Outline

- Review of Engine/Inlet Coupling Work
- Background/Organization of Space Transportation Initiative
- Synergy between High Performance Computing and Communications Program (HPCCP) and Advanced Space Transportation Program (ASTP)
- Status of Space Transportation Effort
  - Planned Deliverables FY01-FY06
  - FY00 Accomplishments (HPCCP Funded)
  - FY01 Major Milestones (HPCCP and ASTP)
- Review Current Technical Efforts
  - Review of the Rocket-Based Combined-Cycle (RBCC)
  - Scope of Work
  - RBCC Concept Aerodynamic Analysis - Dr. Stewart
  - RBCC Concept Multidisciplinary Analysis - Dr. Suresh
Engine Inlet Dynamic Coupling

Comparison of NPARC-ADPAC Solution with Experimental Results

Normalized Static Pressure (Mid-Span)

ADPAC - Advanced Ducted Propfan Analysis Code
NPARC - National Program for Applications Oriented Research in CFD

Results

- Additional blade row was modeled.
- Coupled using unsteady mixing plane technique.
- Simulation results not significantly improved.
- Current effort stopped, documented for possible future reopening.

R1 - Rotor 1
IGV - Inlet Guide Vane
Space Transportation Initiative

Background

• Growing importance of advanced space transportation propulsion systems and simulations to support development & use of advanced space systems.
• Small space transportation simulation effort begun in FY00.
• Evaluation of advanced technologies by Advanced Space Transportation Program (ASTP) highlights importance of advanced system modeling capabilities.
• Computing and Interdisciplinary Systems Office (CISO) proposes for funding under second- and third-generation reusable launch vehicle projects.
  - Third-generation funds
  - Second-generation zeroed-out in FY01 budget
New ASTP Organization

Advanced Space Transportation Program
Garry Lyles, Manager
Steve Clark, Deputy
Eric Hyde, Technical Assistant
Shemy Buschmann, Assistant, Mgr.-Prog. Integration

Business Manager
Janet Crawford (MSFC)

Systems Analysis
Bill Pannell (MSFC)

Program Systems Engineer
Haran Pratt (MSFC)

New ASTP Organization

2nd Generation RLV Investment Area

RLV Focused Project
Shane Swift, Manager (MSFC)
Gary George, Assistant Manager - Rocket
Vacant, Lead/Systems Engineer

Space Liner 100 Investment Area

Uwe Haueter, Manager

Propulsion Technology and Integration Project
John Hub, Acting Manager (MSFC)
Marc Neely, Assistant Manager - Rocket
Craig Arthur, Assistant Manager - Airbreathing
Lance Moore, Airbreathing Lead Engineer
Vacant, Airbreathing Systems Engineer

Propulsion Research and Technology Project
Mark Kern, Manager (GRC)
Catherine McLeod, Assistant Manager

Airframe Technology Project
Dave Bowles, Manager (LaRC)

Launch Technology Project
Scott Jackson, Acting Manager

Operations and Range Technology Project
Dave Taylor, Manager (KSC)

Integrated Vehicle Health Mgmt. Project
Bill Kallie, Manager (ARC)

In-Space Investment Area

Space Transfer Technology Project
Leslie Curtis, Manager (MSFC)
Rae Ann Meyer, Assistant Manager - In-Space
Judy Balzert, Lead Engineer - ProSEDS
Kelly Loomis, ProSEDS Systems Engineer
Lance Harris, In-Space IPA

Propellantless Propulsion Project
Randy Baggett, Manager (MSFC)
Bonnie James, Assistant Manager
Melody Herrmann, Lead/Systems Engineer

Space Transportation Research Investment Area

Adm. Prop. Research Project
John Cole, Manager (MSFC)

Run Lithoford, Lead/Systems Engineer

Breakthrough Prop. Physics Project
Marc Mills, Manager (GRC)

2000 NPSS Review

ASTP Propulsion Story

Second Generation

- Currently cut out of budget by Congress
- Short-term focus — out to FY06
- Huge budget — ~$5B — hardware-oriented
- Four proposal cycles
- Industry-led — hope to team with industry
- Proposed under Cycle 2 — rocket sim. development — still under consideration

Third Generation - SPACELINER100

- Third-generation Spaceliner
- FY01 budget: $445M — foundations — $9.6M
- Mature base (foundation) technologies to enable broad range of concepts to meet Gen 3 goals (FY01-06)
- Mature rocket engine components to enhance T/W, performance, etc. (FY01-06)
- Mature air-breathing components for combined-cycle vehicle thru TRL 6
- Fund university studies to identify new concepts (other than rockets or air-breathers) to meet goal 9

T/W - Thrust to Weight Ratio

2000 NPSS Review
Synergy

- Third-generation reusable launch vehicle funding promised in FY01. Focus on system development:
  - Begin development of rocket engine system simulation
  - Begin development of RBCC system simulation
- HPCCP to focus on high-fidelity and multidisciplinary simulation and prototyping for coupling/zooming/optimization.
- Second-generation reusable launch vehicle funding possible in FY01.
- Future integration.

2000 NPSS Review

Space Transportation Initiative Major Deliverables

<table>
<thead>
<tr>
<th></th>
<th>2000</th>
<th>2001</th>
<th>2002</th>
<th>2003</th>
<th>2004</th>
<th>2005</th>
<th>2006</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>DEMONSTRATE INTEGRATED TECHNOLOGIES (HPCCP)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RBCC Multi-Disciplinary Coupling</td>
<td>Structural thermal analysis of GRC-RBCC engine components</td>
<td>Coupled aerothermal-thermal analysis of joint</td>
<td>Coupled multidisciplinary thermal exhaust systems</td>
<td>Dev. Kit tool release</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pump Multi-Disciplinary Coupling</td>
<td>Unidirectional unsteady aero-structural pump prototype</td>
<td>Bi-directional unsteady aero-structural pump prototype</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Advanced Grid Generation</td>
<td>Beta release for robust hybrid grid code generator</td>
<td>Release grid code as a stand-alone package for Version 1</td>
<td>Grid generation production demonstration and enhancements</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Zooming</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### Space Transportation Initiative Major Deliverables

<table>
<thead>
<tr>
<th>Year</th>
<th>2000</th>
<th>2001</th>
<th>2002</th>
<th>2003</th>
<th>2004</th>
<th>2005</th>
<th>2006</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>ADVANCED SPACE TRANSPORTATION SIMULATION CONCEPTS (ASTP)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>System Simulations</td>
<td>Incremental release of rocket engine simulation</td>
<td>Incremental release of RBCC engine simulation</td>
<td>Incremental release of rocket engine simulation</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>System Simulation Enhancements</td>
<td>Prototype transient rocket capability</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Additional Advanced Capabilities</td>
<td>Enhanced analytical properties package</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Knowledge-Based Engineering</td>
<td>Advanced weight/size calculations</td>
<td>Prototype probabilistic failure prediction - turbopump demonstration</td>
<td>Dev. Kit demonstration</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Prototype development KBE: generation of design geometry of turbopump pump</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Dev. Kit demonstration</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### FY00 Accomplishments and FY01 Milestones

**Accomplishments**
- GRC RBCC concept forebody & boundary layer diverter capability demonstrated.
- Coupled structural-thermal analysis of GRC RBCC inlet demonstrated.
- SRS for space transportation incremental release.
- Acting TFG for space transportation.

**Milestones**
- Coupled aero-structural-thermal analysis of inlet (HPCCP).
- Modify CFD forebody simulation for radiation & skin thermal conductivity (HPCCP).
- Incremental release rocket system simulation (ASTP).
- Formal contractual mechanisms & cooperative agreements in place.
- Space transportation SRS for Version 2 release.

---

SRS - Software Requirement Specification  
TFG - Technical Focus Group  
*2000 NPSS Review*
Technical Effort: Glenn Research Center
RBCC Concept Support (HPCCP)

Motivations

- Requirements in support
  - Complex geometry
  - Physics
  - Accuracy
  - Efficiency
  - Robustness
  - Projects
- Improved multidisciplinary integration of fluid, thermal and structural analysis codes into current design cycles.
- Multidisciplinary analysis well suited to optimization of complete vehicle designs.

Scope

- Prototyping of high-fidelity and multidisciplinary coupling of simulations as a prelude to NPSS tool development.
- Reduction of analysis time.
- Detailed high-fidelity analysis of GRC RBCC concept (GTX).
Rocket-Based Combined-Cycle (RBCC)

Hydrogen fuel injection sites

Translating centerbody

Station 1

Cowl lip

Station 2

Diverter pylon

Station 3

Plug nozzle

Trailing edge of fixed hub containing rocket element

Ramjet duct and nozzle

Forward Spacecraft centerline Aft

2000 NPSS Review
GRC RBCC 3-D Inlet-Forebody Aerodynamic Analysis

Dr. Mark Stewart

2000 NPSS Review

- RBCC, Single-Stage-to-Orbit
- Rocket and Air-Breathing RAM/SCRAM Modes
- Design Questions
  - Diverter performance
  - Forebody boundary layer's effect on inlet

Design point: M=6; altitude=60,000 ft; AOA=4°; Re/t=1.4x10^5
Operating range of interest: M=2.5-10.; AOA=0°
Validation of CFD Solutions

- Comparison with Theoretical Properties
  - Axisymmetry
  - $Y^*$ values

- Comparison with Cone Shock Solutions

- Comparison with Rig 3.1 at AOA=0°; $M=2.0, 2.5, 3.0, 3.5$
  - Forebody boundary layer profiles
  - Forebody static pressure distribution

- Comparison with Independent CFD Solution
Observations

- Results suggest diverter design changes.
- Results clarify some rig results.