

Columbus Thermal Hydraulic Operations with US Payloads

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ABSTRACT

After launch and activation activities, the Columbus module started its operational life on February 2008 providing resources to the internal and external experiments. In March 2008 two US Payloads were successfully installed into Columbus Module: Microgravity Sciences Glovebox (MSG) and a US payload of the Express rack family, Express Rack 3, carrying the European Modular Cultivation System (EMCS) experiment. They were delivered to the European laboratory from the US laboratory and followed few months later by similar racks; Human Research Facility 1 (HRF1) and HRF2.

The following paper provides an overview of US Payloads, giving their main features and experiments run inside Columbus on year 2008. Flight issues, mainly on the hydraulic side are also discussed. Engineering evaluations released to the flight control team, telemetry data, and relevant mathematical models predictions are described providing a background material for the adopted work-around solutions.

INTRODUCTION

Columbus was launched on February 7th, 2008 with the Space Shuttle Atlantis and docked to the Space Station on February 11th. Four pressurized actively cooled ESA payload racks, the European Drawer Rack (EDR), the Fluid Science Laboratory (FSL), Biolab and the European Physiology Module (EPM), had flown to orbit with Columbus. A few days the later other four US Payloads were moved from the US Laboratory (USL) and successfully installed into Columbus, i.e., MSG, ER3, HRF1 and HRF2.

Hereafter the four racks are introduced, giving the main features and a quick glance at the experiments performed on Columbus.

EXPRESS RACK 3

Express Rack 3 (ER3) was delivered to the USL on flight UF-2 in June 2002. It was transferred to the Columbus module shortly after the Columbus was installed on-orbit.

The ER3 rack internal hydraulic configuration is discussed in detail in [1]. The current experiment configuration consists of a single payload, the European Modular Cultivation System (EMCS).

The EMCS is designed to provide a controlled environment for the growth of plants. The experiment container controls temperature (18 to 40 °C), humidity (30 to 95% Relative Humidity), atmospheric composition (O₂, CO₂, N₂) and provides for removal of ethylene. The plants are grown in Experiment Containers mounted on a centrifuge that can provide 0.001 to 2 g of simulated gravity.

Examples of experiments performed in the EMCS include GRAVI which sought to determine the minimum threshold for sensing gravity in lentil roots; TROP1 which investigated the effects of light and gravity on plant roots and sought to determine which genes controlled the plant's response to these environmental conditions; Cell Wall/Resist Wall investigated the role of gravity in the formation of the plant cell walls and in the interaction of the cell wall and cell membranes in maintaining the structure of the plant in a gravity environment; and finally, Multigen investigated the effects of microgravity on multiple generations of plants.

HRF 1 & 2

HRF1 was the first experiment facility to be delivered to the ISS. It was brought to orbit in the MPLM on flight 5A.1 in March of 2001 and was installed in the USL. It was transferred from the USL to the Columbus shortly after Columbus was added to the ISS configuration.

The HRF rack internal hydraulic configuration is discussed in detail in [1]. The current experiment configuration consists of an Ultrasound System, Workstation, and the Space Linear Acceleration Mass Measurement Device (SLAMMD).

The Ultrasound System is a medical device used to perform medical imaging and measure fluid flow rates in biological systems. The Ultrasound is used for experiments and for medical purposes for crew health examinations.

The HRF Workstation consists of a computer in a SIR drawer and a keyboard and monitor deployed in the aisle in front of the rack. The Workstation provides a platform for the operation of HRF software to support experiment operations including operation of the rack, data acquisition and storage, storage of experiment procedures and crew notes.

SLAMMD measures the mass of a crew member's body. An arm extends from the drawer in the rack into the aisle and a crew support fixture is attached to the end of the arm. The crew member rests his belly and chin against supports, and wraps his legs into a leg support. The SLAMMD uses two springs to accelerate the crew member's body and Newton's law is used to calculate the crew members mass.

HRF2 rack contains Pulmonary Function Module (PFM)/Photoacoustic Analyzer Module (PAM), Gas Analyzer System for Metabolic Analysis Physiology (GASMAP), Gas Delivery System (GDS), Refrigerated Centrifuge, and Workstation 2.

ESA has contributed the PFM/PAM which works together with the NASA GASMAP and GDS to provide the Pulmonary Function System (PFS), an integrated system for measuring the flow and composition of inspired and expired gases of crew members.

The Refrigerated Centrifuge is designed to separate mixtures with components of differing densities. It can hold sample sizes of 0.5 ml to 50 ml, and spin them at speeds ranging from 500 to 5000 rpm. It was designed to be capable of maintaining a temperature of down to 4 °C, however, due to an on-orbit anomaly the refrigeration capability is non-functional.

The Workstation 2 is similar in function to the Workstation 1 of HRF1.

The hardware in the HRF1 and HRF2 racks are used together with other on-orbit deployed and crew-worn equipment and monitoring devices to provide a comprehensive suite of health care and human research capabilities. Much of this research is done as collaborative work between ESA and NASA investigators.

MSG

The Microgravity Science Glovebox is the largest glovebox facility provided on-orbit. The glovebox provides a volume of 255 liters that is sealed and kept at a negative pressure to contain any small parts, liquids, or particles. The astronauts can access the experiment equipment inside using glove ports. The gloves can be detached when the containment capability is not needed. There is an airlock to pass small items into the contained volume from outside the glovebox. The glovebox provides lighting, power, a cold plate and an air heat exchanger for cooling an experiment, gaseous nitrogen, a vacuum interface for venting experiment volumes, and data and video interfaces.

The hydraulic system contains no active control components and consists of a series of heat exchangers and cold plates used for cooling both experiments and the rack's avionics system. The rack is calibrated to receive the maximum flow it will need with a ΔP of 40 kPa and can accept up to 136 kg/hr (300 lbm/hr) of water flow. This requires the Water Flow Selection Valve (WFSV) in the Columbus at the payload location for MSG to be partially closed when flow rates less than the maximum are needed.

Experiments conducted in the MSG have included SHERE which studies the effect of preshearing (rotation) on the stress and strain response of a polymer fluid (a complex fluid containing long chains of polymer molecules) being stretched in microgravity; Smoke Point In Co-flow Experiment (SPICE) which determines the point where soot begins to form in the burning of a flame in microgravity; Investigating the Structure of Paramagnetic Aggregates from Colloidal Emulsions (In-Space) which investigates fluids that change properties in response to magnetic fields; and Coarsening in Solid Liquid Mixtures-2 (CSLM-2) examines the kinetics of competitive particle growth within a liquid metal matrix.

HYDRAULIC ISSUES

Even after positive ground testing performed in year 2004 with the HRF Flight Prototype Rack (HRF-FPR) [1], flight operations issues on hydraulic performance of the US Express racks within Columbus were raised. Operations and engineering support teams of both countries worked tightly to tackle these issues. This paragraph provides an overview of the problems that occurred and the engineering evaluations released to the flight control team, showing and discussing the available telemetry data, relevant mathematical models predictions and work-around solutions adopted in-flight. A brief description of the activities for the MSG rack calibration is finally provided.

EXPRESS RACK 3

This section deals with troubleshooting activities performed for an ER3 coolant mass flow rate issue, for which the selected WFSV opening was not sufficient to provide the required flow rate to the avionics and EMCS branches. WFSV position was originally determined running the Active Thermal Control System (ATCS) Thermo-Hydraulic Mathematical Model (THMM) coupled with the ER3 hydraulic model as derived from HRF FPR with the updating of the avionic branch pressure loss according to [2]. WFSV partial stroke was requested, as for any EXPRESS rack type inside Columbus, to reduce to the minimum the risk of possible flow fluctuations as observed on ground test [1] (see also paragraph “HRF WFSV position Selection for Flight Operations”).

Uncertainties and worst case conditions were considered assuming the following:

- All P/Ls of the 1JA mission to receive the maximum nominal flow rate
- Plenum Δp at 40 [kPa] (i.e., lower limit of flight control dead band)
- WFSV position uncertainty of ± 80 steps (3.8% of the complete span) rounded to 5% in the final position selection.

The ER3 nominal configuration considered for the analysis (stage 1JA) was:

- Avionic/subsystem branch open with nominal flow rate of 45 [Kg/hr]
- EMCS branch open with nominal flow rate of 65 [Kg/hr]
- Third branch closed

With the above data an opening of 60% was predicted to be sufficient for the rack needs.

Flight Data 1JA Day 88

Figure 1 and Figure 2 below report the time histories of main hydraulic parameters on flight day 88. In particular the first one collects the WFSV position (red marked) commanded together with the avionic/subsystem leg (dark blue marked) and the EMCS/PL leg flow measurements (turquoise marked) and on the second figure the corresponding plenum pressure drop measured by Delta Pressure Sensor Block (DPSB).

Both plots report some significant figures also shown in Table 1: inadequacy of the WFSV position selected to satisfy the calibration needs was clear.

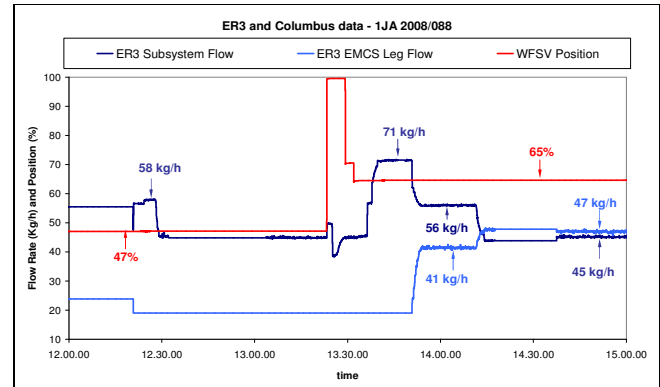


Figure 1 – ER3 & WFSV A1 Status on Day 88

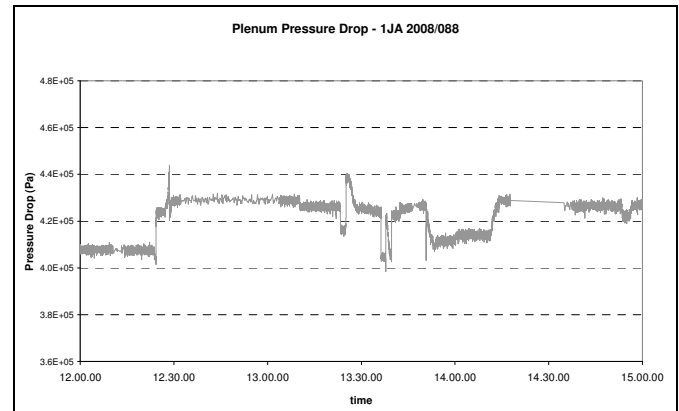


Figure 2 – Plenum ΔP on Day 88

Case	Time	ER3 Flow (Kg/h)		WFSV opening (%)	ΔP Plenum (kPa)
		Avionic	EMCS		
1	12:27:00	58 (fully open)	0 (closed)	47	42.4
2	13:46:00	71 (fully open)	0 (closed)	65	42.5
3	14:05:00	56 (fully open)	41 (fully open)	65	41.3
4	14:51:00	45 (control on)	47 (fully open)	65	42.5
5	18:00:00	45 (control on)	53 (fully open)	73	42.2

Table 1 - ER3 and Columbus data on Day 88

EMCS & ER3 Calibration Data Analysis

As part of the troubleshooting activity, EMCS [3] and the ER3 branches calibration data [4] were reviewed, to correlate the available ER3 THMM. Results from EMCS flow calibration are reported in Table 2

EMCS Test Data	
Δp (Pa)	Flow (Kg/h)
14736	45
16873	50
18475	53
19671	55
22592	60
26750	65
30696	71
35114	75

Table 2 – EMCS test data

ER3 document [4] collects the as run test procedure adopted to calibrate the three branches of the ER3, i.e., the Avionic (aka Sub-System) leg, the Upper Payload Leg (UPL) and the Lower Payload Leg (LPL). Figure 3 below shows the test configuration adopted. Aim of that test was to set the positions of three manual valves (MV1 to 3 in the sketch) for a proper balancing of the inner branches. Five test cases were run with the design goal of 180 [lbm/hr] (81.6 [kg/h]) for the Avionic Leg and 200 [lbm/h] (90.7 [Kg/h]) for each P/L, at 5.1 [psid] (35.16 [kPa]).

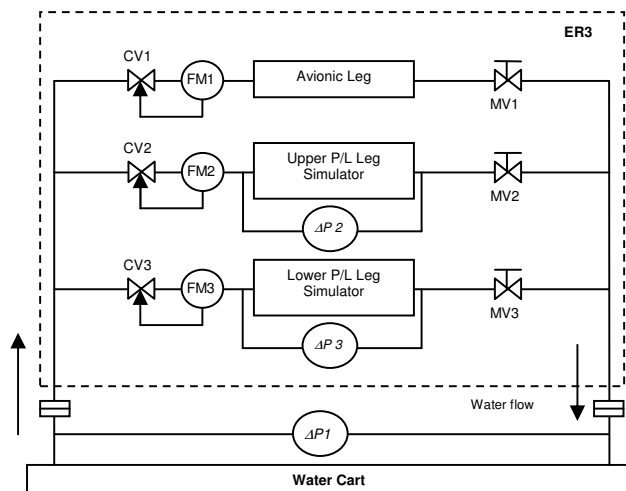


Figure 3 – Test bench for ER3 branches calibration

A key role in the valve trimming was played by the so called P/L Simulators (LPLSim and UPLSim in the following) which had the task to simulate the hydraulic behavior of later experiments to be installed (e.g., EMCS). For each simulator was available the pressure loss reading vs. flow rate. These data, compared with EMCS (see Figure 4), clearly showed that the two simulators adopted for the ER3 calibration had an

hydraulic resistance which was almost half the EMCS one.

Figure 5 shows the hydraulic data of the UPL Leg without the contribution of the UPLSim (UPL Branch), the P/L Leg design point, the hydraulic curves of the ER3 THMM (THMM ICD Updated) adopted for the WFSV original setting and the hydraulic curve of the UPL leg with EMCS installed (EMCS + UPL Branch). The hydraulic resistance, which should be representative for the actual one, is almost twice the design point, which is almost twice the (old) ER3 - THMM one.

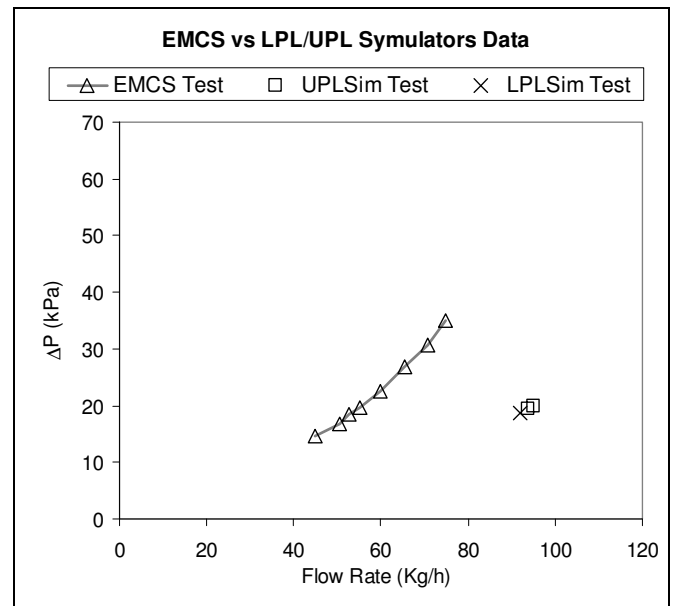


Figure 4 – Test bench for ER3 branches calibration

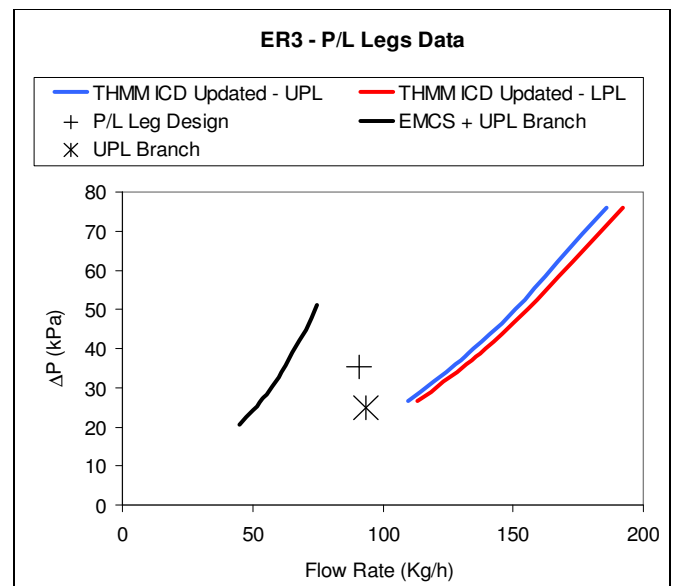


Figure 5 – ER3 P/L Leg Data