2000 NPSS Review

NASA Glenn Research Center
October 4-5, 2000

Space Transportation
Propulsion Systems

Dr. Meng-Sing Liou
Dr. Mark E. Stewart
Dr. Ambady Suresh
Dr. A. Karl Owen

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

**Business Manager**
Janet Crawford (MSFC)

**Systems Analysis**
Bill Pannell (MSFC)

**Program Systems Engineer**
Harlan Pratt (MSFC)

**2nd Generation RLV Investment Area**

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

- Propulsion Technology and Integration Project
  - John Hull, Acting Manager (MSFC)
    - Marc Neely, Assistant Manager - Rocket
    - Craig McArthur, 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 Kahle, Manager (ARC)

**Space Liner 100 Investment Area**

- John Hutt, Acting Manager (MSFC)
  - Marc Neely, Assistant Manager - Rocket
  - Craig McArthur, Assistant Manager - Airbreathing
  - Lance Moore, Airbreathing Lead Engineer
  - Vacant, Airbreathing Systems Engineer

**In-Space Investment Area**

- Leslie Curtis, Manager (MSFC)
  - Carlos Aranda, Assistant Manager - In-Space
  - Vacant, In-Space Lead/Systems Engineer

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

**Space Transportation Research Investment Area**

- John Cole, Manager (GRC)

- Space Transfer Technology Project
  - Leslie Curtis, Manager (MSFC)
    - Bonnie James, Assistant Manager - In-Space
    - Judy Bland, Lead Engineer - ProSEDS
    - Tommy Harris, ProSEDS Systems Engineer
    - Vacant, In-Space IPA

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

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>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>
</tr>
<tr>
<td>RBCC Multi-Disciplinary Coupling</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Structural-thermal analysis of GRC-RBCC effectiveness</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Conduit aerothermal analysis of joint</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Conduit multi-disciplinary computer code</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dev, Kit tool release</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pump Multi-Disciplinary Coupling</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unidirectional unsteady aero-structural pump prototype</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bi-directional unsteady aero-structural pump prototype</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bi-directional unsteady aero-structural pump production</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bi-directional unsteady aero-structural pump Dev, Kit tool</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Advanced Grid Generation</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Beta release for robust hybrid grid code generator</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Release grid code as a stand-alone package for Version 1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grid generation production demonstration and enhancements</td>
<td></td>
<td></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>
</tr>
<tr>
<td>Demonstration of turbopump SS operation zoomed from NPSS rocket sim.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Demonstration of turbopump unsteady operation zoomed from NPSS rocket sim.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dev, Kit demonstration of turbopump unsteady operation zoomed from NPSS</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>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>
</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 RBCC engine simulation</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>System Simulation Enhancements</td>
<td>Prototype transient rocket capability</td>
<td>Incremental release of rocket capability</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Additional Advanced Capabilities</td>
<td>Enhanced analytical properties package</td>
<td>Advanced weighted calculations</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Knowledge-Based Engineering</td>
<td>Prototype probabilistic failure prediction - turbotown demonstration</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 for Scope of Work

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)

- Translating centerbody
- Station 1
- Cowl lip
- Station 2
- Diverter pylon
- Station 3
- Hydrogen fuel injection sites
- Ramjet duct and nozzle
- Plug nozzle
- Trailing edge of fixed hub containing rocket element

Forward

Spacecraft centerline

Aft

2000 NPSS Review

NASA/CP—2001-210673 66
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=80,000 ft; AOA=4°; \( Re/ft=1.4 \times 10^5 \)
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.

2000 NPSS Review