NASA’s Planetary Aeolian Laboratory: 

Guidebook for Proposers
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1.0 NASA Planetary Aeolian Laboratory (PAL)

1.1 What is the PAL?

The Planetary Aeolian Laboratory (PAL) is a facility used for conducting controlled experiments and simulations of aeolian processes (windblown particles) under different planetary atmospheric environments, including Earth, Mars, and Saturn’s moon Titan. The PAL is currently supported by NASA’s Planetary Science Division (prior to 2014 PAL was supported by NASA’s Planetary Geology and Geophysics (PG&G) program). PAL includes apparatus and facilities at NASA-Ames Research Center (ARC) at Moffett Field, CA, and Arizona State University (ASU) in Tempe, AZ has separate equipment to support PAL activities. The PAL includes one of the nation’s largest pressure chambers for conducting low-pressure research. PAL enables scientific research into aeolian processes under controlled laboratory conditions, and enables testing and calibration of spacecraft instruments and components for NASA’s Solar System missions, including those requiring a large volume of low atmospheric pressure.

PAL consists of: (1) the Mars Surface Wind Tunnel (MARSWIT) and (2) Titan Wind Tunnel (TWT) located in the Structural Dynamics Building (N-242) at the NASA ARC in Mountain View, California that is administered by Arizona State University. The MARSWIT and TWT are supported by shops, instrument facilities, and imaging services at NASA-Ames. PAL facilities at ARC also have a full-time technician (an ASU employee working at ARC) to serve planetary users. The supporting facilities on the Tempe campus of Arizona State University include an ambient pressure/temperature wind tunnel (ASUWIT). A vortex (dust devil) generator (ASUVG) also exists at ASU, but is currently the property of the Fulton College of Engineering (it’s use for planetary research could be negotiated). The ASUWIT is part of the ASU School of Earth and Space Exploration (SESE), and is under the operational authority of SESE Professor Ian Walker. The ASUWIT is supported by the staff of the Ronald Greeley Center at ASU.

The Martian Surface Wind Tunnel (MARSWIT) at NASA-Ames was put into operation in 1976, and is used to investigate the physics of particle entrainment by the wind under terrestrial and Martian conditions, to conduct flow-field modeling experiments to assess wind erosion and deposition on scales ranging from small rocks to landforms (scaled) such as craters, and to test spacecraft instruments and other components under Martian atmospheric conditions. MARSWIT is a 13-m long open-circuit boundary-layer wind tunnel within a large environmental chamber that operates at atmospheric pressures ranging from 1 bar to 5 millibars, with maximum speeds of 10.5 m/sec at 1 bar and 100 m/sec at 5 millibars. The wind tunnel is an open-circuit design, but sits on the floor of a large pressure chamber with an inside height of 30 m and an interior volume of 13,000 cubic meters. For low-pressure wind tunnel runs, the chamber is sealed and pumped down, and the open-circuit wind tunnel inside is operated within the low-pressure environment. Evacuating the interior pressure of such a large chamber requires a lot of power, which ordinarily would be quite expensive. PAL draws its vacuum power from the Thermal Physics Facilities’ Steam Vacuum System and can be evacuated to Mars analog pressure (4 torr) in about 45 minutes. Because of the high cost to operate the vacuum system an agreement was struck in which PAL draws its vacuum almost exclusively only as a ride-along with other NASA-Ames projects/facilities that sponsor the activities of the NASA-Ames steam plant. This arrangement is highly cost-effective, but requires advance scheduling of low-pressure runs (requiring pump-downs) well in advance. Aside from this agreement, reserved vacuum service is available, provided sufficient funding is presented and there are no scheduling conflicts.

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The MARSWIT instrumentation includes differential pressure transducers (Setra 239 and MKS 226A) linked to pitot tube apparatus for measuring free-stream wind velocities and deriving wind profiles. Pitot tube options include singular, vertical traversing pitot tubes, and stationary multiport rakes that can be mounted on the test section floor if needed. These have a range of ±0.5 inches of a water column, or approximately 1.25 millibars. The MKS 226A specifies an accuracy of 0.30% of the instrument reading and a resolution of 0.01% of full scale. The Setra 239 specifies an accuracy of 0.14% of full scale. The Setra has been used in MARSWIT for many years and is reliable to measure velocities of 30-100 m/s at low pressure. The MKS is a new addition that will enable measurement of velocities below 30 m/s at low pressure. In addition, a Vaisala model DMP-248 dewpoint and temperature transmitter is used to monitor the temperature and relative humidity within the chamber. A DigiVac model 2L760 digital vacuum gauge measures the chamber pressure from Earth standard to the minimum allowable operating pressure (1 bar to 5 millibars) of the chamber. The MARSWIT is equipped with a high-speed (500k samples/second capability) analog-to-digital data acquisition system from National Instruments, Inc. Installed and operated on a dedicated computer, the system is capable of simultaneously measuring 64 analog channels, each of which can be independently accessed. The system is controlled by the National Instruments software package LabView™. This system allows for the simultaneous acquisition, analysis, and visualization of wind tunnel temperature, pressure, and velocity. Other analog and digital instruments can be incorporated to suit experimental requirements.

The TWT is a remodel of the Venus wind tunnel (operated 1981-1994), and became operational in June 2012. The TWT is a closed-circuit, pressurizable (to 20 bars) wind tunnel with an overall dimension of 6-m by 2.3-m. Included in the remodel were upgrades to a newer, higher performance motor, advanced motor controls, and new instrumentation. Overall tunnel pressure is determined by visual observation of a calibrated gauge (manufactured by Wika Instrument Corp., ± or – 1psig) attached to the front of the tunnel instrument panel. Differential pressure is measured (for flow velocity calculation) by a custom designed sensor (manufactured by Tavis Corp.). This sensor is connected to a stack valve that determines which pitot tube is being “read” (traversing or fixed). The voltage from the sensor is sent to a data acquisition module (manufactured by Measurement Computing Corp.) and processed for interpretation by TracerDAQ software installed on a laptop computer. A test section is designed to allow the substitution of test plates. A test plate specifically designed for boundary layer profile work already exists and can be installed should the need arise.

The ASUWIT consists of a 13.7-m long, 0.7 m high, 1.2 m wide open-circuit boundary-layer wind tunnel that operates under ambient temperature and pressure conditions and is capable of wind speeds of 30 m/sec. Air is pulled through the tunnel by a large fan mounted in the downwind section of the tunnel. A viewing area of the test bed is encased by plexiglass with doors to access the test section for the setup of experiments. The ASUWIT facility can measure wind speed, temperature and humidity inside the tunnel, and physical conditions in the room outside of the tunnel are also collected. These data include laboratory temperature, humidity and barometric pressure. Wind conditions exterior to the building, including wind direction and speed, are also recorded. Independent sources power the pressure transducers, humidity sensors, anemometers, and wind vanes.

The ASUVG consists of a large vertical fan mounted above a moveable table. The table can be moved across the X, Y and Z-axes during experiments. A variable speed motor controls the 0.5 m fan mounted above the testing table. A large board of pressure transducers is available and can be setup to collect wind pressure points in various areas of the test section. Currently the vortex generator’s data is fed to a Windows PC running LabView™. The test section measures 1.2 x 1.2 m. Fan position can be adjusted vertically and horizontally; likewise, the table can be adjusted in
the X, Y and Z directions. The ASUVG has not been used for planetary research since ~2011, and is now the property of the ASU Ira Fulton College of Engineering under the authority of Professor Edward Kavazanjian. If proposers are interested in using the ASUVG, it can be negotiated (please email PAL Director David Williams (David.Williams@asu.edu) to begin negotiations).

1.2 What Data are Produced?

Both the ASUWIT and the MARSWIT are controlled by Windows-based computers running National Instrument’s LabView™ 2010 data acquisition software. The wind tunnels record data such as wind speed, barometric pressure, inside and outside temperature, inside and outside humidity and outside wind conditions (direction and speed). Data are obtained through a National Instruments cDAQ unit. This unit is connected to all sensors and delivers the data to a program running in LabView. LabView collects the raw data and through a series of calculations and conversions, outputs the usable data to a plain text file. This file can then be read into a text editor or imported into standard spreadsheet and graphic software (e.g., Microsoft Excel™).

The MARSWIT LabView™ system’s current configuration measures tunnel temperature, chamber temperature, chamber density, chamber pressure, freestream differential pressure, traverse differential pressure, pitot tube traverse location (height in mm above floor), percent relative humidity, and the calculated velocities of the freestream and traverse sensors. This information is measured simultaneously, saved, and presented in the form of an Excel™ spreadsheet.

Photographic equipment is available at both the ASUWIT and the MARSWIT to obtain both still and digital photographs, and movies of wind tunnel experiments. However, proposers are encouraged to obtain and operate their own photographic equipment as much as possible.

Users of the MARSWIT will have some limited technical support from ARC, but due to the dusty environment of the MARSWIT chamber, access to ARC high speed cameras is not available. High speed cameras can be rented and used, but researchers are expected to operate any photographic equipment they bring to the facility. All of the cameras currently being used in this facility have video capability. The Canon DSLR is capable of single photo, multiple shots at 3.7 fps, or in “movie” mode up to 60 fps (at 720p). The Sony Handycam utilizes a digital video cassette (tape) at 25 fps. Both require standard atmospheric pressure. Two cameras manufactured by Allied Technologies are available for use in low pressure conditions. One is Ethernet connective and the other is FireWire. Both operate at 30 fps.

After May 2013, photographic support of the ASUWIT will become more limited, and any special photographic needs must be negotiated with PAL PI David Williams at ASU.

2.0 Information for Proposers

If you seek to utilize the PAL wind tunnels or vortex generator in NASA-funded research, what do you need to do? The previous section highlights the existing capabilities of the PAL wind tunnels. The following sections describe information necessary to propose research in the PAL facilities at either NASA-Ames or ASU, including required budgetary information.

2.1 Where to Propose to Use the PAL?

The PAL was previously funded by the NASA Planetary Geology and Geophysics (PG&G) program, and as of 2014 PG&G was incorporated into the “Solar System Workings” (SSW) Program, where Announcements of Opportunity to Propose (AO) are released annually as part of NASA’s Research Opportunities in Space and Earth Science (ROSES), typically available in January or February of each year. This should be the primary R&A program to submit proposals to conduct laboratory studies with PAL facilities. Mars-related wind tunnel work and Titan-related wind tunnel work should also be proposed to the "Solar System Workings” Program element in

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future ROSES calls. Funding to use the PAL facilities could also be included in instrument development proposals or proposals to develop instruments for future missions (PICASSO or MATISSE). In these cases, NASA-Ames requires a pro-rated facility charge for non-sponsored usage. (see Section 2.2.2)

2.2 What to include in Proposal Budget?
Although the PAL facilities are funded by NASA, there are still costs associated with the operation and maintenance of these facilities that must be encumbered by the user. This section describes what and how to budget your wind tunnel research for NASA proposals. Because the PAL facilities are administered by ASU (even those at NASA-Ames), you must budget the following items in your proposal as a subcontract to Arizona State University.

2.2.1 Work at ASU Facilities
Because the NASA funding that supports the PAL facilities only covers day-to-day maintenance of the facilities, and because the ASU facilities are operated like a “recharge center” under ASU regulations and must be self-sustaining, PAL users must include in their budgets a users fee of $500/day to use the ASUWT or the ASUVG. This daily fee covers salary for any ASU staff required to support your experiments, the costs for electricity, water, and for wear and tear on the equipment. Additional costs should be included for consumables (e.g., the cost of sand or other materials used during your experiments), special equipment, and any related shipping charges. If you require photographic support from our photographer Mr. Daniel Ball, salary support must be included at a rate of $21.63/hour, plus costs for photographic equipment.

2.2.2 Work at PAL Facilities at NASA ARC
At present, the only additional charges for NASA-funded research from the Solar System Workings program conducted at the PAL facilities at ARC is for consumables, special equipment, and any related shipping charges. Consumables refers to the cost of sand or other materials used during your experiments. If you require materials (e.g., sand) or specialized equipment to use in the PAL wind tunnels, it is your responsibility to budget for these expenses, including delivery and installation costs.

For non-sponsored (i.e., research not funded from the Solar Systems Workings program) projects, such as instrument development proposals or mission projects), NASA-Ames charges a pro-rated facility fee of $1,500/day for operations using the MARSWIT, where a pump down to Mars pressure is required. For use of the MARSWIT when a pumpdown is not required, or for use of the Titan Wind Tunnel (TWT), NASA Ames charges a pro-rated facility fee of $600/day. These charges can be justified in the ASU commitment letter sent by the PAL PI in your proposals. These funds would actually go to your home institution, and then NASA Ames would invoice you for these fees.

We must emphasize that although there is no guarantee of a single pumpdown on any given day, every project that has operated in the MARSWIT in the past 5 years has been provided required pumpdown services. There have been instances when a planned pumpdown was denied for a particular day, but provided the next day (and in some instances 2 pumpdowns in a single day). It is highly unlikely that a project will receive a pumpdown every day of operation. In the past, the facility would be reserved for a week of access, with additional work being conducted into the following week (including pumpdowns) without a charge for the additional days. Regardless, we would like to stress the importance of a high degree of preparedness and advancing planning, working with the PAL engineer at ARC. More than once, opportunities have been lost through no fault of the PAL or the ARC steam plant because of a lack of planning on the PI’s part.

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2.2.3 Travel Expenses to/from PAL Facilities

Of course, to work at the PAL wind tunnels, you will need to budget travel costs to ASU or NASA-Ames. Please follow standard guidelines for research-related travel from your home institution.

2.3 When to Schedule your Work at the PAL

Please email PAL PI David Williams (David.Williams@asu.edu) once your proposal is funded so that your project can be scheduled in the queue of projects to be conducted at the PAL. You will receive a copy of the PAL Administrative Manual, which provides further details on how to arrange and conduct your experiments. All users of the PAL facilities at ARC must meet NASA security, safety, and procedural regulations. All personnel must hold a valid NASA badge or Visitor badge for the period of their scheduled experimental testing. Use of the facility after hours or on weekends must be arranged in advance. Non-US personnel must make arrangements well in advance of their visit (typically 60 days) to successfully secure a Visitor badge. Please consider the ramifications of including foreign nationals and adjust your schedules to accommodate. The process for securing a visitor badge for a foreign national is a multi-step process, involving security clearances and background checks. Not all citizenships require the same level of investigation, so please consider the 60 day rule to be a minimum with the understanding that some citizenships will require considerably longer due to U.S. security concerns. Additionally, please consider the impact on the actual daily schedule of your operations. Any foreign national granted a visitor badge will require the sponsor to accompany them everywhere while on NASA/Ames property. Unless planned for in advance, this requirement may compromise the level of service available at any given time.

As is the case with any government facility, safety is paramount and monitored. In the event that planned research operations become a safety concern, courses are available to certify team members. Safety inspections are unannounced and infractions can result in suspension of a project or escort off of the facility.

*We welcome early and open dialog with any researcher contemplating use of the PAL facilities.*

We welcome all calls to discuss “fitting” a project to the facility. The most successful projects have visited the facilities beforehand, expressing ideas that facilitate the execution of their work, and tailoring their apparatus to a best fit. The limitations of our equipment and our access to low pressure should be clearly understood. For instance, expecting a dedicated pumpdown with immediate access to run an experiment is unrealistic. Expecting to be able to run an experiment for hours with access to vacuum is unrealistic. We operate within the windows of time (typically 15-45 minutes duration) between the scheduled experimentation of the other facilities at Ames. Longer duration experiments would require buying dedicated time and being placed on the Thermal Physics Facility schedule. Furthermore, all facilities face equipment failure, calibration issues, and potential downtime for system upgrades. We are committed to keeping this to a minimum, but as mentioned above, communication can avoid disappointment. We are always open to suggestions from researchers for ideas to improve the PAL facilities.
APPENDICES
A. SAFETY PLAN FOR THE MARSWITT TOWER TEST FACILITY

1.0 Tower test facility

1.1 Facility description
The tower test facility located in building 242 (room 106) is a large vacuum facility suitable for numerous low pressure experiments. It currently houses an air ejector powered open circuit wind tunnel used to study aeolian particle movement at Martian atmospheric pressure. The facility obtains vacuum from the thermal protection facility and high pressure air from an air compressor dedicated to building N242. This compressor produces air flow at a rate in excess of 260 CFM and maintains the air pressure at 170 PSI. The vacuum capability is 2 mm Hg (2.63 mb) and the normal operating pressure of 4 mm Hg (5.26 mb) can be reached in 30 minutes. Vacuum is supplied via a 60 cm. (2 ft.) diameter pipeline, through a system of solenoid controlled pneumatically powered valves, from a five-stage steam ejector plant located in building N234A. The tower is returned to standard atmospheric pressure by opening a 12 inch butterfly valve located on the roof of the building. This valve is solenoid controlled and pneumatically powered. With the valve in an open position the tower will equilibrate in about 45 minutes. The tower cannot be pressurized above atmospheric pressure.

The tower is a pentagon shaped building, designed to accommodate acoustic reverberation testing. Each side of the pentagon is 8 meters long by 30.5 meters high (26.5ft. x 100ft.). The walls are 0.9 meters (3ft.) thick from the floor to 9 meters (30ft.) high and 0.75 meters (2.5ft.) thick for the remaining 21.5 meters (70ft.). The tower floor is a reinforced concrete mat 1.8 meters (6ft.) thick.

There is a rectangular area at the south side of the base of the tower 6.8 meters (22.5ft.) long by 7.6 meters (25ft.) wide and 11.9 meters (39ft.) high. The total volume of the tower is 4000 cubic meters (140,000 cu. ft.).

There is an entrance at the south side base of the tower 7.6 meters wide by 7.9 meters high (25ft. x 26ft.). This entrance is closed by a manually operated, trolley mounted, side rolling steel door. The door is sealed by an inflatable collar running the outside perimeter of the opening, facing the door. There is a roll up door located 1.67 meters (5.5ft.) inside the rolling door. It is not designed to withstand differential pressure and is currently not operational.

Access to the tower from inside the building is provided at the north end of the tower by an entrance of 1.2 meters by 2.4 meters (4ft. x 8ft.) and closed by a trolley mounted, side rolling steel door. This door also is sealed by an inflatable collar running the outside perimeter of the opening, facing the door. There is a hinged steel door 1 meter (3.3ft.) inside the rolling door. This door is not designed to withstand differential pressure.

Access to the tower roof is accomplished by ascending the ladder attached to the tower wall and egress through the 0.7 meter circular hatch (28 inch) in the tower ceiling. The counterbalanced steel hatch opens outward and is sealed with a rubber ring. Originally designed without lugs or latches with the intention of taking advantage of the pressure differential to maintain a tight seal and allowing an instantaneous vent in case of over pressurization, the hatch is now secured with an adjustable cable and pulley.

There is a platform 9.8 meters (32 ft.) above the tower floor at the south end of the building, accessible from the same ladder that leads to the circular hatch in the tower ceiling. A one ton scaffold is secured to the ceiling of the tower by a trolley, bridge, and cable assembly designed to be capable of lifting personnel and equipment from the floor to the ceiling and swiveling 360 degrees to provide access to large structures placed inside the tower for servicing and test preparations. This apparatus is currently inoperative and there are no plans to return it to service.

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There is a three panel plexiglas observation window between the tower and the control room. Each panel is 0.5 meters wide by 0.9 meters high by 0.05 meters thick (19 in. x 36 in. x 2 in.). They are assembled in a frame together creating an overall viewing dimension of 1.5 meters by 0.9 meters (57 in. x 36 in.). Attached to the concrete wall on the control room side of the window is an aluminum safety frame with louvers that will close automatically should the observation window be compromised while low pressure conditions exist inside the tower.

1.2 Wind tunnel

Mars Wind Tunnel (MARSWIT)
The Mars Wind Tunnel is installed in the tower along a north-south axis with the flow toward the south. The tunnel is of open circuit design and is 12 meters long (40 ft.). It is constructed in five sections mounted on casters and can be disassembled. The first three sections are 0.9 meters high by 1.2 meters wide in cross section. The first section includes the entry cone and is constructed of plywood and masonite. The next two sections have a plywood floor, plexiglas walls, and plexiglas ceilings. These two sections comprise the test area. The last two sections are the tunnel diffuser. The vertical dimension of these sections increases from 0.9 meters (3 ft.) to 1.6 meters (5.33 ft.). These sections are of plywood construction and they contain the air ejector and fan drive systems. During low pressure operation, tunnel flow is driven by the air ejector system. This system is powered by pressurized air supplied by an Atlas Copco 75HP air compressor dedicated to building N242. This compressor produces air flow at a rate in excess of 260 CFM with a maximum final pressure of 183 PSI. The compressed air is stored in a 30,000 gallon tank located north of building N242. Pressurized air is supplied to building N242 from this storage tank via a series of two and three inch pipe lines. The air supply for the air ejector system arrives at a nominal pressure of 175 psi and is controlled by a two inch motor driven ball valve. Maximum tunnel flow velocity with this system is 120 m/s (390 ft./sec) at 5.3 millibars (4 mm. Hg). During operation at standard atmospheric pressure, tunnel flow is generated by the fan drive system attached to the end of the tunnel. The maximum tunnel flow velocity with this system is 10 m/s (33 ft./sec.).

Tunnel instrumentation includes a static probe, a traversing boundary layer probe, and a temperature/humidity transmitter. The probes are permanently attached in the test section of the tunnel and the temperature/humidity transmitter is suspended in the tower adjacent to the tunnel. Data from these instruments is delivered to the control room computer for interpretation. A removable flow straightening screen is currently in place to control boundary layer turbulence.

Titan Wind Tunnel (TWT)
The Titan Wind Tunnel (historically, the Venus Wind Tunnel) is a closed circuit wind tunnel with a test section 20 cm. (8 in.) in diameter and 122 cm. (48 in.) long. It has been designed to allow the removal of the test section from the tunnel circuit for access to the test area. Test plates can be substituted, instrumentation and media can be prepared for test runs, and final inspection of bed forms can be documented at the end of a test run. The floor plate installed properly, rests against the curved walls of the test section, level, approximately one third of the diameter distance above the bottom of the test section pipe segment. There are four viewing ports and one instrument port in the test section. One viewing port is located 30 cm. (12 in.) from the upwind end to the center of the 7.6 cm. (3 in.) diameter viewing port, oriented facing out from the center of the tunnel circuit. The other three viewing ports are located 30 cm. (12 in.) from the downwind end of the test section to the center of the viewing ports. One of these viewing ports is located on the top of the test section, providing a view from above. The diameter of this viewing port is 5 cm. (2 in.).

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The other two viewing ports are located on the sides of the test section opposite each other. They are also 7.6 cm. (3 in.) diameter. All viewing port centers match the center of the test section. All viewing port windows are Type W Safety Sight Glass installed in lens holder assemblies (with gaskets) designed to withstand 600 PSI pressure. The instrument port was added in 2010 to accommodate redesigned data collection equipment. It is located on the bottom of the test section at 61 cm. (24 in.). A machined stainless steel plug is fitted to the port assembly, allowing for air line connections to a traversing pitot tube mechanism and electrical wiring for control of the traversing pitot and data collection from the test section. Another pitot tube is located in the straight section of the tunnel circuit, opposite the removable test section in a permanently fixed position in the center of the pipe to measure freestream wind speeds. Both pitot tubes are plumbed to a switch that directs which location measurements are being taken from. A custom designed differential pressure transducer (manufactured by Tavis Corporation) is connected to the switch. The tunnel is powered by a 1.5 HP D.C. variable speed motor which drives an eight bladed fan. The manipulation of gas flow within the tunnel is accomplished by control of the fan speed. The outer shell of the tunnel is constructed of schedule 80, steel pipe. Originally pressure tested to 67 bar, the most recent certification was for pressures up to 20 bar. Modifications implemented for the Titan project include two revised pressurization methods:

In one system, pressurization is achieved by accessing the compressed air supply of building 242. The source of the compressed air is an electrically powered air compressor manufactured by Atlas Copco in 2004, model GA55C. It is a 75 hp unit with a maximum output pressure of 183 psi. The pressurized air passes through a heatless desiccant dryer manufactured by Airtrek Corporation. The twin tower unit is a model TW250 with a drying standard of “dew point at -40 degrees”. The compressed air from this system is stored in a 30 thousand gallon tank, before being delivered inside the building. The delivery pressure varies from 150-165 psi. If the delivery pressure is insufficient for the planned testing, a 2:1 air amplifier manufactured by Interface Devices, Inc. can be utilized to increase the tunnel pressure to the desired level. The other pressurization option accesses a compressed gas cylinder system. This system consists of eight “K bottle” cylinders mounted to a rack assembly with separate valves and regulators for each cylinder, connected by a pressure certified assembly of air lines and valves to the tunnel. This pressurization method provides the option of using a specific, purified gas rather than compressed air.

Inside the tunnel, in the straight section downstream of the motor and fan (and opposite the test section), is the permanent pitot tube, oriented to face into the flow in the center of the flow. Further downstream, inside each of the first two corners are ten curved tubes of 5 cm. diameter. These tubes smooth the flow through the turns and prevent large scale separation and turbulence. Between the two corners there is a hexal honeycomb structure to additionally promote smooth flow. After the second turn and upstream of the test section there is a 47 cm. diameter stilling chamber with another hexal honeycomb flow straightener and a series of four 180 mesh screens. Immediately beyond this point and adjacent upstream of the test section is an aluminum liner insert that provides a smooth transition from 47 cm. section to the 20 cm. diameter test section. Downstream of the test section and before the third corner is an aluminum diffuser insert that smoothly transitions an increase from 20 cm. to 30 cm. diameter. There is a screen following the diffuser to prevent material being circulated into the fan section.

2.0 Operating procedures
2.0 Operating procedures for “pump down” (low pressure operation)

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2.1 Standard sequence

2.1.1 The rotating amber warning light outside the north door is activated.

2.1.2 The wind tunnel fan has been rotated as far as possible away from the exit end and the imaging area access door is securely closed.

2.1.3 The control room door is opened.

2.1.4 The large steel pressure door (south door) is inspected to insure that the seal is inflated. The seal pressure is checked to insure that it is within operating limits of 7-14 kg/cm² (10-20 psi).

2.1.5 After a visual inspection is made of the tower to insure that no one is inside the warning horn is activated.

2.1.6 When the horn stops blowing the interlock key is removed, the pressure door is closed, locked and the seal is inflated and the seal pressure is checked.

2.1.7 The interlock key is removed from the south door and inserted in the control panel. The panel is checked to insure that all doors are indicated closed and all valves are in the proper position. The panel is activated.

2.1.8 When the boiler house gives permission by way of the direct line the tower fluorescent lights are turned off and the valves are opened in sequence to begin pumping.

2.1.9 At the completion of the run the sequence is reversed and when the tower has reached atmospheric pressure the door seals are deflated, the small pressure door is opened and the horn circuit is reactivated by reinserting the interlock key into the horn circuit lock.

2.2 Emergency procedures

2.2.1 Loss of electrical power

When electrical power is lost during a run the effect is the same as when the emergency stop button is pushed, i.e., the control valve opens, bringing the tower to ambient pressure. When electrical power is restored the emergency stop alarm will be activated and it will be necessary to reenter the tower and reset the emergency stop system before proceeding with pump down. No hazard exists due to electrical failure.

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2.2.2 Loss of shop air

Complete loss of shop air during a run would cause loss of control of the operating valve and the exhaust valve. They would remain in whatever position they were in when the air supply was lost. The gate valve for the vacuum line operates from a separate air supply and would still function. There would be a problem in returning the tower to ambient pressure without the exhaust valve. Either an alternate air source (i.e., bottled air) could be used to open the exhaust valve or the tower could be brought to ambient through the electric motor driven air supply valve to the wind tunnel. This may require a lengthy time as the air flow volume is small through the tunnel ejectors.

2.2.3 Loss of auxiliary air pressure

No problem would exist if auxiliary air pressure were lost except the inability to run the wind tunnel.

2.2.4 Loss of vacuum supply

No problem would exist if vacuum supply were lost except test would be interrupted.

3.0 Safety analysis

3.1 Personnel trapped in tower

A potential hazard exists since anyone trapped inside the tower during pump down would be killed if the pressure were reduced low enough. The possibility of this happening is remote since only a few persons are working in and around the facility and these are aware of the activity preceding a pump down. A rotating amber warning light located near the tower north entrance is activated early in the day when pump down is scheduled. A visual inspection and audible voice warning is always made prior to sealing the chamber and when the interlock sequence is begun a loud horn blows inside the tower. If someone should be trapped inside the tower in spite of these precautions there are two emergency stop buttons in the tower, one by the north entrance and one on the tower balcony. When activated these ring a bell in the control room and automatically close
the operating valve and open the exhaust valve. Before pumping down can be reinitiated the alarm must be reset by inserting the proper key in the interlock system inside the tower.

3.2 Structural failure of the Plexiglas window

A failure of the Plexiglas window between the control room and the tower while the tower is pumped down could have catastrophic consequences. While the likelihood of this happening is small, the possibility does exist, since there are high energy sources in the tower such as the high pressure air supply which could malfunction and hurl objects considerable distances and conceivably strike the window.

The opening is protected by a set of steel louvers on the control room side that are designed to close automatically in the event of a window failure. These would greatly reduce the influx of air into the tower and the resulting damage to the control room. The control room is further protected by 8 louvered wall sections that will allow air to enter the control room and reducing any subsequent differential pressure on the walls of the control room.

In the event of occurrence, the emergency stop button on the tower control panel should be activated as quickly as possible, followed by evacuation of all personnel from the control room to outside the building. Activating the emergency stop closes the valve system providing vacuum and opens the exhaust valve to allow re-pressurization.

3.3 Fire in the tower

There is a possibility of fire in the tower due to electrical malfunction or other causes. If the fire were to start while the tower was pumped down it would be inaccessible until the chamber was returned to atmospheric pressure. It is doubtful; however, if a fire could be sustained under this condition due to the lack of oxygen, and if the source was electrical it could be eliminated since all electrical circuits can be shut off from outside the tower.

A fire at other times would be handled by ordinary procedures.

3.4 Electrical hazards

There are no special electrical hazards with the tower except that all equipment should be checked for vacuum operation prior to being installed in the tower. In general 120 volt devices usually operate normally but devices which contain higher voltages often experience failure due

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to arcing. Equipment utilizing convection cooling could also cause problems. Incandescent lamps function satisfactorily but fluorescent lamps do not.

3.5 Additional cautionary comments

3.5.1 Remove all pressure sensitive devices associated with the TWT operation (Wiki pressure gauge, gasket compound tubes, etc.)

3.5.2 All aerosol cans and sealed containers (paint cans, glue bottles, etc.) should be removed from the tower prior to pump down. It should be noted that the boiling point of water is 0°C at 4 mm hg and it will boil and then freeze if left in an open container in the tower.

3.5.3 When cleaning the wind tunnel after a run caution should be exercised not to create large “dust clouds” of material in the tower since such clouds are explosive under certain conditions.

3.5.4 The tower floor area should be thoroughly cleaned periodically, especially after testing since the painted floor is extremely slippery when “dusted” with some of the spherical shaped particles that are being tested.

3.5.5 Finally, as with any system, there are ways to by-pass the safety devices installed to protect the system. It is therefore important to fully utilize the safety features (i.e. interlock system, window shutters) and not by-pass them or disable them for reasons of expediency. Only in utilizing these provisions can the system be operated as safely as possible.
This facility is capable of reproducing the aeolian environment of Earth, Mars, and Titan. The vacuum necessary to simulate Mars is a by-product of other NASA/Ames Research center facilities and cannot be guaranteed for specific days. It is provided to our facility secondarily when it will not adversely affect the testing schedule of the primary facilities. As a result, the periods when vacuum is available are valuable, and it is imperative that research teams be well organized and each experiment well defined. As prerequisite to using this facility it is necessary for responsible parties to provide the specific documentation, review the experimental procedure agreement list, and indicate compliance by signature. This document will be placed in the project file. (Initial each)

1. I have read the facility description and safety plan. 
   
2. I assume responsibility for damage to any and all equipment my research team places into PAL and the test chamber. 
   
3. I have provided a detailed procedure for the proposed experiment, including personnel assignments. (please do not under staff your project) 
   
4. I have provided drawings of the experimental apparatus assembly, including location and orientation in the chamber. 
   
5. I have designed an experiment schedule, defining a timetable allowing flexibility to accommodate vacuum availability, if needed. 
   
6. I have satisfied safety requirements associated with placing test equipment into a low pressure environment, if required. 
   
7. I have accounted for assembly of apparatus, preliminary testing & calibration, disassembly, removal of equipment, removal of test media, & clean-up of the facility in my schedule. 
   
8. I understand that additional safety requirements may have to be met, depending upon the design of the proposed experiment. This may include satisfactory completion of coursework. 
   
9. I understand and agree to wear appropriate safety apparel which includes, but is not limited to steel toed shoes, dust masks, and protective gloves. 
   
10. I understand that using a ladder at a height over four feet will require a safety certification.

Signed: ________________________________  __________________
             Responsible PI                  Date

Printed Name: ________________________________  Organization __________________

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