DUAL-PURPOSE SPACE SIMULATION FACILITY FOR PLASMA THRUSTER AND SATELLITE TESTING

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Project Background

- The Australian National University
  - Research School of Astronomy and Astrophysics (RSAA),
    - Advanced Instrumentation Technology Centre (AITC)
    - National Facility for development of advanced terrestrial & spaceborne instrumentation

  - Research School of Physics & Engineering (RSPE)
    - Space Plasma Power and Propulsion (SP3)

Project Background

- Helicon Double Layer Thruster (HDLT)
  - neutral plasma beam (no neutraliser)
  - accelerating electric field (no high voltage grid)
  - wide variety of fuels
  - scalable in both power & geometry
  - no moving parts
  - increased reliability over other EP thrusters

Project Background

- SP3 required a larger thruster test facility
- AITC required thermal vacuum chamber for space & cryogenic testing
- Consortium for Australian Space Research Program (ASRP) grant
  - Australian National University
  - Airbus Space & Defense
  - Surrey Space Centre
  - Vipac Engineers and Scientists
- Australian Plasma Thruster (APT) Project funded mid-2011 (last round)

S2F Key Design Drivers

- Single Multi-purpose Facility
  - Functional & performance testing of electric propulsion thrusters
  - TVAC testing & vacuum bakeout for space hardware
  - Cryogenic vacuum testing of large astronomical (optical) instrumentation;
  - Rapidly re-configurable

S2F Key Design Drivers

- Thruster Testing Requirements
  - Long, large diameter chamber
  - Non-magnetic material construction
  - Accommodation of thruster test and diagnostic hardware
  - High pumping speeds
  - Radiative cooling to the thruster

S2F Key Design Drivers

- TVAC & Cryogenic Test Requirements
  - Accommodation for Nanosats to mini-satellites
  - Independent control of radiative shrouds & conductive thermal platen
  - High temperature for bakeout
  - Low temperature for testing of cryogenic instrumentation (ideally ~100K)
  - Rates & stability design cost trades

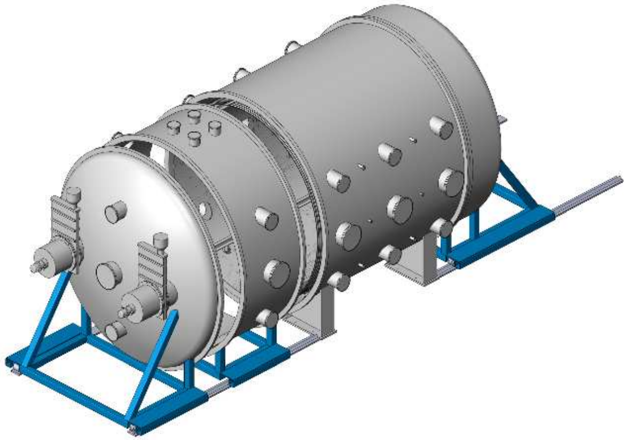
S2F Key Design Drivers

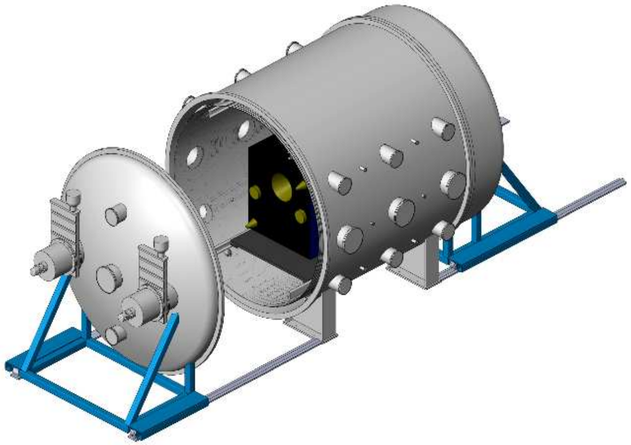
- Operational Requirements
  - Turnkey control system
  - Man-in-the-loop facility operation
  - High degree of safety with facility interlocks
- Pumping Requirements
  - Dry pumps only
  - Rapid pumpdown to <1E-5 overnight
  - Low leak rate

S2F Key Design Drivers

- General Requirements
  - Australian mains power
  - Distributed mass on suspended concrete slab
  - O-ring seals for vacuum connections
  - Cryo-plate for contamination witness samples
  - Several test-item ports
  - Remotely located facility infrastructure

S2F Design Concept





- Fixed main chamber
- Removable thruster annulus
- Thruster annulus design as per Wombat facility
- Translatable rail-mounted endcaps
- Radiative thermal shrouds & conductive thermal platen
- Removable shrouds
- Rear endcap accommodates internal cryopumps

S2F Procurement Approach

- Turn-key design, build & install-to-cost contract, experienced supplier
- Plume Capture System (PCS) and supporting infrastructure works by the AITC engineering team
- Development Timeline
  - Formal RFT issued mid-June 2012
  - Dynavac selected as preferred supplier mid-August 2012
  - CDR concluded mid-November 2012
  - EDC mid-December 2012
  - FAT conducted mid-May 2013
  - Delivery to site early-September 2013
  - Commissioned mid-December 2013

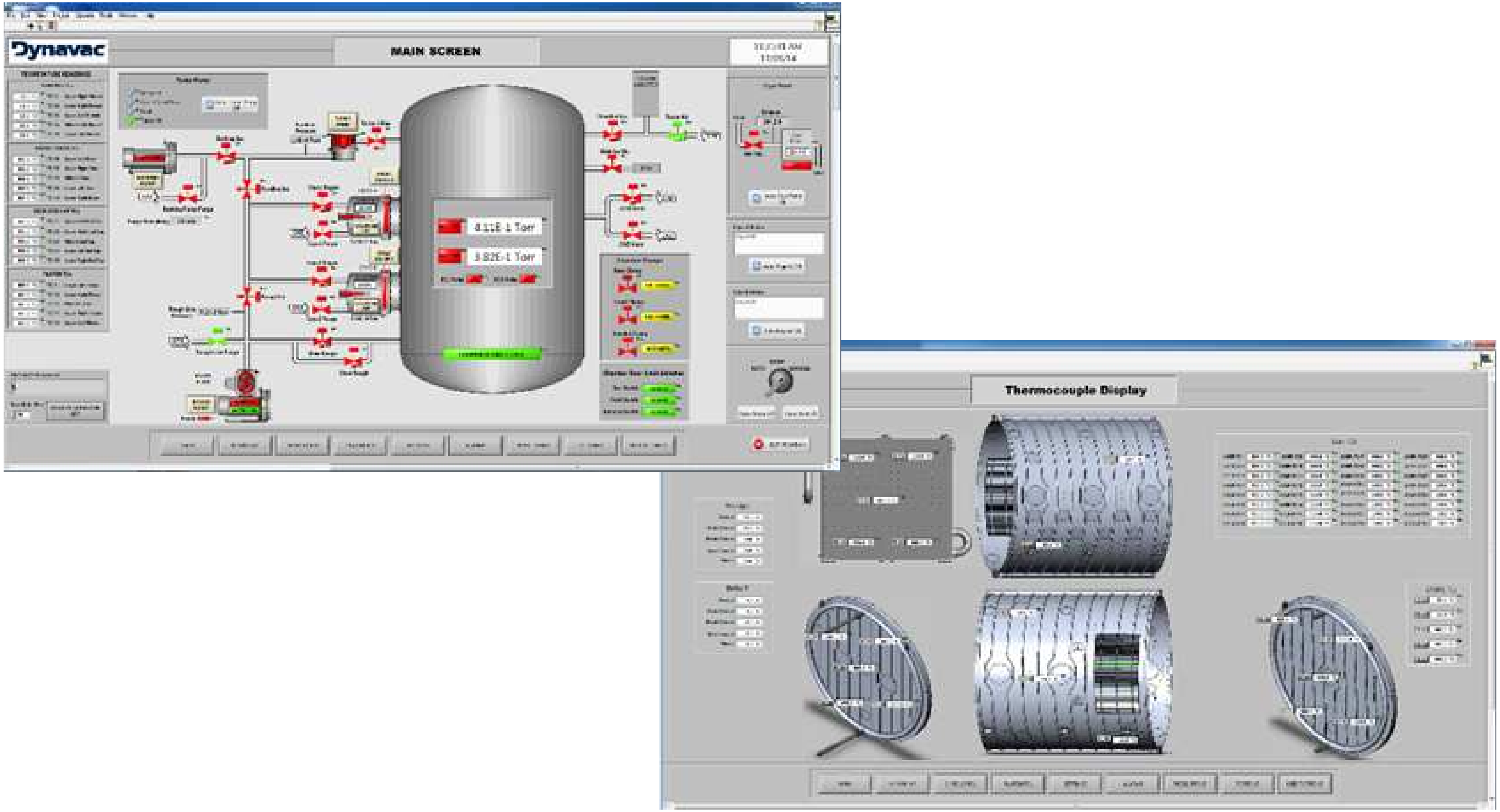
S2F System Description

- Chamber Configuration & Layout
  - Accommodated within AITC Integration Hall
  - 4-segment chamber
    - fixed main chamber
    - translatable endcaps
    - removable thruster annulus
  - Pumping & thermal control equipment on far side
  - Control and DUT near side

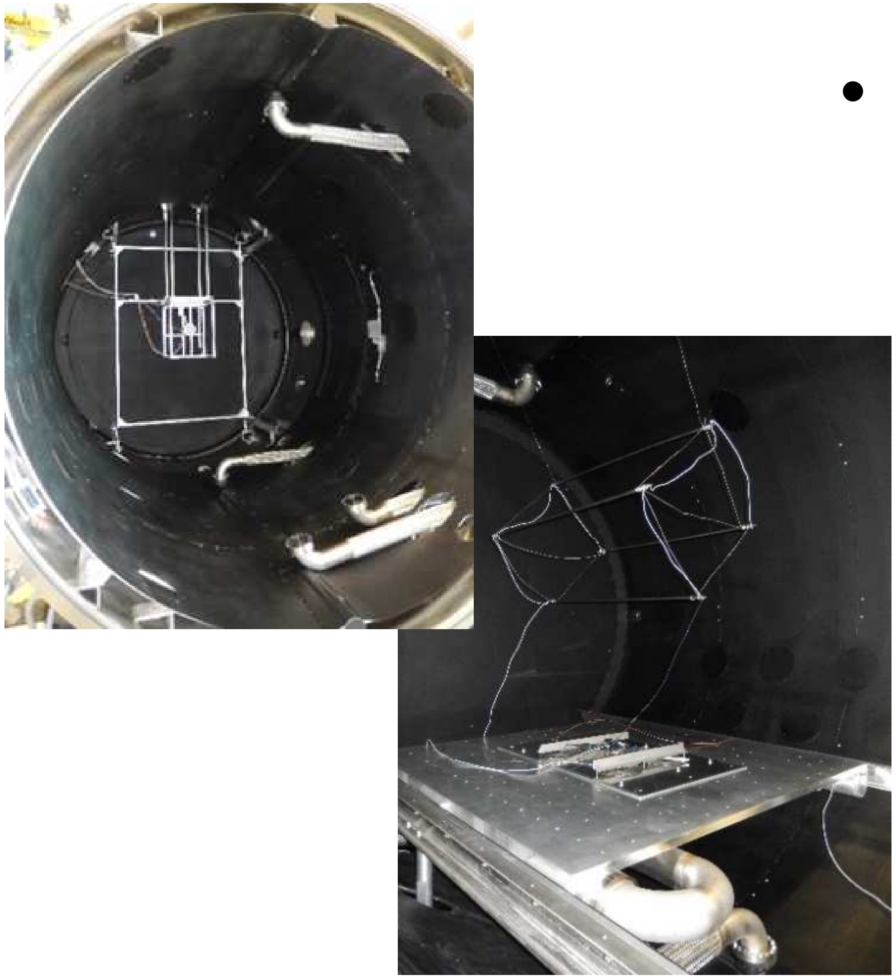
S2F System Description

- Control Subsystem
  - PLC controllers
  - LabVIEW Human-Machine Interface (HMI)
  - Intuitive control software
  - Safe operation (critical items are interlocked)
  - Minimal operator training
  - Key test parameters displayed
  - Data-logging

S2F System Description



S2F System Description

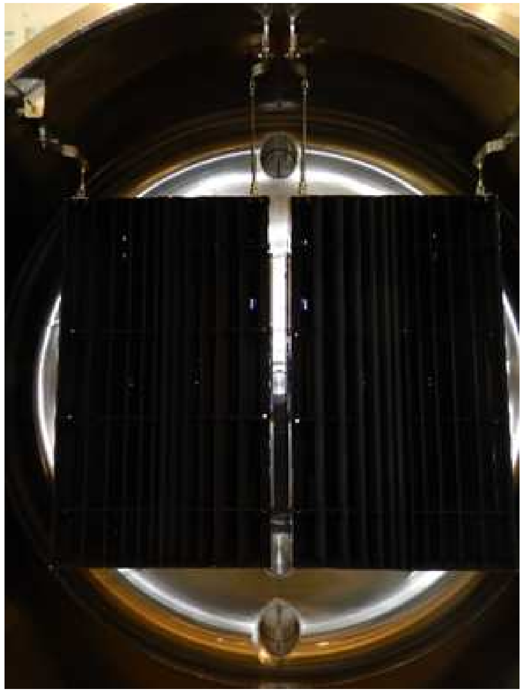


- Thermal Subsystem
  - Radiative thermal shrouds
  - Conductive thermal platen
  - Independent thermal control
  - 2-off 400CFM Dynavac Thermal Conditioning Units
  - GN_2 heat transfer medium
  - High DUT thermal load capacity

S2F System Description

- Thruster Test & Diagnostic Subsystem
  - Thruster Annulus
    - 1.2m long cylindrical chamber section
    - supports thruster under test
    - supports thruster test subsystems
  - Thrust Measurement Subsystem
    - thrust pendulum
    - laser sensor measurement system
    - calibration system.

S2F System Description



- Thruster Test & Diagnostic Subsystem
  - Plume Capture Subsystem
    - 2-off custom internal LN_2 assisted, Gifford-McMahon helium cryocoolers
    - high pumping speed
    - ionised & ballistic non-ionised molecules
  - Plume Diagnostic Subsystem
    - XYZ mechanism
    - ion analysers, Langmuir, emissive, optical probes & magnetic probes
  - Propellant Supply Subsystem
    - supply of test gases

S2F System Description

- Supporting Infrastructure
  - 15000 litre LN_2 tank
    - VJ-reticulated LN2
    - GN_2 vaporiser & supply
  - Hot/Cold GN_2 & pump exhaust to building roofline
  - O_2 monitoring sensors
  - S2F mains power supply & generator backup
  - Chilled water supply

S2F Design Challenges

- Need for interchangeable vacuum chamber sub-assemblies for required operating modes
- Tight site floor plan and floor loading requirements
- Need to meet or exceed operational performance goals while cost-conscious

S2F Design Challenges

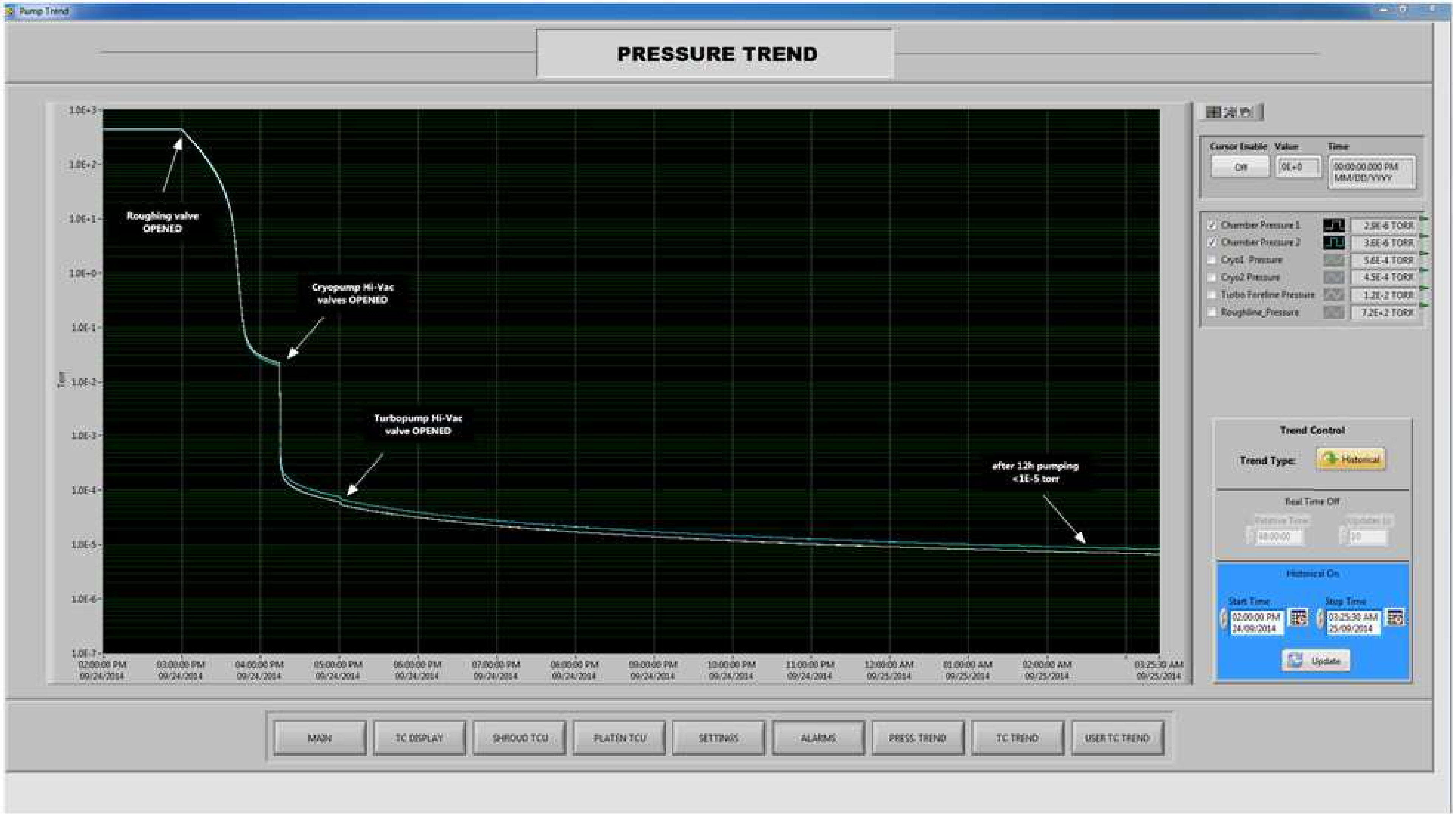
- Great care was put into the engineering design of the chamber
- Careful modelling of the system parameters to best size the thermal control system
- Careful design of thermal pathways
  - piping diameters (to balance pressure drops)
  - pipe spacing (for thermal surface uniformity)
  - enabled system performance goals to be met
  - enabled correct flow rates to individual shroud sections

S2F Design Challenges

- Thermal platen and shroud designed in conjunction with the thermal control system
- Cost-efficient commercial recirculating GN_2-based thermal control system was chosen over a liquid nitrogen cooling and electric heating based system

S2F System Vacuum Performance

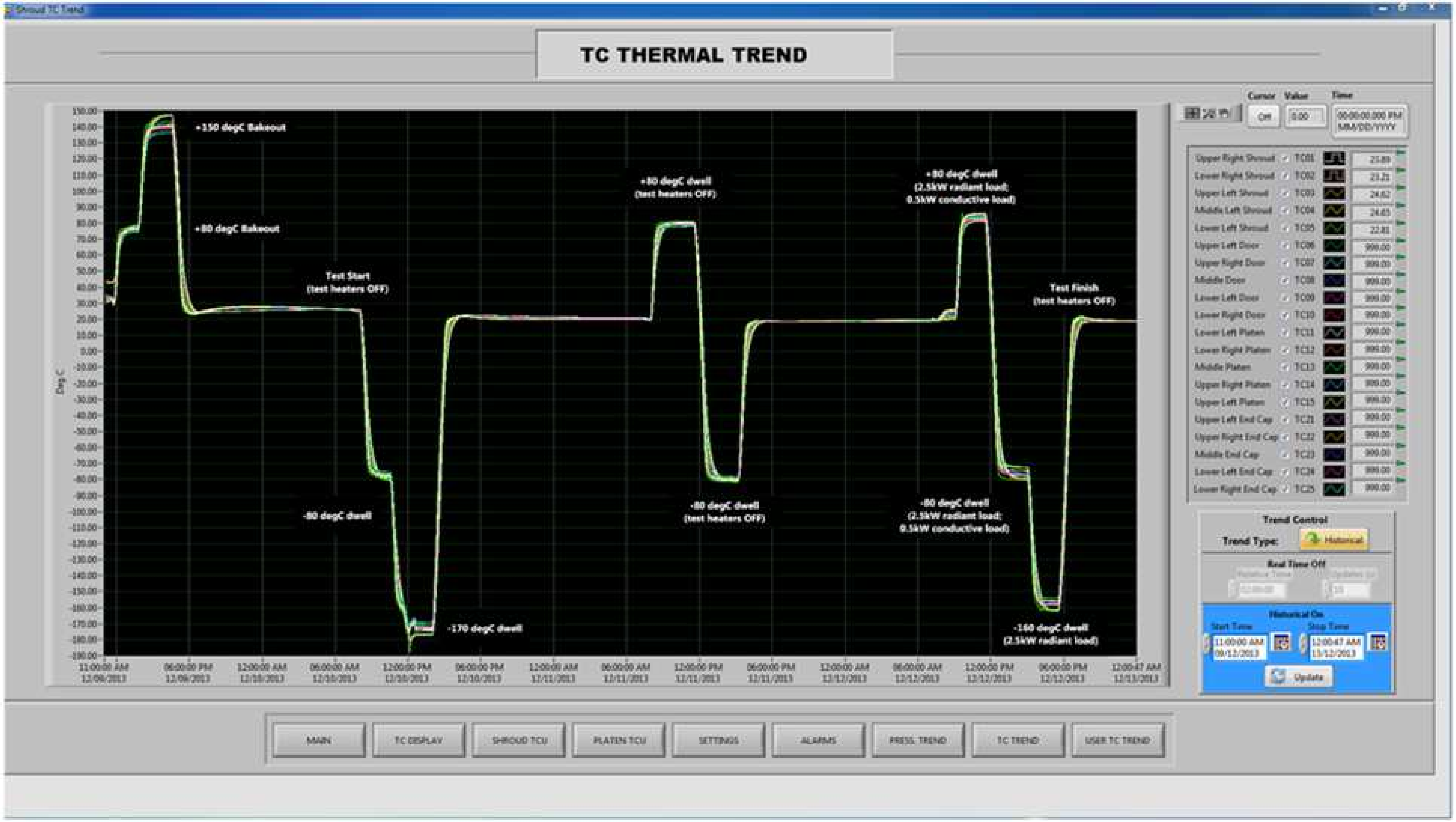
- ✓ Oil-free pumping system
- ✓ O-ring vacuum seals
- ✓ Rapid pumpdown for operations
  - manual & automated pumpdown
  - rough to <3E-2 Torr 2 h
  - pumpdown to <1E-6 Torr: <8 h
- ✓ Excellent ultimate vacuum
  - <3E-7Torr @ 22˚C ambient
- ✓ Low leak rate
  - 24hr rise to: <1E-3 Torr



Pump Trend
PRESSURE TREND
1.0E+3
1.0E+2
1.0E+1
1.0E+0
1.0E-1
1.0E-2
1.0E-3
1.0E-4
1.0E-5
1.0E-6
1.0E-7
Roughing valve OPENED
Cryopump Hi-Vac valves OPENED
Turbopump Hi-Vac valve OPENED
after 12h pumping <1E-5 torr
02:00:00 PM 09/24/2014
03:00:00 PM 09/24/2014
04:00:00 PM 09/24/2014
05:00:00 PM 09/24/2014
06:00:00 PM 09/24/2014
07:00:00 PM 09/24/2014
08:00:00 PM 09/24/2014
09:00:00 PM 09/24/2014
10:00:00 PM 09/24/2014
11:00:00 PM 09/24/2014
12:00:00 AM 09/25/2014
01:00:00 AM 09/25/2014
02:00:00 AM 09/25/2014
03:25:30 AM 09/25/2014
Cursor Enable
Value
Time
Off
0E+0
00:00:00.000 PM MM/DD/YYYY
Chamber Pressure 1
Chamber Pressure 2
Cryo1 Pressure
Cryo2 Pressure
Turbo Foreline Pressure
Roughline_Pressure
2.9E-6 TORR
3.6E-6 TORR
5.6E-4 TORR
4.5E-4 TORR
1.2E-2 TORR
7.2E+2 TORR
Trend Control
Trend Type:
Historical
Real Time Off
Historical On
Start Time
Stop Time
02:00:00 PM 24/09/2014
03:25:30 AM 25/09/2014
Update
MAIN
TC DISPLAY
SHROUD TCU
PLATEN TCU
SETTINGS
ALARMS
PRESS. TREND
TC TREND
USER TC TREND

S2F System Thermal Performance

- ✓ Temperature range
  - -170˚C to 150˚C
- ✓ Transition rate >3K/min
- ✓ Stability at control temp <1K
- ✓ Gradients @ set-point
  - shroud: < 2K; platen: < 0.5K
- ✓ Thermal Capacity
  - 2500W radiant & 500W conductive load @ 193K and 353K
- ✓ TVAC test item capacity
  - 500kg mass; 1.6m x 1.6m x 2.25m envelope


TC THERMAL TREND
+150 degC Bakeout
+80 degC Bakeout
Test Start
(test heaters OFF)
-80 degC dwell
-170 degC dwell
+80 degC dwell
(test heaters OFF)
-80 degC dwell
(test heaters OFF)
+80 degC dwell
(2.5kW radiant load;
0.5kW conductive load)
-80 degC dwell
(2.5kW radiant load;
0.5kW conductive load)
-160 degC dwell
(2.5kW radiant load)
Test Finish
(test heaters OFF)
Trend Control
Trend Type:
Historical
Update
MAIN
TC DISPLAY
SHROUD TCU
PLATEN TCU
SETTINGS
ALARMS
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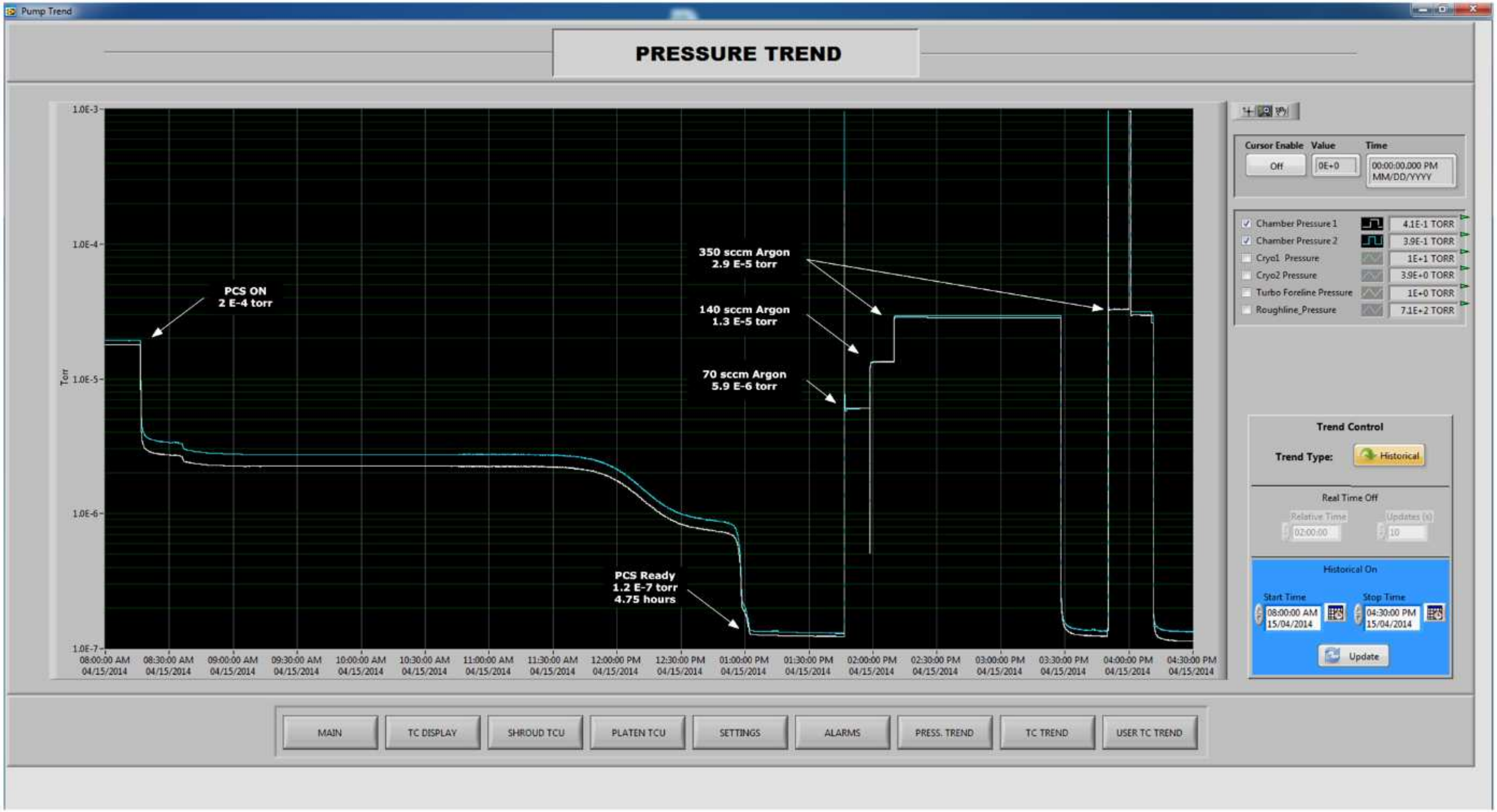
TC TREND
USER TC TREND

S2F Thruster Testing Performance

- ✓ Thrust balance capacity
  - 25kg capacity; 500mm x 840mm x 480mm envelope
- Thrust measurement
  - range: 0mN to 500mN; resolution: 0.1mN; accuracy: < 10%
- ✓ Plume capture capacity
  - 3.9 E-5hPa maintained at 350sccm argon flow
  - 7.9 E-5hPa maintained at 70sccm argon flow
  - 2-orders of magnitude pumping improvement over S2F pumps alone
- ✓ Plume capture system regeneration >2 months
- ✓ Plume diagnostic envelope
  - 1.6m x 1.6m x 2.6m


Pump Trend
PRESSURE TREND
1.0E-3
1.0E-4
1.0E-5
1.0E-6
1.0E-7
Torr
PCS ON
2 E-4 torr
350 sccm Argon
2.9 E-5 torr
140 sccm Argon
1.3 E-5 torr
70 sccm Argon
5.9 E-6 torr
PCS Ready
1.2 E-7 torr
4.75 hours
08:00:00 AM 04/15/2014
08:30:00 AM 04/15/2014
09:00:00 AM 04/15/2014
09:30:00 AM 04/15/2014
10:00:00 AM 04/15/2014
10:30:00 AM 04/15/2014
11:00:00 AM 04/15/2014
11:30:00 AM 04/15/2014
12:00:00 PM 04/15/2014
12:30:00 PM 04/15/2014
01:00:00 PM 04/15/2014
01:30:00 PM 04/15/2014
02:00:00 PM 04/15/2014
02:30:00 PM 04/15/2014
03:00:00 PM 04/15/2014
03:30:00 PM 04/15/2014
04:00:00 PM 04/15/2014
04:30:00 PM 04/15/2014
Cursor Enable
Value
Time
Off
0E+0
00:00:00.000 PM
MM/DD/YYYY
Chamber Pressure 1
4.1E-1 TORR
Chamber Pressure 2
3.9E-1 TORR
Cryo1 Pressure
1E+1 TORR
Cryo2 Pressure
3.9E+0 TORR
Turbo Foreline Pressure
1E+0 TORR
Roughline_Pressure
7.1E+2 TORR
Trend Control
Trend Type:
Historical
Real Time Off
Relative Time
02:00:00
Updates (s)
10
Historical On
Start Time
08:00:00 AM
15/04/2014
Stop Time
04:30:00 PM
15/04/2014
Update
MAIN
TC DISPLAY
SHROUD TCU
PLATEN TCU
SETTINGS
ALARMS
PRESS. TREND
TC TREND
USER TC TREND

S2F System Operations Performance

- ✓ Support multiple testing regimes
- ✓ System reconfiguration with minimum effort
  - personnel: 3-4; duration: 1-day
- ✓ Integrated control system
  - PLC/LabVIEW-based
  - HMI interface and safety interlocks
  - manual & automated operation
- ✓ System status display and logging
- ✓ Test item temperature sensor display and logging
- ✓ Expandable for infrastructure subsystems interface & control

Challenges Overcome

- Very tight schedule and VERY limited funds
- University procurement requirements added a significant cost and several months to the S2F procurement
- Significant new supporting infrastructure required
- Minor technical issues

Current Operational Status

- S2F is operational
- All thruster test subsystems are operational
- S2F currently in use for HDLT and “Pocket Rocket” thruster development testing
- GMTIFS Beam Steering Mirror prototype qualification testing @ 100K early Dec-2104
- TVAC acceptance testing of several University CubeSats in early 2015

Conclusion

- S2F is a unique multi-purpose vacuum test facility
- Only TVAC system in Australia (Asia-Pacific region)

- Cornerstone of a new national facility at the ANU AITC
- AITC facilities provide a one-stop-shop for space AIT

Acknowledgements

- The authors would like to acknowledge the support of:
  - The Australian Commonwealth Government through the ASRP for funding;
  - APT consortium partners: Airbus Defence & Space, Surrey Space Centre, Vipac Engineers and Scientists, The Australian National University;
  - Dynavac, as the S2F system supplier; and,
  - Major infrastructure and subsystem suppliers: BOC Australia, Cryoquip Australia, PHPK Technologies, Shaw Building Group
  - Morgan Advanced Materials for the manufacture of the thruster cavity prototype

without whose support, the S2F would not have been realised