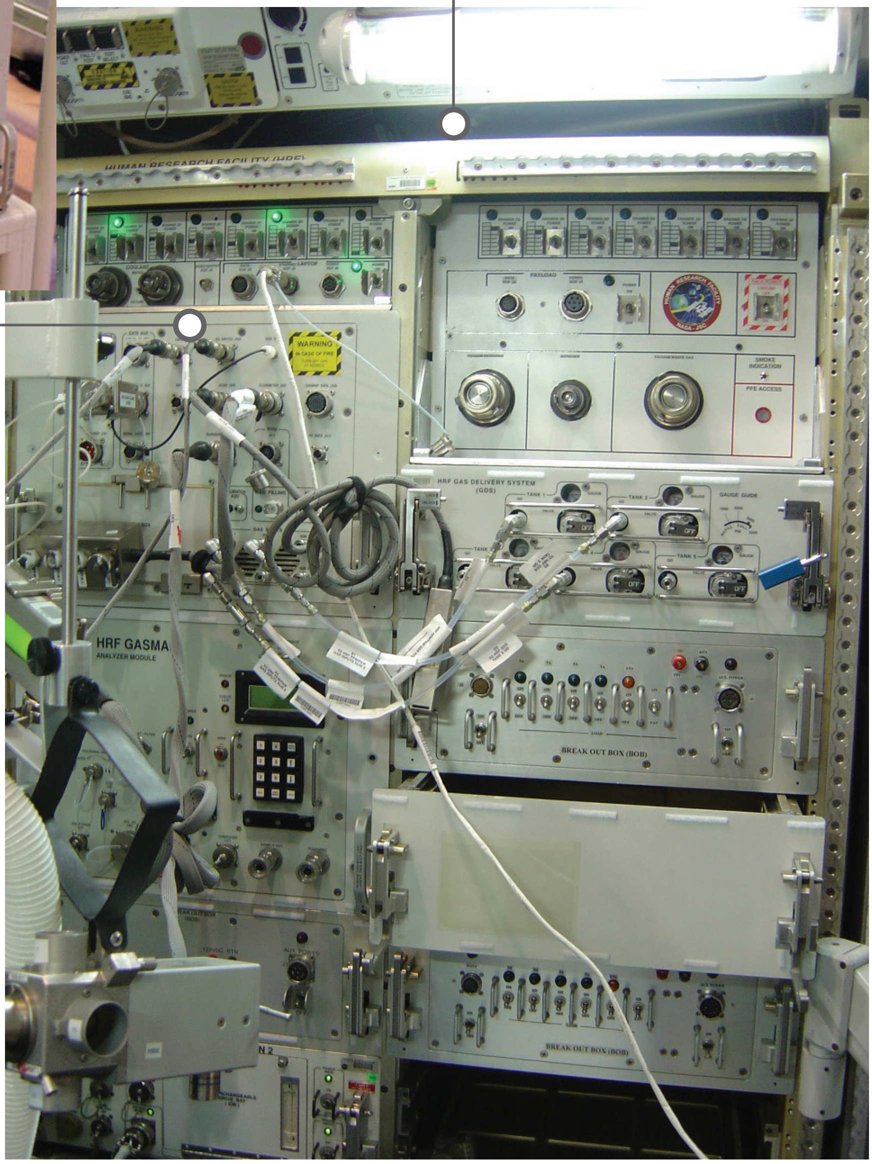
→ PULMONARY FUNCTION SYSTEM (PFS)

Multi-user facility for respiratory and cardiovascular measurements

The Pulmonary Function System is a collaborative development between ESA and NASA. PFS is a respiratory physiology instrumentation package capable of a wide range of non-invasive respiratory and cardiovascular measurements not only in resting positions, but also during physical exercise stress tests. PFS is used attached to the Human Research Facility rack or the European Physiology Modules accomodated in the Columbus Laboratory.
An advantage of the PFS is that it uses an operationally simple but accurate photoacoustic method to gas analysis, as compared to previously-used mass spectrometers.



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HUMAN RESEARCH FACILITY

The Human Research Facility is an on-orbit laboratory that enables life science researchers to study and evaluate the physiological, behavioural and chemical changes in human beings induced by space flight as well as the long-term adaptation to the space flight environment. It's standardized equipment, like the PFS, can support multiple experiments, reducing the amount of equipment transported to and from the Space Station. HRF Racks are International Standard Payload Racks, which use International Sub-rack Interface Standard (ISIS) drawers. These include electrical power, command and data handling, cooling air and water, pressurized gases, and vacuum.

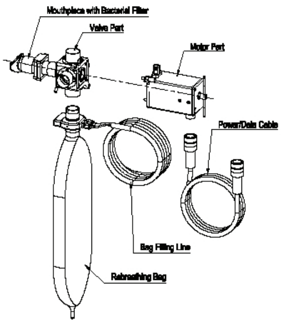
PFS DESCRIPTION

Pulmonary Function System (PFS) is a set of three modular blocks. According to the configuration of these modules, it is possible to create different respiratory instruments in different operational modes for a variety of respiratory and cardiovascular measurements such as:

- breath-by-breath measurements of VO_2, VCO_2, VE
- diffusing capacity of the lung for CO
- expiratory Reserve Volume
- Forced Expired Spirometry
- Functional Residual Capacity
- respiratory exchange ratio VO_2/VCO_2
- residual volume
- total lung capacity
- tidal volume
- alveolar ventilation
- vital capacity
- volume of pulmonary capillary blood
- dead-space ventilation
- cardiac output
- numerous other specialised tests of pulmonary function.

The three PFS modules are the following:
Pulmonary Function Module PFM developed by ESA;
Photoacoustic Analyzer Module PAM developed by ESA;
Gas Delivery System - GDS - developed by NASA.

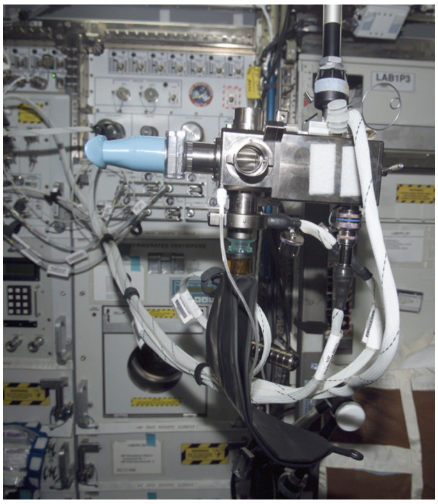
Pulmonary Function Module - PFM
It consists of the
- **Respiratory Valve Unit - RVU,** with
+ **associated flow-meters** and
+ **re-breathing bag**, and an
+ **electronics unit** which are accommodated in an ISIS drawer.
- **Mixing Bag System** - MBS



The PFM when operated together with the PAM plus the GDS forms a respiratory facility capable of a wide range of respiratory and cardiovascular measurements, such those listed above.

RVU - RESPIRATORY VALVE UNIT

The RVU as shown below to the left forms the main interface with the test subject during an experiment. A 7-litre rebreathing bag connects to a flexible valve system that allows gases to pass in different directions during a rebreathing exercise.
The system includes a set of differential pressure flowmeters and turbine flowmeters that can be accommodated at the different locations of the RVU to measure the gas volume passing through. For conducting specific experiments, the rebreathing bag can additonally be enclosed inside a box (Bag-In-Box, shown above to the right), with a flowmeter attached to the bottom, measuring the volume of gas flowing in and out of the bag.



The Respiratory Valve Unit for PFS

Parameter	Specification
RVU breathing path volume:	< 50 ml
Flow resistance (at 5 l/sec):	< 1.5 cm H_2O
Flow path control (default):	Automatic, back-up: manual
Temperature control:	RVU heated
Operational distance from rack:	2 meters (umbilical)
Rebreathing bag fill / emptying:	Automatic, 12 l/min max.
Rebreathing bag fill accuracy:	+/- 1.5% or 15 ml, which ever is the greater
Pressure measurement in mouthpiece:	Yes, +/- 75 mbar, accu- racy 0.2 mbar, response time 30 msec.

The RVU hardware is locker-stowed and deployed in front of the HRF, and is interconnected to the PFS electronics unit, to the PAM and to the GDS during operation.

Mixing Bag System - MBS
The function of the Mixing Bag System is to mix the expired air from the test subject so that the Oxygen and CO_2 levels measured at the Mixing Bag assembly outlet port represent close to mean levels of the O_2 and CO_2 over several breaths. The PFS Differential Pressure Flowmeter Sensor (DPFM) is used to get data to determine the inspired air volume. This volume is used in order to calculate the oxygen uptake and the CO_2 excretion. The benefit of measuring on the inspiration air is that the flow measurement is more accurate and not disturbed by changing gas composition and or humidity levels as would be the case if expired gas is measured.

Specifications

PFS DATA

Power: 205 W (28 V, 10.5 A) range 132 - 252 W

Mass:
PFS module 51 kg
Stowage 13 kg (excl. drawer)
GDS module ~20 kg (incl. drawer)

Volume:
PFS module 1 x 8 PU drawer
Stowage 1 x 4 PU drawer
GDS module 1 x 4 PU drawer

Measurement gases:
Acetylene (C_2H_2)
Carbon Monoxide (CO)
Sulphur Hexafluoride (SF_6)
Methane (CH_4)
Carbon Dioxide (CO_2)
Freon-22 (R-22)
Oxygen (O_2)

Included equipment:
Respiratory Valve Unit - RVU
Mouthpiece pressure - MPP 3 pcs
Turbine Flowmeter
Differential Pressure Flowmeter - DFM
Bag-In-Box system - BIB
Ambient condition monitoring - ACMS
Subject Display

Hardware to be used with PFS:
Mixing Bag System
Respiratory Inductance Plethysmograph, RIP
Continuoues Bloodpressure Device - CBPD

Available Auxiliaries:
8 Analog Inputs ±10 V; 2 Analog Outputs ±10 V;
6 Digital Inputs; 6 Digital Outputs; 1AUX serial line

Gas Concentration Ranges and Corresponding Measurement Accuracy Requirements:

Gas Component	Concentration Range	Range 1	SNR within Range 1	Range 2	SNR within Range 2
O_2	0-100	0-15	>2000*S/SFS	15-100	>300+588(S/SFS)
Freon-22	0-1.2	0-0.5	>400*S/SFS	0.5-1	>200
CO_2	0-12	0-5	>400*S/SFS	5-10	>200
SF_6	0-1.2	0-0.5	>400*S/SFS	0.5-1	>200
CO	0-0.3	0-0.3	>100*S/SFS		
CH_4	0-1	0-0.5	>400*S/SFS	0.5-1	>200

% pp =percent partial pressure.
S =analyser output signal at any particular gas component concentration.
SFS =analyser output signal at maximum operating concentration.
* =Using moving averaging of samples, as necessary.
SNR =Signal to Noise Ratio, defined as the mean of all the digital concentration values acquired for the respective gas component in one second divided by the standard deviation of the same set of values, averaged over one minute.

The MBS breathing valve connection separates the inspiration air from the expiration air. The One-Way Valves inside the breathing valve assembly ensure that the inspiration air is always coming via the "MBS Inspiration Hose" and that the expiration air always flows into the Mixing Bag assembly through the "MBS Expiration Hose".

Photoacoustic Analyzer Module - PAM
The PAM determines the concentration of seven respired gas components that also may contain significant concentrations of nitrogen and water vapour utilizing two photoacoustic analyzers and an oxygen analyzer. The PAM hardware is accommodated within an ISIS drawer which is normally mounted within the HRF rack but this drawer can also be removed from the HRF rack and operated externally.

The PAM contains the following sub-elements:
- Multi-Gas Analyser MGA1 for measuring 3 gases
- Multi-Gas Analyser MGA2 for measuring 3 gases
- Oxigraf analyser for oxygen measurement

Gas Delivery System - GDS - developed by NASA
The Gas Delivery System is used as a sub-component of the Pulmonary Function System. The GDS will provide calibration and respiratory gases for the calibration of the PFS complement of gas analyzers. The GDS is a 4 PU drawer with no power or data interfaces. The GDS will store any combination of five gas cylinders (190 litres of gas each) of calibration and respiratory gas mixtures for use with the PFM. The PFM will then distribute the gas mixtures appropriately to support various science activities.

PHOTO-ACOUSTIC GAS ANALYSIS

The gas sample is exposed to intermittent infrared light. The gas absorbs the light, which means it absorbs energy and is heated causing a rise in pressure. When the light-source is removed, the gas cools down, causing a pressure fluctuation. By choosing the pulsation frequency in the audible range, the pressure fluctuation becomes an acoustic signal and it is possible to pick up the signal using a microphone.
The audible sound recorded by the microphone is analysed, using electronic filters, with each filter designed for the different frequencies given by a chopper wheel. The amplitude of the signal is used to calculate the gas concentration.

Operations and Utilisation

ACCOMMODATION & TRANSPORT

Originally planned for launch in the Columbus Laboratory, ESA was offered an earlier flight opportunity to launch the PFS during ISS flight LF 1 on STS-114 in July 2005, as part of the second NASA Human Research Facility (HRF) to be installed in the Space Station Columbus Laboratory.

OPERATIONAL CONCEPT

For support of European experiments with the PFS, ESA has appointed Damec Research Aps (DK) as the Facility Responsible Centre (FRC). PFS activities are supported and monitored on-line from Odense, Denmark.

UTILISATION SCENARIO

PFS is accommodated in the top left part of the HRF 2 rack. NASA provided gas supply and stowage drawers with equipment and consumables are situated on the right side of the rack. For experiments the Respiratory Valve Unit - RVU is deployed and the crew controls PFS from HRF-2 leptop.

PFS EXPERIMENT EXECUTION

As an example of a regularly used measurement, the determination of Cardiac Output requires the subject to breath special gas mixtures, which include a foreign blood-soluble component (R22) and a foreign blood-insoluble component (SF6). A fixed volume of the gas mixture is rebreathed by the subject from/to a closed bag for some eight breaths. The rate of disappearance of the blood-soluble component is directly proportional to the volume of blood being pumped through the lungs per unit time (i.e. Cardiac Output). The insoluble component is used to determine lung volume and as a correction factor to the soluble component disappearance curve during the first breaths.

Some experiments require the test subject to be under heavy physical load during rebreathing. For this purpose, the Ergometer onboard ISS is used. It is intended to use the system for regular fitness assessment of the crew during their long stay onboard ISS.

The PFM/PAM data management system contains a powerful experiment execution tool. The experimenter can create an experiment flow by defining a sequence of manoeuvres. The system can store a number of experiments, and the crew selects the one to be executed.

The Manoeuvres contain the necessary information for the system to perform a sequence of steps. The Protocol is a Procedure Language that allows commanding to all subsystems, experiment flow control and prompting to the crew. The Graph setup is used to specify which parameters to show on the laptop and in what format. The Acquisition setup specifies the data to be recorded and at what sample rate. The Man-Machine Interface is configured by the Manoeuvre, containing prompts to the crew on top and graphical set-up below.

SCHEDULE

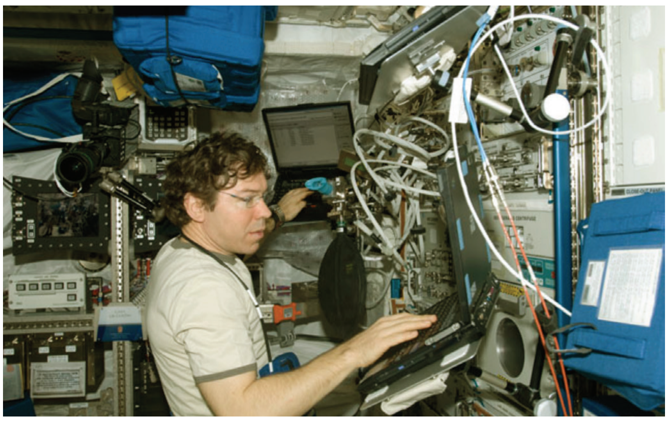
PFS was launched to the ISS on the STS-114 Shuttle Return to Flight mission on 26 July 2005 accommodated in the top left part of the second ISS Human Research Facility, a facility which houses instruments and experiments for undertaking biomedical research.

On 18 October 2005, two and a half months after its arrival, the Pulmonary Function System was powered on for the first time. Powering the facility on was part of the check out and commissioning procedures of the facility that needed to take place to confirm that all systems were functioning properly.
These procedures were carried out by NASA astronaut and Expedition 12 Commander Bill McArthur.

After the upgrade in July 2006, the Pulmonary Function System has the capability of being used to perform Oxygen Uptake Measurements: part of the crew medical operations known as the Personal Fitness Evaluation. These sessions are using the PFS together with the NASA ergometer and ECG equipment.

A first session of the Oxygen Uptake Measurements was performed on 25 July 2006 by ESA astronaut Thomas Reiter. Further OUM sessions were performed on regularly throughout the Astrolab mission. The first scientific use of the PFS equipment was the CARD experiment, which uses the Pulmonary Function System to measure cardiac output. Further experiments, like the ENERGY experiment and others are using PFS to oxygen uptake as part of a study to measure the astronaut's energy requirements before and during long-term spaceflight.

ESA astronaut Thomas Reiter preparing PFS for the CARD experiment in the US laboratory



→ NASA astronaut Mike Barret operating PFS in the Columbus module