Johnson Space Center is more than Mission Control

Main Site: Houston, TX
Civil Servants ~3300
On/near site ~13,000

Additional Facilities:
White Sands, NM
Neutral Buoyancy Lab
Ellington Field, TX
We Achieve the Impossible with Bold Explorers and Incredible Machines!
International Space Station: Challenges met every day

• Remote hazardous environment
• Complex systems engineering and integration
• Continuous operations with six member crew
• Focus on sustainability with limited resupply
NASA Johnson Space Center Space Flight Services

- Integrated Human Space Vehicle Systems
- Life Support Systems & Environmental Control
- Flight Design
- Integrated Environments Testing and Analysis
- Mission Operations
Program Partnerships

We engage our Program partners by providing

- Technical Expertise
- Analysis & Test Support
- High Fidelity Simulation & Modeling
- In-house Development
- Technology Maturation

The outcome we strive to achieve is that partners embrace us as an integral partner who fulfills our commitments and proactively brings credible solutions forward while maintaining a work environment that emphasizes continual learning and development.
Changing Policy Environment

Priorities:
1. Retire the Space Shuttle no later than 2010
2. Complete the International Space Station
3. Develop and fly the Crew Exploration Vehicle by 2014
4. Return to the Moon no later than 2020
5. Extend human presence across the solar system and beyond

Policy Focus:
Advance U.S. Scientific, Security, Economic interests

Priorities:
1. Protect the Earth’s Environment
2. Enhance Relevance to Earth Science
3. Green Aeronautics
4. Human Spaceflight Technology Development

Policy Focus:
Tech., Environment, Commercial, Int’l
Trend is increasing commercial, multinational collaboration
- Complex Integration, Systems Engineering, Partnership
- ISS Program is Prototypical Example of Success

Competition

Collaboration
Exploration Domain Evolution

NASA Human Exploration

NASA SMD, Robotic Precursors, Observatories

Deep Space

Solar System

Cis-Lunar

LEO

Comm. Space

Aero
Advanced Technology Can Reduce Cost of Spaceflight

- Cryo Storage and Transfer
- In-Situ Resources
- Aero Braking/EDL
- Advanced Propulsion
- Nano Materials/Structures
- Advanced Avionics / AI

Mars Mission Mass / Cost vs. Technology
Machine vs. Biological Intelligence

Evolution

- Humans
- Primitive Animals
- Reptiles

Equivalent Biological Evolution Timescale:

- 4.2 Billion years
- 4.3 Billion years
- 4.4 Billion years
- 4.5 Billion years

Growth in Supercomputer Power

Logarithmic Plot

- Required for Human Brain Neural Simulation for Uploading (2025)
- Required for Human Brain Functional Simulation (2013)

Flops (floating point operations)

Year


Doubling time = 1.2 years

Trendline

Planned

NASA
Budget

NASA FY2012 Proposed Space Technology Budget ($1024M)

<table>
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<tr>
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</tbody>
</table>
Technology Development Areas

Tammy Gafka, James Smith, Omar Hatamleh
NASA/Johnson Space Center
Houston, Texas

Collaborations with Airbus (Toulouse, France / Hamburg, Germany)
April 2011
Composite Structures – Technology Needs

Technology Needs

• Large Composite Manufacturing
• Composite Damage Tolerance/Detection
• Light-weight Composite Joining
• COPVs/Composite Cryotanks
• Elevated Temperature Designs
• Multi-Functional Designs/Human Habitation (Certification Methods)

Goals

• 25-30% structural weight savings compared to metallics
• 20-25% cost savings compared to metallics
• Technical Maturity: consistent, predictable response
Composite Structures – Large Structure Manufacturing

**Structural Concepts**

- **Stiffened**
  - Skin / Stringer Stiffened
  - Isogrid / Orthogrid Stiffened
  - Hat Stiffened

- **Hybrid**
  - PRSEUS

- **Sandwich**
  - Corrugated Sandwich
  - Foam Sandwich
  - Fiber Reinforced Foam Core
  - Honeycomb Sandwich

**Automated Fabrication**

**Out-of-Autoclave/Out-Time Studies**

<table>
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<tr>
<th>Process Step</th>
<th>Sandwich Time (days)</th>
<th>Skin-Stringer Time (days)</th>
<th>Fluted Time (days)</th>
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<tr>
<td>Inner skin</td>
<td>12</td>
<td>12</td>
<td>12</td>
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<tr>
<td>Film adhesive</td>
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<td>Film adhesive 12</td>
<td>Film adhesive 12</td>
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<tr>
<td>Core</td>
<td>10</td>
<td>stringer charge 5</td>
<td>flute charge 7</td>
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<td>Core splicing</td>
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<td>Core rework</td>
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<td>Film adhesive</td>
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<tr>
<td>Outer skin</td>
<td>12</td>
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<td>Outer skin 12</td>
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<tr>
<td>Final bag</td>
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<td>Final bag 8</td>
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<td>Total 41</td>
<td>Total 55</td>
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<td>Allowable 40</td>
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<td>Margin</td>
<td>-28</td>
<td>Margin -1</td>
<td>Margin -15</td>
</tr>
</tbody>
</table>
The Issue...

Mitigations Through Technology Development:

– Damage tolerant material systems
– Late-in-flow production NDE / IVHM to reduce “design-to” damage thresholds
– Novel ground-based protection mechanisms (e.g. shielding, impact-indication coatings…)
– Late-in-flow repair materials and techniques
Advanced joints that
• efficiently transfer load
• limit permeability (for tanks and habs)
• are compatible with space environments
Technical Challenges

- Hydrogen Permeability
- Immature Out-of-Autoclave Material Systems
- Manufacturing and NDE Scale-Up
- Damage Tolerance
- Design Allowables at Representative Environments
- Integrated w/ Structural Elements
- Verification/Certification
Composite Failure Concerns

- Damage propagation from impacts
  Mitigated by Damage Control Plan

- Manufacturing variability
  Mitigated by qualification tests which include burst tests after thermal and pressure cycle tests

- Stress rupture (creep-like) failure
  Catastrophic failure after a given time at stress levels
  Mitigated by this proposed phased test approach
High temperature (500+ deg F) material systems (composites, core, adhesives) with controlled impact energy absorption needed for re-entry/landing vehicle heat shields
Composite Structures - Multi-Functional Designs

JSC Composite Structure Roadmap

- **Vehicle Focus**
  - Composite Core for Inflatable Habitat (1,2, 3,4,5)
  - Lunar Electric Rover (1,2,3,4)

- **Component & Mfg Focus**
  - CFM/ISS MMOD Shield (1,2)
  - Cryo Composite Tanks (3,5)
  - Comp Heatshield (5)

- **Technology Development**
  1) Composite Skin/Stringer and Sandwich Panel Technology
  2) MMOD
  3) Single Wall Technology
  4) Permeability
  5) Radiation
  6) Damage Tolerance/Health Monitoring

- Crewed Mission Beyond Moon (1,2, 3,4,5)
To enable long duration space flight, vehicle risk mitigation requires on-orbit ability to first, protect, then...

- detect
- inspect
- repair

...an anomalous structure/mechanism

Candidate technologies needed for on-orbit inspection of manned systems:

1. Visual Cameras with Illuminators
2. Laser-Based Systems: next generation of the systems used on Orbiter including 3D borescopes
3. Micro-Wave SAF Video Imagers
4. Time-Domain Terahertz Computed Axial Tomography Line Scanner
5. X-ray Back-Scatter
   - Backshell TPS and structure inspection at suspect MMOD impact sites
6. Hit Grid Imbedded in the RTV Bond Layer
   - Damage to this layer recorded mechanically
   - Impact sensing to the panel level
   - Damage sensing: impact to face sheet(s) or not
8. Charge Time of Arrival
   - Impact and location based on conducted emission

Some of these NDE technologies are also applicable to ground processing
Applied Nanotechnology

**Advanced Life Support**
- Regenerable CO₂ Removal
- Water recovery

**Power / Energy Storage Materials**
- Proton Exchange Membrane (PEM) Fuel Cells
- Supercapacitors / batteries
- Quantum Wire

**Electromagnetic / Radiation Shielding and Monitoring**
- ESD/EMI coatings
- Radiation monitoring

**Thermal Protection and Management**
- Ablators and ceramic nanofibers
- TPS repair materials
- Passive / active thermal management (spacesuit fabric, avionics)

**Multi-functional / Structural Materials**
- Primary structure
- Inflatables

**Nano-Biotechnology**
- Health monitoring (assays)
- Countermeasures
The Nanotechnology Group’s Current Projects:
• Self healing multifunctional Composites
• Gas Absorption: MOF Nanomaterials
• Solar Cells – Band Gap Engineered High Efficiency Solar Cells
• Aluminum/Nanocomposite Materials – Aluminum having the strength of steel yet the weight of aluminum.

Our Main Focus Areas:
Energy: this area includes energy storage, energy generation, and energy systems
Environmental Control and Life Support Systems: This area is primarily the systems required to ensure the astronauts health and survivability. It includes air systems, temperature control, food, waste, humidity control, space suites, life support systems, radiation protection, etc.
Nanomaterials: This includes nanocomposites, Improved damage tolerance, structural health monitoring, self repair materials, multifunctional materials, lightning strike protection, coatings, and textiles/fabrics, seals, thermal materials
Life Sciences (nano-biotechnology): crew health, nanomedicine

Possible Areas of Collaboration:
Nanocomposites: Nanotechnology offers self healing capabilities, lightning strike protection (multifunctional capabilities), and high structural strength.
Gas/Energy Storage: We have interest in hydrogen, carbon dioxide, methane, and oxygen gas storage. This has applications for fuel storage for long duration space missions and terrestrial applications for sustainability efforts.
Other Energy Storage: We also have interest in ultra capacitors, fly wheels and batteries.
Energy Generation: Our interests include solar cells, fuel cells, piezoelectrics, and thermoelectric.
Gas Separation: We are interested in areas to more efficiently separate gases for applications such as bioreactors.
• Definition
  – ASTM F42: "process of joining materials to make objects from 3D model data, usually layer upon layer, as opposed to subtractive manufacturing methodologies"
  – Born out of rapid prototyping
  – “Add instead of subtract”

• Why?
  – Put material where you want it
  – Waste less material on chips
  – Make complex geometry
  – Reduce part count
  – Gradient materials
  – “On-demand” from model
## Selected NASA Additive Systems

<table>
<thead>
<tr>
<th>Laser Engineered Net Shaping (LENS)</th>
<th>Electron Beam Free Form Fabrication (EBF3)</th>
<th>Selective Laser Melting (SLM)</th>
<th>Electron Beam Melting (EBM)</th>
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<td>JSC</td>
<td>LaRC</td>
<td>LaRC</td>
<td>MSFC</td>
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<tr>
<td>-Laser</td>
<td>-Electron Beam</td>
<td>- Laser</td>
<td>-Electron beam</td>
</tr>
<tr>
<td>-Gas-delivered powder</td>
<td>-Wire</td>
<td>-Power bed</td>
<td>-Powder bed</td>
</tr>
<tr>
<td>-0.010”</td>
<td>-0.125”</td>
<td>-0.005”</td>
<td>-0.005”</td>
</tr>
<tr>
<td>-Ti, Steel, Inconel</td>
<td>-Al, Ti, Steel, Inconel</td>
<td>-Al, Ti, Steel, etc.</td>
<td>-Al, Ti, Steel, Inconel, etc.</td>
</tr>
</tbody>
</table>

![Novel structures created by LENS](image1)

![Image2](image2)

![Image3](image3)

![Image4](image4)
Fracture Mechanics & Fatigue Crack Growth Analysis Software
www.nasgro.swri.org

Integrated modules with user-friendly graphical interfaces:
• Calculate FCG life, critical crack size, or stress intensity factors
• Store, retrieve, and curve-fit FCG and fracture toughness data
• 2-D boundary element program to calculate SIFs and stresses

New Development Focuses
• Include Mode II and III fracture modes (currently only Mode I)
• Fracture/fatigue models in support of damage tolerance for composites
Structural Analysis Capabilities Within NASA/JSC

James P. Smith, Ph.D.
NASA/JSC/ES2
James.P.Smith@nasa.gov
Software Programs

• NASA/JSC has access to a number of analysis programs for a wide area of analysis
  – Structural design (Pro/Engineer)
  – Pre/post-processors (MSC/PATRAN, I-DEAS)
  – Structural dynamics (MSC/NASTRAN, LS-Dyna, ADAMS, in-house codes for multi-body contact dynamics (flex and/or rigid), in-house codes for coupled loads analysis and modal characterization from service data, AutoSEA)
    • Coupled loads analysis
    • Berthing contact analysis
    • Aeroelastic analysis
    • Random vibration
  – Structural analysis (MSC/NASTRAN, Abaqus, Ansys, I-DEAS, StressCheck)
    • Material yielding
    • Stability analysis
    • Hardware verification
    • Optimization
Treadmill-2/COLBERT Anomaly

- Mis-use by the ISS crew of the COLBERT system caused a suspect condition of the structural integrity of the downstream joint.
- Nonlinear material, geometric, and contact analysis performed to assess if there was reserve capacity in the bracket attach hardware.
ISS Radiator Anomaly

- An anomaly occurred on ISS where a radiator panel sheet separated from the support structure.
- The root-cause analysis utilized LS-Dyna to recreate the problem using fully nonlinear behavior, including tearing.
• In support of the Orion program, a drop test was performed. During the test, a coupling system intended to pull a chute did not separate. A combination of analysis and testing was performed to determine the root cause.
• Contact analysis performed to determine the loads going through bolts holding the halves together and to determine if excessive displacements are a source of binding.
• Flight failure shows evidence of plastic deformation in one of the fasteners.
Extraction Force Transfer Coupling Failure

- Externally applied loads with multi-body contact between finite element models

Slight slipping here

Gap is approximately .036
Orion Support - CM Splashdowns

HS Stress

Case 62234
Time = 0

Case 62337
Time = 0

TO VIEW ANIMATIONS, POWERPOINT MUST BE IN FULL SCREEN “SLIDE SHOW” MODE
Friction Stir Welding and Laser Peening

Omar Hatamleh, Ph.D.
NASA/JSC/ES2
Omar.hatamleh-1@nasa.gov
Friction Stir Welding

• Friction Stir Welding (FSW) is a solid-state metal joining process producing high-strength, defect-free joints in metallic materials. The process employs a pin tool with a low rotational speed and applied pressure that "mechanically stirs" two parent materials together to produce a uniform weld.

• The process employs a pin tool with a low rotational speed and applied pressure that "mechanically stirs" two parent materials together to produce a uniform weld.
• Partnership between NASA, the State of Louisiana, and the University of New Orleans
• NCAM combines education, research, and manufacturing to provide leadership in technology.
• Located in New Orleans, Louisiana at NASA's Michoud Assembly Facility (MAF), which is managed by Marshall Space Flight Center in Huntsville, Alabama
• NCAM has three machines for FSW called the Universal Weld Systems or UWS 1-3, in the order in which they were installed.

Source: http://www.ncamlp.org/about/about.html
FSW at JSC

- JSC equipment includes an MTS FSW Process Development System (PDS)
- The PDS is a fully instrumented research system that is capable of simultaneous force-controlled operation of three independent axes (X, Z, Pin)
- The PDS can do research work and process development for the larger MTS systems at the Michoud Assembly Facility which use the same weld head

NCAM UWS#1 & UWS #2

Capacity
- 16 ft. x 21.5 ft. x 10 ft. of linear motion
- 2 axis of gimbal motion of the weld head
- 30 ft. rotary table with one rotational degree of freedom

http://www.ncamlp.org/technology/fsw-UWS1.html

Capacity
- 40 ft. 10 in. X-Axis x 22 ft. 8 in. Y-Axis x 12 ft. 2 in. Z-Axis of linear motion
- 2 axis of gimbal motion of the weld head
- 22 ft. rotary table with one rotational degree of freedom
- 40 ft. x 20 ft. flat weld area with T-slots

http://www.ncamlp.org/technology/fsw-UWS2.html
NCAM UWS #3

- MTS Robotic Weld Tool (RWT)
- 6-axis integrated weld system
- Capable of fixed pin / retractable pin / self reacting Friction Stir Welds
- Combined axis of motion allows for complex curvature welding
- Control system provides coordinated motion for all 7 axes of the UWS3One of the largest, most advanced FSW machines in the world
- Floor level turntables

Capacity

• 2 axis of gimbal motion of the weld head; pitch: +5° to -95°, roll: ±15°
• Three 20 ft. annular ring rotary tables, each with one rotational degree of freedom
• 20 ft. outer diameter, 15 ft. inner diameter annular turntables with unlimited rotary motion and locking capability
• Two columns, each with an independently operated weld head
• 7 degrees-of-freedom (DOF) delivered through 5 physical axes

<table>
<thead>
<tr>
<th>X-axis</th>
<th>Y-axis</th>
<th>Z-axis</th>
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<tbody>
<tr>
<td>93 ft.</td>
<td>22 ft. 5 in.</td>
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<tr>
<td>Each weld machine</td>
<td>Each weld machine</td>
<td>Each weld machine</td>
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</table>

Note: UWS3 has 2 weld machines that share a common X-rail. Each weld head can access any of the 3 turntables.