A remote, autonomous laboratory for Antarctica with hybrid power generation *

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SUMMARY: *The AASTINO (Automated Astrophysical Site Testing INternational Observatory) is a remote laboratory that has been operating at Dome C station on the Antarctic plateau since January 2003. It is designed to run throughout the Antarctic winter without intervention, and to collect data on the astronomical qualities of the site. A Stirling engine and a pair of solar panels power the observatory. Command, control and communication is via the Iridium satellite network. A supervisor computer system controls all aspects of engine and power source management, communications, instrument control, and data collection. The AASTINO system is designed with the capability to run completely autonomously in the event of communications failure.*

1 INTRODUCTION

A precursor laboratory, the Automated Astrophysical Site Testing Observatory (AASTO) has been collecting atmospheric data relevant to astronomy from the US Amundsen-Scott South Pole station for the last decade.[1,2] The AASTINO (Automated Astrophysical Site Testing INternational Observatory) represents the next step in a program to develop fully automated site testing laboratories, capable of being deployed to even more remote locations on the Antarctic plateau.

The French/Italian station at Dome C (75 S, 123 E, 3250m) on the Antarctic plateau has been operating during the summer months (Nov, Dec, Jan) since 1990. A winter-capable station is currently under construction and is planned to be open for the winter of 2005.[3] Many factors suggest that the atmospheric conditions at this site are ideal for an astronomical observatory, and are superior to the conditions found at even the best mid-latitude sites. The complete absence of strong surface winds, the stability of the wintertime surface layer temperature profile, and the flat ice surface indicates that the boundary layer turbulence should be very low.[4] The low temperatures throughout the atmosphere indicate that transmission at infrared and sub-millimetre wavelengths should be much higher than found at typical mid-latitude sites, while the sky background in the thermal infrared should be very low. A full characterisation of the atmospheric parameters at Dome C relevant to astronomy has motivated the development of the AASTINO. In future, the AASTINO may be deployed to higher and more remote locations on the plateau, such as Dome F and Dome A, which are potentially even superior to Dome C for astronomy.

The structure of the AASTINO is a heavily modified version of the "Igloo Satellite Cabin" manufactured by Malcolm Wallhead and Associates, Tasmania. The original Igloo consists of an "igloo-shaped" outer fibreglass casing with ~40mm thick internal polyurethane sprayfoam insulation. It is approximately 4m × 6m in size, with eight floor panels and sixteen wall panels. In the AASTINO, six of the wall panels include an instrument port on the roof and are built as a fibreglass/foam/fibreglass sandwich to provide additional mechanical strength. The AASTINO shelter is designed for modularity and (relative) ease of assembly; it can incorporate a range of different power systems and instruments, and can be assembled by a team of three people under Antarctic plateau conditions in a day.

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Figure 1: The AASTINO installed in front of Concordia station.

The AASTINO was assembled on an ice sled at Dome C station in January 2003. It is situated on a 2m high artificial ice hill approximately 200m NE of the new Concordia station that is currently under construction, as shown in Figure 1. In its first year of operation the AASTINO ran unattended for approximately five months (from Feb 5-July 1 2003). Close to real time data from the AASTINO, including engine diagnostics, instrument raw and processed data, and webcam images are published electronically.[5] It is intended that the AASTINO run unattended through the 2004 winter season. The longer-term plan for the AASTINO is to deploy an updated version to Dome A (4200m above sea level) over the 2007-8 season as part of the International Geophysical Year. Figure 2 is an internal picture of the AASTINO showing power generation, thermal management, and instrument system(s), which are discussed in the following sections.

2 POWER GENERATION

2.1 Alternatives

Providing heat and power for even a small Antarctic plateau experiment for a full 12 months is an interesting challenge. The physical altitude at Dome C is 3250m and the pressure altitude is some 20% higher. The ambient atmospheric pressure ranges from 630 to 660mbar. The average temperature over the summer months is approximately −30° C, while temperatures in winter can drop well below –80° C.[6] As it is mostly dark for six months of the year, solar power can only be used through the summer months. Similarly, the wind speed on the plateau is so low (mean wind speed at Dome C is only 2.9m.s^{-1})[4] that wind power is all but impractical. Nuclear power (for example, in the form of a

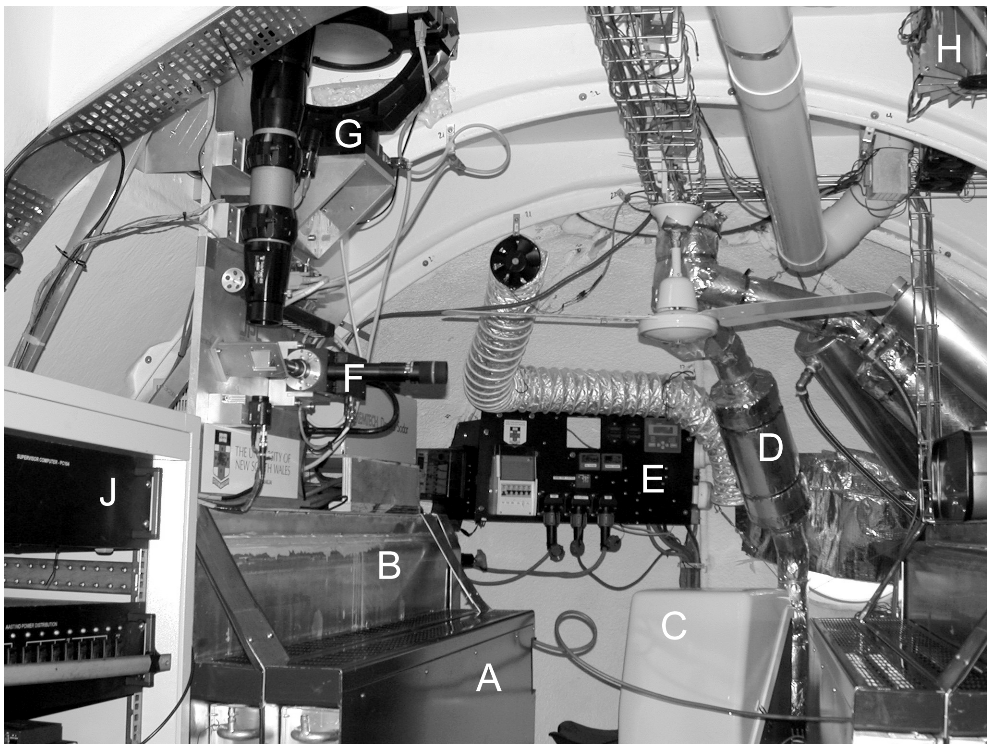

Figure 2: Internal picture of the AASTINO, showing various components of the engine system: heat exchangers (A) mounted on the internal fuel tanks (B), the WhisperGen Stirling engine (C), its exhaust system (D), and the power system control panel (E). The MASS instrument (F) and associated optics (G) is mounted on the left hand fuel tank. The heat sink for the external SUMMIT instrument can be seen in the top right cornor (H). Electronics rack containing power distribution unit and supervisor computer is at the front left (J).

Radioisotope Thermo-electric Generator) is ruled out by cost and environmental considerations. This leaves batteries and chemical-fuelled systems. The highest energy-density primary batteries currently available are lithium thionyl chloride, at 2.5MJ/kg. These cannot compete with fossil fuel (43MJ/kg for Jet-A1) when it comes to powering a full-size laboratory. Not only does the weight of batteries to be transported become prohibitive, but the cost per unit of energy is astronomical. There are a number of alternative fossil fuel power sources that were considered in the initial design phase for the AASTINO. These include thermo-electric generators, photo-thermal generators, internal combustion diesel generators, fuel cells, and Stirling engines.

Propane burning thermo-electric generators (TEGs) are a mature technology and have no moving parts, but have very poor efficiency. TEGs have been used in a series of Automated Geophysical Observatories located across the Antarctic continent over the last decade, but have proved unreliable and are no longer used. Problems experienced with the Antarctic TEGs include leaks in the freon-based cooling loop, and water vapour from the exhaust fumes condensing, forming an ice plug, and choking off the exhaust.[7]

Internal combustion diesel generators have successfully been operated remotely at Antarctic sites (for example at the Italian coastal station of Terra Nova Bay) and there are several advantages to such technology. It is mature, reasonably efficient, and relatively inexpensive. However, generators in the ~1kW range require regular maintenance, have noxious exhaust, and useable heat is difficult to extract. This necessitates a high level of redundancy. For example six independent engine systems are employed at the Terra Nova Bay site to supply power to instruments over the winter months.[8]

Fuel cells are probably the ideal heat and power source for such remote applications, and have previously been tested in an Antarctic environment.[9] They are efficient, reliable, have no noxious exhaust and low running costs. However, this technology is currently immature and it will be a number of years until commercial products are available at reasonable cost.

Against these alternatives the external combustion Stirling cycle engine was chosen as the most appropriate power source for the AASTINO. Such engines are low maintenance, quiet, relatively inexpensive, clean burning, and reasonably efficient. Additionally, the waste heat is easily extracted in a useable form. Various fuel alternatives were considered for this type of engine, including LPG, hexane, diesel, kerosene, JetA1, and JP8. The choice of Jet-A1 aviation fuel was motivated by the ready supply of this fuel in Antarctica, and the low freezing point (approximately -50° C). Despite this low freezing point, heated internal fuel tanks are required to keep the fuel liquid during the lowest outside winter temperatures.

While the long Antarctic night precludes solar power for most of the winter months, the permanent sun from September to March, combined with the high percentage of cloudless days at the Dome C site, implies that solar power is a very effective power source over summer. The AASTINO thus employs a pair of solar panels that reduce fuel consumption and provide limited power in the event of an engine malfunction. Although solar-cell/diesel-generator hybrid energy systems have been used previously for remote area power supply,[10] the solar-cell/Stirling-generator hybrid energy system used in the AASTINO is, to the authors' knowledge, a unique design.

2.2 The AASTINO power system

The power source for the AASTINO must be capable of providing electrical power to a number of instruments (discussed in section 5), thermal management components (discussed in section 3), and the communications and computing system required to control these systems (discussed in section 4). In the first year of operation (2003) the AASTINO required 94W continuous and 184 W peak of electrical power. The AASTINO power budget for the 2004 season, shown in Table 1, has a requirement of 157W continuous and 400W peak, as a result of an increase in the number of instruments and the system complexity. A further increase in power demand is expected for the 2005 season.

Table 1
AASTINO power budget

Unit	Voltage (V)	Power (W)
Computer and Communications		**30**
PC104	24	5
Moxa	12	10
Ethernet hub	12	8
Iridium phone	4.4	5
Dallas	5	2
Thermal system		**22-100**
Eurotherm	24	10
Coolant fans	24	12–40
Outlet fans	24	0–20
Room fans	240 AC	0–30
Instruments		**105-270**
SODAR	12	60–90
SUMMIT	24	5
MASS	12	5
MASS gimbal	24	10
AWS	12/24	2
External	220 AC	0–135
Webcams	12	15
Webcam server	12	8
TOTAL		157–400

The primary power source chosen to provide this is the WhisperGen PPS16 24VDC engine, a co-generation system based on a small four-cylinder double-acting Stirling engine, manufactured by WhisperTech Limited, New Zealand. The manufacturer’s specifications give a maximum generation of 750 W of electrical power and 5 kW of heat at sea level.[11] Two complete fully independent engine systems (“Sid” and “Nancy”) are installed in the AASTINO for redundancy. The feasibility of running such engines at high altitude in an Antarctic environment was demonstrated by a series of tests in the AASTO at the South Pole station during the winter of 2002.[12]

The WhisperGen engine is primarily designed to operate in stop-start mode. For the AASTINO a continuous operation (float charge) mode is preferable to reduce stress on engine components. In this mode the engine runs at a low power level, continuously charging a battery bank according to the changing energy demand. The battery bank consists of a series of four 200Ahr 6V sealed lead-acid batteries (Sun-gel 6SG200), which are float charged at a voltage between 27-30V depending on the battery temperature. Engine logs over the first year of operation at Dome C show an average gross output power of approximately 250W. This includes power used by the engine sub-systems, with 50-120W being drawn by the AASTINO systems. Excess energy of 40-100W is dumped into an engine clamp resistor when the generated power exceeds demand. The fuel consumption at this power level is approximately 0.5lt/hr, which represents 6-7 months of operation with the AASTINO’s two 1200 lt internal fuel tanks. For the second winter of operation two 1000lt external fuel tanks have been installed to extend operating lifetime and to cope with expected increase in power demand. A 24V DC fuel pump is installed inside the AASTINO to automatically refill the internal tanks before the outside temperature is low enough to freeze the external supply.

High-velocity high-temperature exhaust gas is necessary to avoid ice formation in the external exhaust stack in the extremely low external temperatures. The standard WhisperGen engine has an internal secondary heat exchanger that is used to extract additional useful heat from the exhaust. This has been removed in the AASTINO engines. Additionally, lagging of all internal exhaust pipes (with Rockwool insulation) and keeping them as short as possible, although reducing the heat available to the room, significantly increases the final exhaust temperature. In order to increase the exhaust gas velocity the external copper exhaust pipe is reduced in diameter close to the output. This reduces the maximum available output power (by ~20%) as the air flow provided by the blower at full power is reduced. Because of the low power requirements, however, this power reduction is not consequential.

To reduce fuel consumption and allow limited functionality in the event of an engine malfunction, two 72 cell 150W monocrystalline silicon solar panels (BP 2150S) are installed outside the AASTINO. The panels are mounted vertically facing due North to take advantage of the last and first appearance of the sun low on the horizon in late May and early August respectively. The power generated from the solar panel system is controlled with a Maximum Power Point Tracker (AERL Maximiser 600B). The highly reflective and flat ice surface surrounding the Dome C station increases the solar flux, while the panel efficiency increases because of the very low temperatures. Over 400W has thus been obtained from the panels despite a nominal specification of 300W. While this power is enough to operate the majority of AASTINO systems and some of the instruments, several instruments that draw large current, are not cold rated, or require a dark sky, can only be run when the engines are producing heat as well as power.

3 THERMAL MANAGEMENT

The WhisperGen’s internal engine management processor determines the appropriate power level (fuel and air flow rates) for the engine to maintain a specific coolant temperature. This is measured with a sensor close to the output coolant flow, and can be set by the user (in the range 45-70° C). The required power level is determined essentially by the rate at which the coolant system dissipates engine heat into the room.

An identical independent coolant system is used for each engine. Each system is driven by a brushless 24V DC magnetically coupled pump (Clark Solutions NH-30PX) running a glycol/water mix at 10 litres/min through ¾ inch stainless steel braided teflon hose. Engine heat is transferred to the room via two separate hydronic naturally convecting heat exchangers (copper finned coils mounted at the top of a stack) which are mounted beside the internal fuel tanks.

Four brushless 24 V DC variable fans (PAPST 4400F) giving up to 50lt/s airflow each are located at the bottom of each heat exchanger. This allows for additional cooling capacity via forced convection. Tests at UNSW have shown that heat output for each exchanger can be increased threefold via forced convection. In the AASTINO a Pulse Width Modulated (PWM) signal generated by the WhisperGen engine management processor is converted to an analog DC voltage which controls fan speed.

Tests on the unmodified WhisperGen engines at UNSW confirmed maximum power levels of 800W electrical and 6kW of heat, comfortably in excess of specifications. In float charging mode the unmodified engine was found to generate 4.5kW of heat at fuel/air rates corresponding to 250W of electrical power. Removing the secondary exhaust heat exchanger of the WhisperGen redirects the engine heat from the primary coolant loop to the exhaust gas temperature, and drops the useful heat output by ~25%, giving ~3.5kW at 250W. Both the lower atmospheric pressure at Dome C and the exhaust pipe reduction decrease the available maximum heat and electrical power, as the maximum mass flow rate of air is decreased. However, fuel consumption also decreases, as the generated heat is simply proportional to the fuel flow rate.

Specifications from the manufacturer of the Igloo Satellite Cabin give a requirement of 0.5kW of heat to maintain a 58° temperature difference at -40° C, for the standard size 3m diameter dome cabin. The modified AASTINO has approximately three times the surface area of the standard cabin. As a rough approximation it is thus expected that the 3.5kW of heat generated by the engines is appropriate to maintain the internal temperature above 0 degrees in mid winter (i.e. an 80° difference), and will be too much heat in the summer (i.e. an 80° difference at -30° external temperature will give an internal temperature of 50°). The AASTINO thermal management system is thus designed to exhaust excess heat when appropriate. Internal temperature is measured with a pt100 platinum resistance thermometer. A Eurotherm 2416PID temperature controller regulates the room temperature via two 150 mm brushless fans which exhaust the warm room air via PVC ducting, causing cold outside air to be drawn in through a separate inlet duct.

The thermal properties of the AASTINO structure could not be assessed until the first winter of operation. Data from this winter show that as the outside temperature dropped, the AASTINO internal temperature was no longer well correlated with external temperature, but was strongly correlated with external wind chill factor (as recorded by an Automatic Weather Station installed within 40km of the Dome C site), as shown in Figure 3. A temperature difference of 60-70° in calm conditions, dropping to 40° in strong winds, indicates a significant heat loss through either the room air vents or the AASTINO seals in windy conditions. This problem was addressed for the second winter season of operation by improving the internal seals and decreasing the diameter of the exhaust air ducting.

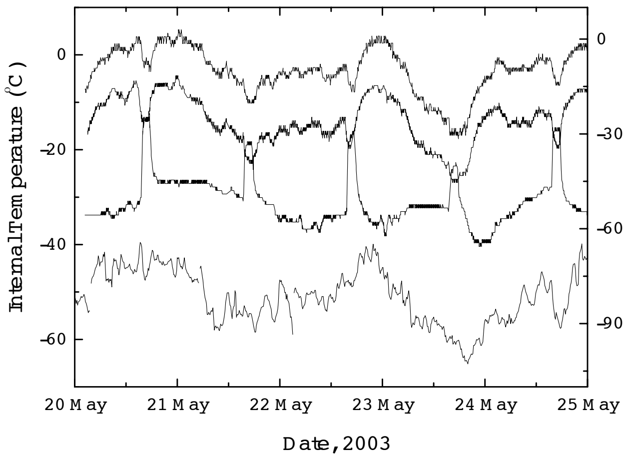

Figure 3: Top three plots show internal AASTINO temperature (left axis) at three levels: ceiling, middle, floor (from top plot down). Bottom plot shows external wind chill factor (right axis) from AWS data. The five sudden drops in ceiling temperature (and corresponding rises in floor temperature) occur as a result of the room circulation fans switching on.

The first season of operation showed a remarkable stratification of the temperature inside the AASTINO, with a temperature difference as high as 40° between the floor and ceiling; see Figure 3 for an example. Such strong stratification is commonly experienced in Antarctic buildings. To eliminate this problem, a set of 150mm 24V DC brushless Papst fans were installed with flexible aluminium ducting to provide circulation of the room air. These fans, however, were found to produce enough acoustic noise to interfere with the operation of one of the instruments. In the second season of operation the small DC fans where replaced with a lower noise 1.2m diameter 3-bladed AC ceiling fan.

4 COMMAND AND CONTROL

4.1 Hardware

A schematic of the complete system architecture for the AASTINO is shown in figure 4. The 24VDC power generated by the engines in parallel with the solar panels charges the 24VDC 200 Ahr battery bank. This power is distributed to non-critical systems such as the room temperature control system, and the external (Precipitation monitor) instrument via a series of 35A circuit breakers. The

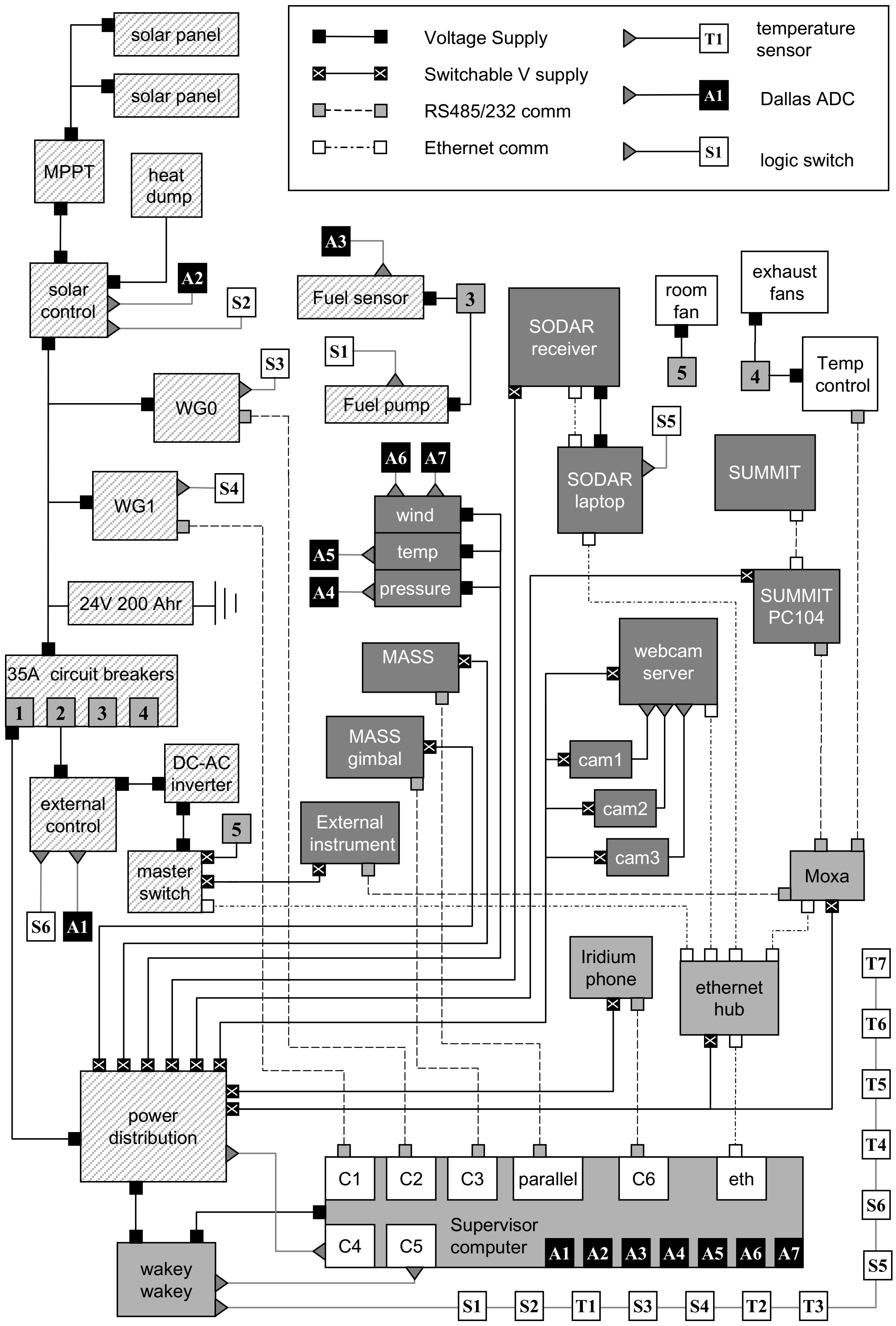

Figure 4: Schematic of AASTINO systems. Each of the AASTINO sub-systems (power generation and distribution, computing and communications, thermal management and instrumentation) is shaded differently.

only AC devices in the AASTINO are the external instrument and the internal ceiling fan – these are both supplied from an Ethernet-controlled mains switch (APC Masterswitch) running from a 500W DC-AC inverter. Critical systems (computing, communications, and instruments) all operate from the DC bus and are powered through a power distribution unit that contains a series of DC-DC converters controlled via Infineon BTS442 high-side switches. Power is supplied to the central "Supervisor" computer via a "wakey-wakey" board (see later).

The Supervisor computer is used to control all of the AASTINO systems. This computer is a DSP TPP3 PC104 system with a 300MHz Celeron processor, 512MB of semiconductor memory, and two (extended temperature version) 1GB M-Systems FDD 2.4" IDE Plus Flash Disks (one for the operating system, the other for data), running on a GNU/Linux operating system (Red Hat 9 with a custom 2.4.23 Linux kernel). In addition, the computer has an Ethernet connection capable of 100Mbps full-duplex, two USB ports, 4 serial ports, and a parallel port. The PC/104 stack consists of the processor board, a Parvus 8-channel serial board, and a (DGE Systems D104-PCS20) power supply board. The use of a solid state disc drive is motivated by the desire to eliminate all moving components (such as standard spinning hard drives) in order to increase the system reliability. Standard hard disc drives are often damaged by operation after exposure to extreme low temperatures and low atmospheric pressures. IDE Compact Flash memory drives have been used in the past but have also proven unreliable in remote applications. The choice of PC104 stack allows a modular system. Through many years of operation of remote computer systems the GNU/Linux operating system has been found to be very satisfactory. We have found it to be essential to verify the operation of the computer at low temperatures, since unexpected problems can occur. For example, one brand of solid-state disk, rated to -40° C, was found to fail intermittently at 0° C.

The supervisor computer communicates with the various AASTINO sub-systems and instruments via either a local Ethernet hub, the PC104 parallel port, or directly via one of the PC104 or Parvus expansion board serial ports. An Ethernet to serial device server (Moxa Nport Server Lite) provides another four serial ports on the local Ethernet hub. Two serial ports are used for communication and control of the engines (via RS232/485), four serial ports are used for instrument control (MASS, MASS gimbal, External, and SUMMIT), one is used for room temperature control, and one is connected to a Motorola Iridium handset for communication (to UNSW). One instrument (SODAR) and a video server, with input from four separate webcams, communicates through the local Ethernet. One instrument (MASS) is also controlled via the PC104 parallel port.

Two serial ports each run a separate Dallas Semiconductor 1 wire bus (on RJ45 cable). This bus contains a number of temperature sensors (using DS1820 chips), optically isolated logic switches (employing DS2450 chips) located at various internal points around the AASTINO, and analog to digital converters (using DS2450 chips). This bus allows many subsystems to be power-cycled, and provides status information on other systems. Additionally, the Dallas line runs through the power distribution unit that contains semiconductor logic devices to power-cycle each of the instruments, and the Iridium phone. The first device on the Dallas bus is the wakey-wakey board. This board will power cycle the Supervisor computer every 15 minutes unless it receives a watch-dog signal from the Dallas bus. Thus if either of the two critical systems, the computer software or the Dallas bus, crashes or hangs, the computer will be forced to power-cycle and reset both itself and the Dallas bus.

4.2 Software

The software is based on standard GNU/Linux tools, with application programs written in Java, C, perl, tcl and bash. In a few cases (e.g., control of the WhisperGen engines via RS-485, and control of the MASS telescope mount) we have had to write our own device drivers. Each major instrument component has been written as a standard System V service that can be started/stopped using the usual administration tools. A crucial part of our software philosophy is to do as much as possible on one computer, even to the extent of running multiple almost-real-time processes (such as engine/telescope control). This has avoided the complexities of relying on multiple computers, and synchronising activities between them.

4.3 System control

A key feature of the AASTINO system is its semi-intelligent autonomous operation. This is motivated by the low bandwidth connection (2400 baud) available on the Iridium satellite network. While it allows data transfer and some degree of command control, it is too slow and unreliable for real time control. Separate scripts on the Supervisor thus control the instruments and the web-camera, the Iridium communication system, the engine management and solar power control system, the room temperature regulation system, and the Dallas chain. All scripts are designed to run the complete AASTINO system automatically in the event of a communications failure. The instruments are each controlled via programs on either a separate computer (in the case of SODAR and SUMMIT) or on the Supervisor computer (for MASS, the external instrument, the AWS sensors, and the webcams). For each instrument a script called daily from the Supervisor crontab file verifies communication, functionality, and data collection, and will power-cycle and reset the instrument according to its control program if any problems are encountered.

Due to various software issues, a remote (dial-in) connection *to* the AASTINO computer via Iridium phone is not possible. Communications must therefore originate *from* the AASTINO. Once per hour the Supervisor computer attempts to connect to a computer as UNSW. If the connection is successful, the latest instrument, engine, and system diagnostic data are then automatically uploaded to a local computer and then transferred to the publicly-accessible AASTINO website.[5] An example of a subsection of a daily engine log is shown in Figure 5. If a successful connection is not obtained at least once per day the Supervisor computer will power-cycle itself and all AASTINO systems.

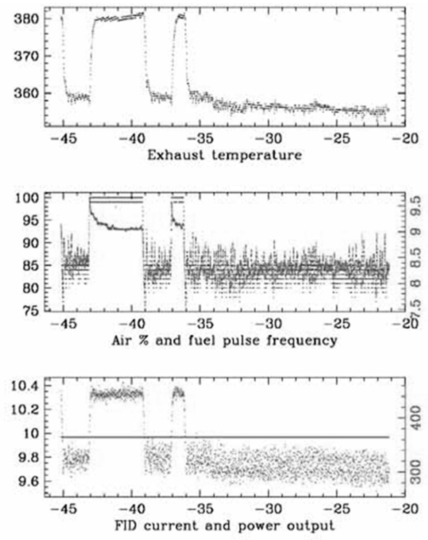

Figure 5: Example of engine log data for 24 hours on 24 March 2004. Top plot shows exhaust temperature (degrees C), middle plot shows air flow rate (percentage of maximum) and fuel rate (proportional to the fuel pump pulse frequency in Hz), bottom plot shows Flame Ionisation Detector (FID) current (in μA) and output power in Watts. The periodic peaks in all parameters are due to the 100W external instrument switching on; the increased power demand causing the engine to automatically switch from partial to full power.

Although the WhisperGen engine processors are encoded with some degree of automation a higher level of control is required to make critical decisions in the event of actual or potential engine failure. This is accomplished by a script on the Supervisor computer that examines engine data for anomalous readings, and takes action according to a predetermined fault tree. This script will also set the AASTINO into a "solar only" operating mode if both engines have failed. In this mode, available power is conserved by not attempting engine restarts and only operating low-power instruments. Additionally, solar power will be alternatively switched between charging or heating the battery bank depending on the battery temperature and charge status.

Success of the autonomous operation of the AASTINO was demonstrated in the first winter season. An electronics component failure during a period of extreme cold weather caused the engines to fail and hence the batteries to freeze on the 1st July 2003. In late-August the solar panels began to charge the batteries and the Supervisor restarted a limited numbers of AASTINO systems. A second electronics component failure in the power supply to the Iridium phone then occurred, causing a loss of communication. Despite this lack of communication the AASTINO system continued to run completely independently and collected data until Dome C station opened again in November 2003.

5 INSTRUMENTS

The AASTINO is designed to operate with a suite of site testing instruments to monitor several atmospheric parameters of relevance to astronomy. Important atmospheric characteristics include the distribution of turbulence, the atmospheric temperature and opacity, the cloud cover, and the rate of snowfall.

The SODAR (SOnic Detection And Ranging) is an acoustic radar that measures the distribution of turbulence throughout the lowest 900m of the atmosphere.[13,14] The MASS (Multi-Aperture Scintillation Sensor), developed by the Cerro Tololo Inter-American Observatory, measures the scintillation index of the atmospheric turbulence in four concentric apertures with photo-multiplier tubes; from this the vertical turbulence profile can be derived.[15] This instrument is fed by an 85 mm refracting telescope and sidereostat mirror, mounted on one of the internal AASTINO fuel tanks, that looks through a thick glass window in the AASTINO roof. The SUMMIT (SUB-MilliMetre Tipper) measures the 350 μm atmospheric flux at a range of airmasses with a Barnes pyroelectric detector fed by a rotating parabolic off-axis mirror. The sky temperature and opacity is then determined by calibration against two blackbodies maintained at different temperatures.[16]

Cloud cover statistics are determined by two instruments. The ICECAM takes regular sky images over a 30 degree field-of-view with a low light level Watec 902-HS visible CCD camera connected to the AASTINO video server.[17] COBBER (Cloud OBservER) determines the presence of cloud by measuring the thermal emission from the atmosphere with a mid-infrared Perkin-Elmer TPS534 thermopile detector imaged by a ZnSe hemispheric lens. The AASTINO system also provides power to and collects data from a Vaisala FD12 Visibility Meter (installed in collaboration with Gerhard Krinner of the Joseph Fourier University of Grenoble), which determines the rate of snow accumulation. A set of standard meteorological sensors measuring external temperature, ground wind speed and direction, and ground level pressure is also installed close to the AASTINO.

Figure 6: An example of a webcam image taken by the AASTINO on 14 March 2003 (6 weeks after station close), showing sunrise behind Concordia station.

Additionally, a number of visible light CCD cameras (Watec 902-HS) are installed on a local (AXIS 2400) video server at points around the AASTINO. These webcams have taken the first ever images of sunset and sunrise at Dome C station (see Figure 6), and provide useful indications of outside conditions (such as snow and ice accumulation on instruments, clouds cover, and winds).

Several more instruments are being developed for future deployment as part of the AASTINO facility. These instruments will measure the near and mid infrared sky brightness, the (0–30 m) ground layer turbulence, and the sub-millimetre phase stability.

6 CONCLUSION

The AASTINO is a fully autonomous observatory designed to run independently at Dome C station on the Antarctic plateau – one of the most remote locations on the Earth. This project has demonstrated the feasibility of the hybrid (Stirling engine/solar panel) power system for such applications and has proved the robustness of a unique command and control system. Additionally it has provided valuable information on the atmosphere above Dome C that lends strong motivation to the development of an astrophysical observatory at this site. Continued operation of the AASTINO is planned until 2007, when it is intended to deploy an updated version to Dome A – the highest point on the Antarctic plateau. At an altitude of 4200 m this site is the coldest on the planet, and potentially offers even superior atmospheric conditions for astronomy to Dome C. The AASTINO represents an important step towards the development of completely autonomous unmanned Antarctic research stations. By eliminating the need for life-support systems (except for brief maintenance visits during the summer), fuel consumption, pollution, environmental impact, and costs can all be dramatically reduced. The success of the AASTINO system described here has implications for any remote low to moderate power (~1 kW) system. For example, the application of many of the software and control systems used in the AASTINO is currently being investigated as an alternative to supply power for major international radio astronomy projects such as the Square Kilometre Array proposed for possible construction in remote areas of the Australian outback. For further details of the AASTINO project see http://www.phys.unsw.edu.au/~mcba/aastino.

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