ Heat sink temperature
- ✓ Coldtip temperature
- ✓ Coldtip heat lift
- ✓ Input power (drive level)
- ✓ Coldtip temperature control

EMI/ EMC(1)

Test evaluation for conducted and radiated emissions and susceptibility

- RE02 E-field radiated emission
- RE01/04 H-field radiated emission
- CE01/03 conducted emission
- In-rush current
- RS01 H-field radiated susceptibility
- CS01/02 line ripple conducted susceptibility
- CS06 current transient conducted susceptibility
- Variables:
- ✓ Input power (drive level)
- ✓ Drive frequency
- ✓ Vibe suppression
- ✓ Coldtip temperature control

LAUNCH VIBRATION(2)

Demonstrate ability of assembly to withstand predicted launch dynamics environment with margin

- Low-level sine sweep
- Random vibration
- Variables:
- ✓ Flight acceptance levels
- ✓ Protoflight levels

1. Testing performed in JPL building 179 Laboratory
2. Tests performed in JPL's Environmental Test Laboratory (ETL) in building 144

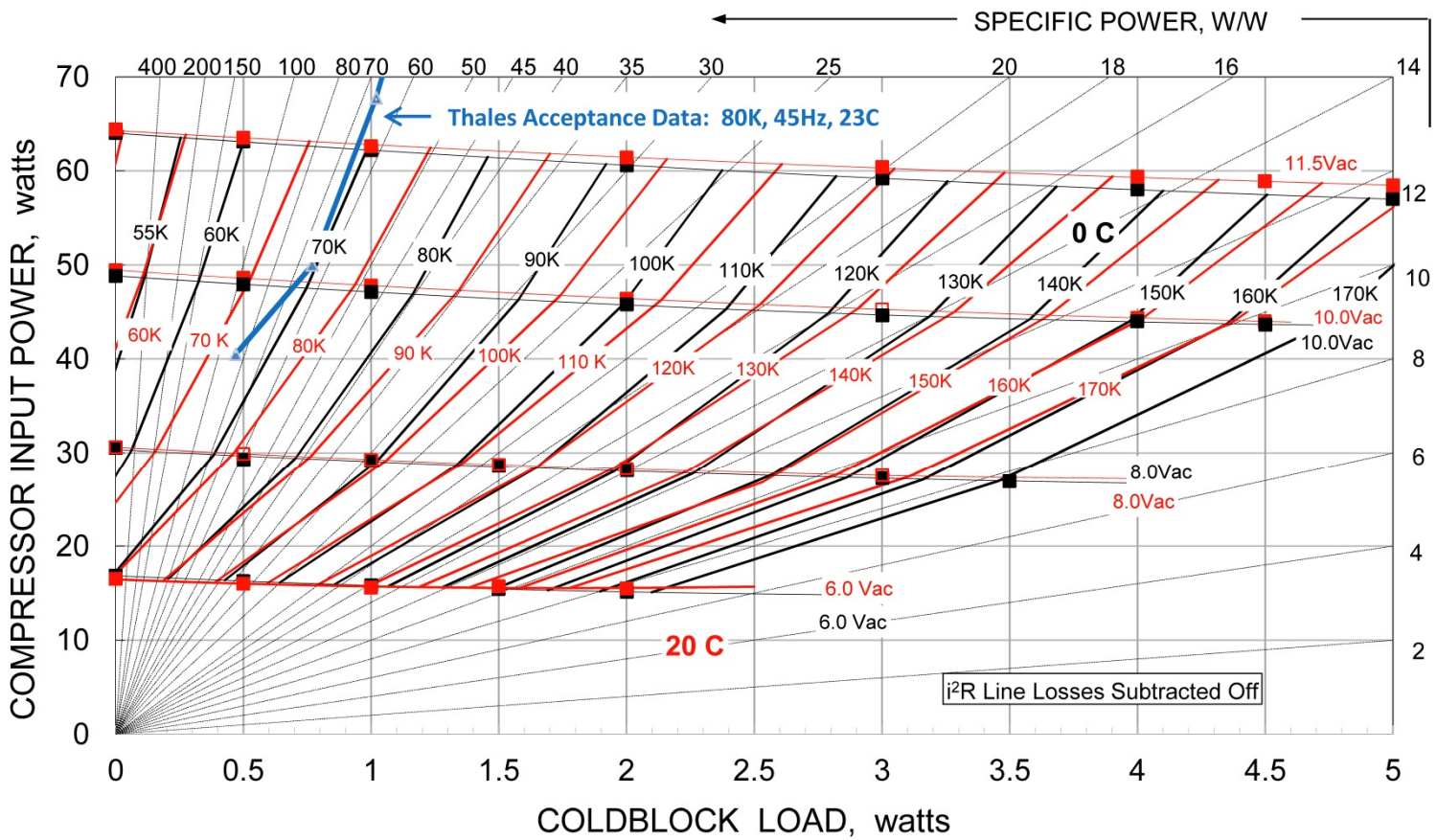
Thermodynamic Performance with Heat Sink at 0°C and 20°C

Jet Propulsion Laboratory
California Institute of Technology

THALES LPT9510 PULSE TUBE COOLER

SENSITIVITY OF THERMAL PERFORMANCE TO HEAT REJECT TEMPERATURE

DRIVE FREQUENCY = 45 Hz

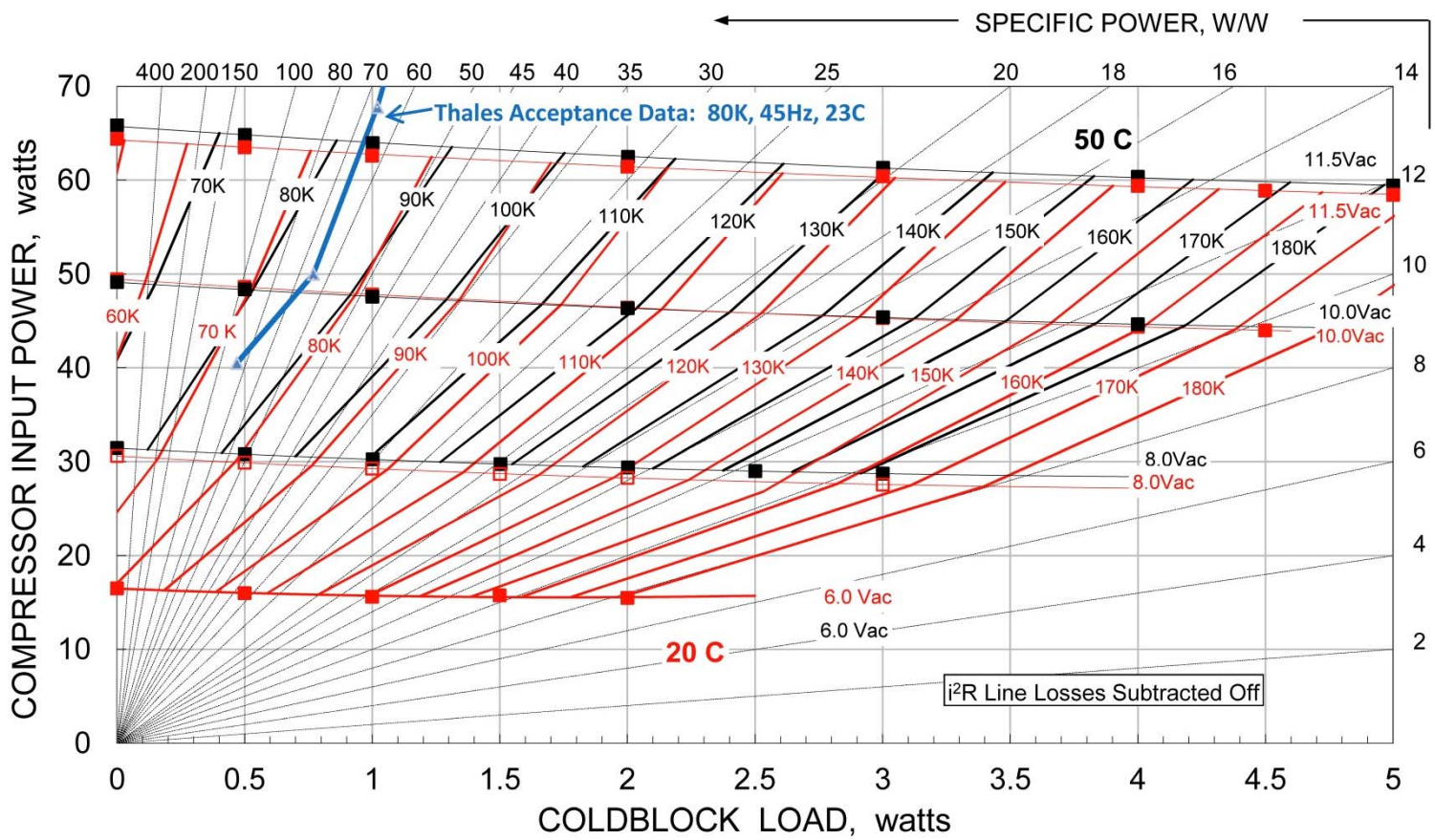


Thermodynamic Performance with Heat Sink at 20°C and 50°C

THALES LPT9510 PULSE TUBE COOLER

SENSITIVITY OF THERMAL PERFORMANCE TO HEAT REJECT TEMPERATURE

DRIVE FREQUENCY = 45 Hz

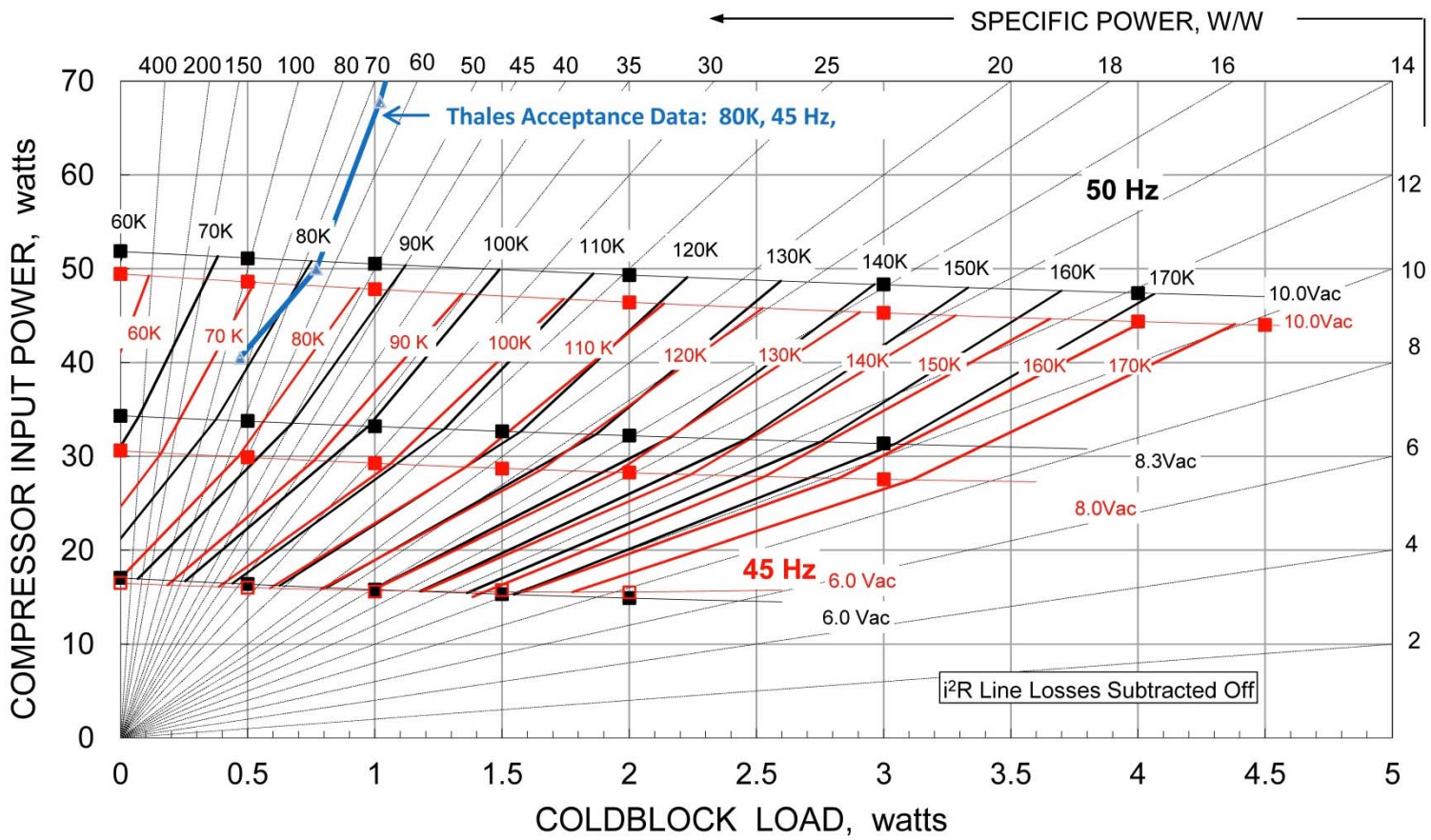


Thermodynamic Performance with Drive Frequency at 45Hz and 50Hz

THALES LPT9510 PULSE TUBE COOLER

SENSITIVITY OF THERMAL PERFORMANCE TO DRIVE FREQUENCY

HEATSINK TEMPERATURE = 20°C

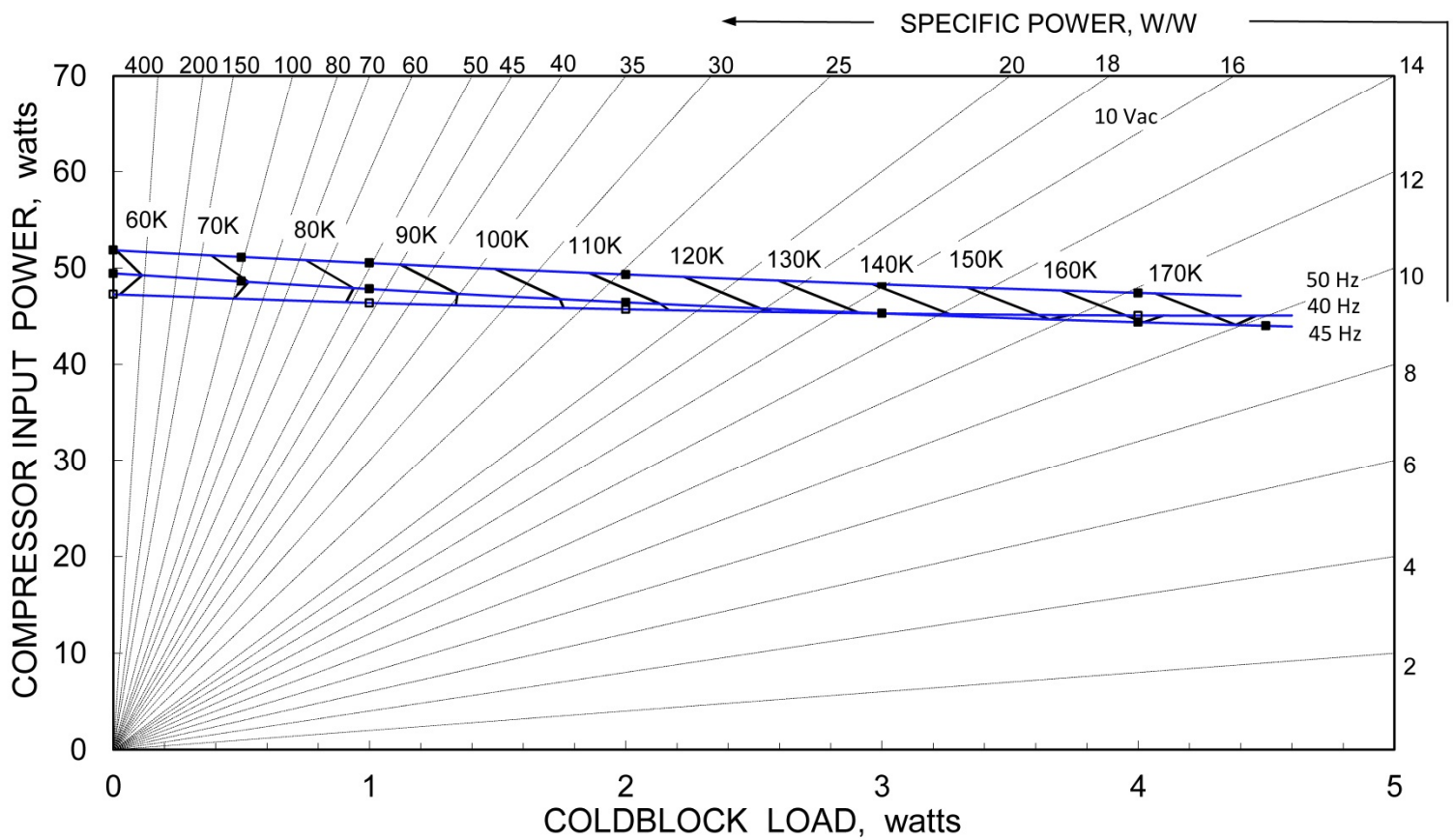


Thermodynamic Performance with Drive Frequency at 40Hz, 45Hz and 50Hz

THALES LPT9510 PULSE TUBE COOLER

SENSITIVITY OF THERMAL PERFORMANCE TO DRIVE FREQUENCY

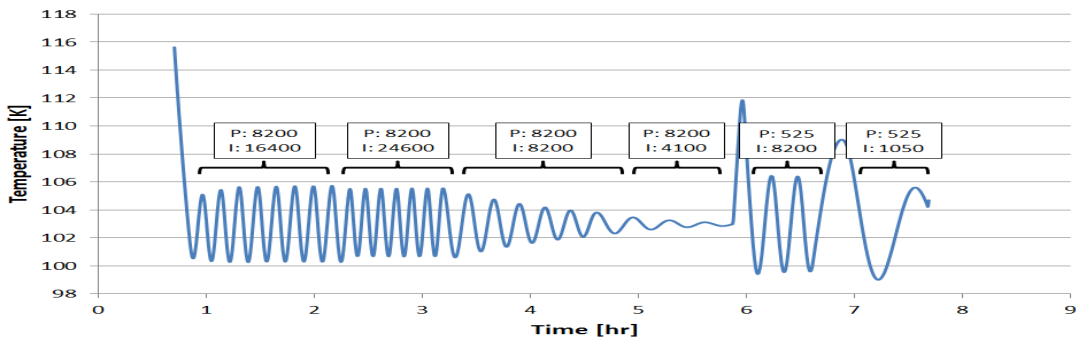
20°C COOLER SKIN TEMPERATURE; 10 Vac

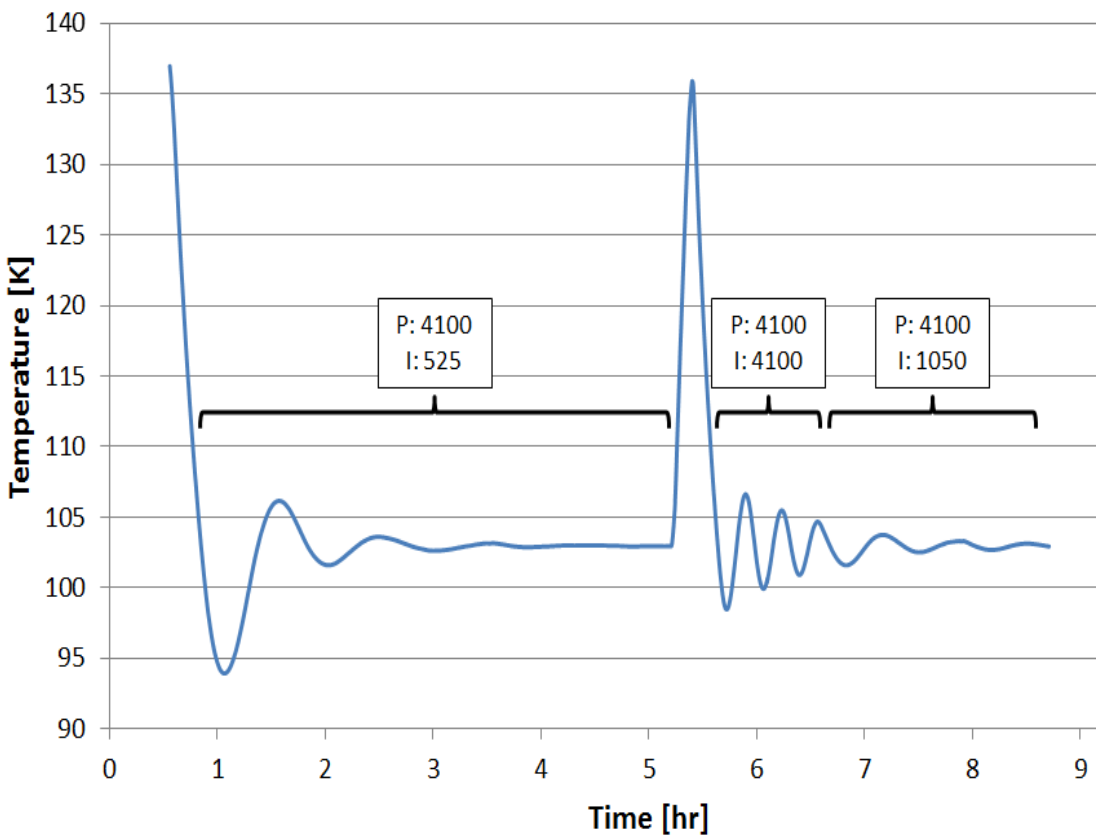


Closed-Loop Temperature Control Test Summary

- Iris Technology LCCE used to test cooler temperature control sensitivity of PI loop
- All tests shown were run at a 45 Hz drive frequency in temperature mode with a set point of 100K
- Peak drive limit of 50%, and 28 V input to the LCCE
- All but the last test used a heat load of 0.5 W on the coldtip
- Thermal mass attached to coldtip is 87.5gm of copper
- Optimal PI settings found for above conditions are:
  - P= 32700, and I = 525-2100

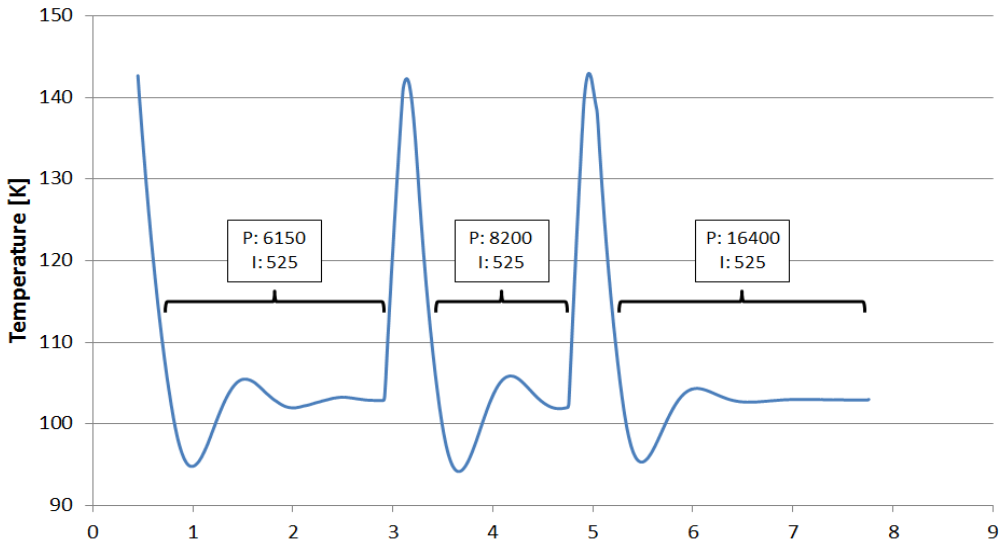
Temperature control tests with set P and varying I
Cooler Driven with LCCE

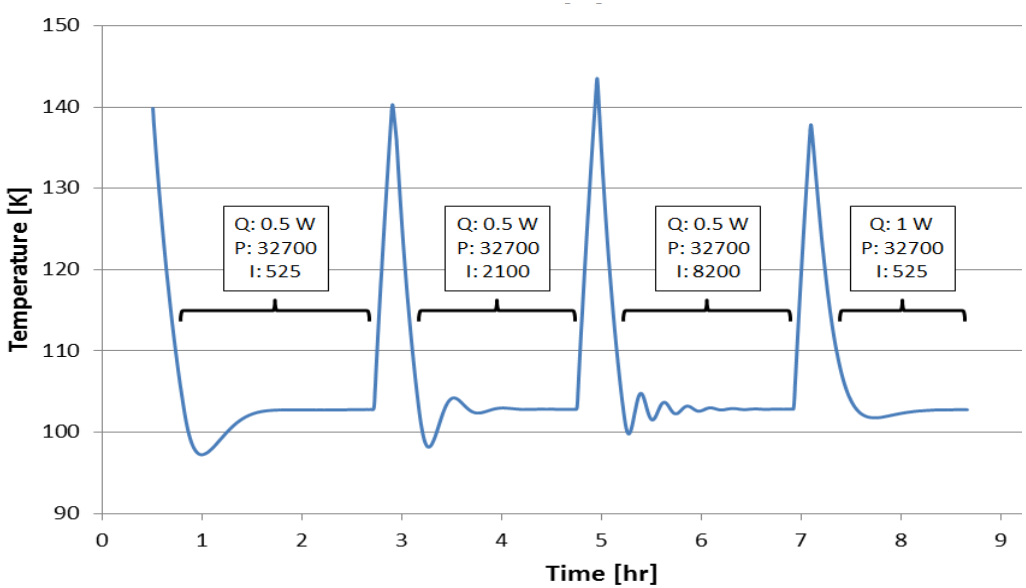




Plots with identical time and temperature scales

Temperature control tests with set P and varying I Cooler Driven with LCCE (Cont'd)

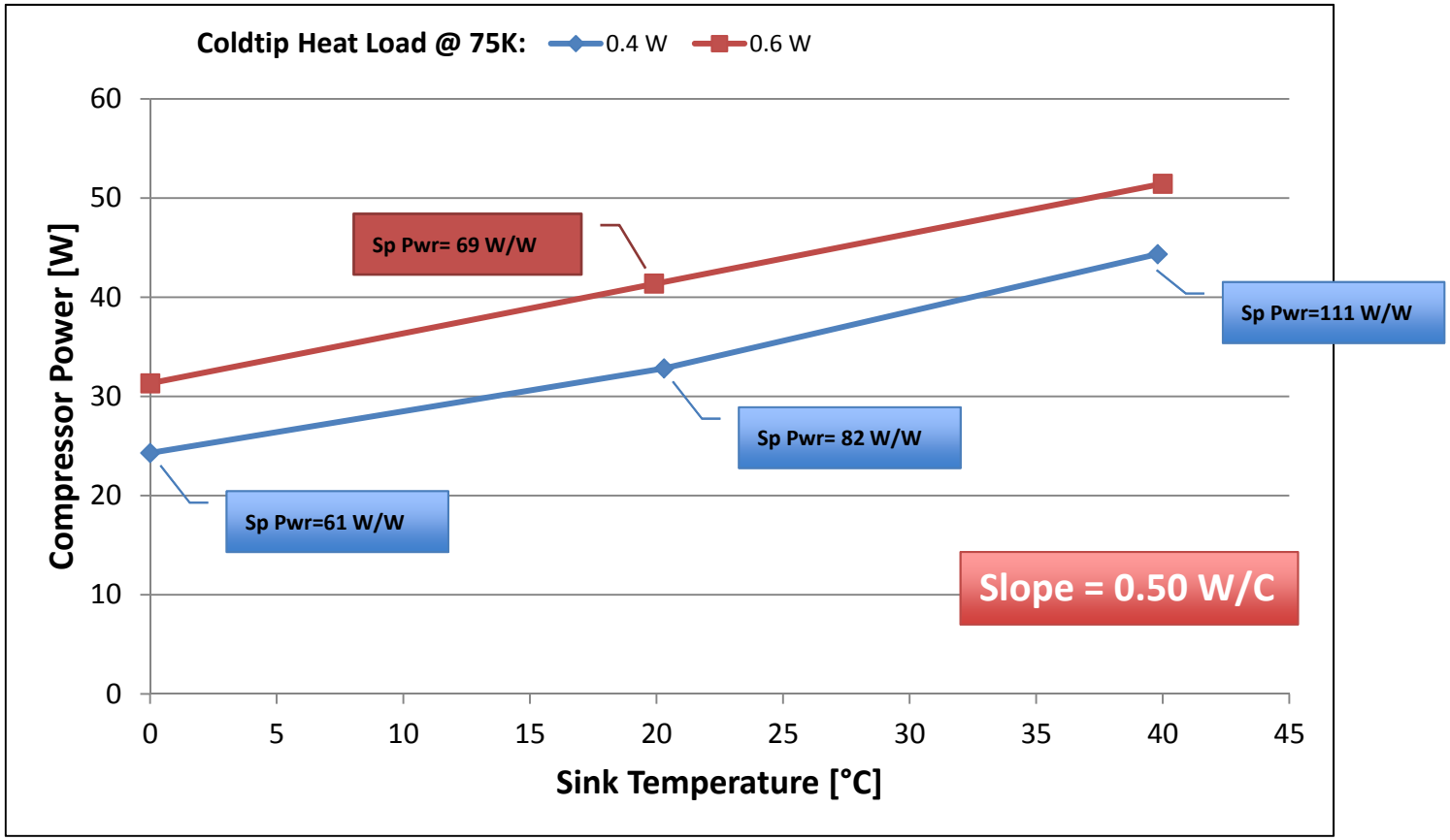




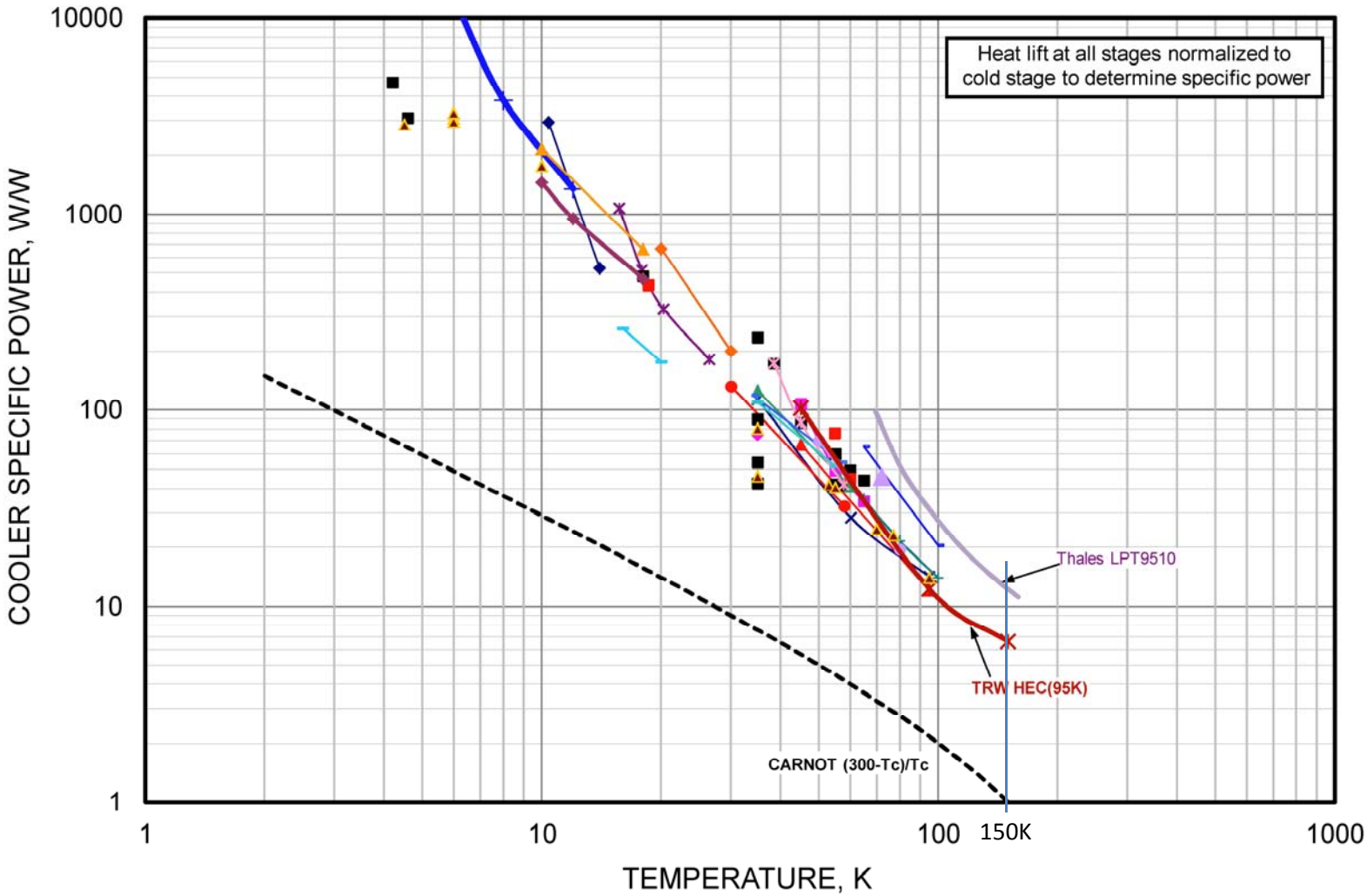
Plots with identical time and temperature scales

Optimal PI settings found for above conditions are:
P= 32700, and I = 525-2100

Cooler Performance Sensitivity to Sink Temperature



Cooler specific power as function of Temperature Data for Development and Flight Coolers

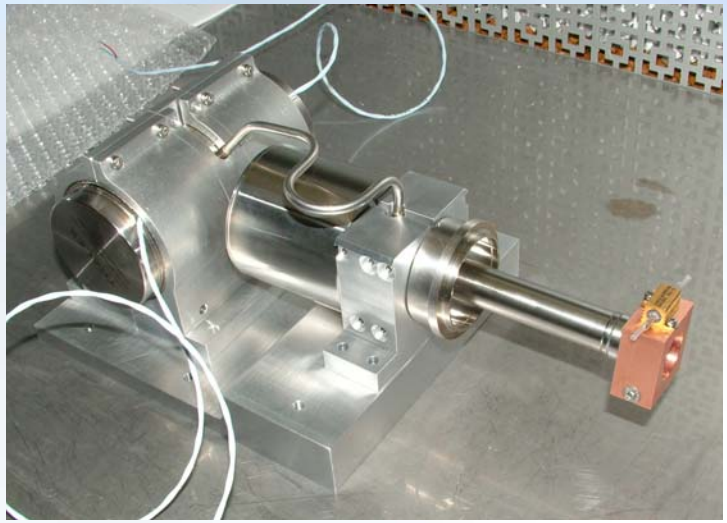


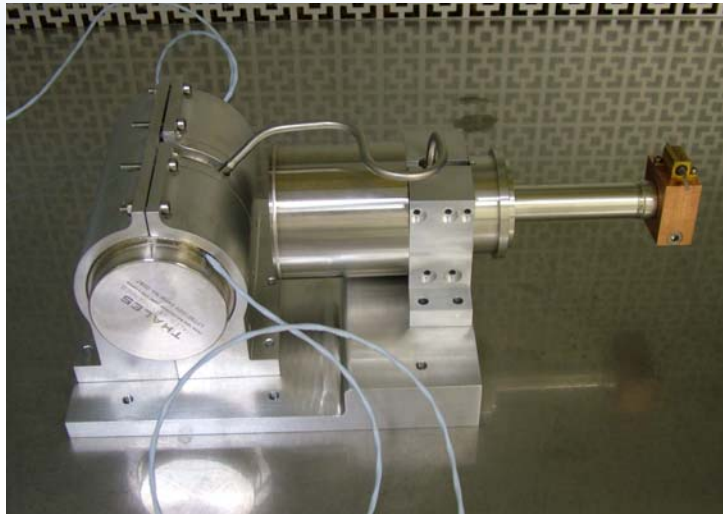
Overall Thermodynamic Performance Assessment

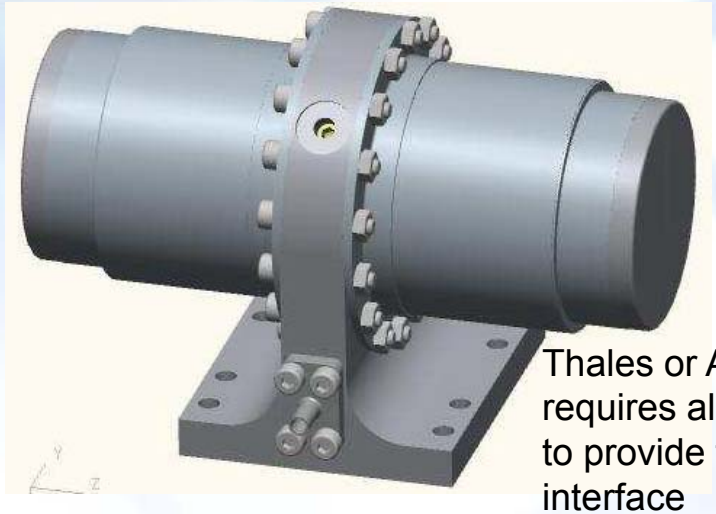
- Compared to the state-of-the-art Northrup Grumman pulse tube cooler (High Efficiency Cooler – HEC):
  - At 100K the specific power of the LPT9510 is ~2.3X higher
  - At 150K the specific power of the LPT9510 is ~1.9X higher
- Will target performance improvement for LPT9510 by a factor of 2X at 100K
  - This will result in a specific power of <13 W/W (compared to ~25W/W measured on current COTS unit)
  - Assuming 90% efficient drive electronics the cooler system specific input power will be <14.4 W/W

Compressor Structural/Thermal Mounting Interface

JPL clam-shell interface requires clamping entire compressor to provide sufficient heat transfer area



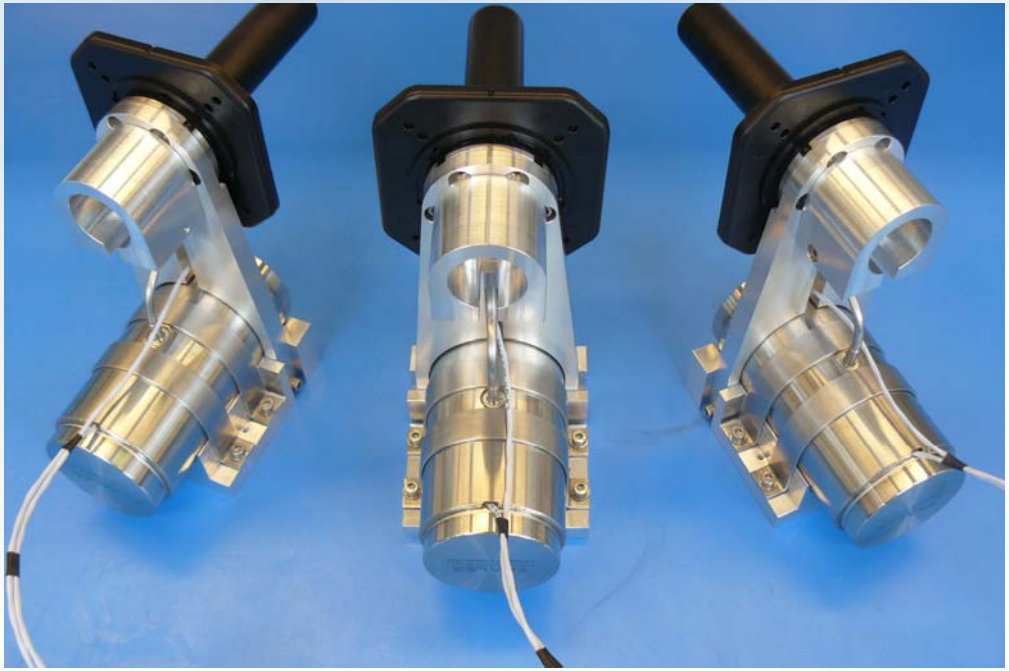




Thales or Air Liquide design requires aluminum centerplate to provide thermal/mechanical interface

Compressor Structural/Thermal Mounting Interface

Thales COTS clamps

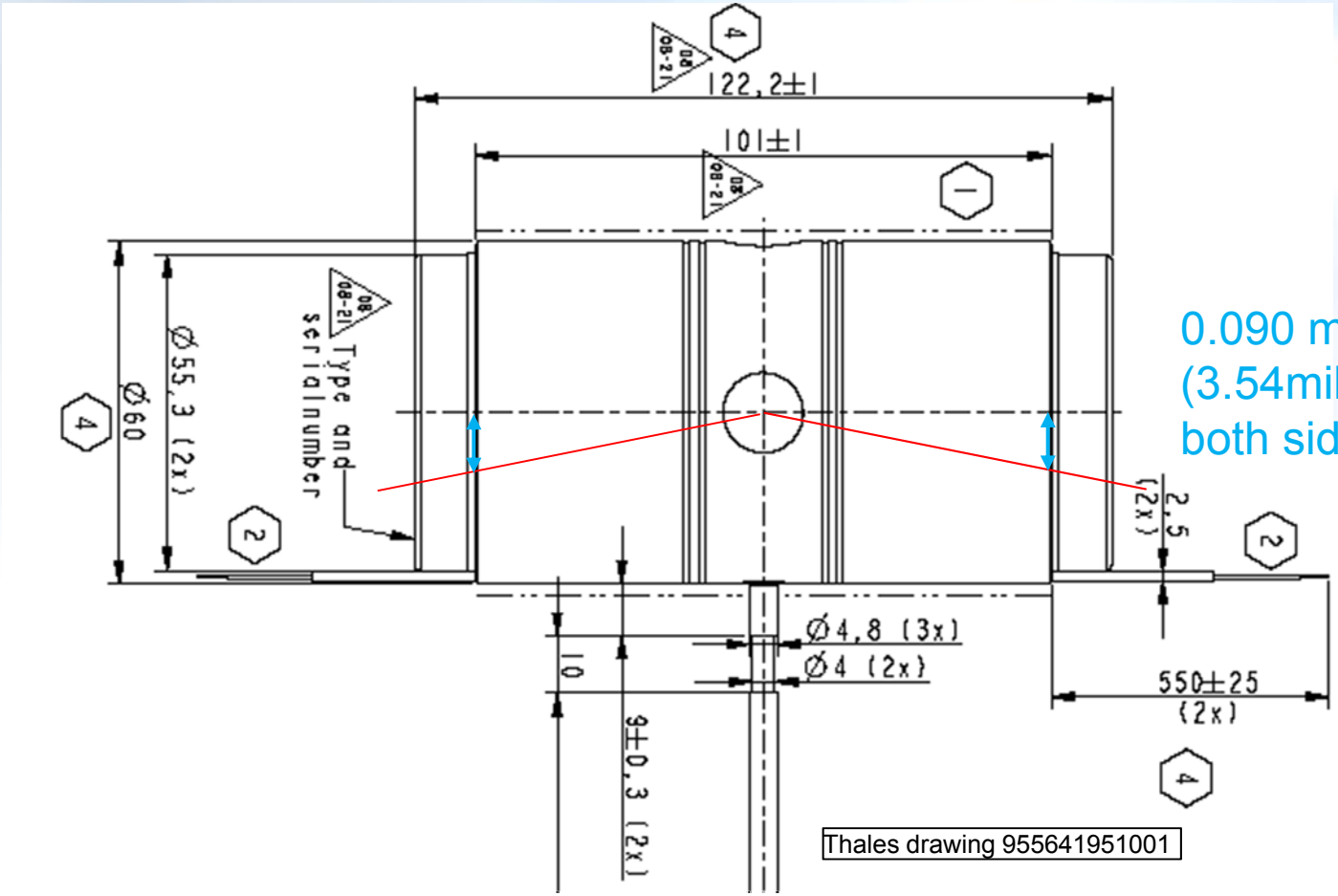


Thales COTS clamps for ground applications not suitable for operation in vacuum environment

- Contact area between compressor body and heat sink is small because of the cylindrical geometry
- Ground applications rely on gas conduction across mating the surfaces and active air cooling

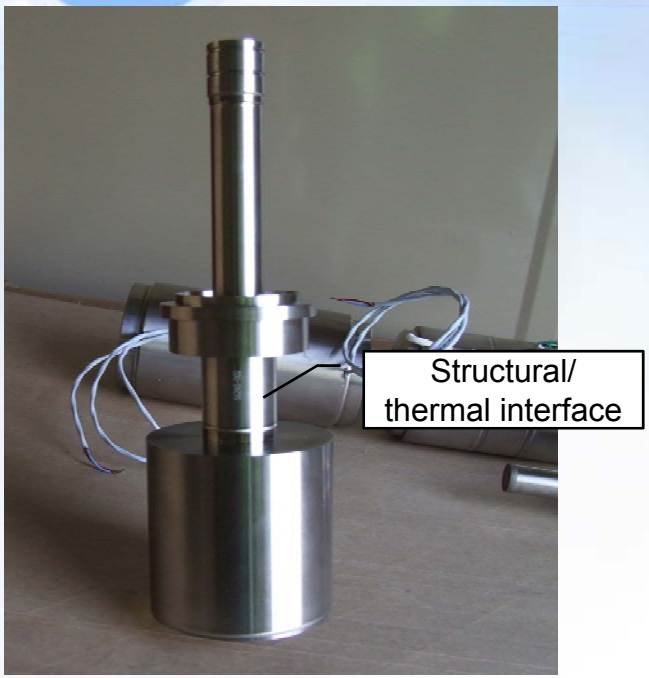
Compressor Halves Alignment Measured at JPL

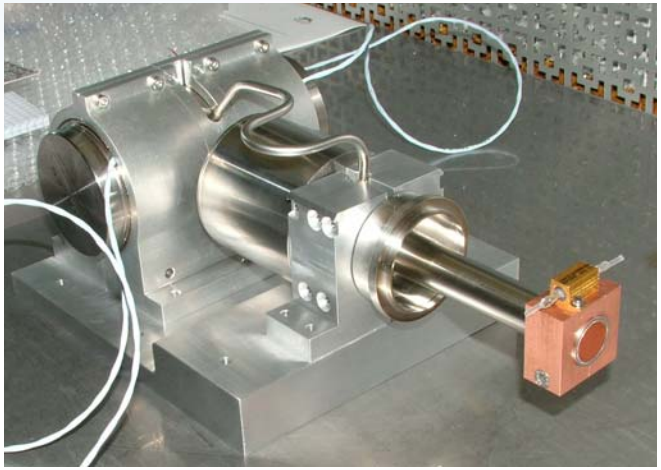
What is Thales requirement for alignment of compressor halves?

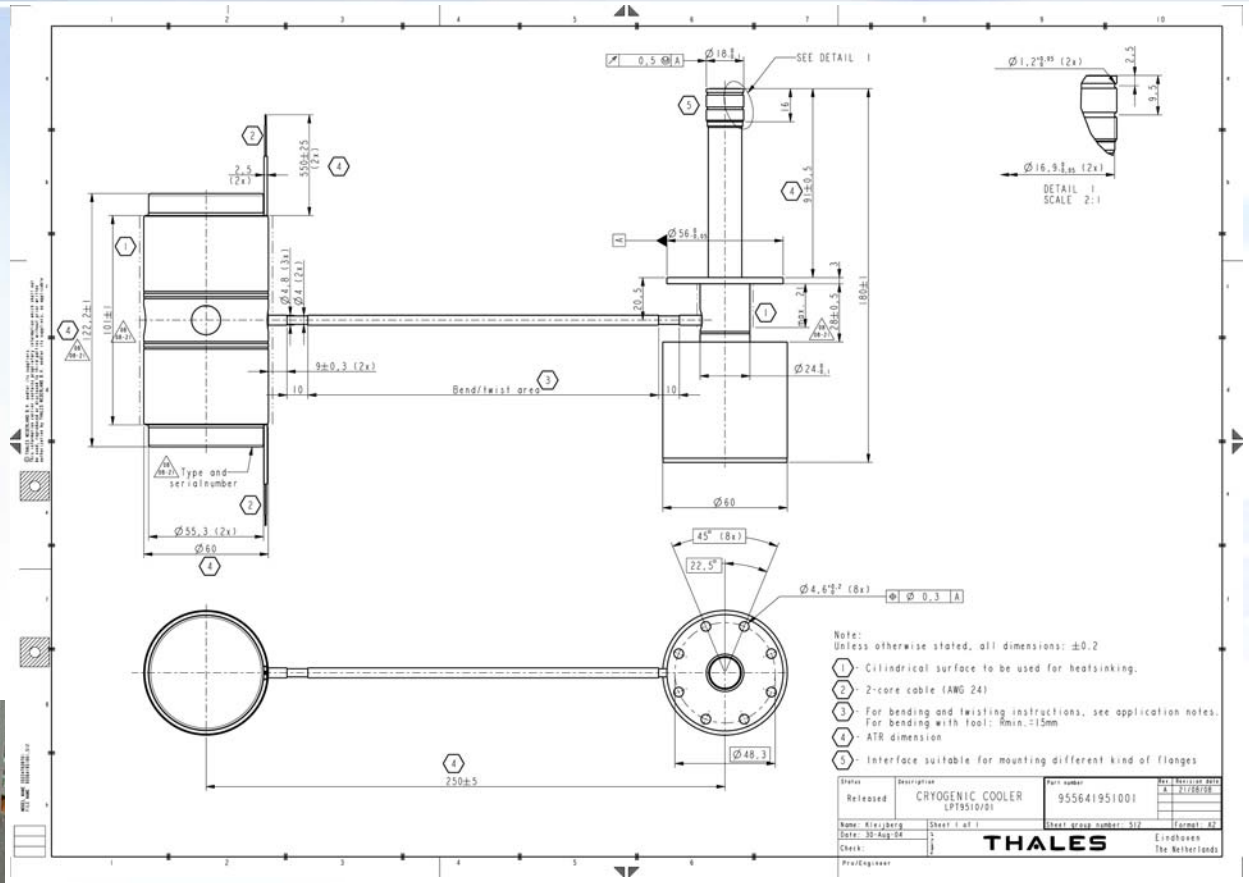


0.090 mm max (3.54mils) offset, both sides

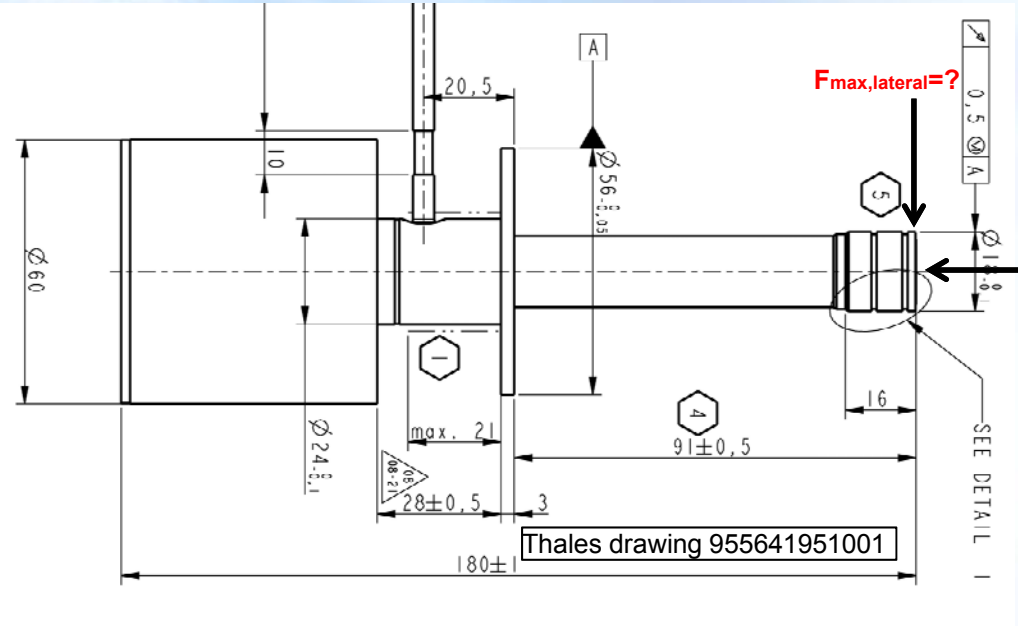
Cold Head Structural/Thermal Mounting interface

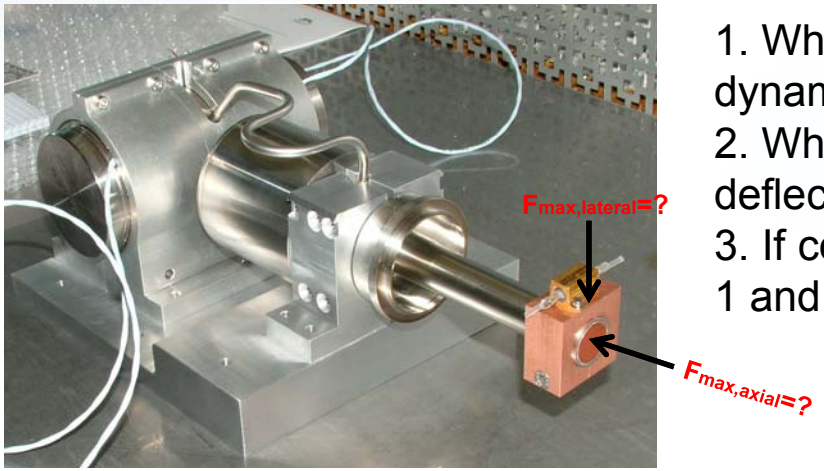






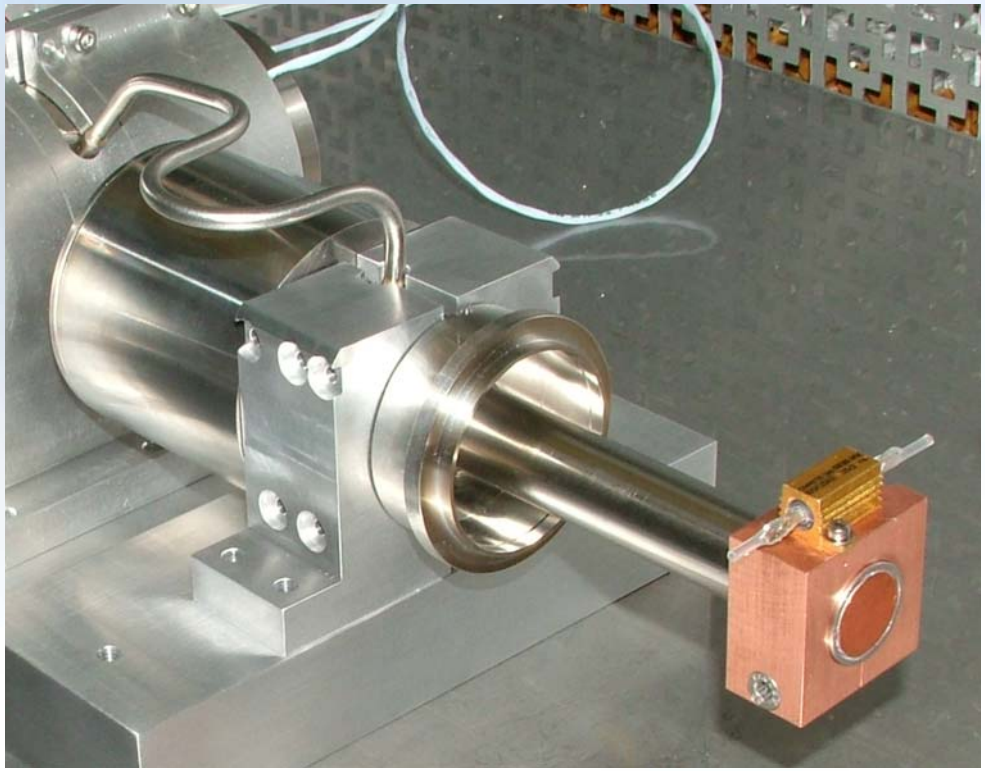
Allowed Coldtip Mechanical Loads





1. What is the allowed maximum lateral and axial static and dynamic mechanical loads on the coldtip?
2. What is the maximum allowed static and dynamic deflection of the coldtip?
3. If cooler is operating will it impact the answers to question 1 and 2? If so, what is the impact?

LPT Cold Block Heater



JPL heater block:
Mass of copper block: ~87.5g

Thales coldtip design options available to customers?

Summary

- Significant progress made to date on testing LPT9510
- Will begin exported vibration testing in the next few weeks
- Flight qualification testing (thermal, vibe, EMI/EMC) will commence in 1st quarter CY13
- Need to start developing plans for performance improvements including potential mechanical design modifications to simplify/improve integration on payloads
- In parallel will commence testing of LPT9710