Rocket Propulsion for the 21st Century (RP21)

Partners in Rocket Propulsion Technology Development
## RP21 Goals

### Boost and Orbit Transfer Propulsion

<table>
<thead>
<tr>
<th>Goal</th>
<th>2017</th>
<th>2027</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reduce Stage Failure Rate* (RP)</td>
<td>75%</td>
<td>75%</td>
<td>Baseline (B)</td>
</tr>
<tr>
<td>Improve Mass Fraction (Solid)</td>
<td>18%</td>
<td>38%</td>
<td>5%</td>
</tr>
<tr>
<td>Increase ISP % (Solid/Liquid* (RP))</td>
<td>2%/0%</td>
<td>5%/4%</td>
<td>1%/B</td>
</tr>
<tr>
<td>Increase Thrust to Weight % (Liquid, (RP))</td>
<td>103%</td>
<td>103%</td>
<td>10%</td>
</tr>
<tr>
<td>Reduce Engine Turn Time (Reusable)</td>
<td>&lt;8hrs</td>
<td>&lt;4hrs</td>
<td>B</td>
</tr>
<tr>
<td>MTBO/MTBR (Missions, Liquid)</td>
<td>50/100</td>
<td>50/100</td>
<td>10%</td>
</tr>
<tr>
<td>Decrease Motor Health State Uncertainty</td>
<td>20%</td>
<td>50%</td>
<td>10%</td>
</tr>
</tbody>
</table>

### Spacecraft Propulsion

<table>
<thead>
<tr>
<th>Goal</th>
<th>2017</th>
<th>2027</th>
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</tr>
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<tbody>
<tr>
<td>Increase Efficiency (ET/ES/EM)</td>
<td>15%/15%/10%</td>
<td>65%/35%/30%</td>
<td>B/B/B/B</td>
</tr>
<tr>
<td>Decrease EP System Dry Mass (ET/ES/EM)</td>
<td>0%/50%/50%</td>
<td>75%/90%/90%</td>
<td>B/B/25%</td>
</tr>
<tr>
<td>Decrease Flexible Prop. System Wet Mass</td>
<td>35%</td>
<td>65%</td>
<td>B</td>
</tr>
<tr>
<td>Increase Chemical Prop. Density Isp</td>
<td>5%</td>
<td>15%</td>
<td>&lt;1%</td>
</tr>
<tr>
<td>Decrease Chemical Prop. Dry Mass</td>
<td>10%</td>
<td>40%</td>
<td>B</td>
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</table>

### Tactical Propulsion*

<table>
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<th>Goal</th>
<th>2017</th>
<th>2027</th>
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</tr>
</thead>
<tbody>
<tr>
<td>Increase Total Impulse (RS&amp;Smokey/MS)</td>
<td>20%/33%</td>
<td>35%/45%</td>
<td>B</td>
</tr>
<tr>
<td>4 Pulse motors</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RS/Smokey Total Impulse Penalty</td>
<td>10/0</td>
<td></td>
<td>B</td>
</tr>
<tr>
<td>Minimum Smoke Increase Total Impulse</td>
<td>5%</td>
<td>25%</td>
<td>B</td>
</tr>
<tr>
<td>Increase Density Isp</td>
<td>5%</td>
<td>7%</td>
<td>B</td>
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* Additional Backup goal information exists

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PA Clearance Number 16272

Distribution A: Approved for public release; distribution unlimited
Liquid Propulsion
USET
(Upper Stage Engine Technology Program)

- Validated new suite of LOx/Hydrogen rocket engine M&S tools through heavily-instrumented 4,000 hp, 90,000 rpm turbopump
- Risk reduction work, up’d TRL of components allowing SMC/LR NGE program to enter post-milestone B, saving years on the schedule and $multi-M’s in cost
- Verified and Validated suite of tools to greatly reduce the amount of physical testing by conducting better M&S during design
- NGE with SMC/LR and tools used in current NGE risk reduction work, Hydrocarbon Boost, >45 M&S tool-specific transitioned to industry, DOD, NASA

In-House:
- Test stand Buildup
  - Design of new facility hardware
  - Hardware Fabrication
  - Hardware Installation
- In-house tool validation and verification
- On-site rapid data reduction and analysis

The WOWs:
- SMC/LR requested TTP transition to NGE
  - Key member of AUSEP (Affordable Upper Stage Engine Program) IPT
  - Conducted Risk Reduction work on USET contract to support AUSEP TRL requirements
  - Most highly instrumented, highest tip speed and suction of any turbopump ever tested

Program Complete
**HC Boost**  
(Hydrocarbon Boost Program)

<table>
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<tr>
<th>• HCB establishes advanced, modern, domestic LRE Tech Base</th>
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<tr>
<td>- Establishes Ox-Rich Staged Combustion (ORSC) tech base for U.S.</td>
</tr>
<tr>
<td>- Required to replace Russian RD-180 on EELV</td>
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<tr>
<td>- Support industry, high-risk replacement effort of RD-180</td>
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<tr>
<td>- Combustion modeling &amp; validation</td>
</tr>
<tr>
<td>- Fuel thermal stability, engine cooling, injector design</td>
</tr>
<tr>
<td>- Subscale preburner being tested</td>
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<th>The WOWs:</th>
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<tr>
<td>- Design, build, test ORSC LOx/Kerosene Liquid Rocket Engine Tech Demonstrator</td>
</tr>
<tr>
<td>- 250K-lbf with high Throttle Capability (SOTA is 2:1) – Enables mission flexibility</td>
</tr>
<tr>
<td>- ORSC is a higher performing engine resulting in a smaller launch vehicle or an increase in delivered payload</td>
</tr>
<tr>
<td>- We are only gov’t lab doing Liquid Rocket Engine R&amp;D for launch needs</td>
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Solid Propulsion
Goals: Reduce predictive uncertainty of future state of a motor on an individual basis by 20%/50% (near/far term goals)

Sensors
- to include: temperature, humidity, case damage, propellant slump, acceleration, and TVA displacement and load

Initial state and inspection data

Data processing and storage

Analysis

Command & control

First integration of motor specific sensor data to advanced aging models to provide a individualized service life estimate

In-House:
- Validation of A&S modeling capability
- AFNWC funded supported for ANDES improvement (Automated NDE Data Evaluation System)

The WOWs
- Potential to provide millions in cost avoidance
- Provide accurate, near-real-time motor health condition (diagnostics)
- Provide individualized service life estimates (prognostics)
- Transition opportunity ~ 2018
What are we doing? Developing new solid rocket motor (SRM) components and M&S tools that decrease inert weight by 20%.

Tech Reason? New M&S tools may show possibility of higher efficiencies from SRM designs.

Transition? Working directly with the AF Nuclear Weapons Center to insert new capabilities.

In-House: Experiments to validate new models

The WOWs
- The AFNWC propellant task is part of a plan that may save $2.1B in future acquisition costs
- We are only gov’t lab doing solid rocket motor R&D for launch & strategic needs
In-Space Propulsion
Electric Propulsion

What are we doing? Developing new technologies that enable less expensive, more maneuverable and more agile s/c

Customer Why? Reducing launch mass substantially reduces launch cost, increases payload fraction, and enables missions otherwise not possible (e.g. AEHF)

Tech Reason? Plasma propulsion increases Isp by 10x, reducing s/c propellant 10x, enabling lighter and/or more capable s/c

Transition? • Tech demos: FalconSat-5–demonstrated low power propulsion and spacecraft impact
• Operational systems: AEHF–enabling high mass spacecraft directly supporting warfighter

In-House:
• Test facilities
• 8 vacuum chambers
• Thruster design
• Diagnostics
• Validation of M&S
• Mod/Sim Program
• Advanced numerical methods

AEHF SV2 Sensor Package

The WOWs:
• AEHF requested assistance with thruster performance verification; flew SV-2 onboard diagnostics package
• AFRL-modified HET baselined for future AEHF satellites
AFRL Developed Advanced Monopropellants

What are we doing? Providing advanced propellant with higher performance and much lower toxicity than hydrazine

Customer why? Faster operational response with reduced costs can be attained with greater mission capabilities

Tech Reason? Energetic ionic liquids provide low vapor toxicity and high energy density

Transition? NASA GPIM flight in 2015

In-House:
- Fully characterized small scale safety & hazard properties
  - Passes all safety requirements
  - DOT approval for transport
- First successful thruster firings
- Pilot scale propellant production
  - Advanced monopropellant cost = hydrazine cost
  - Supplying transition programs

Small Spacecraft Benefits Trade Analysis

- NTO/MMH Bipropellant
- AFRL Advanced Monopropellant
- Hydrazine Monopropellant

Advanced monoprops can perform like bipropellant in small craft!

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Where Are We Going Next?

Address National Deficiencies/Customer Needs

- Refocus on future needs (cost, manufacture, scale, time)
- Liquid Rocket Engines: Modular Rocket Engine
- Solid Rocket Motors: Post-Boost Control Systems (PBCS)

  Tactical (AFRL/RW, ATBT, Japan DEA/PA)

- In-Space: Tech Demo Restoration, FRCs vs. Electrospray Thrusters, Bipropellant Thrusters

- In-house: Sub-scale Integrated SRM Demos, Composites Facility for SRMs, SRM Diagnostics & Combustion M&S, Continuous Flow Reactors, Continuous Flow Mixers, 6.1 RDEs for in-space & LREs, expansion of world-class injector facility