Electrified Aircraft Propulsion (EAP) Educational Briefing

12/19/2018

M. Deans, R. Jansen, P. Loyselle, S. Schnulo, C. Smith, I. Delgado
National Aeronautics and Space Administration - Glenn Research Center

C. Stelter
National Aeronautics and Space Administration - Langley Research Center
Agenda

- Guidelines/Rules
- Proposal Best Practices
- Overview of NASA’s Vision for Electrified Aircraft Propulsion (EAP)
- Overview of the needs in the specific area of battery technology, as it relates to EAP
- Overview of the needs in the specific area of additively-manufactured, multi-functional heat exchanger technology, as it relates to EAP
Guidelines/Rules
Discussion Guidelines/Rules

• This is an educational brief and includes discussions of general programmatic goals
  — NASA will not discuss if/how any of these goals are included in a given ongoing or forthcoming solicitation
  — For any solicitation, please refer to the goals/metrics stated within those requests for proposals (RFPs)/solicitations; proposals must be responsive to the stated requirements of those specific solicitations and not to any other stated or perceived need
  — Forthcoming solicitations may also contain other guidance, technical needs, and or challenge areas; please review solicitations fully

• Because of pending/formulating proposals, NASA will not assess, prioritize, discuss, or answer questions on proposed or ongoing technologies/solutions by those in this forum
  — Also note that this is an open forum with others in attendance
Proposal Best Practices
Small Business Innovation Research (SBIR) & Small Business Technology Transfer (STTR) Programs - Overview

• Because of ongoing/pending/future proposals/solicitations, specifics of the SBIR/STTR solicitation will not be discussed in this forum

• SBIR is a Small Business set-aside program for Federal R&D – including potential for commercialization

• STTR is a sister program for cooperative R&D between small business concerns and U.S. research institutions – including potential for commercialization

• For more information on NASA’s SBIR/STTR program, please see https://sbir.nasa.gov/
  – The next Phase I solicitation cycle is anticipated to start in ~early to mid January
  – Note that public listings of past awards and companies are searchable at https://sbir.nasa.gov/advanced_search

• See the Small Business Administration website for additional helpful information including links to other agency SBIR sites/solicitations: https://www.sbir.gov/
The proposal process begins right now, not after the solicitation is released.

Writing a winning a proposal is a long term process that involves:
- Understanding the needs and interests of NASA
- Interacting with the technical community
- Reading the solicitation carefully
  - Do not assume it is the same as last year
  - Reread it again, your competition did

Provide all of the required information, forms, and surveys

Make sure you properly address all of the listed evaluation criteria from the solicitation
  - Organize it in a way that makes it clear to the reviewers

Explain (early and concisely) how your effort will benefit NASA interests.
SBIR/STTR Proposal – Writing Responsive Proposals

• Know your Vision
  — Target your work/proposal to the appropriate subtopic – be responsive

• Know the Context
  — Read the solicitation carefully
  — Understand the scientific and technological importance of your idea (who cares, big picture)
  — Understand the programmatic relevance of your idea
  — Use National Academy reports, conference reviews, NASA Strategic Plans, Roadmaps for guidance

• Justify Why You and Not Somebody Else
  — Justify and clearly define your firm and roles of the team

• Define the State of the Art
  — Demonstrate your grasp of the field; offer a short, well-researched overview of relevant science and technology; cite key references
  — Demonstrate an understanding of the state of the art and how you will advance it
Describe Your Contribution
- What will your work contribute to the field? Scientific knowledge, increased capabilities, applications to NASA’s missions?
- Don’t over-claim or over-reach; justify the claimed factors of gains

Defend Your Proposal
- Can you do the job on schedule/budget?

Understand and Respect Your Audience
- Make sure your abstract, charts, etc. are clear/concise; make it so the reviewer can easily identify the information for the evaluation criteria
- Make sure you address all selection criteria; somebody will be checking
- Make your key idea clear; repeat
- Neatness, including spelling and grammar, counts
- Reviewers are NASA subject matter experts; they understand the field and technical area but may not already know the details of your specific innovation, especially if it differs significantly from the state of the art
A competitive proposal will clearly and concisely:

- Describe the proposed innovation **relative** to the **state of the art** AND the relevance/significance of the proposed innovation to the **needs of the subtopic**
  - Compare your anticipated/target metrics vs. the state of the art; **state both**
  - State how your metrics address the subtopic metrics/goals; if improving a different subcomponent metric that feeds into improvements on the stated subtopic metric or goal, discuss how these metrics are **derived/involved**

- Address the scientific, technical, and commercial merit and feasibility of the proposed innovation, and its relevance and significance to NASA interests.
  - State what the known **risks/challenges** are and **how** your innovation and/or development plan will **address** them
  - Work Plan: **What** will be done, **where** it will be done, and **how** the R/R&D will be carried out
    - Clear development plan with clear metrics and decision gates where appropriate
  - For all of these, describe also the ‘**why**’
A competitive proposal will clearly and concisely (continued):

- Provide a strategy to address technical, market, and business factors pertinent to the development, demonstration, and transition into products and services for NASA mission programs, the commercial aerospace industry, and other potential markets and customers.
  - Is there a demonstrated understanding of what is needed to *infuse* this concept?
  - End-applications may inform what key developments are needed and justify approach.
  - Is your design and development/test plan *informed by end-applications* to justify further investment and *encourage transition* to use?
  - Do *key* milestone *tests* and *prototypes/deliverables justify* continued investment/acceptance of the technology?
  - Is your development lifecycle within and beyond this development program *continuous* or does it leave *gaps*?

STTR: Provide information to convince NASA that the cooperative effort is a sound approach for *converting* technical information resident at the Research Institution (RI) into a *product or service* that meets a need described in a Solicitation research topic.
References:

• For source material for this presentation and additional guidance, please see the SBIR website; one helpful tool is the interactive participation guide and links therein: https://sbir.nasa.gov/guide

Overview of NASA’s Vision for Electrified Aircraft Propulsion (EAP)
41,030 New Aircraft Deliveries
$6.1 Trillion Market Value
Asia-Pacific Market is Nearly 40% of New Aircraft Deliveries
78% of New Aircraft Deliveries are Single Aisle Class (including Regional Jets)
New Market for Urban Air Mobility

Top 20 Megacities

- New York, USA 20.6M
- Moscow, Russia 16.1M
- Delhi, India 24.9M
- Beijing, China 21M
- Osaka-Kobe-Kyoto, Japan 17.4M
- Tokyo, Japan 37.8M
- Shanghai, China 23.4M
- Jakarta, Indonesia 30.5M
- Guangzhou-Foshan, China 20.5M
- Sao Paulo, Brazil 20.3M
- Nairobi, Kenya 4.4M
- Jakarta, Indonesia 30.5M
- Mumbai, India 17.7M
- Kolkata, India 14.6M
- Dhaka, Bangladesh 15.7M
- Bangkok, Thailand 14.9M
- Karachi, Pakistan 22.1M
- Mexico City, Mexico 19.4M
- Cairo, Egypt 15.6M
- Los Angeles, USA 15M

Large projected market—McKinsey analysis of demand by 2030 in 15 major U.S. cities:
• 500 Million annual UAS package deliveries
• 750 Million annual passenger trips

Extrapolation to the global market would likely increase demand by 5 to 10x
Benefits of Electrified Aircraft Propulsion

• Improvements to highly optimized aircraft like single-aisle transports
  – Potential fuel burn reduction estimated using turbo electric distribution to Boundary Layer Ingestion thruster in addition to other benefits from improved engine cores or airframe efficiencies.

• Enabling new configurations of VTOL aircraft
  – Enable new VTOL configurations with the potential to transform transportation and services.

• Revitalizing the economic case for small short-range aircraft services
  – The combination of battery-powered aircraft with higher levels of autonomous operations could reduce the operating costs of small aircraft operating out of community airports resulting in economically viable regional connectivity.
Types of Electrified Aircraft Propulsion

Electrified Aircraft Propulsion (EAP) systems use electrical motors to provide some or all of the thrust for an aircraft

- Turboelectric systems use a turbine driven generator as the power source. Partially turboelectric systems split the thrust between a turbo fan and the motor driven fans.

- Hybrid electric systems use a turbine driven generator combined with electrical energy storage as the power source. Many configurations exist with difference ratios of turbine to electrical power and integration approaches.

- All-electric systems use electrical energy storage as the only power source.
### Example Missions

**THIS IS NOT STRICT DEFINITIONS, THEY ARE JUST A FEW REPRESENTATIVE EXAMPLES**

<table>
<thead>
<tr>
<th>Mission</th>
<th>Number of Passengers</th>
<th>Typical Range</th>
<th>Typical Speed</th>
<th>EAP Configurations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Urban Mobility</td>
<td>&lt;=4</td>
<td>&lt;50 miles</td>
<td>&lt;200 miles/hr</td>
<td>• All electric</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• Hybrid Electric</td>
</tr>
<tr>
<td>Thin Haul</td>
<td>&lt;=9</td>
<td>&lt;600 miles</td>
<td>150-250 miles/hr</td>
<td>• Hybrid Electric</td>
</tr>
<tr>
<td>Short Haul Aircraft</td>
<td>40-80</td>
<td>&lt;600 miles</td>
<td>350-500 miles/hr</td>
<td>• Hybrid Electric</td>
</tr>
</tbody>
</table>
| Single Aisle             | 150-190              | 900 mile typical mission, 3500 mile maximum range | ≈600 miles/hr | • Hybrid Electric
<p>|                          |                      |                 |                   | • Turbo Electric                    |</p>
<table>
<thead>
<tr>
<th>Technology Area</th>
<th>Urban Air Mobility</th>
<th>Thin Haul / Short Haul</th>
<th>Single-Aisle</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power Distribution</td>
<td>• Flight Critical</td>
<td>• Flight Critical</td>
<td>• Flight Critical</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• High Voltage (&gt;1000)</td>
</tr>
<tr>
<td>Energy Storage</td>
<td>• 400 W-hr/kg (at system level)</td>
<td>• 400 W-hr/kg (at system level)</td>
<td></td>
</tr>
<tr>
<td>On Aircraft Power Generation / Turbines</td>
<td>• Light Weight / High Efficiency IC engine, turbine, or fuel cell</td>
<td>• Flight Weight MW turbogenerator</td>
<td>• Combined thrust and MW power extraction</td>
</tr>
<tr>
<td>Propulsion / Airframe Integration</td>
<td>• Highly distributed</td>
<td></td>
<td>• Projected PAI benefit</td>
</tr>
<tr>
<td>Autonomy</td>
<td>• No pilot operation</td>
<td>• Reduced pilot operation</td>
<td></td>
</tr>
</tbody>
</table>
Exploring Concepts for Urban Air Mobility

Open, publicly-available reference vehicle configurations
- Cover a wide range of technologies and missions
- Provide focus for trade studies and system analysis
- Assess failure modes and hazards of concept vehicle electrified propulsion architectures

- One passenger (250-lb payload)
  - 50-nm range
  - electric quadrotor

- Fifteen passengers (3000-lb payload)
  - 8x50 = 400-nm range
  - turbo-electric tiltwing

- Six passengers (1200-lb payload)
  - 4x50 = 200-nm range
  - hybrid side-by-side helicopter

- Six passengers (1200-lb payload)
  - 2x37.5 = 75nm range
  - turbo-electric Lift+Cruise VTOL
Learning from Development & Flight with the X-57

X-57 “Maxwell”

- Cruise-sized wing: enabled by distributed electric propulsion system for takeoff/landing performance
- High-efficiency cruise propellers: electric motors mounted at wingtips
- All-electric propulsion system: 40+ kWh battery, 240 kW across 14 motors
- Fully redundant powertrain
- Documented safety reviews and safe operational procedures

Key learning on more electric systems that can help the community
Example Short Haul

- NASA PEGASUS: Parallel Electric-Gas Architecture with Synergistic Utilization Scheme (PEGASUS) is a novel hybrid electric regional aircraft that strategically locates multiple electric and hybrid electric propulsors to obtain aerodynamic benefits. 48 Passengers, Range 200-600 miles, speed 300 knots (345 miles/hr)

![Diagram showing PEGASUS aircraft with propulsors depicted as red, black, and green squares]

Batteries assumed to be 500W-hr/kg
Example Single Aisle Partial Turboelectric

- NASA STARC-ABL: fuel burn reduction 7-12%, same range, speed, airport infrastructure. Same turbine/airframe technology, advanced 2-3MW power system, BLI, turbogenerator integration.

- Boeing SUGAR Freeze: fuel burn reduction 56% for 900 mile mission, utilizes a truss-braced wing combined with boundary-layer ingesting fan in an aft tail cone to maximize aerodynamic efficiency. The aft fan is powered by a solid oxide fuel cell topping cycle and driven by a superconducting motor with a cryogenic power management system. Batteries could be added to these concepts for airport taxi, reduction of peak turbine power, etc.
Example Single Aisle Parallel Hybrid Concepts

- Airframe/propulsion remains relatively decoupled

**UTRC hGTF** — On-going, optimized geared turbofan engine for cruise by adding boost power for take off and climb
  - Parallel hybrid, 150 passenger, 900 nm
  - 2.1 MW machines, 1000 W-hr/kg batteries
  - 6% reduction in fuel burn and 2.5% reduction in energy usage

**Boeing Sugar Volt**
  - Parallel hybrid, 150 passenger, 900 nm
  - 1.3 and 5.3 MW machines considered
  - Fuel off-loaded 750 W-hr/kg batteries charged from grid
  - 60% fuel burn reduction

**R-R LibertyWorks EVE** — On-going, parametrically optimized engine with hybrid climb & cruise segments
  - Parallel hybrid, 150 passenger, 900 nm
  - 28% reduction in fuel burn for a 900-nm mission
  - Up to a 10% total energy reduction for a 500-nm mission
  - Optimizing for minimum fuel usage predicts an 18 percent reduction in total fleet fuel usage.
# Battery Needs Based on Missions

**THESE ARE NOT STRICT REQUIREMENTS, THEY ARE BASED ON A FEW REPRESENTATIVE EXAMPLE STUDIES**

<table>
<thead>
<tr>
<th>Mission</th>
<th>Power Level</th>
<th>Specific Energy</th>
<th>Cycles</th>
<th>Reliability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Urban Air Mobility</td>
<td>200-500kW</td>
<td>250 – 400 Whr/kg</td>
<td>≈25-50/day</td>
<td>Flight Critical</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>12,000/year</td>
<td></td>
</tr>
<tr>
<td>Thin Haul</td>
<td>200-500kW</td>
<td>300 – 600 Whr/kg</td>
<td>≈4-12/day</td>
<td>Flight Critical</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2600/year</td>
<td></td>
</tr>
<tr>
<td>Short Haul Aircraft</td>
<td>500-1500kW</td>
<td>300 – 600 Whr/kg</td>
<td>≈4-12/day</td>
<td>Flight Critical</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2600/year</td>
<td></td>
</tr>
<tr>
<td>Single Aisle</td>
<td>1000-5000kW</td>
<td>750 – 1000 Whr/kg</td>
<td>≈4-8/day</td>
<td>Important / Flight</td>
</tr>
<tr>
<td></td>
<td></td>
<td>minimum</td>
<td>2000/year</td>
<td>Critical</td>
</tr>
</tbody>
</table>
Conclusion

• There is potential for aircraft with more electric propulsion systems to have tremendous impact on a number of aviation markets.
• Small prototype electric aircraft are flying (1-2 persons).
• NASA and Industry are making investments in technology to enable larger electric aircraft.
• NASA and Industry are making investments in aircraft demonstrations and certification standards to help enable the transition to certified production aircraft.
• NASA is working to address some of the key enabling technical challenges to realize this new capability.
Overview of Battery Technology
# Battery Needs Based on Missions

**THESE ARE NOT STRICT REQUIREMENTS, THEY ARE BASED ON A FEW REPRESENTATIVE EXAMPLE STUDIES**

<table>
<thead>
<tr>
<th>Mission</th>
<th>Power Level</th>
<th>Specific Energy</th>
<th>Cycles</th>
<th>Reliability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Urban Air Mobility</td>
<td>200-500kW</td>
<td>250 – 400 Whr/kg</td>
<td>≈25-50/day</td>
<td>Flight Critical</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>12,000/year</td>
<td></td>
</tr>
<tr>
<td>Thin Haul</td>
<td>200-500kW</td>
<td>300 – 600 Whr/kg</td>
<td>≈4-12/day</td>
<td>Flight Critical</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2600/year</td>
<td></td>
</tr>
<tr>
<td>Short Haul Aircraft</td>
<td>500-1500kW</td>
<td>300 – 600 Whr/kg</td>
<td>≈4-12/day</td>
<td>Flight Critical</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2600/year</td>
<td></td>
</tr>
<tr>
<td>Single Aisle</td>
<td>1000-5000kW</td>
<td>750 – 1000 Whr/kg</td>
<td>≈4-8/day</td>
<td>Important / Flight Critical</td>
</tr>
<tr>
<td></td>
<td></td>
<td>minimum</td>
<td>2000/year</td>
<td></td>
</tr>
</tbody>
</table>
High Specific Energy

> 400 Whr/kg battery level

- Higher energy chemistry
- Improved, lightweight packaging
- Multifunctionality
- Improved functional thermal operation window
High Specific Power

Capability to respond to aircraft power needs without sacrificing specific energy density

- Hybrid chemistries
- Electrode configurations
- Cell and/or battery configurations
- Rapid recharge capability
Cycle Life

High Cycle life without sacrificing specific energy density

Cycles per year: 2000 - >10,000

• Improved battery chemistries
• Improved electrode configurations
• Improved cell and / or battery configurations
Safety

Safe battery design without sacrificing performance and/or specific energy density

• Improved battery chemistries
• Nonflammable components
• Thermal runaway propagation prevention
• Improved cell and battery configurations
• Improved sensing and predictive modeling
Reliability

Minimize cell and battery failures

• Improved battery chemistries to improve consistent performance
  • Wide environmental operating envelope
  • Wide performance operating envelope

• Improved cell and battery configurations
  • Connections
  • FOD
  • Matching Impedance

• Minimize moving parts
Thermal

Minimize the impact of the thermal subsystem to the overall battery specific energy density

• Wide environmental (temperature) operating envelope
  • Improved battery chemistries with large range of operational temperature

• Improved cell and battery design
  • Optimize passive thermal rejection
  • Improved thermal materials
Advanced Configurations

Optimal designs to maximize specific energy densities, performance, reliability and safety

• Multifunctionality
  • Structure
  • Thermal
  • Other?

• Improved cell designs
• Advanced packaging concepts
• Advanced fabrication methods to improve
  • Utilization
  • Specific Energy Density
  • Performance metrics
Conclusion

There is a need for significant advancements in energy storage technologies for future aircraft needs.

Higher Specific Energy
Higher Specific Power
Higher Cycle Life
Safety
Reliability
Thermal Management
Overview of Heat Exchanger Technology
Technical Challenges Overview

• The problem: Electric aircraft propulsion (EAP) requires electric components that produce low grade heat loss. Managing this heat requires heat exchangers, which in turn add a weight penalty that may cancel out the benefits of EAP.
• What advanced materials or manufacturing processes can make the most lightweight, multifunctional heat exchangers?
• What other functions could a heat exchanger provide that might offset its weight penalty? (i.e. structural, managing heat from another system, etc.)
• What applications of a multifunctional heat exchanger can produce the most impact?
Possible Application: Small Recuperated Turbine Engine

- On Demand Mobility (ODM) may find benefit in a hybrid solution.
- Fully electric vertical takeoff and landing (VTOL) vehicles are have limited range abilities.
- Hybrid electric may allow the completion of more missions in a day because aircraft will not be on the ground as long or as often charging. This may also lead to a reduction in the number of vehicles required to meet demand, driving down cost.
- Hybrid electric might also allow the service of “megaregions” (bottom right), or people that commute further distances than the range that can be supported by batteries.
- Further, hybrid electric may offer a near term solution as battery technology continues to mature to the energy densities needed for air taxi operations.

The Problem: Gas Turbines lose some efficiency benefit at small power scales

- Turbine engines have roughly 2x the specific power of Internal Combustion engines at small power scales
- However, at small power scales they are not as efficient (right)
- Can we improve the efficiency of turbine engines while preserving the specific power benefit?

![Graph showing SFC (kg/kWh) vs. Shaft Power (kW)]

GOAL

Improving Efficiency

Interruption internal combustion

Turbine engines
Why recuperation?

- Recuperation uses waste heat from the turbine to heat up air going into the combustor for an efficiency benefit.
- Recuperators add significant weight to the system.
- Can we design a recuperated turbine engine system without a weight penalty by leveraging:
  - Advanced materials?
  - Additive manufacturing?
  - Multifunctionality?
Benefits of Ceramic Matrix Composites in Propulsion Systems

CMCs are enabling materials for aero-propulsion and other high temperature extreme environment applications.

SiC/SiC CMCs offer significant advantage over superalloys at 1/3 density.

Coated CMC Components from NASA Programs
Additive Manufacturing of CMCs

Long term research efforts have now resulted in various applications.

Efforts in this very promising field are now underway.

Materials and processing challenges are quite similar.

Conventional Manufacturing

- Customized parts in small volumes are time consuming and expensive to produce.
- Complex shape fabrication issues: mold design, dimensional tolerances, etc..
- Manufacturing of multifunctional parts are challenging.

Additive Manufacturing

- Small series of ceramic parts can be manufactured rapidly and cost-effectively.
- Specific molds are not required.
- Different designs can be optimized (no major cost of changes)
- Parts with significant geometric complexity.

Material and Process Challenges

- Property and behavior of starting materials
- Sintering and densification challenges
- Process modeling
- Mechanical behavior
- NDE and in-situ damage characterization
- Material and property databases
Applications of Additively Manufactured SiC

• SiC is a lightweight (3.2 g/cc), thermally conductive (~40 w/mK) material with high temperature capability (>1200°C).

• Innovative manufacturing development of SiC could enable heat exchangers with up to 50% weight reduction, compared to metals.

• Lightweight heat exchangers can be used to improve the efficiency small of hybrid electric aircraft- such as the ones envisioned for On-Demand Mobility.

• Initial studies have shown that ceramics, such as SiC can be printed, but extensive studies on the material optimization and durability have yet to be explored.
Due to the multiple properties involved in selecting the material with which to construct the heatsink, sometimes the best material is not one which is necessarily the strongest in any one property.

Sometimes constraints such as use temperature over-ride otherwise attractive properties.

In this way, a high performance aluminum alloy may be ideal for certain applications (like a structural heatsink for thermal management of electrical systems) by non-ideal in others (such as a high temperature jet turbine recuperator).

Metals often excel where impact resistance and toughness are required with lightweight alloys becoming feasible for lower use temperatures.

Metals (instead of ceramics) are also useful where both thermal management and mechanical strength are desired in the same part, such as this structural heatsink.
Possible Application: Thermal Structural Management for Enabling Electrified Aircraft

The Problem:

Component inefficiencies produce low-grade waste heat generated in motors, batteries, and power electronics for electrified aircraft.

Ref: https://www.nasa.gov/aeroresearch/X-57/technical/index.html
Need: A Multifunctional Aircraft Skin Panel

- Can a system-level light-weight benefit be shown for a structurally/thermally optimized aircraft skin panel*?

- Can an efficient path to manufacturability be shown for a structurally/thermally optimized aircraft skin panel*?

*Aircraft skin panel includes stiffened structure.
Can a system-level light-weight benefit be shown for a structurally/thermally optimized aircraft skin panel?

• Heat Exchanger Design Space
  – Lightweight topologies
  – e.g. lattice frame materials, branching structures?
• Aircraft Location: wing, fuselage, nacelle
• Heat exchanger integrated into the aircraft skin
• Meets structural requirements
• Optimized for weight
• Demonstrated light-weight benefit at a system-level
Can an effective path to manufacturability be shown for a structurally/thermally optimized aircraft skin panel?

- **Material Selection**
  - High thermal performance
  - High mechanical performance
  - Low density
  - Manufacturability by advanced additive methods

- **Additive Manufacturing**
  - Prototyping
  - Complex topology
  - Scalability
  - Maintaining performance
  - Path to certification
Q&A and Introductions

• You are welcome to ask questions but please be aware of the guidance/rules

• When speaking, you are welcome (but not mandated) to introduce yourself and your company/institution if you so choose for the awareness of all of those participating

Guidance/Rules:

• This is an educational brief and includes discussions of general programmatic goals
  — NASA will not discuss if/how any of these goals are included in a given ongoing or forthcoming solicitation
  — For any solicitation, please refer to the goals/metrics stated within those requests for proposals (RFPs)/solicitations; proposals must be responsive to the stated requirements of those specific solicitations and not to any other stated or perceived need
  — Forthcoming solicitations may also contain other guidance, technical needs, and or challenge areas; please review solicitations fully

• Because of pending/formulating proposals, NASA will not assess, prioritize, discuss, or answer questions on proposed or ongoing technologies/solutions by those in this forum
  — Also note that this is an open forum with others in attendance