Integrated High Payoff Rocket Propulsion Technologies Program Material Development Plan

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Michael Stropki, AFRL/ML
Brian Stucke, AFRL/ML
Brian Reed, NASA/GRC

4th Conference on Aerospace Materials, Processes, and Environmental Technology
September, 2000
• IHPRPT Goals
• IHPRPT Materials Working Group (IMWG)
• Materials Plan Development
• IMWG PRDA Status
• National Materials Plan for Rocket Propulsion
• Summary
IHPRPT Is . . . .
A DoD / NASA / Industry Initiative Which Will “Double” Rocket Propulsion Capability by 2010

September, 2000
## IHPRP Goals

### Boost and Orbit Transfer Propulsion

<table>
<thead>
<tr>
<th>Goal</th>
<th>2000</th>
<th>2005</th>
<th>2010</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reduce Stage Failure Rate</td>
<td>25%</td>
<td>50%</td>
<td></td>
</tr>
<tr>
<td>Improve Mass Fraction (Solids)</td>
<td>15%</td>
<td>25%</td>
<td>35%</td>
</tr>
<tr>
<td>Improve ISP (sec)</td>
<td>14</td>
<td>21</td>
<td>26</td>
</tr>
<tr>
<td>Reduce Hardware Costs</td>
<td>15%</td>
<td>25%</td>
<td>35%</td>
</tr>
<tr>
<td>Reduce Support Costs</td>
<td>15%</td>
<td>25%</td>
<td>35%</td>
</tr>
<tr>
<td>Improve Thrust to Weight (Liquids)</td>
<td>30%</td>
<td>60%</td>
<td>100%</td>
</tr>
<tr>
<td>Mean Time Between Removal (Mission Life-Reusable)</td>
<td>20</td>
<td>40</td>
<td>100</td>
</tr>
</tbody>
</table>

### Spacecraft Propulsion

<table>
<thead>
<tr>
<th>Goal</th>
<th>2000</th>
<th>2005</th>
<th>2010</th>
</tr>
</thead>
<tbody>
<tr>
<td>Improve $I_{\text{tot}}/\text{Mass}_{\text{wet}}$ (Electrostatic/Electromagnetic)</td>
<td>20%/200%</td>
<td>35%/500%</td>
<td>75%/1250%</td>
</tr>
<tr>
<td>Improve ISP (Bipropellant/Solar Thermal)</td>
<td>5%/10%</td>
<td>10%/15%</td>
<td>20%/20%</td>
</tr>
<tr>
<td>Improve Density-Isp (Monopropellant)</td>
<td>30%</td>
<td>50%</td>
<td>70%</td>
</tr>
<tr>
<td>Improve Mass Fraction (Solar Thermal)</td>
<td>15%</td>
<td>25%</td>
<td>35%</td>
</tr>
</tbody>
</table>

### Tactical Propulsion

<table>
<thead>
<tr>
<th>Goal</th>
<th>2000</th>
<th>2005</th>
<th>2010</th>
</tr>
</thead>
<tbody>
<tr>
<td>Improve Delivered Energy</td>
<td>3%</td>
<td>7%</td>
<td>15%</td>
</tr>
<tr>
<td>Improve Mass Fraction (Without TVC/Throttling)</td>
<td>2%</td>
<td>5%</td>
<td>10%</td>
</tr>
<tr>
<td>Improve Mass Fraction (With TVC/Throttling)</td>
<td>10%</td>
<td>20%</td>
<td>30%</td>
</tr>
</tbody>
</table>

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September, 2000
Benefits from Achieving Goals (1)

- Payoffs in increased capability, increased reliability and reduced cost are enormous.

- Achievement of the technology goals would provide the following possibilities for system performance improvements:
  
  - Increase from 25k pounds payload to 65k pounds on a reusable launch vehicle.
  - 92% increase in payload on an expendable launch vehicle.
  - Average annual savings of $648M per year for space launch (based on the National Mission Model over 20 years with Atlas, Delta, Titan IV and Shuttle and including operations cost, hardware costs and cost of failure).
  - 45% increase in satellite life (approximately $240M/satellite savings).
  - 500% increase in satellite repositioning.
  - 100% increase in range/payload capability for a tactical missile.

(1) Information from IHPRPT Point Paper by Dr. Robert C. Corley.
IHPRPT Materials Working Group (IMWG) Activities

**Feb 97** Materials Working Chartered by IHPRPT Steering Committee

**Mar 97** Working Group Membership Established

**Apr 97** Status Brief to ODDRE

**May 97** Inaugural Meeting of IMWG

**Jun-Sep 97** Review/Analysis of ARPP’s & 48 SBIR Evaluations

**Aug 97** IHPRPT Materials DTO MP.29.01 Established

**Oct 97** NASP Lessons Learned Workshop & 2nd Meeting of IMWG

**Jan 98** 3rd IMWG Meeting & Status Brief to ODDRE

**Feb 98** DTO Briefing at Reliance Meeting

**Feb 98** Brief to IHPRPT Steering Committee

**May 98** 4th IMWG Meeting

**Jun 98** Status Brief to ODDRE

**Jul 98** Brief to IHPRPT Steering Committee

**Nov 98** IMWG Chair Meetings at Industry Sites

**Dec 98** DTO Briefing at Reliance Meeting

**Jan 99** Status Brief to ODDRE

**Feb 99** Brief to IHPRPT Steering Committee & Reliance

**Jun 99** IMWG Weekly Telcons

**Jul 99** Brief to IHPRPT Steering Committee

**Oct 99** IMWG - Component Lead Meeting

**Feb 00** Brief to IHPRPT Steering Committee

**Mar 00** Execution/PRDA Development Meeting

**May 00** Materials PRDA Released
IHPRPT Materials Working Group

**Process**
- Evaluate Requirements and Develop Materials Plan for IHPRPT Liquid, Solid, and Spacecraft Propulsion Goals
- Co-Chairs: AFRL - Michael Stropki; & NASA-MSFC - Corky Clinton

**Team**

**Government**
- **USAF**: AFRL Materials & Manufacturing Directorate (ML); Propulsion Directorate (PR)
- **Army**: ARL, MCOM
- **Navy**: NAWC, NSWC
- **NASA**: MSFC, GRC, LaRC

**Industry**
- ARC
- Aerojet
- Alliant
- Boeing/Rocketdyne
- Kaiser-Marquardt
- Primex
- Thiokol
- TRW
- UT Chemical Systems
- UT Pratt & Whitney

Considering Addition of Materials Suppliers

**Product - Materials Plan**

**Materials Weight, Durability, & Performance Improvements For**

- Turbopump Housing
- Ducts, Line, Valves
- Thrust Chamber
- Nozzles
- Chamber
- Catalyst/Thermal Bed
- Optics(Grids)
- Case / Insulation
- Exit Cone
- Nozzle
- Throat
- Solids: B&OT/Tactical
- Materials Plan for IHPRPT Developed
  - Developed by IHPRPT Materials Working Group (IMWG)
  - Addresses Liquids, Solids, Spacecraft, Tactical Components
  - Category Prioritization Developed with Industry and Government Representatives - Continuing Iterative Process

- Air Force Funding Allocated for Materials Development

- Formula for Program Execution (Iterative Process)
  - Materials Execution/Funding Allocation per IMWG Plan
  - Coordinate with IHPRPT Component Leads
  - Coordinated with NASA Plans in Materials Technology for Integrated Space Transportation Plan (ISTP) (Currently part of IMWG process)
  - IHPRPT Steering Committee Approval
  - Execute Plan Through AFRL/ML PRDA Process

September, 2000
• Materials and Processes Science & Technology Program (Not Component Development)
  – Up to sub-scale development as required
  – Component development *not* part of this M&P program

• IMWG Materials Program Has Transition Path to Component Program (Traceability) Through IHRPPT Component Leads

• Materials Vendors /Propulsion Primes to Be Contractually Connected Through PRDA

• Program Maintains Flexibility to Allow for:
  – New developments in materials and processes
  – Adjustments to materials and processes maturation
  – Phase III initiatives (i.e., new starts)
Materials Plan Development
IHPRPRT M&P Program Progression

Critical Component Requirements
- Determine/Coordinate on Key Components
- Assess Materials Requirements
- Combined DOD, NASA, Industry Activities
- Use ARPP, Tech. Leads, IMWG

Scale-up, Property Verification, Component Dev
- Take THE Best Materials Approach; Scale-up Process to Verify
  - Material Uniformity
  - Thermal, Physical and Mechanical Properties
  - Process Reproducibility
  - Failure Mechanisms
- IHPRPRT Scale Up
  - Refine Design
  - Produce Full Scale Components
  - Further Define Component Failure Mechanisms
  - Provide Component for Demonstration Testing
- Validate Demonstration Exit Criteria for Demo Testing

M & P Dev/Subscale Demonstration
- Develop/Characterize Materials Based on the Assessment
  - Process Development/Evaluation
  - Preliminary Configuration Assessment
  - Measure Preliminary Thermal and Mechanical Properties
  - Conduct Environmental Assessment
  - Assembly Considerations
- Subscale Component Demonstration/Validation

Component Verification
- The M & P Technology Transition to IHPRPRT Demo Team
  - Process
  - Properties
  - Subcomponent Performance
  - Failure Mechanisms
- Participate in Component Demo Phase ATD Development

September, 2000
IHPRPT Materials Plan

2000

Examples from Plan Development Process
## IMWG Program Support To Propellant Management Devices (PMD)

### COMPONENTS

<table>
<thead>
<tr>
<th>COMPONENT</th>
<th>CANDIDATE MATERIALS PROGRAMS</th>
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</thead>
<tbody>
<tr>
<td>HIGH</td>
<td></td>
</tr>
<tr>
<td>HOUSING - Ox Compatible</td>
<td></td>
</tr>
<tr>
<td>HOUSING - LH2 Compatible</td>
<td></td>
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<tr>
<td>LINES, DUCTS &amp; VALVES</td>
<td></td>
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<tr>
<td>MED</td>
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<tr>
<td>ROTATING ELEMENTS</td>
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*Other M&P Critical Needs May Emerge for Phase II & III Based on Iterative Process*
## Oxygen-Rich Turbopump Housing

<table>
<thead>
<tr>
<th>Component Objectives</th>
<th>Material Candidates</th>
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<tbody>
<tr>
<td>Oper. Temp</td>
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</tr>
<tr>
<td>Ultimate Strength (Long./Trans)</td>
<td>• Candidate A</td>
</tr>
<tr>
<td>Shear Strength (Long/Trans)</td>
<td>• Candidate B</td>
</tr>
<tr>
<td>Elastic Modulus (Long/Trans)</td>
<td></td>
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<tr>
<td>Shear Modulus</td>
<td></td>
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<tr>
<td>Poisson’s Ratio</td>
<td></td>
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<tr>
<td>Fracture Toughness</td>
<td></td>
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<tr>
<td>Thermal Shock</td>
<td></td>
</tr>
<tr>
<td>Density</td>
<td></td>
</tr>
<tr>
<td>CTE (Long/Trans)</td>
<td></td>
</tr>
<tr>
<td>Elastic Modulus (Long/Trans)</td>
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<td>Shear Modulus</td>
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<td>Thermal Shock</td>
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<tr>
<td>Density</td>
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<tr>
<td>CTE (Long/Trans)</td>
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</table>
**Candidate Material A**

### Current Properties

- Very little data developed to date
- Demonstrated oxidation resistance
- Limited matrix strength and ductility data available

### Technical Issues / Risks

- Demonstrate oxidation resistance and promoted combustion resistance; mech properties, characterization
- Establish design and analysis methodology; data
- Develop interfaces and attachment approaches
- Fabricate sub scale components
- Validate life/performance

<table>
<thead>
<tr>
<th>Current Tasks</th>
<th>Total($K)</th>
<th>ORG</th>
<th>FY99</th>
<th>FY00</th>
<th>FY01</th>
<th>FY02</th>
<th>FY03</th>
<th>FY04</th>
<th>FY05</th>
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<tr>
<td>Metal Matrix Composite -</td>
<td>XXX</td>
<td>NASA</td>
<td>XXX</td>
<td>XXX</td>
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<tr>
<td>Turbopump Demo</td>
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<td></td>
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<tr>
<td>NASA-SBIR</td>
<td>XXX</td>
<td>NASA</td>
<td>XXX</td>
<td>XXX</td>
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**Total Current**

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**Planned M&P Programs**

- D&A to Est. Requirements
- Develop Interfaces and attachments
- Examine alternative approaches/materials
- Validate life/performance

**PRDA Task TBD**
IMWG PROGRAM SUPPORT TO Combustion and Energy Conversion Devices (C&ECD)

**COMPONENT**  | **CANDIDATE MATERIALS PROGRAMS**
---|---
**HIGH**  
LT WGT THRUST CHAMBER (Ph II & III)  |  
**MED**  
HI TEMP COMPOSITE TECHNOLOGY (NOZZLE)  |  

Other M&P Critical Needs May Emerge for Phase II & III Based on Iterative Process
<table>
<thead>
<tr>
<th>COMPONENT</th>
<th>CANDIDATE MATERIALS PROGRAMS</th>
</tr>
</thead>
<tbody>
<tr>
<td>NOZZLE</td>
<td><em>Programs that will apply to Tactical and to B/OT</em></td>
</tr>
<tr>
<td>- Low-Eroding Throats</td>
<td></td>
</tr>
<tr>
<td>INSULATION</td>
<td></td>
</tr>
<tr>
<td>CASE</td>
<td></td>
</tr>
<tr>
<td>NOZZLE</td>
<td></td>
</tr>
<tr>
<td>- Low Cost Components</td>
<td></td>
</tr>
<tr>
<td>CASE</td>
<td></td>
</tr>
<tr>
<td>NOZZLE</td>
<td></td>
</tr>
<tr>
<td>- Exit Cone Ablative</td>
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</tbody>
</table>
IMWG Program Support To Spacecraft

COMPONENT

HIGH

CATALYSTS

ION ENGINE
OPTICS

CHAMBER MATLS

CANDIDATE MATERIALS PROGRAMS
IMWG PRDA Status
### IHPRPT Materials PRDA Schedule

<table>
<thead>
<tr>
<th>Mar</th>
<th>Apr</th>
<th>May</th>
<th>Jun</th>
<th>Jul</th>
<th>Aug</th>
<th>Sep</th>
<th>Oct</th>
<th>Nov</th>
</tr>
</thead>
<tbody>
<tr>
<td>PRDA Dev</td>
<td>PRDA Approval &amp; Release</td>
<td>White Papers Received</td>
<td>White Papers Reviewed</td>
<td>Letters to Contractors &amp; 2nd PRDA Release</td>
<td>Proposals Received</td>
<td>Tech Eval Completed</td>
<td>PR’s Complete</td>
<td>Negotiations and Award</td>
</tr>
<tr>
<td>Mar 23 (Workshop 21 &amp; 22)</td>
<td>May 26</td>
<td>June 30</td>
<td>July 21</td>
<td>July 28</td>
<td>Aug 30</td>
<td>Sep 30</td>
<td>Oct 15</td>
<td>DEC ‘00</td>
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</table>

September, 2000
### Liquid Boost and Orbit Transfer

<table>
<thead>
<tr>
<th>Topic</th>
<th>Team</th>
<th>Topic Lead</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. LOX Turbopump Housing</td>
<td>AFRL/ML/PR, NASA MSFC, NASA LaRC, NASA GRC</td>
<td>Benji Maruyama</td>
</tr>
<tr>
<td>2. LH2 Turbopump Housing</td>
<td>AFRL/ML/PR, NASA MSFC, NASA LaRC, NASA GRC</td>
<td>Benji Maruyama</td>
</tr>
<tr>
<td>4. Thrust Chamber Jacket</td>
<td>AFRL/ML/PR, NASA MSFC, LaRC, GRC</td>
<td>Dan Miracle</td>
</tr>
</tbody>
</table>
# IMWG PRDA Topics

**Solid Rocket Motor Boost & Orbit Transfer/Tactical**

<table>
<thead>
<tr>
<th>Topic</th>
<th>Team</th>
<th>Topic Lead</th>
</tr>
</thead>
<tbody>
<tr>
<td>7. Insulation and Case</td>
<td>AFRL/ML/PR, NASA MSFC, Aerospace Corp.</td>
<td>Derek Linco</td>
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</tbody>
</table>

**Spacecraft**

<table>
<thead>
<tr>
<th>Topic</th>
<th>Team</th>
<th>Topic Lead</th>
</tr>
</thead>
<tbody>
<tr>
<td>8. Catalyst/Thermal Bed</td>
<td>AFRL/ML/PR, NASA GRC</td>
<td>Steve Steel</td>
</tr>
<tr>
<td>9. Optic Grid</td>
<td>AFRL/ML/PR, NASA GRC</td>
<td>Kristen Kearns</td>
</tr>
<tr>
<td>10. Oxidation Resistant Chamber Mat.</td>
<td>AFRL/ML/PR, NASA GRC</td>
<td>Kumar Jata</td>
</tr>
</tbody>
</table>
IMWG PRDA Status
OMC Study for Phase III Applications

• OBJECTIVES:
  • Assess OMC technology for feasibility of application to Liquid Propulsion Components. (LH2 turbopump housings, lines, ducts, valves and a thrust chamber structural jacket identified in materials plan for Phase III development).
  • Provide assistance in determining scope and direction to future DOD and NASA investment in OMC’s for liquid propulsion components.
  • Performed by a “Blue Ribbon” materials and processes group including propulsion expertise with no affiliations to an organization that could bid on topics in a future IHPRPT Materials OMC PRDA.
  • Posture for timely Materials PRDA II (6 month duration).
  • Present findings at appropriate space materials or propulsion conference (e.g. NSMMS).
National Materials Plan
for
Rocket Propulsion
• Under IMWG Initiative, Developing Strategy and Process for Coordinating IHPRPT Materials Plan with NASA Materials Planning for ISTP.

• Product will be a Joint IHPRPT - ISTP Materials Development Roadmap.

  – Maximize use of resources (avoid duplication).
  – Provide opportunities for cooperative programs.
  – Rebuild National leadership in propulsion technology.
Coordination of IMWG and NASA ISTP efforts towards development of the National Rocket Propulsion Materials Plan is in progress.

- Key NASA materials experts participation on IMWG Technical Teams for PRDA drafting and white paper evaluation.
- NASA/MSFC has assigned specific responsibility for 2nd Gen/3rd Gen RLV synergistic technologies coordination to the RLV Focused Technology Project.
- Dissemination of 3rd Generation RLV Program planning results to IMWG PRDA Technical Teams supporting white paper evaluation (in progress).
- NASA-led 2nd Generation RLV proposals will be assessed for potential overlap with IMWG white papers (in progress).
- Industry-led 2nd Generation RLV proposals will be assessed for potential overlap with IMWG proposals.

September, 2000
1. DOD (AF) Funds IMWG PRDA for IHPRPT Materials Requirements
2. NASA Augments Funding or Specific Tasks for Increased NASA Materials Requirements
3. NASA Funds NRA for ISTP Unique Requirements (Focused on 2nd & 3rd generation goals)
4. IMWG Develops Joint Materials Roadmap as Part of IMWG Plan

September, 2000
National Materials Plan for Rocket Propulsion
NASA ISTP - IMWG

Current Activity

IHPRPT Materials Plan

PRDA Developed by AF/Navy - NASA Team

PRDA Released 29 May 00

Final Proposal Review in Progress by AF/Navy - NASA Team

Under the Auspices of the IHPRPT and ISTP Programs

Strategy

Utilizing AF/Navy - NASA Engineers to Develop Plans, Prepare Solicitations, and Evaluate Proposals

Review Requirements and Approaches for Areas of Commonality

NASA ISTP Planning

Third Generation RLV Planning May 00

NASA-Led Second Generation RLV Proposals July 00

Industry-Led Second Generation RLV Proposals Fall 00

September, 2000
National Materials Plan for Rocket Propulsion
NASA ISTP - IMWG
Next Steps

IHPRPT Materials Plan

Recommendations Addressing Opportunities and Development of Joint Roadmaps Led by the DOD-NASA IHPRPT Materials Working Group

Develop Joint Roadmaps that Reflect:
- Joint opportunities
- Funding
- Milestones
- Transition

Leveraging - thru industry contracts
Collaboration - information sharing
Joint Projects - Joint funds on project
Project Enhancement - applying funds to existing contract

“National Materials Plan” for Rocket Propulsion

Linkage/Input to Joint Roadmap
Development/National Plan through NASA IMWG Representative(s)

NASA ISTP Plan

September, 2000
Summary

• IMWG Government and Industry Members, Together With the IHPRPT National Component Leads, Have Developed a Materials Plan to Address the Critical Needs of the IHPRPT Community.
  – Liquids Boost and Orbit Transfer.
  – Solids Boost and Orbit Transfer.
  – Tactical.
  – Spacecraft.
• Criticality of Materials’ Role in Achieving IHPRPT Goals Evidenced by the Significant Investment Over the Next 5 Years.
• Materials Plan Is a “Living” Document to Assure Appropriate Focus and Progress.
• Excellent Response to IMWG PRDA With 50 White Paper Proposals Received for the 10 Topic Areas.
  – Final Reviews in Progress.
• National Rocket Propulsion Materials Plan, Coordinating IHPRPT and NASA Activities, Being Developed by IMWG.