Astronaut Thermal Exposure: Re-Entry After Low Earth Orbit Rescue Mission

David B. Gillis, MD PhD MPH
Stana Ilcus, MD
Phil Stepaniak, MD
Grant Bue

Douglas Hamilton, MD PhD
Chang Son, PhD

5/6/2009

David Gillis, AsMA Annual Meeting 2009
Participants

David B. Gillis, MD PhD MPH, Presenter
Douglas Hamilton, MD PhD
Stana Ilcus, MD
Grant Bue
Larry Kuznetz, PhD
Jason Norcross, MS
Chang Son, PhD
Phil Stepaniak, MD
J. D. Polk, DO, MS
Terry Guess
Hubble Space Telescope
STS-125 Hubble Telescope Repair Mission EVA Tasks

Install a new Wide Field Camera 3

Photo Courtesy of NASA
STS-125 Hubble Telescope Repair Mission EVA Tasks

Install Cosmic Origins Spectrograph

David Gillis, AsMA Annual Meeting 2009

Photo Courtesy of NASA
Repair the Space Telescope Imaging Spectrograph

STIS is capable of probing the complex environment around young stars and their dusty debris disks

Photos Courtesy of NASA

The capabilities of STIS were used to study the highly complex eruptive variable star Eta Carinae

Spectrographic signature of a Black Hole

5/6/2009

David Gillis, ASMA Annual Meeting 2009
STS-125 Hubble Telescope Repair Mission EVA Tasks

Install New Outer Blanket Layer

Photo Courtesy of NASA
Add a Soft Capture & Rendezvous System for eventual controlled deorbit about 2014
STS-125 Hubble Telescope Repair Mission EVA Tasks

Replace the “A” side Science Instrument Command & Data Handling module

David Gillis, AsMA Annual Meeting 2009
STS-125 Hubble Telescope Repair Mission EVA Tasks

Repair the Advanced Camera for Surveys
STS-125 Hubble Telescope Repair Mission EVA Tasks

- Replace Rate Sensor Unit Gyroscopes
- Replace the Fine Guidance Sensors
- Replace the 3 batteries

Photo Courtesy of NASA
Shuttle Crew Cabin Thermal Environment

Orbiters oriented at 90 deg angle
Clearance between Orbiters is 30 ft

LON Orbiter
(STS - 400)

LON SRMS grappled to stowed SM4 OBSS EFGF,
Line fixed to Manipulator

SM4 Orbiter
(STS - 125)

Crew self-transfers from SM4 Airlock to LON Airlock by SM4 SRMS
Potential Hubble Repair Shuttle Mission and ‘Plan to Fly’ Potential Rescue Flight

- **Nominal**
  - Service Mission 4
  - Contingency Shuttle Crew Support (CSCS) with Food bars, sleeping bags & LiOH
  - Power down 6.9 kW
  - EVA

- **TPS Repair**
  - HST Deploy
  - Power down 4.8 kW
  - EVA

- **Unsuccessful**
  - HST Repair
  - 3 days

- **Dual Pad**
  - 7 Days Launch to Launch
  - RNDZ EVA

- **LON Rescue**
  - Launch Delay Margin
  - RNDZ EVA

Graphics Courtesy of NASA
Shuttle Crew Cabin Thermal Environment

Nominal SM4 Mission (No CSCS) With CSCS Capability

- **Ascent Performance Margin** (vehicle specific)
  - Jan 1402 lbs
  - Feb 1392 lbs
  - Mar 1652 lbs
  - Apr 1742 lbs

- **Discovery**
  - 304 nm Rendezvous Altitude
  - 22,500 lbs HST SM4 Control Wt
  - 7 crew/11+2 day
  - 5 EVAs
  - 338 lbs Tile/RCC repair kits
  - 1457 lbs Aft Lead Ballast
  - 8562 lbs Middeck

Graphics Courtesy of NASA
Shuttle Crew Cabin Thermal Environment

Probability of Launch Delay > X Days

Probability

Days

Graphics Courtesy of NASA
Shuttle Crew Cabin Thermal Environment

LiOH CO2 Scrubbing - 25 Days

<table>
<thead>
<tr>
<th># LiOH Canisters</th>
<th>Change-Out Interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>88</td>
<td>Nominal pre- &amp; post-sleep</td>
</tr>
<tr>
<td>82</td>
<td>16 hr (FD 10), max 7.6 mmHg</td>
</tr>
<tr>
<td>78</td>
<td>16 hr (FD 04), max 7.6 mmHg</td>
</tr>
</tbody>
</table>

ECLSS Requirements

- **N2 Supply**: about 35 days
- **Supply H2O Dumps**: 7 KW Power Level
  - 4 Dumps for 25 days
- **Waste H2O Dumps** based on nominal waste generation rate for 7 crew,
  - 9 dumps required for 25 days

WCS based on nominal waste generation rate 7 crew, can support ~ 17 days
Air Velocity magnitude distributions at Y-sections

Marked fore to aft decreases in air velocity in the modeled Rescue mid deck ‘ditch’ section

Graphics Courtesy of Boeing & Chang Son, PhD
A volume-averaged ppCO2 is to 6.28 mmHg.

What is the relationship of this single point average to the inspired micro-environment of the crewmember?
Case 1: ppCO₂ at Y-sections (5.5 hours)

Off-scale (>13.5) ppCO₂ values at face are shown in white.

CFD model of CO₂ shows discrepancy between crew breathing volume and general mid deck levels of CO₂.

ppCO₂, mmHg

Upper scale >= 13.5
Lower scale <= 5.5

Graphics Courtesy of Boeing & Chang Son, PhD
11 person rescue Shuttle re-entry, no wave-off-forecast middeck temp profile, comparing 3 ICU/TELC configurations.

Cold Soak, previous nite

Suit-Up

Region of Interest
Re-Entry

Cabin
Nominal Temp Limit, 75 F

Nominal Entry Configuration, 14.7 psia (TD=283.73)
DTO-664 illustrates temperature spreads in Shuttle crew cabin
Shuttle Air Revitalization System
Cabin Air Return System

ARS CABIN AIR RETURN SYSTEM

SUPPLY DISTRIBUTION
Flight Deck 50%
Middeck 41%
ECLSS Bay 9%

AIR RETURN DISTRIBUTION
Flight Deck 91%
Middeck 3%
ECLSS Bay 6%

612 LB/Hr

50 LB/Hr
Three ICUs stacked under Mid-Deck Lockers
## Follow-on Analysis – Middeck

### STS-326 Middeck crew core temperatures

<table>
<thead>
<tr>
<th></th>
<th>Core Temperature for TD-1.5</th>
<th></th>
<th>Core Temperature for TD-1.0</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>@ TD</td>
<td>@ Egress</td>
<td>@ TD</td>
<td>@ Egress</td>
</tr>
<tr>
<td>0 Orb Waveoff</td>
<td>99.0</td>
<td>99.7</td>
<td>98.8</td>
<td>99.5</td>
</tr>
<tr>
<td>1 Orb Waveoff</td>
<td>99.7</td>
<td>100.4</td>
<td>99.5</td>
<td>100.3</td>
</tr>
<tr>
<td>2 Orb Waveoff</td>
<td>100.4</td>
<td>101.1</td>
<td>100.4</td>
<td>101.1</td>
</tr>
</tbody>
</table>

**Results did not take reduced middeck flow bulk analysis into account.**
Middeck Flow Rate Assumptions
from Brian Dunaway email on 05/14/2008

- **Outlet 1 and 2 to Flight Deck**
  - Flow rate of 68 cfm
- **Outlet 2 to Flight Deck**
  - Flow rate of 68 cfm
- **Outlet 3: to toilet rack**
  - Flow rate of 11 cfm
- **Outlet 5: Aft floor inlet**
  - Flow rate of 51 cfm
- **Outlet 6: Starboard gap from ECLSS Bay**
  - Flow rate of 5.5 cfm
- **Outlet 7: Port gap from ECLSS Bay**
  - Flow rate of 5.5 cfm

**Total ventilation flow rate from HX**: 147 cfm

Green boxes: ICUs

Additionally to ventilation from HX shown in the Figure, seven ICU inlets/outlets with 45 cfm each are introduced into the model (+315 cfm and -315 cfm total)

CFD by Boeing
Follow-on Analysis – Middeck CFD

Plane cuts for post-processing

Graphics Courtesy of Boeing & Chang Son, PhD
Follow-on Analysis – Middeck CFD On-Orbit

Temperature distributions over Y-planes; Case 3 @ 170.21 hr

Note: Red is temp at or above 95 F, Peak temp = 112 F

Graphics Courtesy of Boeing & Chang Son, PhD
Follow-on Analysis – Middeck CFD

Temperature distributions over Z-planes; Case 3 @ 170.21 hr

Graphics Courtesy of Boeing & Chang Son, PhD
Follow-on Analysis – Middeck CFD

Pathlines issued from ICU1

- Back flow from ICU 1 outlet to ICU 2 inlet due to jet interaction with the neighboring crew-member
- Interaction of the jets with the obstacle/crew

Max local temp: 112 °F

Graphics Courtesy of Boeing & Chang Son, PhD

T, °F

 Cooler 
95
93
91
89
87
85
83
81
79
77
75
73
71
69
67
65
Follow-on Analysis – Middeck CFD

Temperature distributions over Y-planes; Case 1 @ 170.71 hr

Graphics Courtesy of Boeing & Chang Son, PhD
Geometry model for Middeck

**Green:** ICU wall
**Purple:** ECLSS
**Blue:** Inlets to Middeck Cabin
**Red:** Outlets from Middeck Cabin

Graphics Courtesy of Boeing & Chang Son, PhD
Inlet 7: Aft floor inlet
Flow rate of 51 cfm

Outlet 3: to toilet rack
Flow rate of -11 cfm

Inlet 8: Starboard gap from ECLSS Bay;
Flow rate of 5.5 cfm

Inlet 9: Port gap from ECLSS Bay;
Flow rate of 5.5 cfm

Inlets 1, 2, 3, 4:
Stbd diffusers
Flow rates of 20 cfm each

Outlet 1 to Flight Deck
Flow rate of -88.5 cfm

Outlet 2 to Flight Deck
Flow rate of -88.5 cfm

Inlet 5: Port semicircle
Flow rate of 46 cfm

Total ventilation flow rate from HX: 177 cfm

Green boxes: seven ICU inlets/outlets with 45 cfm each are introduced into the model (+315 cfm and -315 cfm total)
Post-mitigation CFD model of Mid Deck

Temperature profile over Y-planes; Case 1 @ 167.55 hr

Plane Y-ECLOID1

Plane Y-ECLOID2

Plane Y-ECLOID3

Plane Y-ECLOID4
Post-mitigation CFD model of Mid Deck

Temperature profile over Y-planes; Case 2 @ 167.05 hr

Plane Y-ECLOID1

Plane Y-ECLOID2

Plane Y-ECLOID3

Plane Y-ECLOID4
Post-mitigation CFD model of Mid Deck

Temperature profile over Y-planes; Case 3 @ 168.05 hr
Post-mitigation CFD model of Mid Deck

Temperature profile over Y-planes; Case 3 @ 168.05 hr
Post-mitigation CFD model of Mid Deck

Temperature distributions over Z-planes; Case 3 @ 168.05 hr

Plane Z-ECLOID

Plane Z-3/4 height

Plane Z-centre
Six Basic Environmental Variable That Affect Human Response to a Thermal Environment

1. Air Temperature
2. Radiant Temperature
3. Humidity
4. Air Movement
5. Human Metabolic Heat Generation
6. Human Clothing Being Worn

These six factors define human thermal environments.

Defining environmental limits in terms of only air temperature are insufficient in many situations and ignores, or implies assumptions regarding the other 5 environmental variables.

Radiation temperatures may greatly effect an individual environment.

Assumptions regarding each of the six basic variables need to be explicitly stated rather than implied but not specified.
Post-mitigation CFD model of Mid Deck

Temperature profile over X-planes; Case 1 @ 167.55 hr

Plane X-aftdiff
Plane X-ECLOID2
Plane X-ECLOID7
Plane X-ICU1
Plane X-ICU7
Pathlines colored by air temperature; Case 1 @ 167.55 hr

Pathlines from ICU 2 outlet

Pathlines to ICU 2 inlet

Weak back flows from ICU2 outlet to ICU2 and ICU3 inlets

Most of the air is from outside, few pathlines come from ICU2 and ICU3 outlets

5/6/2009

David Gillis, AsMA Annual Meeting 2009
Mitigations for Safety - Procedures

- Full cold soak night prior to deorbit
- Orbital Wave-off for weather not supported, full-day wave-off with suit doffing
- Delayed, staggered suit-up for de-orbit
- Modify deck stowage to reduce interference with air flow
- Early securing of avionics post-landing (to reduce cabin thermal load prior to hatch opening
- Early hatch opening and increased ground cooling with lower air temperature
- Re-entry with visors open
STS-125 is currently scheduled to launch 12 May 2009

Photo courtesy of NASA
STS-400

STS-400 will be prepared to launch within 7 days of Rescue requirement notice

- STS-400 is also on the Pad, prepared to launch on no later than
- 7 days after notification of Rescue Mission Requirement

Photo courtesy of NASA
Mitigations for Safety - Engineering

- Remove Duffy ducts, open diffusers
- Use TELCs on for Commander & Pilot
- Modify location of aft starboard ICUs, eliminating the X3 Stack and eliminating ICU exhaust air directed onto astronaut
- Improved engineering data of ICU performance
- Improved ACES heat rejection understanding
- Use 600 BTU in Mid Deck temperature modeling and core temperature predictions
- Verify adequacy of Mid Deck temperature control using CFD models in addition to lumped parameter models
Mitigations for Safety - Core Temperature Limits

- Require Flight Deck CDR & Pilot core temperature predictions not to exceed normal (approximately 98.6 degrees F) during re-entry for a high level of cognitive performance.

- Require Mid Deck crew member core temperatures not to exceed 99.9 degrees F during re-entry to protect for cognitive and physiological ability to execute a Mode VIII escape should that become necessary.