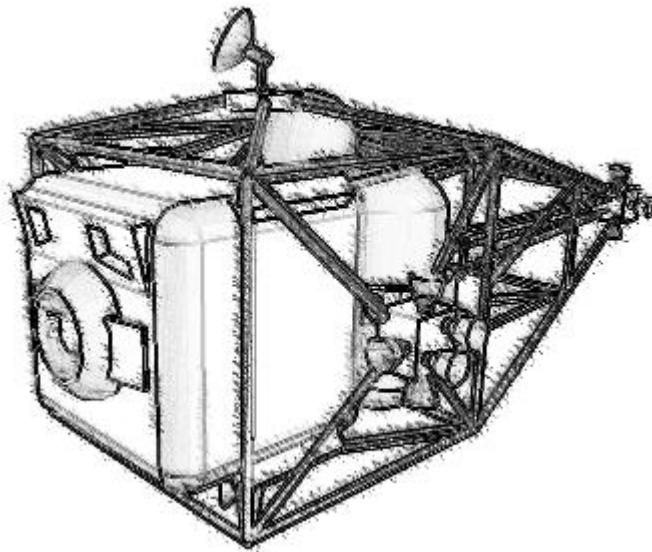




**Orbiter**  
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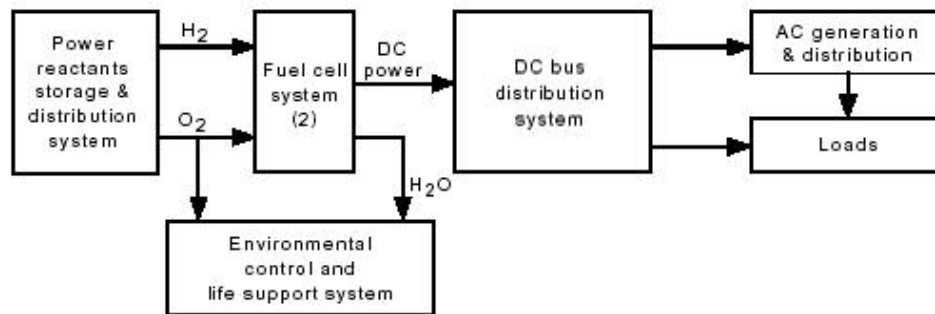
# **Dragonfly Operations Handbook (Rev. 0.9.35)**



**November 22 2002**

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# I.ELECTRICAL POWER SYSTEM



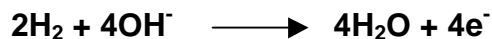
The Electrical Power System

## Description

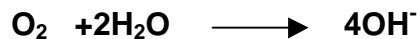
The electrical power system (EPS) consists of the equipment and reactants that produce electrical power for distribution throughout the space vehicle, and fulfill all power requirements of the vessel. The EPS operates during all flight phases. For nominal operations, very little flight crew interaction is required by the EPS. The vessel has no primary hydraulic system, and thus all operating & motor power is electrical-based.

The EPS is functionally divided into three subsystems: power reactants storage and distribution (PRSD), two fuel cell power plants (fuel cells) + one battery, and electrical power distribution and control (EPDC).

The two fuel cells generate all 28-volt direct-current electrical power for the vehicle through an electrochemical reaction of hydrogen and oxygen. At the hydrogen electrode (anode), hydrogen is oxidized according to the following reaction:



forming water and releasing electrons. At the oxygen electrode (cathode), oxygen is reduced in the presence of water. It forms hydroxyl ions according to the following relationship:



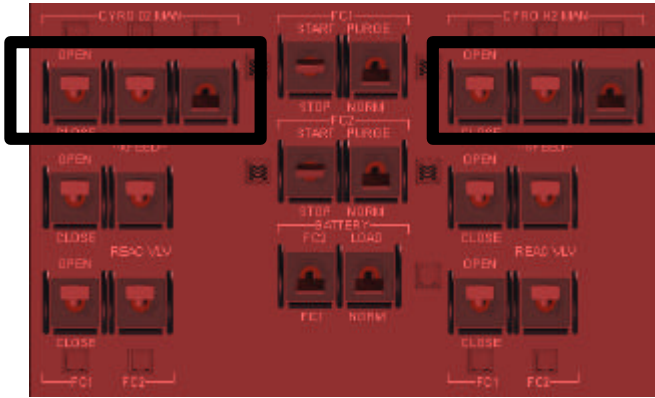
The net reaction consumes one oxygen molecule and two hydrogen atoms in the production of two water molecules, with electricity and heat formed as by-products of the reaction.

The power reactants storage and distribution system stores the reactants (cryogenic hydrogen and oxygen) and supplies them to the two fuel cells that generate all the electrical power for the vehicle during all mission phases. In addition, the subsystem supplies cryogenic oxygen to the environmental control and life support system (ECLSS) for crew cabin pressurization. The hydrogen and oxygen are stored in three tanks each at cryogenic temperatures (170°K for liquid oxygen and 70° K for liquid hydrogen) and supercritical pressures (above 731 psia for oxygen and above 188 psia for hydrogen).

The system stores the reactant hydrogen and oxygen in double-walled, thermally insulated spherical tanks with a vacuum annulus between the inner pressure vessel and outer tank shell. Each tank has heaters to add energy to the reactants during depletion to control pressure. Each tank is capable of measuring quantity remaining.

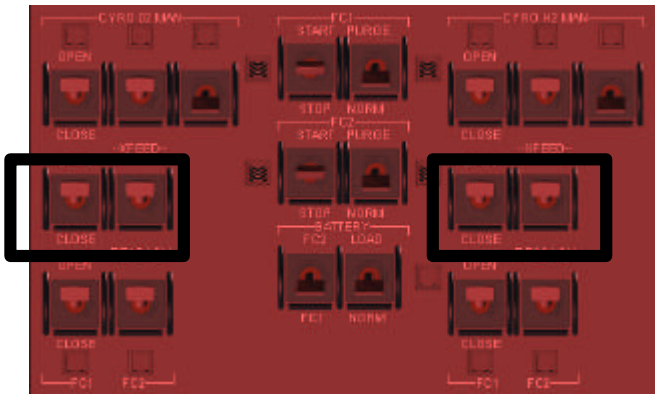
## Power Reactants Storage and Distribution (PRSD)

PRSD is controlled by switches located in the upper-left corner and lower-left corner of panel L1 (main electrical panel). The switches can direct the flow of cryogenic reactants and isolate parts of PRSD in case of leaks.



The top row of switches control isolation valves for each of the three oxygen and hydrogen tanks (TK ISOL VLV). When set to close (down pos.) a DC powered engine will mechanically close reactant access to PRDS. Typical setting is tanks 1& 2 open, tank 3 isolated. Isolation motor operation is indicated by a TB(talk-back) indicator above each switch. TB will show white when isol. motor is stopped and barberpole when motor is operating or is damaged. Typical closing time for an isol. valve is

about 3 seconds. Given that isol. valves operation is necessary in certain circumstances to start/restart the fuel cells, the power needed for motor operation is provided directly by the battery rather than from a DC bus. Care must be taken that a minimum power capacity is stored in the battery to assure isol. valve functioning in case of fuel-cell shutdown.



Second row of switches controls cross-feed valves in the cryogenic manifold (XFEED). Normal piping configuration is tank 1 supplying reactant to FC1, tank 2 supplying reactant to FC2 and tank 3 functioning as back-up and ECLSS supply. By positioning the XFEED switch 1 to open, tanks 1 and 3 will supply reactants to both FC1 and ECLSS. Positioning the XFEED switch 2 to open, tanks 2 & 3 supply reactants to FC2 and ECLSS. Opening both XFEED valves, tanks 1,2 & 3 supply reactants to FC1,

FC2 and ECLSS.

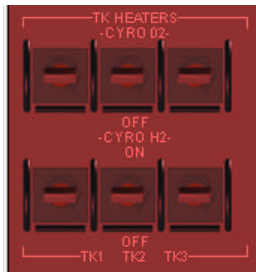
Last two switches on the last row (REAC VLV) control the reactant valves to the respective fuel cells. Same operating procedures apply as for the tank isolation valves, with a closing time of ~3 seconds and a power supply from the ships' battery.



Lower on the panel, two switches (CRYO ISOL VLV) control isolation valves that separate PRSD manifolds from external vent valves. Additionally in the case of O2 it separates flow from the cryogenic O2 manifold to the ECLSS systems.

OVB DUMP valves represent a high capacity overboard vent valve, for quick discharge of reactants in case of emergency. OVB VENT valves are safety overpressure valves, that pneumatically open when reactant pressure exceed certain safety

limits. In the case of O<sub>2</sub>, the safety overpressure valve will open at 920 kPa and re-settle at 910 kPa. For H<sub>2</sub> the overpressure valve will open at 450 kPa and re-settle at 400kPa. For the H<sub>2</sub>O waste tank, the valve will open at 1.000kPa and re-settle at 900kPa. The two H<sub>2</sub>O vent valves are non-propulsive, in that it will not affect the state vector of the ship. H<sub>2</sub> and O<sub>2</sub> valves, both BUMP and OVP will impact a small propulsive (-y axis) force when discharging. The high-capacity DUMP valves might take up to 10 second for opening/closing. A TB will indicate when the motor is operating. Additionally a OP/CL indicator will permanently indicate the respective position of the DUMP valve. Power for the high-capacity DUMP valve motor is also supplied by the battery.



TK HEATERS switches control electrical heaters that are located inside each cryogenic tank. Middle position (AUTO) will automatically turn the heaters on/off to maintain reactant pressure within operational limits. As the tanks are depleted, the TK HEATERS should be turned to the off position to save electrical power and to prevent an overheating of the reactants. Basic FC operation is based on supercold reactants flowing throughout the FC stack for cooling purposes. Excessive heating of the reactants in order to maintain pressure means warmer reactants will enter the FC stack, which might lead to a FC overheating.

Tank heaters are powered by their own DC bus, HTRS bus, linked to DC1.

### Fuel Cells & Battery



In normal operation mode, only one fuel cell (FC1) is active, running on reactants supplied by tanks 1 & 2. In case of exceeding power loads only, or as a back-up, FC2 might be started also. The two TB indicators monitor proper reactant flow into the respective FC. The TB will indicate white at nominal flow and barberpole if flow is less than nominal. The START/STOP switch controls power from the battery to the reactant pumps that direct O<sub>2</sub> and H<sub>2</sub> flow to the respective reaction plates inside the FC stack. The START switch must be held in the START momentary position for approximately 15-20 seconds until FC chemical reactions can supply enough power to the fuel pumps for self-sustainability, which is indicated by the two reactant TB turning white. The second PURGE/NORM switch will trigger the automatic purge sequence for the respective fuelcell. When set to purge, the

pumps will direct as much as 900gr/min of reactants to the FC, for the high volume of reactants to clean the FC stack from diverse chemicals and residuals accumulated inside the FC stack during operation. FC purging can be confirmed by the high-flow indicated on the REACTANT FLOW indicator at the bottom-right part of the panel. Another indicator for FC purging is the FUEL PH monitor, located at the center of the panel. dPH should never exceed 1.5 for normal FC operability. As the dPH rises, FC performance is seriously affected and more reactants will be used to produce power until eventually the chain reaction will collapse. Because a small reactant flow rate will not clean any of the residuals and impurities inside the FC, running the FC at idle load will need a purge at smaller intervals than running the FC at normal power loads.

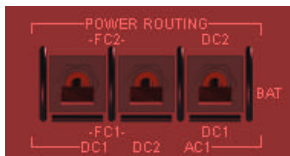
The resulting water from the FC chemical reaction will run to a H<sub>2</sub>O waste tank. Pressure in this tank can be monitored on the H<sub>2</sub>O WST TK indicator. The H<sub>2</sub>O OVP VENT should always be set to on during a FC purge sequence, to prevent damage from overpressuring the tank, or to prevent water from the tank, running up the piping back to the FC where it can kill the chemical reaction.

The last row of switches control battery reloading from power supplied by either FC1 or FC2. Note that the CB BT LOAD(circuit breaker) must be in the push (close) position (by default opened) for loading to occur. The TB indicator will show barberpole if power is being sent to the battery.

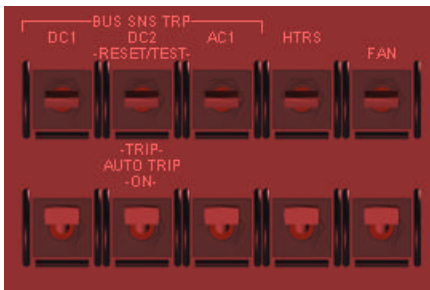
## Electrical Power Distribution and Control (EPDC)

Electrical power inside the ship is provided through two main Direct Current busses (DC1 & DC2) and one main Alternative Current bus (AC1). While most essential equipment is connected to DC1, it is possible to route power to these equipments using the back-up DC2 in case of a problem with DC1. AC power, through AC1, is needed for radar antennas operations and radar antennas electrical pitch & yaw motors.

The three POWER ROUTING switches are used to direct DC and AC loads to respective FCs or battery. From left to right, setting whether



DC1 bus is linked to FC1 (down), the battery (middle) or FC2 (up). DC2 bus is linked to FC2 (down), the battery (middle) or FC2 (up). AC1 bus is linked to the DC1 bus (down), directly to the battery (middle) or to the DC2 bus (up). Note that the AC1 bus cannot be directly tied to a FC cell, as power must be converted by a static inverter into AC current. These static inverters exist only for DC1, DC2 and battery. Amperage and volts of the respective busses, battery and fuel cells can be monitored by the indicators located just above these switches.



Once linked to a power source, the respective DC and AC busses need to be re-mounted (turned on) for them to provide power. The respective CB (circuit breakers) need to be positioned in the pushed (close) position and the respective BUS SNS TRP switch must be brought to the momentary –RESET/TEST- position. If there is a problem within the bus, pressing this switch will cause an automatic disconnect of the bus from the power source, indicated by the respective CB popping back to the open position.

CB indicators are located in the panel. If the voltage and amperage limits, the CB indicator will remain and power will be routed through. Pressing the same switch to its momentary –TRIP- position will automatically trip the respective bus.

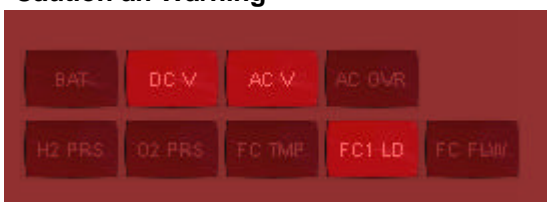


upper-right part of the are within operating in the pushed position that respective bus.

NOTE. A bus should never be set to –TRIP – position, under normal circumstances, if connected to a FC load, much like an electrical instrument should not be instantly unplugged. Rather, that bus should be switched to battery or a non started FC and wait for the AUTO TRIP to automatically & safely shut down the respective bus.

The second row of switches (AUTO TRIP) if set to ON will automatically trip the respective bus if an out-of-limits situation occurs, such as low or high voltage, preventing equipment damage. The AUTO TRIP switch must be in its ON position during a bus re-start to ensure a safe auto-shutdown of the bus.

## Caution and Warning



Caution and warning displays on the electrical panel are located on the lower-left side. They present the crew with non-critical out-of-limits situations, making it easier to identify a problem.

The respective C/W will trigger under the following circumstances:

BAT – Battery load. Less than 10kWh left in the battery, or battery overcharged.

DC V – Direct Current Voltage. One of the main DC busses (DC1 or DC2) has a voltage higher than 30 volts or lower than 27 volts.

AC V – Alternative Current Voltage. The main AC bus (AC1) has a voltage that exceeds 38 V or lower than 35 V

AV OVC – AC bus Overload. More than 100 amperes of load onto AC1

H2 PRS / O2 PRS – Cryogenic pressure is less than 200kPa

FC TMP – FC 1 or 2 temp stack is larger than 350K

FC1 LD – Fuel Cell 1 Load. Fuel cell 1 is either overloaded (>200amps) or under-loaded (<20amps)

FC FLW – Fuel Cell Flow. Reactant flow inside FC1 or FC2 is larger than the nominal 7.5 kg/h

## EPS Procedures & Checklists

### A. Normal operation switch positions :

O2 TK1 ISOL VLV – OPEN  
O2 TK2 ISOL VLV – OPEN  
O2 TK3 ISOL VLV – CLOSE  
O2 XFEED 1 - OPEN  
O2 XFEED 2 - OPEN  
O2 REAC VLV FC1 – OPEN  
O2 REAC VLV FC2 – OPEN  
FC1 PURGE – NORM  
FC2 PURGE – NORM  
BAT LOAD – FC1 , NORM  
H2 TK1 ISOL VLV – OPEN  
H2 TK2 ISOL VLV – OPEN  
H2 TK3 ISOL VLV – CLOSE  
H2 XFEED 1 - OPEN  
H2 XFEED 2 - OPEN  
H2 REAC VLV FC1 – OPEN  
H2 REAC VLV FC2 – OPEN  
TK HEATERS – ALL AUTO  
O2 ISOL VLV – OPEN  
H2 ISOL VLV – OPEN  
O2 OVB DUMP – CL  
H2 OVB DUMP – CL  
O2 OVP VENT – CL  
H2 OVP VENT – CL  
H2O OVP VENT – CL BOTH  
BUS SNS TRP AUTO TRIP – ALL ON

CB BT LD – OPEN  
CB – ALL OTHER CLOSED

POWER ROUTING  
DC1 – FC1  
DC2 – FC2  
AC1 – DC2

### B. FC1 START:

O2 TK1 ISOL VLV – OPEN  
H2 TK1 ISOL VLV – OPEN  
O2 REAC VLV FC1 – OPEN  
H2 REAC VLV FC1 – OPEN  
FC1 PURGE – NORM  
H2O OVP VENT – CL BOTH  
BAT LOAD – NORM  
FC1 START – HELD UNTIL TB TURN WHITE  
H2O OVP VENT – OP BOTH



## EPS Procedures & Checklists

(cont.)

### C. FC2 START (OPTIONAL)

- O2 TK1 ISOL VLV – OPEN
- O2 TK2 ISOL VLV – OPEN
- H2 TK1 ISOL VLV – OPEN
- H2 TK2 ISOL VLV – OPEN
- O2 XFEED 1 - OPEN
- O2 XFEED 2 - OPEN
- H2 XFEED 1 - OPEN
- H2 XFEED 2 - OPEN
- O2 REAC VLV FC2 – OPEN
- H2 REAC VLV FC2 – OPEN
- FC2 PURGE – NORM
- H2O OVP VENT – CL BOTH
- BAT LOAD – NORM
- FC2 START – HELD UNTIL TB TURN WHITE
- H2O OVP VENT – OP BOTH

### C. DC1 START

- POWER ROUTING DC1 – FC1 / FC2 / BAT
- CB MN1 – PUSH CLOSED
- BUS SNS TRP AUTO TRIP DC1– ON
- BUS SNS TRP DC1 - RESET/TEST

### D. DC2 START

- POWER ROUTING DC2 – FC1 / FC2 / BAT
- CB MN2 – PUSH CLOSED
- BUS SNS TRP AUTO TRIP DC2– ON
- BUS SNS TRP DC2 - RESET/TEST

### D. AC1 START

- POWER ROUTING AC1 – DC1 / DC2 / BAT
- CB AC1 – PUSH CLOSED
- BUS SNS TRP AUTO TRIP AC1– ON
- BUS SNS TRP AC1- RESET/TEST

### E. HTRS / FAN BUS START

- CB HTRS – PUSH CLOSED
- CB FAN – PUSH CLOSED
- BUS SNS TRP AUTO TRIP HTRS– ON
- BUS SNS TRP HTRS- RESET/TEST
- BUS SNS TRP AUTO TRIP FAN– ON
- BUS SNS TRP FAN- RESET/TEST

## II. ENVIRONMENTAL CONTROL AND LIFE SUPPORT SYSTEM (ECLSS)

### Description

The ECLSS maintains the spacecraft's thermal stability and provides a pressurized, habitable environment for the crew and onboard avionics. The ECLSS also manages the storage and disposal of water and crew waste. ECLSS is functionally divided into three systems:

1. **Pressure control system**, which maintains the crew compartment at 103kPa with a breathable mixture of oxygen and nitrogen. Nitrogen is also used to pressurize the supply and wastewater tanks.
2. **Atmospheric revitalization system**, which uses air circulation and water coolant loops to remove heat, control humidity, and clean and purify cabin air.
3. **Active thermal control system**, (*not implemented*) which consists of two Freon loops that collect waste heat from orbiter systems and transfer the heat overboard, either through radiators or ammonia boilers.

As Dragonfly has not yet been equipped with active thermal control systems, most cooling & heating operations are done by passive control systems, whereas supercold cryogenic reactants are heated prior to entering the FC stack, thus cooling electrical equipment. The same is done with the wastewater, which is circulated throughout the vessel. As the water in the wastewater tank overheats, any boiling excess will be vented through two non-propulsive vent valves. The only unbalanced thermal reaction is that of the FC, which, in the absence of active cooling equipment will overheat within 5-8 hours. The only cooling possibility for a FC is either shutting down (alternatively using FC1 / FC2) or purging.

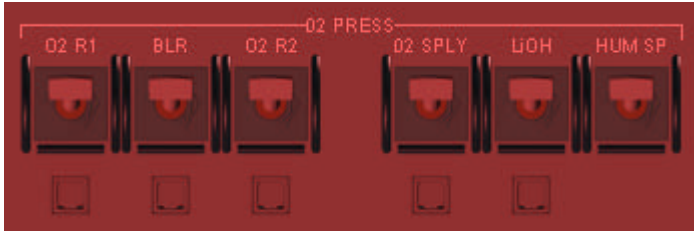
### Pressure control system

The pressure control system normally pressurizes the crew cabin to  $103 \pm 10$  kPa. It maintains the cabin at an average 70-percent nitrogen (27 kg) and 30-percent oxygen (9kg) mixture that closely resembles the atmosphere at sea level on Earth. The system also provides the cabin atmosphere necessary to cool cabin-air-cooled equipment. Oxygen partial pressure is maintained automatically between 20 and 23 kPa, with sufficient nitrogen pressure of 78.3 kPa added to achieve the cabin total pressure of  $103 \pm 10$  kPa. Positive and negative pressure relief valves protect the structural integrity of the cabin from over- and underpressurization respectively. The pressure control system nitrogen is used to pressurize the supply and wastewater tanks.



Nitrogen is stored into two, identical, 3-liter tanks, serviced at a temperature of 288°K, that contain up to 20kg of N2 each. The provided nitrogen is enough to re-pressurize the cabin and docking hatch for up to 6 docking hatch re-pressurizations (EVAs). The two N2 TK1 and N2 TK2 switches, located on panel O1 (main ECLSS panel), control isolation valves to each of the two N2 tanks. When closed, N2 from that tank is not provided to either the pressure control system or as pressurizer for the wastewater-cooling loop. A second set of ISOL VLV control N2 flow from the tanks to the pressure control system. Note that N2 will continue to pressurize the wastewater tank, even with both of the ISOL VLV closed if any of the N2 TK valves are open. The N2 SPLY switch will close the N2 from the pressure

control system to be vented into the cabin, though N2 from the tanks, might continue to flow, either as pressuriser for the wastewater tanks, either to the overpressure vent valves. N2 pressure is regulated at the N2 SPLY valve to a nominal pressure of 78-80kPa. The XFEED switched must be in its open position for tank 2 to provide N2 pressurization to the cabin. During normal operations only N2 tank 1 will be used for cabin pressurization and N2 tank 2 for wastewater cooling loop pressurization. A set of 2(one for each tank) high-capacity N2 OVB DUMP valves will quickly discharge overpressurised N2 from the N2 pressure control system. Though the N2 tanks have no heaters to raise tank pressure, it is possible for excess heat from the wastewater cooling loop to transfer to the N2, thus overheating and overpressurising the N2 tanks. To avoid damage to the tanks, the two valves can be used to quickly discharge the overheated N2 and bring the tank pressure to a safer value.



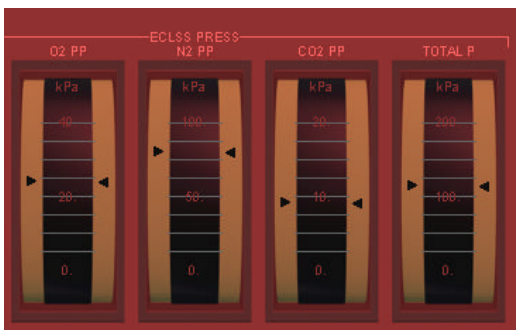
Oxygen from the power reactant storage and distribution system (cryogenic oxygen supply system) is routed to the pressure control oxygen system, first to a pressure regulator (O2 R1) that reduces oxygen pressure to a lower 280-290 kPa. At this pressure an electrical

boiling plate (BLR) can transform the cryogenic oxygen to its gaseous form by heating it to a service temperature of 295°K (22°C). The pressure gas from the boiler plate is then passed through a second pressure regulator (O2 R2) that releases oxygen into the O2 pressure control system at 23-25 kPa and at an ambient temperature of 22°C. The same O2 SPLY valve as for N2, controls O2 discharge into the cabin circuit.

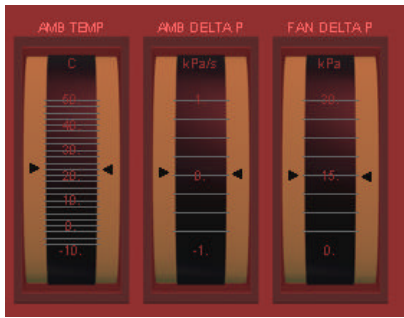
### Atmospheric revitalization system



Two electrical fans provide the continuous air circulation needed in the cabin. Air from the cabin is directed into an air revitalization circuit, whereas CO2 is removed by LiOH canisters and humidity is controlled by a DC-powered humidity separator. Both fans function on an independent bus (DC FAN) that can be connected to either DC1 or DC2 main busses. From the LiOH and HUM SP the air piping then interleaves with cryogenic H2 passing from the H2 cryo tanks to FC1, thus cooling the air to a lower 22-25 C before returning it to the cabin.



Most of the cabin air properties can be monitored on the top indicators on panel O1. O2 partial pressure, N2 partial pressure, CO2 partial pressure and total ambient pressure. Left indicators show cabin atmosphere status, while right indicators show docking hatch atm. status.



Ambient temperature can also be monitored on this part of the panel. Ambient delta Pressure / delta Temperature can also be monitored to indicate eventual cabin leaks or depressurizations. A third indicator monitors the pressure difference between cabin air and atmospheric rev. system. A 0 delta pressure indicates an improper functioning of the two circulating fans, and that air is not circulated.

## ECLSS Procedures & Checklists

- A. Normal operation switch positions :
- N2 TK1 – OPEN
  - N2 TK2 – OPEN
  - N2 PRESS ISOL VLS – BOTH OPEN
  - N2 PRESS XFEED – CLOSED
  - N2 SPLY – OPEN
  - N2 OVB VENT – BOTH CLOSED
  
  - O2 PRESS R1 – CLOSED
  - O2 PRESS BLR – OPEN
  - O2 PRESS R1 – OPEN
  - O2 SPLY – OPEN
  - O2 LiOH – OPEN
  - O2 HUM SP – OPEN
  
  - CAB FAN 1,2 – OP