EVOLVING THE FLUIDS INTEGRATED RACK (FIR) THERMAL CONTROL SYSTEM MODEL FROM AN ANALYSIS TOOL TO A DESIGN AND DECISION TOOL.

Paul Gebby
Northrop Grumman Information Technology
Cleveland, Ohio

ABSTRACT

The Fluids Integrated Rack (FIR) is a NASA GRC developed facility to be installed in the US Lab on the ISS in 2004. Its purpose is to house, sustain, and support microgravity fluid physics experiments. The first useful rack level thermal model was developed in Excel. This model routed resources, predicted heat exchanger performance, and predicted environmental temperatures in the science volume. The fidelity and capability of the model has increased with the development of a rack level model in Matlab/Simulink. This new model can account for transients, conceptual changes, and variations in active thermal control systems. These improvements in rack level modeling have allowed the FIR design team to save time and schedule on vendor developed parts, model various control schemes, and map operational characteristics during experiment cycling. Future plans for the model include the addition of temperature modeling of key components, blower performance (pressure versus flow rate and power consumption), and integration of test results and PI provided hardware.

INTRODUCTION

The Fluids Integrate Rack (FIR) is a NASA Glenn Research Center developed facility which will be located aboard the US lab on the International Space Station, Figure 1. The FIR is one of two racks in the Fluids Combustion Facility (FCF). The purpose of the FIR is to provide a platform for performing fluids experiments in a microgravity environment. The foundation of the FIR design is to provide researchers with common experimental tools already in orbit. Thus eliminating the need to refly common equipment. This will reduce the cost of performing experiments for NASA and the research community.

One of the FIR design requirements is to provide a stable thermal environment to the region where experiments will be performed. The details of the thermal requirements are to provide researchers the ability to select a temperature with a tolerance on spatial uniformity. This requirement originates from the temperature dependent optical characteristics of experimental fluids. This paper outlines how the FIR thermal team is accommodating this requirement.

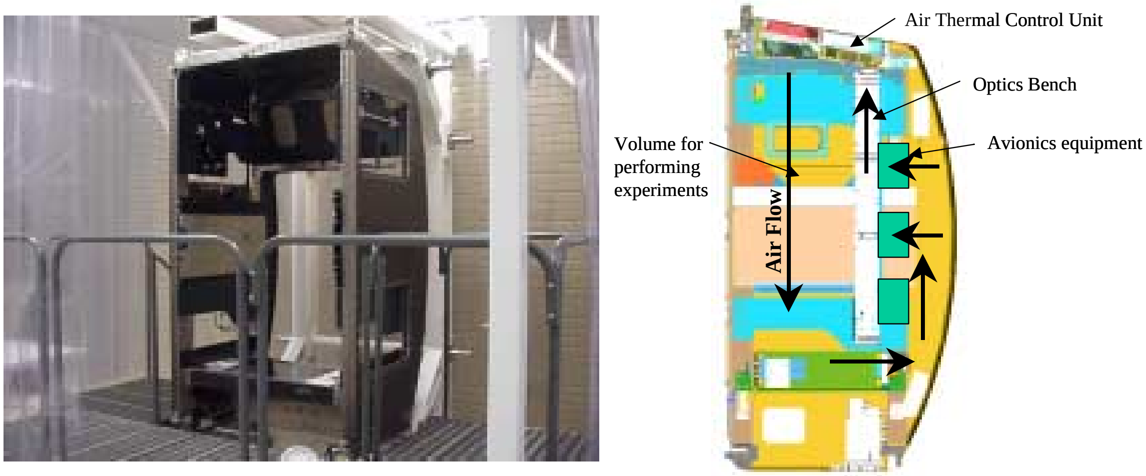

Figure 1: Fluids Integrated Rack

SYSTEM LEVEL THERMAL MODEL DEVLOPMENT

Early in the design of the FIR, the thermal team used a system level thermal model that was developed in Excel, Figure 2. The model routed resources and used expected heat exchanger performance to predict environmental temperatures in the science volume. As the FIR design evolved it became clear that this requirement required a transient analysis using active thermal control systems to prove compliance. Matlab/Simulink was utilized because the software easily accommodates control related analysis, has a user friendly drag and drop interface and quick solution times. Typical experiment solutions times were roughly three minutes.

Total air CFM	
Water Flow Rate (lbm/hr)	
PI Volume Temp	
FSAP Exit Temp	
C-IPSU Exit Temp	
Total Q	
Q air	
Package	Heat Dissipation
FSAP	140
PI-FSAP	133
C-ISPU #1	135
C-IPSU #2	135
Color Camera	40
DCMs (PI Volume Cameras)	0
DCM #2 (20 watts each)	0
White Light	192
YAG Laser	75
Diode Laser	0
IOP	160
ATCS	126
Smoke Detector	3
ARIS Actuators	33
ARIS Drivers	77
WFCA	12
PI Specific (AIR)	500
PI Specific (Water)	0
Cable Losses	35
Total 28 VDC Air	1683
Total 120 VDC Air	36
Total 28 VDC Water	0
Total 120 VDC Water	77
Total Air	1719
EPCU	206
Total Dissipation	2002
Water Intel T	65.00
Water Delta T	35.00
Water Exit T	100.00
Total Water Flow Rate	195.61
Primary Flow Rate	195.61
Secondary Flow Rate	0.00
EPCU Delta T	3.60
ARIS Water Detla T	1.35
ATCU Water Exit T	95.06
Air Side Delta T	30.06
Design Flow Rate	203.12
Air Side Flow Rate	203.12
Air Exit Temp	77.22
Air Return Temp	107.28
DCM #1 Flow Rate	0.00
DCM #1 Air Exit T	109.50
DCM #2 Flow Rate	0.00
DCM #2 Air Exit T	109.50
CCIAM Flow Rate	4.40
CCIAM Ait Exit T	109.50
PI Volume Air Flow	198.71
PI Volume Heat	500.00
PI Volume Delta T	8.94
PI Volume Exit T	86.15

Figure 2: Initial system level thermal model developed in Excel

The above figure illustrates the initial system level thermal model. The data provided is out of data and is provided for illustrative purposes only.

The transient system level thermal model uses nodal representation of components and solves simultaneous state equations through time. The system is comprised of the optics bench, avionics equipment, Air Thermal Control System (ATCU), and the Water Thermal Control System (WTCS).

Optics bench

The optics bench is modeled as a duct that funnels heated exhaust airflow from the avionics equipment back to the air thermal control system. Heat is convected from the internal exhaust airflow to the front structure of the optics bench. Where it is conducted through the structure convected to the air flow for the science volume. A lumped capacitance model was used for transient conduction. Heat transfer coefficients were calculated from CFD results and a flat plate in parallel flow calculations.

Airflow impedance curves were developed with CFD results until test results became available. The curves were used when airflow was reduced to update the system pressure drop and compare that result with the ATCU fan curves for air flow rate and predicted fan RPM and power requirements.

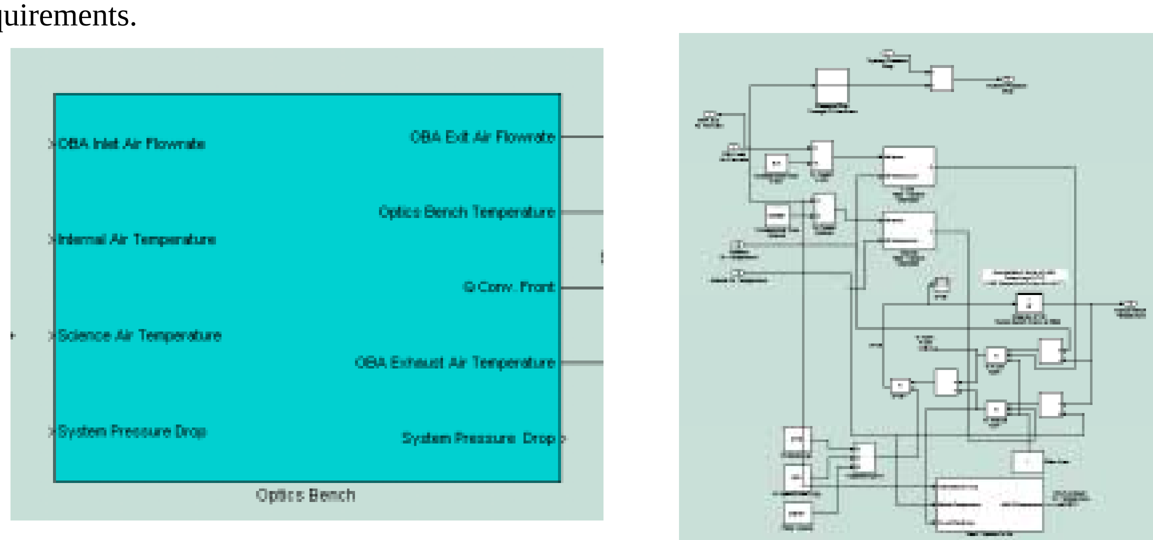

Figure 3: Optics bench

Avionics equipment

Each piece of avionics equipment was modeled as node with defining state equations. Initially CFD analysis predictions were used to supply data until test results became available to integrate. Exhaust air temperature versus time predictions were used to incorporate ramping power rates to simulate when the equipment is turned on or off and power levels for varying operational modes. Airflow and inlet temperature are monitored to make sure equipment don’t exceed their operating environment. Usually base lined through testing. Airflow impedance curves were developed with CFD results until test results became available. The curves were used when airflow was reduced to update the system pressure drop.

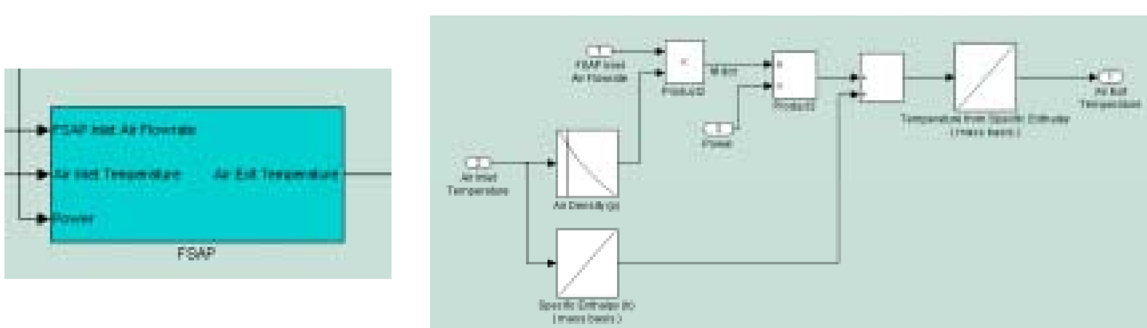

Figure 4: Typical avionics equipment

Air Thermal Control System

The Air Thermal Control System (ATCU) consists of two fans, a compact heat exchanger and related ducting. For the fans, fan and power curves were incorporated into the model. For the heat exchanger, initially constant effectiveness was used for heat transfer. This was later replaced with a matrix of effectiveness values based on air and water temperature and flow rates from testing.

Water Thermal Control System

The Water Thermal Control System (WTCS) consists of two valves and support plumbing. The valves regulate water flow rates to the ATCU heat exchanger and water cooled science equipment. The positional tolerance of the valve is 3% and they are restricted to operate slowly in order to not interfere with other station payloads. The valves on the station also have positional tolerances associated with them.

Development of Initial data for system level thermal modeling

While developing the FIR, substantial effort was place in using concurrent engineering techniques due to compressed schedules and possible cost savings. The mechanical design team used Computer Aided Design (CAD) models to represent geometry. Pro-E from Parametric Technologies was utilized and all geometry was modeled in 3D using solid models. The reasoning behind this effort was that the models would be exchanged with structural and thermal teams to reduce model development and analysis times. Other benefits included improved accuracy, mass and cg calculations, virtual inspections for interference conditions and ease of assembly, tracking of individual components, and developing bills of materials. Exchange of data from the mechanical design team to the structural and thermal teams were accommodated using step and iges translators. Thermal models for all equipment were developed using two software platforms. If the analysis centered around convection as the primary mechanism for heat transfer, FloTherm was used. Flotherm by Flomerics is a Computational Fluid Dynamics (CFD) software that is based on a finite volume solution. It accounts for convection, conduction, and radiation. If conduction is the primary mechanism for heat transfer, Patran and TAS were used. Patran is a FEA preprocessor developed by Macneal-Schwendler. Thermal Analysis System (TAS) from Harvard Thermal uses a finite element method to convert geometry into an accurate resistor/capacitor representation which is then quickly and accurately solved using a finite difference method. If thermo-structural distortion was being analyzed, usually the static structural Patran model was used and imported into TAS. The thermal analysis was performed and the results were exported, in a Nastran format, for inclusion into the structural analysis.

The results from the above analysis were initially incorporated into the system level thermal model. As hardware is being built and tested, test results are being incorporated into the model to assist in further refining predictions.

Results

The following figures illustrate some of the results obtained from the transient analysis. The graphs help visualize system and component interactions. Temperature values, Y axes, are not included on the graphs because trends are being investigated. The analysis is focused as a design tool not a form of verification.

The following load case had constant station resources, rack and science power. The graphs illustrate component/nodal temperatures, y axes, as a function of time, x axes.

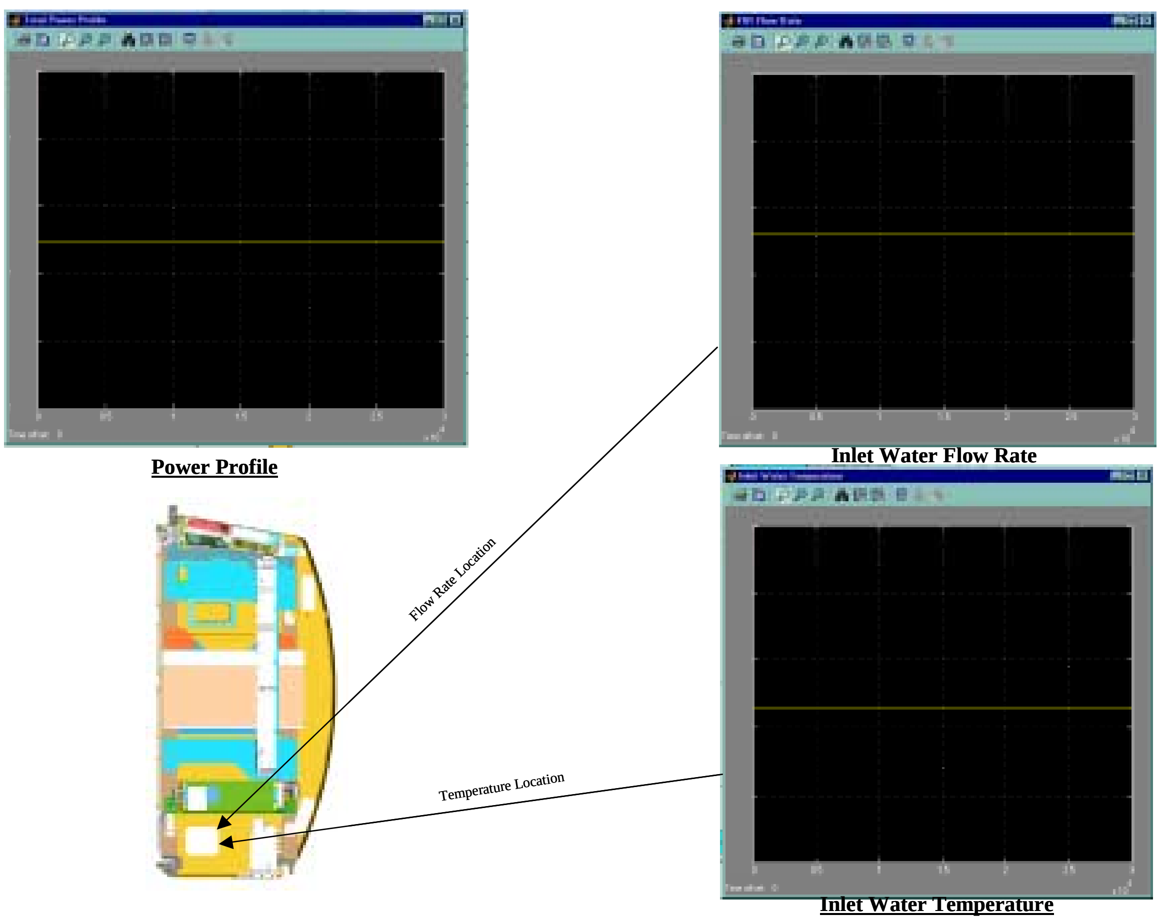

Figure 5: Constant station resources, rack and science power

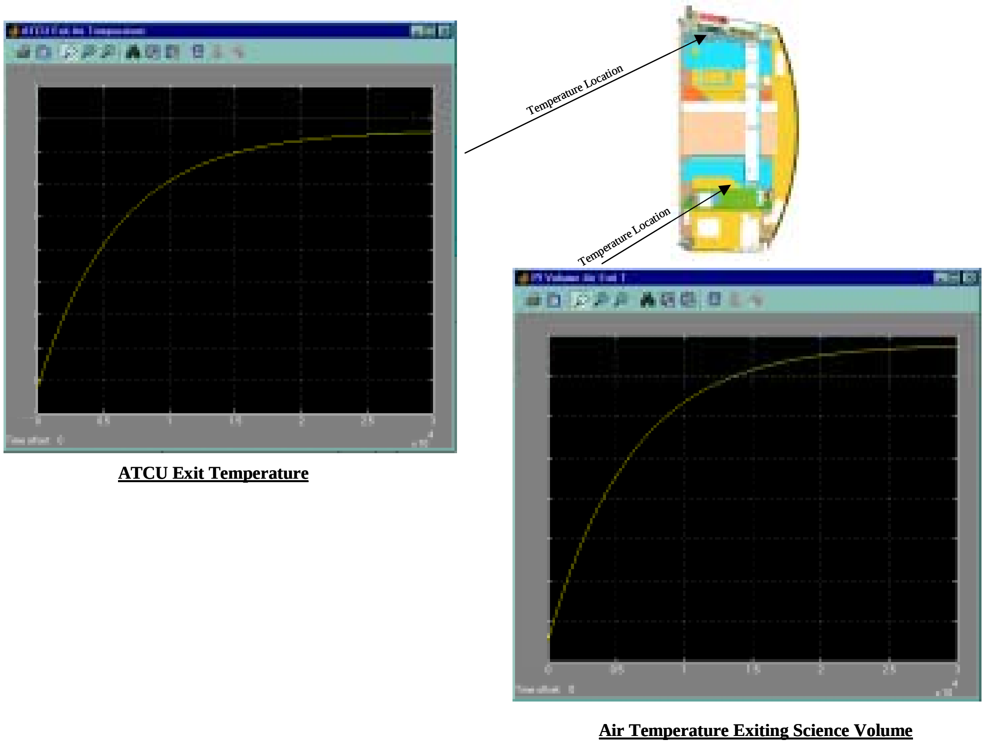

Figure 6: Science volume predictions

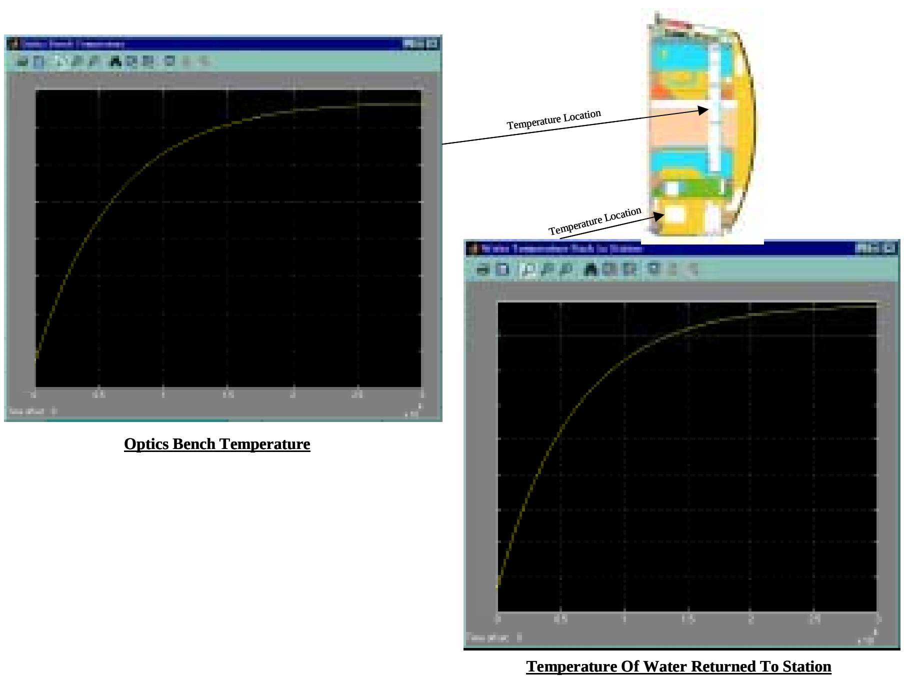

Figure 7: Optics bench and return water temperature predictions

The trends indicates that with constant inputs to the FIR, the science volume, optics bench and return cooling water gradually approach a steady state condition as expected. Currently the FIR thermal team is investigating the effects of varying external conditions such as orbital variations of water flow rates and temperatures and thermal capacitance within the system. Further analysis objectives include designing an active thermal control system to accommodate science requirements.

CONCLUSIONS

The transient thermal system model is assisting the development team in understanding how the FIR will thermally respond during a variety of operating modes and in the development of active thermal control system for the FIR. Performance data from analysis and testing is being embedded into the model. Control techniques are evolving to fulfill system thermal requirements while accommodating hardware and station restrictions.

ACKNOWLEDGEMENTS

The author wishes to thank the follow individuals for their assistance.

James McDade
FIR Manager
Northrop Grumman Corporation

John Merry
FIR Lead System Engineer
Northrop Grumman Corporation

David Pantano
Thermal Engineer
Analex Corporation

Patrick Loney
Thermal Engineer
Northrop Grumman Corporation

NOMENCLATURE, ACRONYMS, ABBREVIATIONS

ATCU	Air Thermal Control Unit
CAD	Computer Assisted Design
CFD	Computational Fluid Dynamics
FIR	Fluids Integrated Rack
GRC	Glenn Research Center
ISS	International Space Station
NASA	National Aeronautics and Space Administration
RPM	Revolutions Per Minute
TAS	Thermal Analysis System
WTCS	Water Thermal Control System