Title of Research: Design of Test Support Equipment for Advanced Space Suits

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NASA Center: Johnson Space Center

Research Focus

As a member of the Space Suit Assembly Development Engineering Team, I designed and built test equipment systems to support the development of the next generation of advanced space suits. During space suit testing it is critical to supply the subject with two functions: (1) cooling to remove metabolic heat, and (2) breathing air to pressurize the space suit.

The objective of my first project was to design, build, and certify an improved Space Suit Cooling System for manned testing in a 1-G environment. This design had to be portable and supply a minimum cooling rate of 2500 BTU/hr. It needed to supply cooling water at a variable temperature and flowrate.
My next project was to design and build a Breathing Air System that was capable of supply facility air to subjects wearing the Z-2 space suit. The system needed to intake 150 PSIG air and regulate it to two operating pressures. It also had to provide structural capabilities at 1.5x operating pressure.

Research Methods

Both projects followed a similar design methodology. The first task was to perform research on existing concepts to develop a sufficient background knowledge. Then mathematical models were developed to size components and simulate system performance. Next, mechanical and electrical schematics were generated and presented at Design Reviews. After the systems were approved by the suit team, all the hardware components were specified and procured. The systems were then packaged, fabricated, and thoroughly tested. The next step was to certify the equipment for manned used, which included generating a Hazard Analysis and giving a presentation to the Test Readiness Review Board.

Results

The Space Suit Cooling System is a robust, portable system that supports very high metabolic rates. It has a highly adjustable cool rate and is equipped with digital instrumentation to monitor the flowrate and critical temperatures. It can supply a variable water temperature down to 34°F, and it can generate a maximum water flowrate of 2.5 LPM.

The Breathing Air System is capable of supplying air at both 4.3 and 8.3 PSIG operations. It has instrumentation to monitor flowrate, as well as inlet and outlet pressures. The system has a series of relief valves to fully protect itself in case of regulator failure.

Main Conclusions

Both of these test support systems will perform critical roles in the development of next-generation space suits. They will used on a regular basis to test the NASA's new Z-2 Space Suit. The Space Suit Cooling System is now the primary cooling system for all advanced suit tests.

Abstract (400 words)

As a member of the Space Suit Assembly Development Engineering Team, I designed and built test equipment systems to support the development of the next generation of advanced space suits. During space suit testing it is critical to supply the subject with two functions: (1) cooling to remove metabolic heat, and (2) breathing air to pressurize the space suit.

The objective of my first project was to design, build, and certify an improved Space Suit Cooling System for manned testing in a 1-G environment. This design had to be portable and supply a minimum cooling rate of 2500 BTU/hr. The Space Suit Cooling System is a robust, portable system that supports very high metabolic rates. It has a highly adjustable cool rate and is equipped with digital instrumentation to monitor the flowrate and critical temperatures. It can supply a variable water temperature down to 34°F, and it can generate a maximum water flowrate of 2.5 LPM.

My next project was to design and build a Breathing Air System that was capable of supply facility air to subjects wearing the Z-2 space suit. The system intakes 150 PSIG breathing air and regulates it to two operating pressures: 4.3 and 8.3 PSIG. It can also provide structural capabilities at 1.5x operating pressure: 6.6 and 13.2 PSIG, respectively. It has instrumentation to monitor flowrate, as well as inlet and outlet pressures. The system has a series of relief valves to fully protect itself in case of regulator failure.

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thoroughly tested. The next step was to certify the equipment for manned used, which included generating a Hazard Analysis and giving a presentation to the Test Readiness Review Board.

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Crew and Thermal Systems Division

Advanced Space Suit Test Support Equipment

Jeffrey A. Watters

B.S. Mechanical Engineering, University of Wyoming: August 2013

Space Suit Assembly Development Engineering | EC5: Space Suit and Crew Survival Systems Branch

Space Suit Assembly Engineer

Team Role

Design and build space suit test equipment to support the development of the next-generation of advanced space suits.

Personal Responsibilities:

- Design, build, and certify a space suit cooling system for manned testing in a 1-G environment.
- Engineer a system to supply breathing air to suited subjects.
- Create mechanical and electrical schematics in AutoCAD.
- Utilize Pro/ENGINEER to design and model part assemblies.
- Specify and procure component hardware.
- Conduct professional presentations:
  - Design Reviews (DR)
  - Test Readiness Reviews (TRR)
  - Hazard Analyses (HA)

Professional Training

Space Vehicle Mechanisms (24 hrs)

- Gained a working knowledge of moving mechanical assemblies and high-performance materials used in the space environment.
- Used real-world examples to simulate design troubleshooting.
- Learned valuable lessons that will greatly benefit my future academic and professional careers.

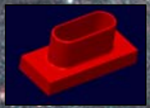
Detailing in Creo Parametric 2.0 (24 hrs)

- Learned how to quickly create detailed drawings using information captured within 3-D design models.
- Learned how to create production drawings suitable for manufacturing.

EMU LCVG Adaptor

Task Objective

Design a way to implement full body ventilation for testing in the Mark III Space Suit.



Design Features:

- Enables ventilation cooling in advanced suit tests, a capability we have never had before.
- Liquid-only cooling leads to an overly humid suit.
- Combines conduction-based cooling with forced convection cooling for greater efficiency.

Space Suit Size Modeling

Task Objective

Use 3D modeling to determine largest allowable size for the Display & Control Module (DCM) on a 5th percentile subject.

Space Suit Cooling System

Project Objective

Design and build a portable space suit cooling system that will interface with Class 1 LCVGs (Liquid Cooling and Ventilation Garments).

Background:

Space Suit Cooling

- During space suit testing, subjects require cooling to remove metabolic heat.
- Heat is removed using a Liquid Cooling and Ventilation Garment (LCVG).
- Cooling water is currently supplied by an ice water bath via the Portable Cooling Box.

Current System:

Portable Cooling Box (PCB)

- Modified ice chest
- Submersed bilge pump supplies ice water
- 12V power supply + GFCI power strip

Disadvantages of the PCB:

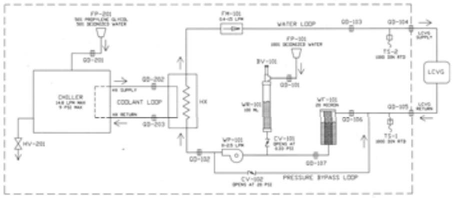
- Ice must be replaced and water must be drained for every test.
  - Ineffective method of cooling.
  - Creates an unnecessary burden on suit technicians.
- No flowrate control: ON or OFF only
- Cooling water supplied only at **32°F**.
  - No water temperature control.
  - Supplying too cold of water leads to *vasoconstriction*, the body's natural defense against cold temperatures.
    - Blood vessels constrict, reducing blood flow.
    - Body retains heat and subject can actually **over-heat!**

Design Requirements:

- Supply cooling water at sub 40°F temperatures
- Flow at least 240 lbm/hr (1.8 LPM) of water with 40 feet of 3/8" tubing and an LCVG connected
- Minimum cooling capacity of 2500 BTU/hr
- Max pressure of 25 PSIG
- Portable packaging

Technical Schematic:

Space Suit Cooling System



Design Features:

- Adjustable fluid temperature supplies water down to 34°F
- Adjustable water flowrate into the LCVG with a max flow of 2.6 LPM (340 lbm/hr)
- Custom Front Panel control box
- Color-coded fluid lines to designate coolant/water and supply/return
- Short circuit protection (GFCI)

Design Overview:

- 1000W recirculating benchtop chiller mounted to a modified utility cart
- Dual external fluid loop system:
  - Coolant loop: Supplies the heat exchanger with a low temperature glycol/water mixture
  - Water LCVG loop: Circulates cooling water from the heat exchanger to the suit subject's LCVG
- Pressure bypass loop with check valve to prevent system over-pressurization
- Remote fill-port system to easily fill coolant and water lines
- 100 mL water reservoir with one-way valve
- Removable water filter with custom gas trap
- Drain with shutoff valve

Line Color Designations:

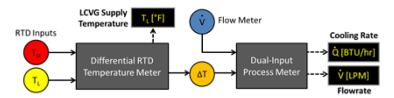
- Water
- Glycol
- Return
- Supply

Digital Instrumentation:

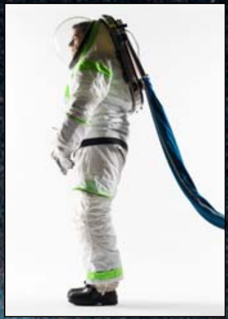
- Fluid temperature [°F]
  - Chiller outlet temperature
  - LCVG supply/return temperatures
- Volumetric flowrate [LPM]
- Cooling rate calculator [BTU/hr]: combines, multiplies, and scales sensor data into a meaningful statistic

$$\dot{Q} = \dot{m}\, c_p (T_H - T_L) \rightarrow \dot{Q} = (c_p\, \rho)(\dot{V})(\Delta T)$$

Process Diagram: Instrumentation



Breathing Air System



Project Objective

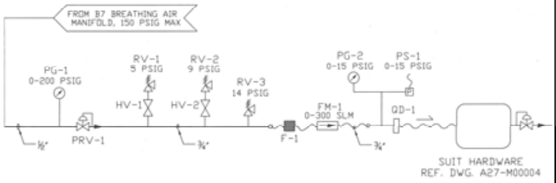
Develop a system to supply facility breathing air to test subjects wearing the Z-2 space suit.

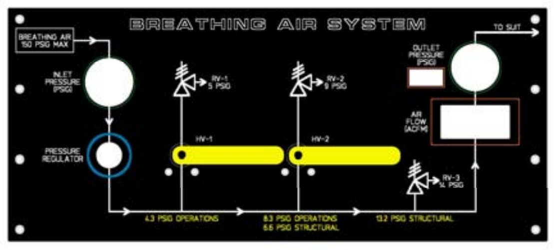
Design Requirements:

- Utilize facility breathing air: 150 PSIG max
- Max Allowable Working Pressure: 15 PSIG
- Function at two operating pressures:
  - 4.3 ± 0.1 PSIG (EMU suit pressure)
  - 8.3 ± 0.5 PSIG (zero pre-breathe)
- Provide structural test capabilities at 1.5x operating pressures
- Flow 6 ACFM at operating pressures
- Completely protect itself with relief valves

Technical Schematic:

Breathing Air System





Design Overview:

- Pressure regulating valve:
  - 500 PSIG max inlet pressure
  - 0-30 PSIG variable outlet pressure
- Three integrated relief valves protect the suit at all operating pressures
- Two hand valves to select relief valve based on desired operating mode
- Custom Front Panel box
- System instrumentation:
  - Analog inlet pressure gauge [PSIG]
  - Analog outlet pressure gauge [PSIG]
  - Digital pressure transducer [PSIG]
  - Digital flow meter [ACFM]
- Inline air filter to protect flow meter