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

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ABSTRACT

The Space Simulation Facility (S2F) is a dual purpose system designed to conduct plasma thruster testing and thermal vacuum qualification of satellites and instrumentation. Commissioned in 2013 at the Australian National University's Advanced Instrumentation and Technology Centre (AITC), the S2F brings a diverse range of new measurement capabilities to Australia. The S2F is a Dynavac-built system capable of thermal cycling from -170˚C to +150˚C at 3˚C/min average ramp rate. A removable platen and shroud assembly accommodates test articles up to 500 kg with volumes up to 1.6m x 1.6m x 2.25m. A plume capture system and moveable 1.2 m long chamber annulus allows for plasma thruster test and diagnostic configurations up to 1.6m x 1.6m x 2.2m with offline thruster installation capability. The S2F system is capable of pumping from atmosphere to a pressure below 1E-5 Torr in less than eight hours. Twenty-five available thermocouple channels and 33 test unit readings allow for detailed test article monitoring and data collection. The S2F was conceived for maximum flexibility and the ability to support a wide range of projects well into the future. Initial supported projects include instrumentation evaluation for the Giant Magellan Telescope, the Australian Plasma Thruster, and three Australian CubeSats. Here we will present a detailed overview of the project goals and design considerations, as well as the initial test projects undertaken in S2F.

INRODUCTION

Project Background

The Research School of Astronomy and Astrophysics (RSAA) is a research school of The Australian National University. Its mission encompasses the advancement of the observational and theoretical frontiers of astronomy and astrophysics and their enabling technologies; the provision of national and international scientific leadership, and the training of outstanding scientists. The RSAA is located at the Mount Stromlo Observatory (MSO), a 20-minute drive from the centre of Canberra, Australia's capital city.

The Advanced Instrumentation and Technology Centre (AITC) is a special-purpose national facility at MSO. It provides engineering support to RSAA astronomers, as well as design, manufacturing and testing capabilities for precision instrumentation and spaceborne hardware. It is also home to a research and development program focusing on the next generation of large optical telescopes.

The AITC has created a new national capability for the Australian space community, connecting researchers and industry partners from around the country and across the globe, and providing a state-of-the-art payload development and systems integration resource.

The Space Plasma Power and Propulsion (SP3) group are a division of The ANU Research School of Physics and Engineering, and are an international quality research team undertaking fundamental research in plasma physics, applied to space propulsion, space science and materials processing. The SP3 is located on the main ANU campus near the centre of Canberra.

The SP3 undertakes research into low temperature plasmas and their applications, including: computer simulations (fluid and particle-in-cell) and plasma modelling, plasma processing of surfaces, atmospheric pressure plasmas, fuel cell catalysts and space plasma thrusters, i.e. the Helicon Double Layer Thruster (HDLT), the Pocket Rocket electrothermal plasma thruster and the Dual Stage 4 Grid (DS4G) ion thruster).

Figure 1: Advanced Instrumentation & Technology Centre, Mt Stromlo Observatory, Canberra, Australia

The SP3 group is a major innovator in this area, with a number of patents in the last few years and a large number of international visitors spending time at ANU.

The HDLT design uses radio frequency to create an inductively/wave coupled plasma expanding and accelerating it in a magnetic nozzle. It has unique advantages over other plasma engines in that it:

- has the ability to employ a wide variety of fuels;
- has an accelerating electric field without a high voltage grid immersed in the plasma stream, thereby dramatically increasing operational reliability;
- produces a neutral plasma beam (the source of thrust is from the accelerated ions), thereby eliminating the need for a neutraliser and also increasing reliability;
- can be scaled up or down in power and geometry, and,
- has no moving parts.

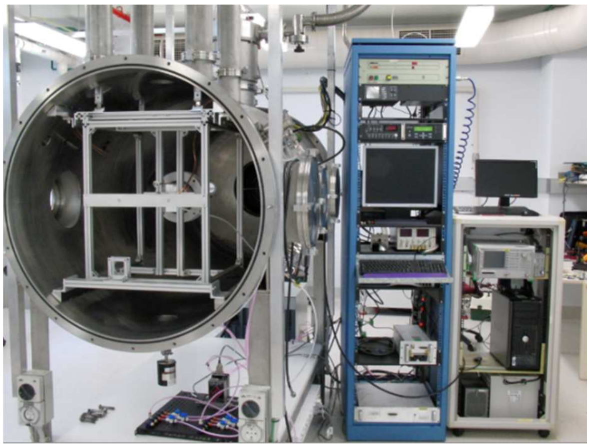

Figure 2: Upgraded SP3 Wombat Thruster Test Facility

Figure 3: HDLT Under Test in SP3 Wombat

The Australian Federal Government announced "The Australian Space Research Program (ASRP)" in October 2009. The objective of the ASRP was to develop Australia's niche space capabilities by supporting space-related research, innovation and skills in areas of national significance or excellence. A total of 14 grants were awarded over four competitive phases, totaling $40 million AUD.

At that time, in 2009, the SP3 team had already experimentally verified an early HDLT laboratory prototype at the European Space Agency, ESTEC facility in Noordwijk, The Netherlands. The SP3 laboratories possess a number of small thruster test facilities that provided a sound capability for the basic thruster research. The largest of these is the Wombat Chamber, but at ~1m diameter x 2m long, it was considered too small for thruster performance testing and space qualification.

The RSAA was in the process of establishing a national facility for the integration and test of terrestrial and spaceborne instrumentation, and required a cryogenic vacuum test facility in support of the GMTIFS (GMT Integral Field Spectrograph) instrument for the Giant Magellan Telescope (GMT), as well as a mid-sized thermal-vacuum chamber for spacecraft testing.

SP3 teamed together with Airbus Space & Defense in 2006 (formerly EADS Astrium) and the Surrey Space Centre in 2009 to propose funding for the "Australian Space Plasma Thruster Project". However, a host was necessary for the large space simulation chamber proposed and so the AITC joined the collaborative project along with Vipac Engineers and Scientists.

The objectives of the project were to progress the HDLT technology along the TRL path from a laboratory thruster to a space-ready prototype, and also to develop and deploy a multi-purpose test facility to support both thruster testing and space simulation. The Australian Plasma Thruster Project was successful in the final (fourth) round of the program, and the project consortium was awarded a contract from the Australian Commonwealth in mid-2011.

All aspects of the ASRP contract were fully completed by December 2013. The new test facility, designated the "S2F" (Space Simulation Facility), and nicknamed "Wombat XL", is now operational, and thruster development activities are underway.

S2F KEY DESIGN DRIVERS

A Multi-Purpose Facility

The design of the S2F would need to provide a single facility that could enable:

- functional & performance testing of electric propulsion thrusters;
- TVAC testing & vacuum bakeout for space hardware;
- cryogenic vacuum testing of large astronomical (optical) instrumentation; and also,
- be readily & rapidly re-configurable from one configuration to the next.

Thruster Testing Requirements

Thruster testing, particularly HDLT testing, necessitated a long chamber (a minimum length of 4m), and a chamber constructed from non-magnetic materials to avoid interference and possible end-effects. A large diameter was also required, particularly in the vicinity of the thruster. Minimum clearances defined a chamber of at least 3m diameter. Thruster test and diagnostic hardware also needed to be accommodated within the chamber, and high pumping speeds were required to maintain a high vacuum despite the injection of propellant into the chamber. Finally, it was important to provide a means of radiative cooling to the thruster, to sink as much as 2kW of RF power applied to the thruster.

TVAC & Cryogenic Test Requirements

The S2F would be required to accommodate spacecraft from Nanosat size, up to 500kg mini-satellites that could reasonably be expected to be developed in-country over the next 20-years. This would be accomplished by the use of radiative shrouds and a conductive thermal platen that could be independently controlled. The thermal subsystem was to provide the highest practicable temperature for bakeout, as well as maintain the lowest practicable temperature for testing of cryogenic instrumentation (ideally ~100 K).

Thermal performance was the main area that could be traded against the price for the system.

Operational Requirements

A turnkey control system was required that would enable man-in-the-loop operation of the facility, whilst providing a high degree of safety with facility interlocks.

The main requirements for the pumping system were as follows:

- the use of dry pumps only to eliminate the potential for oil contamination;
- a rapid pumpdown to <1.3E-5hPa (<1E-5Torr) overnight;
- a low leak rate to ensure that the chamber could hold vacuum beyond 24 hours, in the case of a pump or system failure.

General Requirements

Other requirements included the following:

- the ability to operate to Australian mains power requirements;
- a distributed mass so as not to overload the AITC Integration Hall suspended concrete slab floor;
- the use of O-ring seals for all repeatable vacuum connections;
- a separate cryogenic-plate for contamination witness samples;
- several test-item ports at various points chamber; and,
- that the facility infrastructure to be remotely located from the S2F (4.5m below the Integration Hall floor, in the plant room area below).

Design Concept

A number of configurations for the facility were studied and traded. These ranged from a "thruster can" at one end of the chamber (similar to the ESTEC test configuration for the HDLT), support of the test item from the front endcap, and the "thruster annulus" concept. The latter was ultimately selected, as this configuration was considered to be optimal for the thruster test configuration. It allowed for the thruster test-item to be self-contained, and enabled the thruster to be integrated into the annulus "off-line" whilst the chamber was in use for TVAC testing. It also provided a TVAC configuration of the required capacity, and the overall dimensions and mass could be accommodated within the AITC Integration Hall. The initial concept is depicted in Figures 4 and 5 below

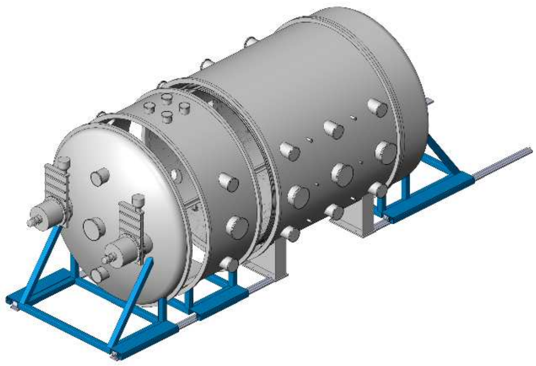

Figure 4: S2F – Proposed Thruster Test configuration

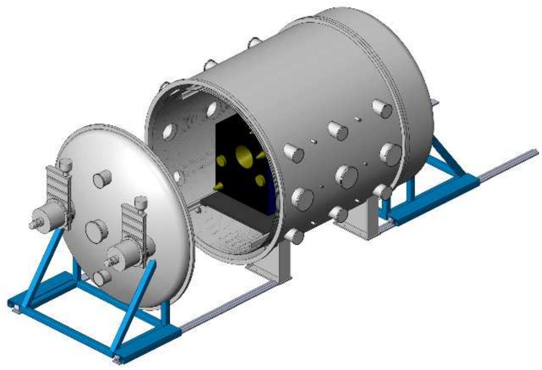

Figure 5: S2F – Proposed TVAC Test configuration

The design concept was based on a fixed main chamber, removable thruster annulus and translatable, rail-mounted endcaps. The chamber would be fitted with both radiative thermal shrouds and a conductive thermal platen, with independent control of both. The thermal platen, main and rear shrouds were to be readily removable for thruster testing. The rear endcap would be deeper to accommodate high capacity internal cryopumps for thruster plume capture. The thruster annulus would be similar in design to the (upgraded) Wombat facility, providing a commonality in design, and enabling a direct comparison of thruster testing between the two chambers.

S2F DEVELOPMENT

Market research

As usual, once the contract was awarded, the APT team had to deliver on our promises. The AITC engineering team had experience in the design, build and operation of small (<1m) chambers, and also a wealth of space and instrumentation experience. However, we still faced a number of challenges.

There are no Australian suppliers for this type of equipment, and therefore no one group with the prerequisite experience. Local suppliers were offering to provide equipment and subsystems only. The main expertise is located in the US and Europe. We found that identifying potential suppliers was indeed difficult - internet searches were generally inconclusive (companies don't seem to advertise); the best source was the trade list from the IEST conference!

When contacted, the S2F was too "small" for some suppliers, yet too big for others. The tight budget scared some away, and it seemed that Australia is at the end-of-the-world to many. Also, no-one in the industry had considered, much less delivered, a multi-purpose chamber such as required for the S2F.

Procurement Approach

As there was not the time, money nor local expertise to fully design, construct and integrate such a large system; it was decided early in the project to procure the S2F as a turn-key design, build & install-to-cost contract from an experienced supplier. It was also determined, due to the compressed schedule that the Plume Capture System (PCS) – the internal cryo-pumps, would be procured separately. Similarly, the infrastructure works required to accommodate the S2F in the Integration Hall would be undertaken by the AITC team.

The University contracting rules mandated that a formal tender process be adopted. This requirement significantly restricted the time available to deliver the S2F to meet ASRP project milestones.

Development Timeline

Following the identification of potential contractors by an ROI process, a RFT was communicated to twelve respondents in mid-June 2012. Three tender responses were submitted, two from European suppliers, and one from the US by the closing date some four weeks later.

Dynavac presented the most cost-effective proposal, and was selected as the preferred supplier in mid-August 2012. Even though the formal supply contract was not formally executed until mid-December 2012, Dynavac kicked off the work immediately, and the S2F CDR was successfully concluded in mid-November 2012.

The S2F Factory Acceptance Test (FAT) was conducted in mid-May 2013, less than 6-months after CDR. The system was disassembled and shipped to MSO, arriving early September 2013. Installation and commissioning was undertaken over two phases: assembly, set-to-work and vacuum acceptance testing were completed by end-September, with TVAC acceptance testing completed mid-December (once the liquid nitrogen (LN_2) infrastructure had been installed).

As the S2F design drove facility infrastructure requirements, a concurrent design approach was adopted. Even so, the final design of supporting of infrastructure could not be completed until after the S2F CDR. This required careful management of interfaces and requirements, and ultimately led to delays in fully commissioning the S2F.

S2F DESIGN

The design and engineering of the S2F required overcoming a few unique project challenges. The greatest technical challenge of the project was ensuring that the various vacuum chamber sub-assemblies, for operating both Thruster Testing and Thermal Vacuum Testing, were easily interchangeable and manageable in the allotted Integration Hall floor plan. More generally, it was important to ensure the project would meet or exceed operational performance goals while remaining cost-conscious, particularly with regard to thermal and pumping performance.

In order to ensure successful chamber conversion between the Thruster Testing mode and Thermal Vacuum Testing mode in the space available for the S2F system, great care was put into the engineering design of the chamber. While the main chamber body is fixed to the laboratory floor, the other chamber subsections are designed to be translatable on a rail system mounted on the floor to ensure proper chamber alignment. The rail system consists of two rails, one “V” shaped and the other flat, to prevent binding. The Thruster Testing subsystem can be inserted or removed from the rail system using an overhead crane in less than half a day.

Properly designing the thermal control system to achieve the system performance goals required careful modelling of the system parameters to best size the thermal control system. By optimising the thermal piping networks for the shroud and platen, thermal surface uniformity and ramp rate could be maximised while utility consumption could be minimised. This required fully modelling the thermal surfaces and piping network, and designing the thermal pathways, the piping diameters (to balance pressure drops), and pipe spacing (for thermal surface uniformity) to meet system performance goals. By designing the thermal platen and shroud in conjunction with the thermal control system, a cost-efficient commercial recirculating gaseous nitrogen based thermal control system was chosen over a liquid nitrogen cooling and electric heating based system[1].

The Pumping Subsystem also presented an opportunity where experienced design would provide considerable cost savings while meeting system performance goals. Water vapor is the dominant out-gassing product when pumping down chambers to high vacuum after roughing out the volumetric air in the chamber. Cryopumps offer an excellent pumping speed value (L/s/$) when compared with mechanical pumping technologies. By utilising a combination of surface out-gassing estimates, chamber pumping network conductance calculations, and previous experience, a cost-effective and robust combination of a dry roughing pump and blower, turbomolecular pump, and set of cryopumps was selected for atmosphere to high vacuum pumping. The turbomolecular pump both allows for keeping the chamber under vacuum during cryopump regeneration and helps to further pump the chamber after the roughing pump has bottomed out until the cryopump crossover pressure is reached.

SYSTEM DESCRIPTION

Chamber Configuration & Layout

The S2F is a 4-segment vacuum chamber. The main chamber is fixed over load-bearing points on the floor, and rails at either end of the main chamber accommodate translation of chamber end caps & thruster annulus. The chamber is pumped by a dry roughing pump and two 400mm (16”) cryopumps, each of which can be gated-off from the chamber. Likewise, a turbopump for pumping of residual gas molecules, and a residual gas monitor for analysis are installed via pneumatic gate valves. Two Thermal Conditioning Units (TCUs) provide the heating and cooling for the thermal subsystem.

All facility pumping and thermal control equipment are located on the far side of the S2F. (They were located beside the S2F as there was not sufficient space to accommodate them in the plant room below.)

Figure 6: S2F Emplacement in AITC Integration Hall

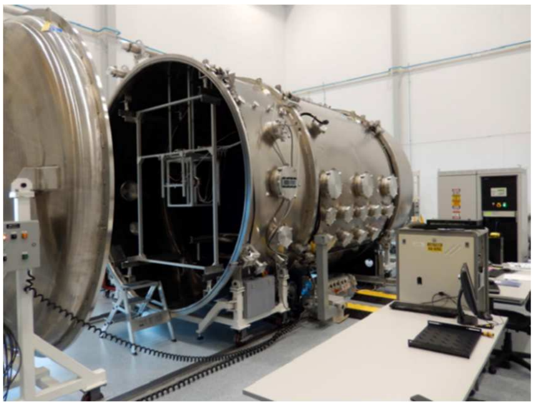

Figure 7: S2F – Thruster Test Configuration

Control Subsystem

The S2F control rack, operator console and primary test ports are located on the near side of the chamber for easy access during testing. The Control Rack uses PLC controllers and is accessed via a LabView Human-Machine Interface (HMI). All aspects of the S2F can be controlled by this software program. The S2F control software is intuitive and allows safe operation (critical items are interlocked) by operators with a minimal amount of training. The control software also displays system status and key test parameters. Logging of all data can be manually set.

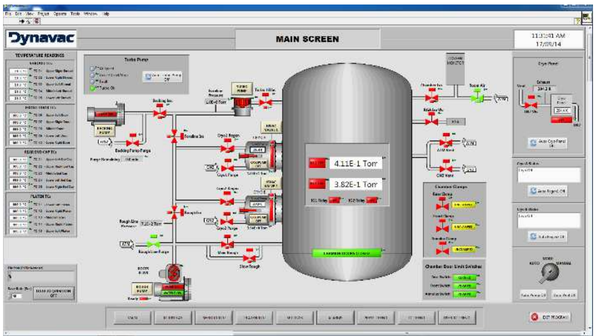

Figure 8: S2F Control HMI - System Status & Control

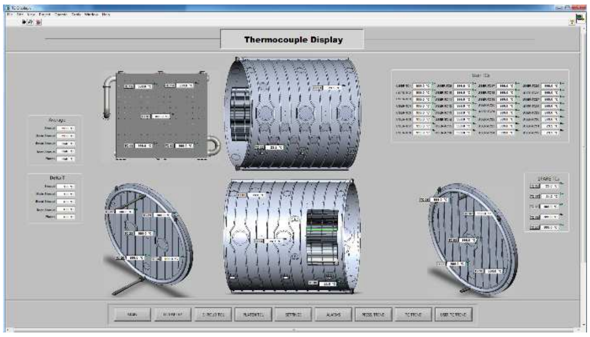

Figure 9: S2F Control HMI – System Thermocouple

Additional test ports/viewports are fitted to endcaps; upper and lower chamber rails permit mounting of test equipment within the chamber and the main shroud has stud interfaces for future albedo heaters.

The extended rear endcap accommodates two internal cryopumps that form part of the thruster plume capture system.

Thermal Subsystem

The S2F thermal subsystem comprises a radiative shroud and a conductive thermal platen within the chamber, each driven by a $0.2m^3/s$ (400CFM) Dynavac TCU, and independently controlled.

The main shroud sits on rails fixed to the main chamber and is removable (when necessary for thruster testing) using a dedicated trolley. The rear shroud is fixed to the rear endcap and is also removable to provide access to PCS in thruster test mode. The front shroud is fixed to the front chamber endcap. The thruster annulus is not currently fitted with a shroud, but provision has been made for future installation that will effectively provide a longer TVAC chamber. The system can still operate in TVAC mode with the thruster annulus installed, providing cooling for the thruster, if required.

The TCUs recirculate gaseous nitrogen (GN_2) as the heat transfer medium, carried externally via vacuum-insulated pipework. Bayonet fixtures on the ends of the pipes allow the chamber to be readily opened and closed. The pipework is removable to enable reconfiguration of the system for thruster testing.

The thermal platen is supported by rails running the length of the main chamber and can accommodate a 500kg test item. The platen can be withdrawn from the chamber onto a trolley, for storage, or for installation of a large test item. The platen can be removed by disconnecting the internal flanges. The internal con-flat connections are easily accessible from the operating end of the chamber.

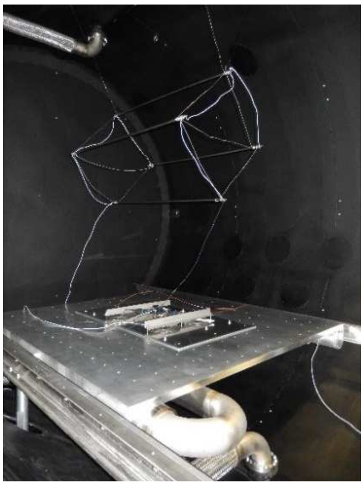

Figure 10: Thermal Platen with Test Heaters

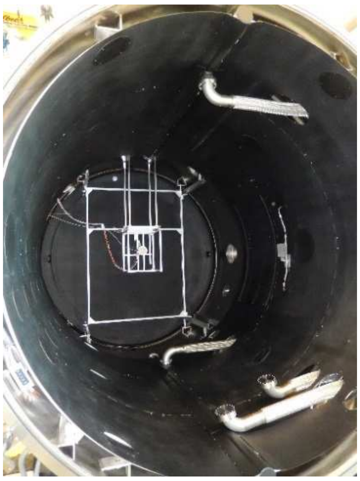

Figure 11: View of TMS from Rear of S2F Main Chamber

Figure 12: Thrust Measurement Subsystem

Thruster Test & Diagnostic Subsystem

Thruster Annulus

The Thruster Annulus is a 1.2m long cylindrical chamber section that houses the thruster under test, and a number of thruster test subsystems. It is removed from chamber by means of the overhead crane, and can be positioned on the rails to the front of the chamber, or anywhere within the Integration Hall. In this way, the thruster test item can be integrated and functionally tested away from the main chamber.

Thrust Measurement Subsystem (TMS)

The TMS comprises a thrust pendulum, a thruster mechanical interface module, laser sensor measurement system and a calibration system. The thrust pendulum is supported from the top of the annulus and is the same design as implemented in the Wombat Facility. It provides a large envelope for a thruster test item that is suspended from the lower face of the pendulum. A static frame houses the measurement system: a thrust calibration system, a laser interferometer and a voice-coil damping system. Calibration weights are deployed by a stepper motor under vacuum to physically displace the thrust pendulum from its rest position. Pendulum displacement is measured by the laser and when correlated to the calibration mass, provides a measure of horizontal thrust up to 0.5N with a 0.1mN precision. The voice coil system can provide damping of the pendulum oscillations when required.

Plume Diagnostics Subsystem

The Plume Diagnostics Subsystem (PDS) supports electrostatic probes such as ion analysers, Langmuir probes, emissive probes, optical probes such as fibre-optics bundles and magnetic probes, on an XYZ mechanism carried by the platen rails. The stages can be driven to position the probes to sample the thruster plume, from inside the thruster envelope and downstream of the thruster for the length of the chamber.

Propellant Supply Subsystem

The Propellant Supply Subsystem enables the supply of test gas to the thruster from an external supply via a mass flow controller, over the range 0-350sccm (argon).

Plume Capture Subsystem

The Plume Capture Subsystem (PCS), as the name implies, traps the ionised and ballistic non-ionised gas molecules produced by the thruster and maintains a high vacuum within the chamber. A pair of custom internal cryopumps (supplied by PHPK Technologies) provide a large capture area and are driven by liquid nitrogen-assisted, Gifford-McMahon helium cryocoolers.

When operational, the PCS provides a high pumping capacity (rated at 180m^3/s nitrogen and 70m^3/s xenon,) that enables thruster testing at high flow rates for several weeks, before regeneration.

A 4-layer MLI blanket mounted off the rear face of the rear shroud effectively eliminates the radiant heat-load onto the PCS pumps during TVAC operations and high temperature bakeout.

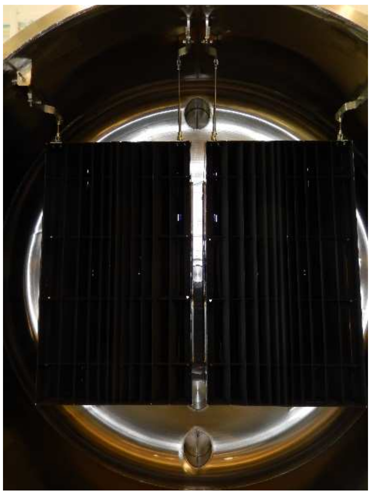

Figure 13: PCS Pumps Mounted to Rear Endcap

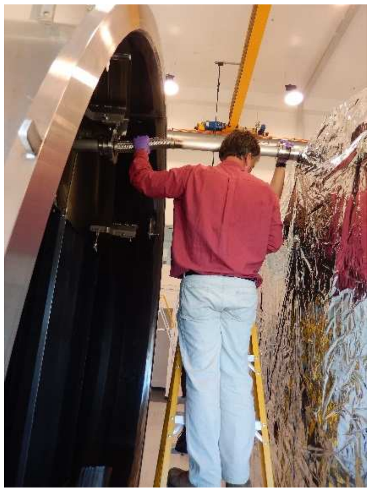

Figure 14: Removal of Rear Shroud

Supporting Infrastructure

LN_2/GN_2 supply

LN_2 is provided to the S2F from a horizontal 15m^3 LN_2 tank situated some four metres below, and adjacent to, the Integration Hall floor. As a result, the tank is pressurised to 850kPa (8.5bar) nominal pressure during operation (maximum of 1600kPa (16bar)). LN_2 is reticulated to the S2F by VJ-insulated pipework as well as to termination for a future small chamber and a standpipe for filling dewars. Exhaust of all hot/cold GN_2 vapours to the exterior of the building, above the roof line is also achieved by vacuum-insulated pipework.

O_2 monitoring sensors in the Integration Hall are interlocked to the main LN_2 supply pneumatic valves to terminate LN_2 flow in the case of a leak.

Dry GN_2 at 830kPa (120PSI) is supplied to the S2F and reticulated throughout the general facility from a vaporiser running off LN_2 tank

Mains power supply

A new mains switchboard provides power to S2F and all supporting subsystems. A manual changeover switch allows for generator power to be used to run the system in the event of planned (or potential) mains power outage.

Chilled water supply

A 30kW water chiller with a 600kPa (6bar) pump delivers water to the S2F manifold to provide cooling for the facility pumps and compressors.

S2F SYSTEM PERFORMANCE

S2F system performance was validated over two Site Acceptance Tests (SATs), and later, during early thruster testing. The S2F met, and in some cases exceed, performance expectations. S2F vacuum and thermal performance met all requirements, as did the thruster test subsystems developed for use with the S2F. Measured performance is provided below (refer to Figures 15, 16 and 17, and Table 1).

One of the key operational requirements was the ability to reconfigure the S2F safely and with a minimum number of trained personnel. The S2F design satisfies this requirement with ease:

- The thruster annulus can be moved in and out with the use of the overhead gantry crane and slings.
- The thruster annulus can be housed on the S2F floor rails, or independently anywhere within the Integration hall.
- The thermal platen is connected to its TCU via two conflat flanges and is easily removed from the front of the chamber and onto its storage trolley by three personnel. Access to the flanges is from the rear of the chamber by translating the rear endcap.
- The rear shroud is removable and is stored on its own trolley. The process is relatively straightforward, but is complicated slightly by the tight space to the rear of the chamber. Removal and reintegration can be achieved by four personnel in a half day.
- The main shroud can also be removed for hi-energy thruster testing. Again, access to the chamber to the re-entrant conflate flanges is achieved from the rear of the chamber.

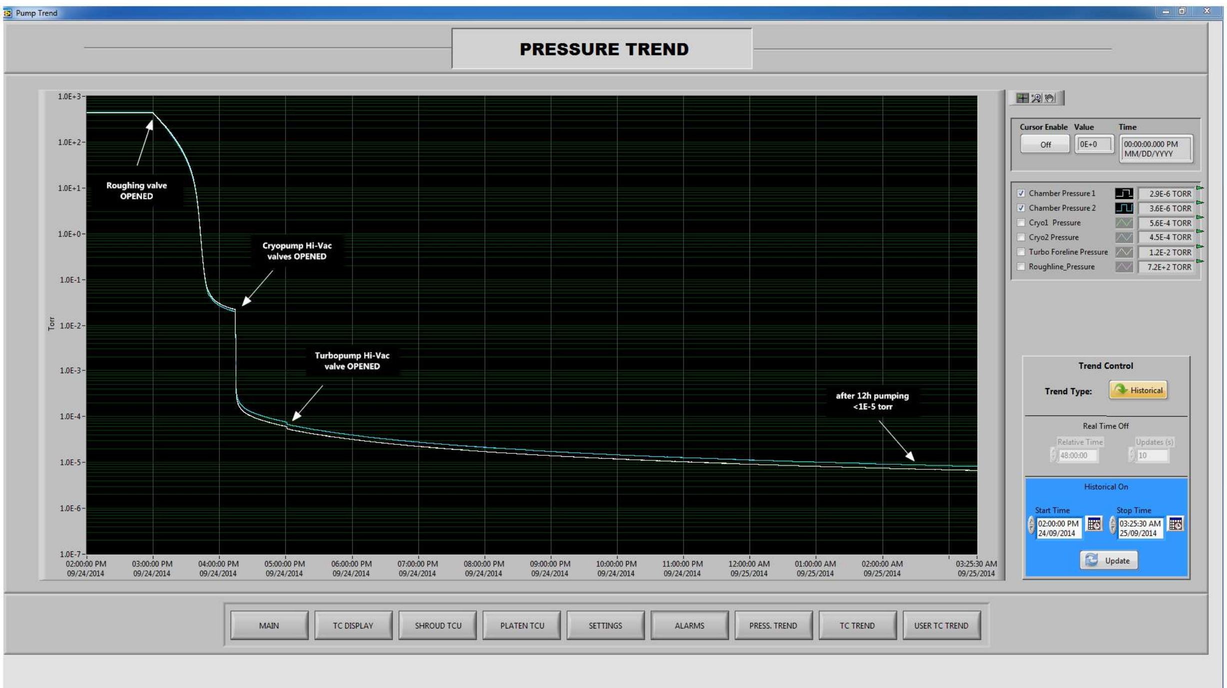

Figure 15: S2F Typical Chamber Pumpdown Plot ("wet chamber")

Table 1: S2F Performance Summary

S2F Vacuum Performance	S2F Thermal Performance
✓ Oil-free pumping system ✓ O-ring vacuum seals ✓ Rapid pumpdown for operations: • manual & automated pumpdown • chamber rough to 40hPa: 2 hours • chamber pumpdown to <1.3E-6 hPa: <8 hours ✓ Excellent ultimate vacuum: • <4E-7hPa (<3E-7Torr) @ 22˚C ambient ✓ Low leak rate: • 24hr leak pressure rise to: <1.3E-3hPa	✓ Temperature range: 103K (-170˚C) to 423K (150˚C) ✓ Transition rate: >3K/min ✓ Stability at control temp: <1K ✓ Thermal gradients at set-point: • shroud: < 2K • platen: < 0.5K ✓ Absorbs 2500W radiant load and 500W conductive load @ 193K and 353K ✓ TVAC test item capacity: • 500kg mass; 1.6m x 1.6m x 2.25m envelope
Thruster Testing Performance	**Operations 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	✓ 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

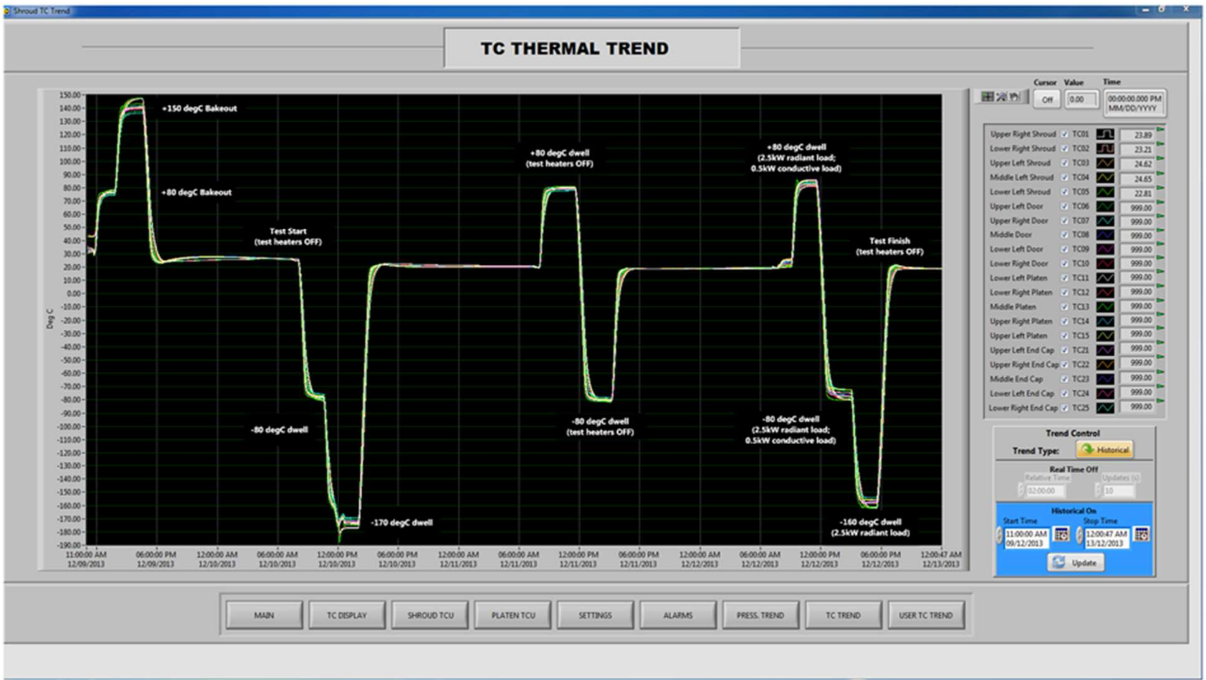

Figure 16: S2F TVAC Acceptance Test Results

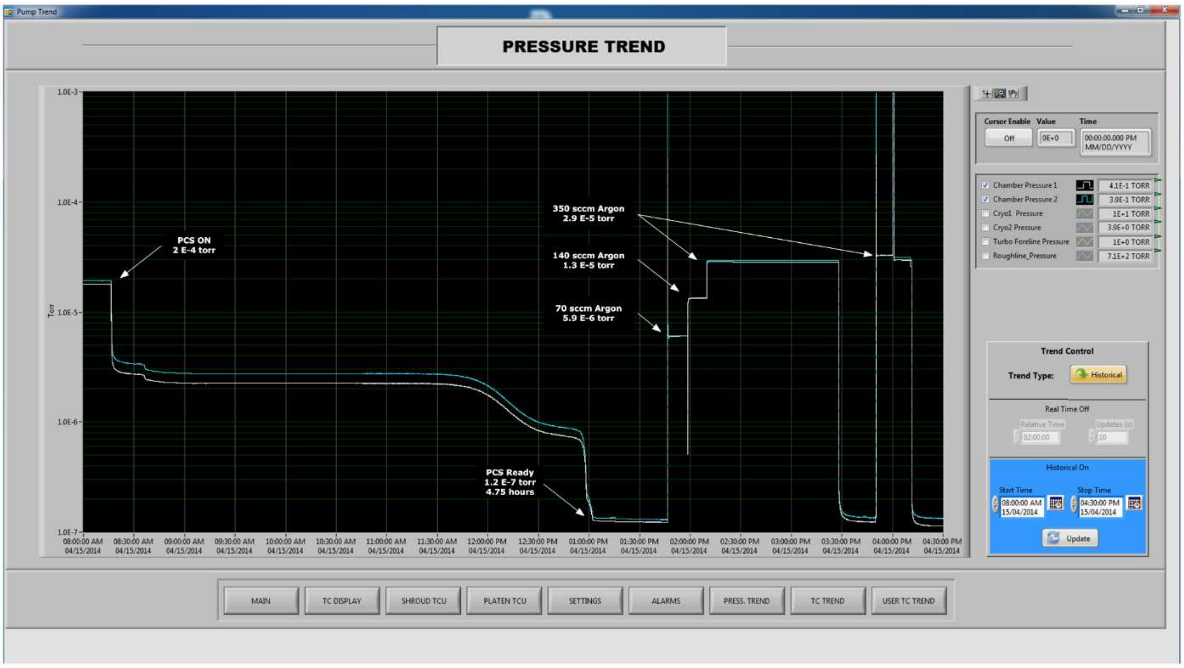

Figure 17: PCS Acceptance Test Results – Argon Fuel

CHALLENGES OVERCOME

The majority of challenges faced by the project team were due to a very tight schedule and VERY limited funds. All aspects of the ASRP contract were required to be completed with two years (including the design, procurement and deployment of the S2F). The last round of ASRP funding was some 10% less than requested for the project. (In the end, the ASRP program was extended by 6-months, and some additional funds were provided towards the end of the project.)

One of the key issues faced related to the status of the University as a “Commonwealth Authorities and Companies Act (CAC Act)” body. This additional level of administration and oversight added a significant cost and several months to the S2F procurement.

The S2F also placed demands on the existing building beyond the original design specifications. Significant new infrastructure was required to support S2F, and as requirements could not be finalised before the S2F CDR, the late kick-off of infrastructure works resulted in the late delivery of VJ insulated pipework, necessitating that the S2F be commissioned over two SAT campaigns.

Technical issues, by comparison, were minor in nature, and were addressed during the final stages of S2F assembly and testing:

- The pneumatic clamps did not provide sufficient clamping pressure to overcome the slight endcap distortion to make proper vacuum seal. The addition of manual clamps at each interface solved this problem.
- The endcap drive system needs modification to stop chamber misalignment. The drive needs to be applied to the one wheel only. The interim solution of removing drive belts and translating the endcaps manually is working well.
- The TCU transformers (240V/110V single-phase) have failed on a couple of occasions. These have been replaced with locally manufactured transformers with higher rated capacity.
- The water chiller (compressor) fails at high ambient temperatures (>30˚C cf specified operation to 45˚C). A design for a new chilled water supply system design in progress, utilising redundant chillers, pumps and a heat-exchange system for improved reliability.

CURRENT OPERATIONAL STATUS

The S2F is operational and is currently being used for HDLT and "Pocket Rocket" thruster development testing. At time of writing, the TMS and PCS thruster test subsystems are operational, and the PLD subsystem is ready for integration.

The S2F will be reconfigured at the end-November 2014 in support of GMTIFS Beam Steering Mirror prototype qualification testing @ 100K.

The S2F will also be utilised for TVAC acceptance testing of several University CubeSats in early 2015.

CONCLUSION

The S2F is a unique multi-purpose vacuum test facility designed to provide safe and cost-effective testing, and with the flexibility to undertake a number of different types of test regime within the one facility.

The S2F is the cornerstone of a new national facility at the ANU AITC for the assembly, integration and testing of space instrumentation and hardware. It is the only TVAC system in Australia (and the Asia-Pacific region) and combined with the vibration test facility, electromagnetic compatibility chamber, mass properties testing and cleanrooms, will allow hardware developers to complete all instrumentation and space hardware tests in the one facility.

The S2F has also enabled and facilitated the ongoing development of electric propulsion thruster technology by the SP3 group, in-house, in a world-class facility.

Figure 18: S2F – the corner stone of a national facility for instrumentation assembly, integration & test

ACKNOWLEDGEMENTS

The authors would like to acknowledge the support provided by the Australian Commonwealth Government through the ASRP for funding; to our APT consortium partners: Airbus Space & Defense, Surrey Space Centre, Vipac Engineers and Scientists, The Australian National University; to Dynavac, as the S2F system supplier; and to major infrastructure and subsystem suppliers: BOC Australia, Cryoquip Australia, PHPK Technologies, Shaw Building Group and also the many other Australian suppliers and contractors involved in completing the project. Without their support, the S2F would not have been realised.

In addition, SP3 would like to thank Morgan Advanced Materials for the manufacture of the thruster cavity prototype.

REFERENCES

1. Pollara, R. A., "*Improved thermal vacuum chamber temperature performance via gaseous nitrogen Thermal Conditioning Units*", Proceedings of the 2014 European Conference on Spacecraft Structures, Materials and Environmental Testing, April 2014.