# NASA Advisory Council Aeronautics Committee Report

Mr. John Borghese
Chair, NAC Aero Committee
NASA Kennedy Space Center
November 1, 2019

# Areas of Interest Explored at Current Meeting

*Topics covered at the Aeronautics Committee Meeting held on July 24-25, 2019 at NASA Glenn Research Center:*

- ARMD Strategy Overview
- Propulsion Transformation - Electric Propulsion*
- Autonomy Strategy*


* These topics have related findings provided by the Aeronautics Committee

# Aeronautics Committee Membership

**Mr. John Borghese**, Chair
Collins Aerospace

**Dr. Eric Allison**
UBER Elevate

**Mr. Peter Bunce ***
General Aviation Manufacturers Association

**Mr. Andrew Cebula ***
Airlines for America

**Mr. Darin DiTommaso ****
GE Aviation

**Mr. J. Scott Drennan**
Bell, Textron Inc.

**Ms. Lisa Ellman ***
Commercial Drone Alliance

**Mr. Eric Fanning ***
Aerospace Industries Association

**Dr. Michael Francis**
Aerospace Executive, Technologist and Consultant

**Mr. Michael Hirschberg ***
Vertical Flight Society

**Dr. Greg Hyslop**
The Boeing Company

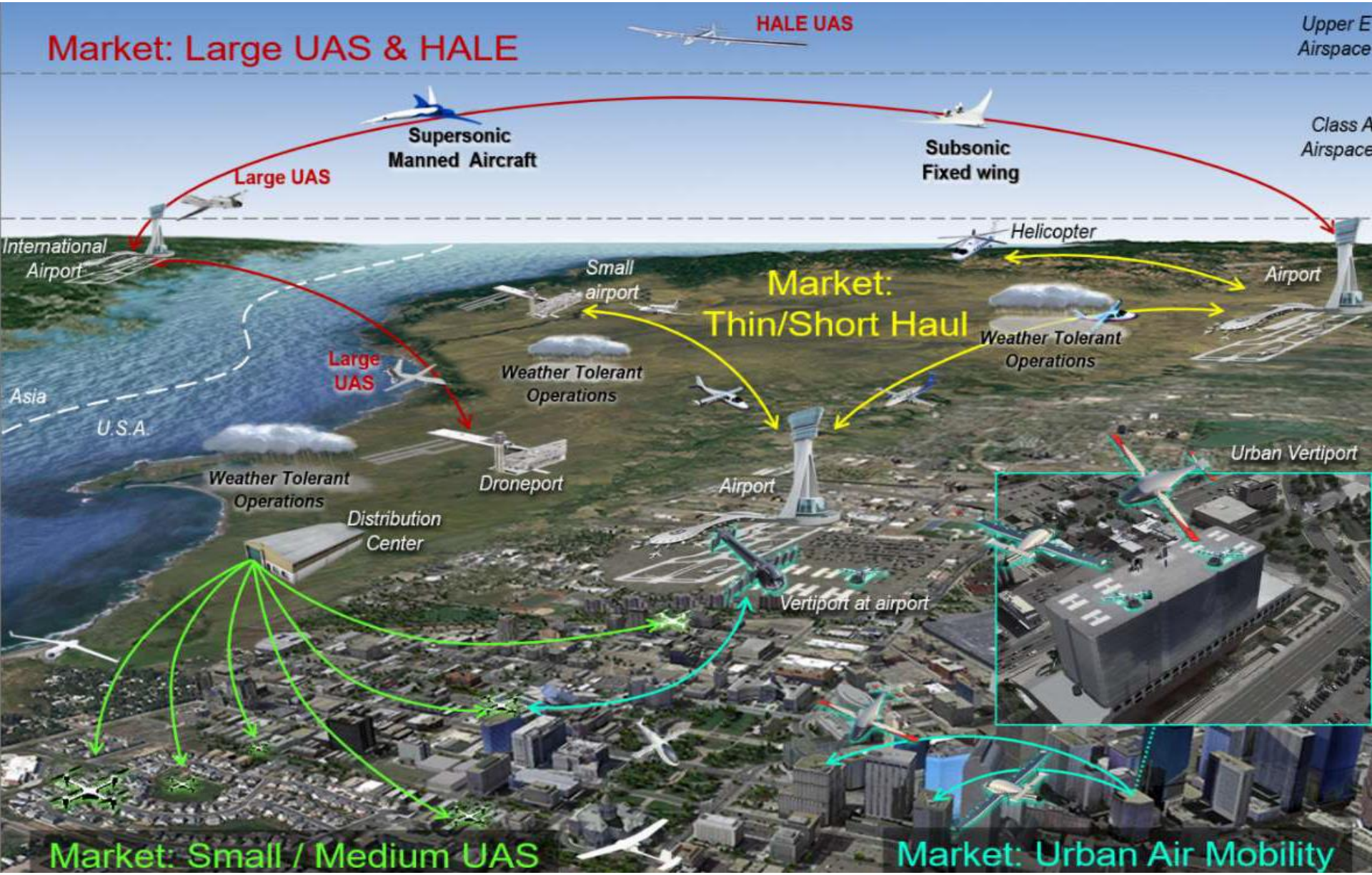
**Mr. Anil V. Nanduri**
Intel, Drone Group

**Dr. Tom I-P. Shih**
Purdue University

**Dr. Karen Thole**
Pennsylvania State University

*** New Representative Members**
**** New SGE member**

# Future Airspace Operational View



# Benefits of Electrified Aircraft Propulsion

- Improvements to highly optimized aircraft like single-aisle transports

- Help open Urban Air Mobility market

- Revitalizing the economic case for small short-range aircraft services

# Electrified Aircraft Propulsion – Big Picture
## (a range of vehicles and range of needs)

| | UAS | UAM | Small A/C | RJ | Single Aisle | Twin Aisle |
|---|---|---|---|---|---|---|
| |  |  |  |  |  |  |
| **Implementation Timeframe** | All electric vehicles in operation | All electric or hybrid applications being developed | | Potential for hybrid or turbo-electric within 10 years | | Significant progress needed for practical implementation |
| **NASA Role** | NASA research not needed | NASA focus on informing standards, regulations and design tools | | NASA focus on enabling technologies, demonstrating benefits, addressing safety needs | | Still too long term – not yet a NASA focus |
| | | **Small Scale EAP** | | **Transport Scale EAP** | | |

# NASA EAP Strategy

*All & Hybrid Electric, Distributed Propulsion*

- On Demand Mobility
- Small Vehicle Focused

*Turbo and Hybrid Electric, Distributed Propulsion*

- Energy Efficient Propulsion
- Transport Class Focused

**AATT/RVLT & IASP/X-57**

Enable New Aero Efficiencies

Power Sharing

Distributed Thrust Control

Standards and Means of Compliance

**Fundamental Challenges (e.g. materials)**

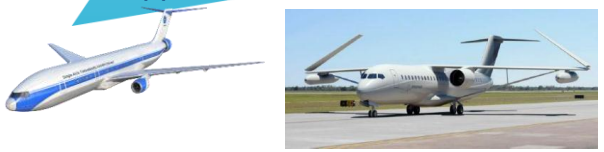
Enable New Aero Efficiencies

High Efficiency Power Distribution

Power Rich Optimization

Non-flight Critical First Application

**AATT/AAVP & UEST/EAP/IASP**



***Energy & Cost Efficient, Short Range Aviation***

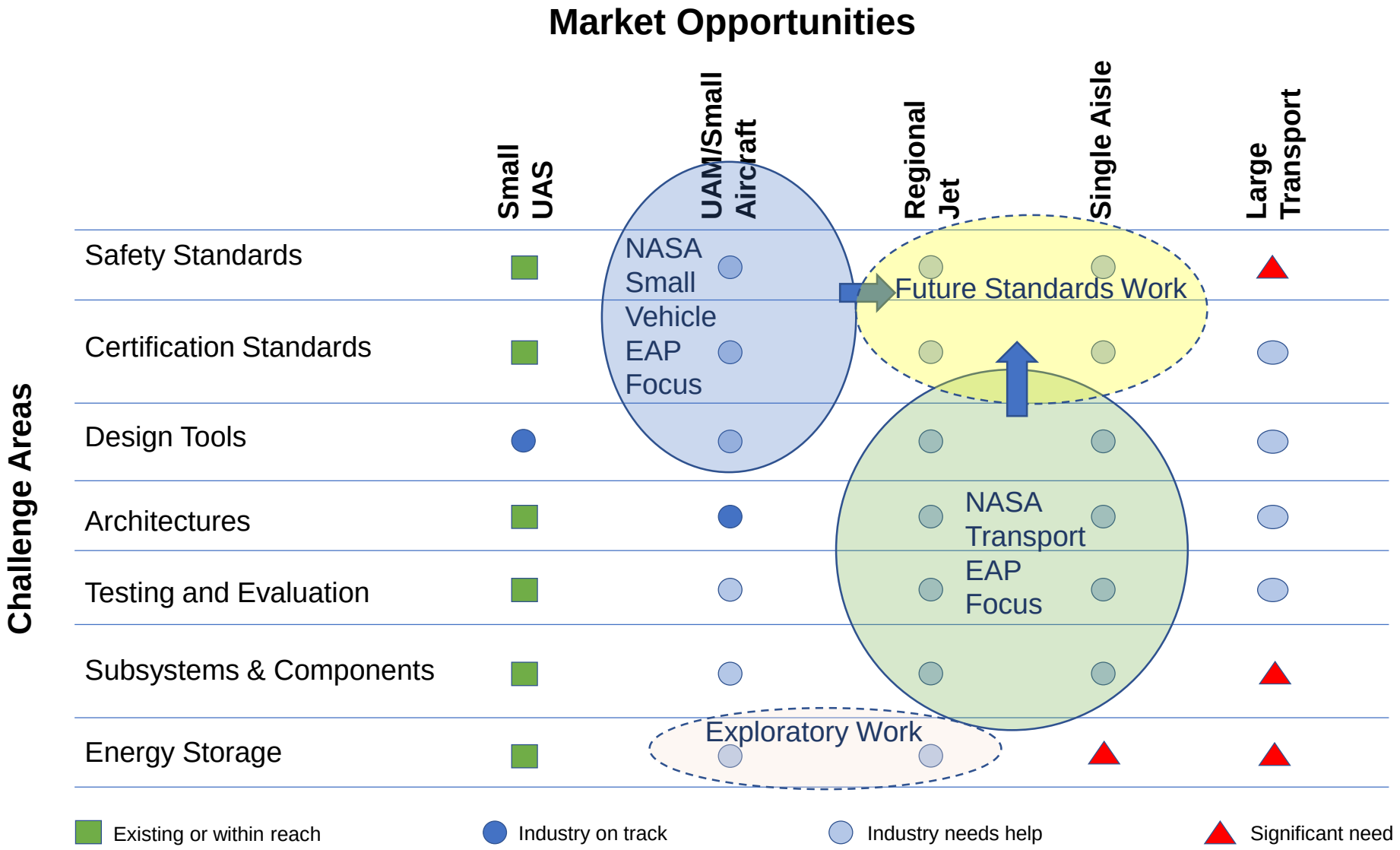
**Leverage learning at smaller scale to inform scale-up**

***Energy & Cost Efficient, Transport Aviation***

## NASA Small Vehicle EAP

## NASA Transport EAP

# EAP Challenges Across Multiple Vehicle Classes



# Electric Aircraft Propulsion – Potential Game Changer

*Why 1MW+ is Important…*

- 1MW is broadly applicable: Regional - Air Transport
- Opens new markets for U.S. industry and retains our competitiveness

*Why 1MW+ is Difficult...*

- Existing MW+ are large, heavy and not efficient
- Reducing weight and integration challenges are key for success

*Why EAP Flight Testing is Crucial…*

- Flight research needed to advance EAP TRL
  - Powertrain
  - Electrical and Thermal
  - Turbine Integration

*Advances and TRL Maturation Required in Key Technology Areas:*

- Electric Machine Weight/ Efficiency
- Electric Power Distribution Weight/ Efficiency
- Turbine Engine Integration
- EMI Mitigation
- Thermal Management
- Energy Storage

# Summary

- More electric systems will impact aviation ranging from small all-electric vehicles to larger aircraft with hybrid or turbo-electric propulsion.
- US industry collaboration interest is high and international competition fierce with increasing R&D budgets in pursuit of more electrified vehicles
- NASA has developed strategy that provides leadership and a vision for this more electric future and addresses key areas where industry needs assistance.

# Committee Recommendation for ARMD AA – Propulsion Transformation – Electric Propulsion

The Committee applauds NASA's research in Electrified Aviation Propulsion. Research is being performed in many relevant areas: aero efficiencies, compliance and certification, tools for better design trades and new materials such as insulators. The Committee recommends that NASA consider developing and maintaining a database of battery and cell test results to share with industry. The idea is to have an energy power storage (e.g., cells, batteries, etc.) laboratory within the current NASA infrastructure dedicated to testing specific electric aircraft propulsion. This lab would test against standardized protocols and make the results available to industry to accelerate the adoption of electrified powertrains. This approach could be expanded to other system components, such as power electronics in the future. The Committee further recommends that NASA explore other promising aircraft electric propulsion technology alternatives, such as fuel cell variants currently in use in automobile and bus transport vehicles. There are potential applications to the Mars mission so it will benefit not only ARMD but also NASA as a whole.

# Committee Recommendation for ARMD AA – Propulsion Transformation – Electric Propulsion

**Major Reasons for the Recommendation:**

Both large and small innovative companies in the emerging electric aircraft industry are struggling to solve the energy storage problem. While significant progress is being made in the electric motors and lift systems, battery capacity with safe and efficient integration into air vehicles remains the critical component for success. Significant research is being performed at the University level. However, the immense challenge of transitioning these battery technologies is accomplished at very few manufacturing companies due to the difficulty of achieving large-scale consistent manufacturing processes at scale. These manufacturing companies do not readily reveal their latest cell capability to small companies. Other electric propulsion alternatives suitable for aircraft applications (i.e. lightweight, high power/energy density) are in early stage development. NASA can fill this critical gap by providing a responsible, credible, and consistent testing methodology that industry can access. Other electric propulsion alternatives suitable for aircraft applications (i.e. lightweight, high power/energy density) are in early stage development. NASA could provide a test bed capability for these emerging technology capabilities, providing significant value to the emerging US electric aircraft marketplace. The country wants to lead in this technology area and the value to the US economy is tremendous.

# Committee Recommendation for ARMD AA – Propulsion Transformation – Electric Propulsion

**Consequences of No Action on the Recommendation:**

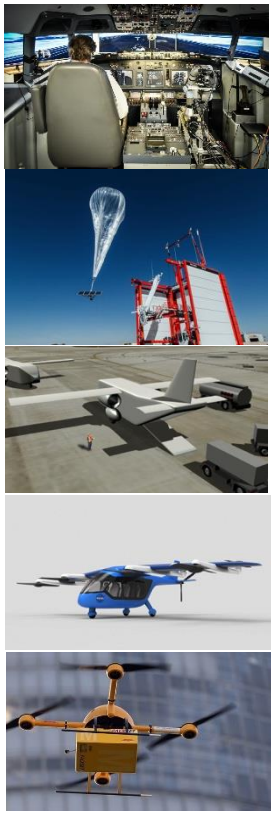
The lack of extensive testing on new battery cell and other emerging electric propulsion technologies, along with the lack of supporting data will impede the small electric aircraft industry from developing the most efficient vehicles for this emerging market.

# The NASA Aeronautics Autonomy Value Proposition

- NASA acts as a catalyst to ***accelerate*** the advancement of autonomous aviation systems and ensure U.S competitiveness
  - Leads the creation of ***national-level large-scale systems*** enabled by autonomy
  - Resolves critical technical bottlenecks with ***targeted R&D***
  - Builds paths to ***implementation***
    - Identifies and validates approaches to certification and operational approval
    - Speeds processes to achieving compatible systems operating procedures, and minimal viable products
  - ***Leads and coordinates*** the aviation stakeholder community
    - Defines realizable long-term objectives and track community progress
    - Develops system-wide industry consensus standards to enable markets
- NASA's aeronautics domain expertise ***bridges the gap*** between intelligent systems and civil aviation
  - Applies emerging machine intelligence technologies to aviation applications
  - Applies domain expertise in integrated human-machine operations, airspace management, and aviation safety

# Traditional and Emerging Markets

1. Long-haul reduced crew operations for civil markets and DoD
2. High altitude long endurance operations
3. Autonomous cargo aircraft
4. Urban Air Mobility (UAM) and thin haul operations for passengers and cargo
5. Small Unmanned Aircraft Systems (UAS)



# NASA Aeronautics – Leading the Path to Autonomy

- Autonomy is a fast-growing area of industry interest with high stakes for US competitiveness
- NASA Aeronautics is committed to take the leadership role in enabling autonomous flight and operations
  - *Leadership and ownership of targeted technical work*
  - *Facilitation, coordination, and collaboration with industry, academia, and OGAs*
  - *Ensure goals are met for critical autonomous missions*
- NASA is expanding its autonomy portfolio and will enable industry's use cases through collaborative innovation and close cooperation with the FAA
- NASA, Industry, and FAA Collaborative R&D will focus on vehicle autonomy, airspace operations, and certification approaches to enable autonomous missions

ARMD coordinated autonomy strategy is planned for completion in Fall 2019

# The NASA Aeronautics Autonomy Approach

- What are we working on?
- Why are we working on it?
- Did we get it right?
  - Market Opportunities
  - Challenge areas
  - Applications/MVPs
- How will we execute?
  - NASA internal R&D
    - Not one mega-program – better way to do in-house research
    - Flexible, responsive, collaborative, agile
  - Critical partnerships
    - Coordinate pace of advances with stakeholders
    - Understand industry needs and gaps to be filled
    - Stay up to date with evolving autonomy technologies
    - Achieve consensus where needed (e.g., for community standards)

# Committee Finding for ARMD AA – Autonomy Strategy

The Committee finds that NASA has developed a reasonable strategy for advancing this important area of contemporary aeronautics research and development. The strategic focus on national level, large scale applications such as future air traffic management, unmanned air systems, and emerging urban air mobility provides both motivation for NASA involvement and rationale for specific targeted programs. In addition, the plan to develop assurance methods for complex, machine learning-based systems recognizes the need to address future aviation autonomy capabilities beyond the reach of industry investment timelines. The importance of the human operator-intelligent machine relationship is also recognized as a major challenge relevant to the broadest class of aviation systems. Additional areas that require long term NASA attention include cyber-security and -resiliency, especially in the case of networked multi-platform systems-of systems. A companion NASA technology roadmap focused on stimulating fundamental advances would also be helpful. To facilitate those advances most germane to the aviation enterprise, NASA should continue its collaboration with the universities to increase interest and motivation in autonomous systems, while involving the students since they are the next generation of NASA engineers. Other suggestions on where NASA can provide significant value in autonomy include:

# Committee Finding for ARMD AA – Autonomy Strategy (cont.)

- Certification of Autonomous Systems – Current approaches to hardware and/or software system verification and validation are ill-suited to today's complex and highly automated systems, often resulting in prohibitively expensive (… in time or money) test and certification programs. These methods are fundamentally incompatible with emerging autonomous capabilities that incorporate machine learning as part of their design. The ability to establish trust in and the requisite level of safety for these systems is a critical challenge for all applications that expect to exploit high levels of autonomy as a key feature of their management and operations. Certification methods that are compatible with learning systems and which focus on assessing operational safety are essential to the continued evolution of all the applications mentioned above. NASA, along with its industry and university partners, can play a key role in leading the development of these methods and motivating their adoption by federal regulatory organizations, especially the FAA.

# Committee Finding for ARMD AA – Autonomy Strategy (cont.)

- Datasets for testing of autonomy under all relevant flight conditions – The FAA currently has methods and test cases for the certification of aircraft subsystems. For example, there are 34 test cases that support Terrain Aware Warning System certification. There are no current datasets or test approaches to certify autonomous capabilities at the aircraft level. This class of data sets with supporting simulation capability can help catalyze the industry toward developing more robust autonomous systems. NASA has already amassed significant datasets that would be useful to this end. Publication of these datasets would be beneficial.

# Committee Finding for ARMD AA – Autonomy Strategy (cont.)

- Continuation of the UTM construct – NASA's Unmanned Air Traffic Management (UTM) initiative has captured the attention of the commercial unmanned air vehicle (UAV) industry and served as an initial catalyst to enable more widespread airspace operations, including high density air traffic, at lower altitudes. The UTM effort over the last 4 years on TCL-1 through TCL-4 has demonstrated NASA's role in providing global leadership in air traffic management for this new operational arena. Given the anticipated expansion in low altitude operations from UAM and larger UAS platforms, more needs to be done to grow the capabilities of UTM for these emerging applications, as well as to enable the effective transition of UTM to the FAA. The role of increasingly autonomous capabilities in coping with the demanding timelines and added complexity of the airspace can be anticipated. The Committee therefore believes that this program should continue with an expanded operational scope. Ideas to consider include adopting an "X Plane" approach to excite the public and motivate the industry for this important technology. A follow on to UTM could involve the assignment of special case airspace such as TRACON to provide a more realistic environment for UTM maturation.

# Committee Finding for ARMD AA – Autonomy Strategy (cont.)

- Lastly, while the NASA strategy for autonomy has matured since the introduction of the “Assured Autonomy” Strategic Thrust over 4 years ago, detailed program level plans demonstrating an integrated, comprehensive approach to advance the autonomy agenda have been elusive. The Committee urges that ARMD formulate a long term, integrated Program Plan to address the challenges embodied in the Autonomy strategy, including the allocation of adequate financial investment and suitable personnel resources that demonstrate NASA’s commitment to this important area for 21st century aeronautics.

# BACK-UP

# 2019 NAC Aeronautics Committee Work Plan

| SPRING | SUMMER | FALL |
|---|---|---|
| ARMD Strategy and FY20 Budget Overview | Autonomy Strategy | System Wide Safety Assurance |
| Progress on the University Leadership Initiative | Propulsion Transformation – Electric Propulsion | **NASA Aeronautics Transformation Planning** |
| Airspace Research Vision Beyond NextGen | | Supersonic Market Developments and LBFD Status |

**March 20, 2019 at HQ** **July 24-25, 2019 at GRC** **November 21-22, 2019 at LaRC**

# FY 2020 Budget Request - Aeronautics

| $ Millions | FY 2018 | FY 2019 | FY 2020 | FY 2021 | FY 2022 | FY 2023 | FY 2024 |
|---|---|---|---|---|---|---|---|
| **Aeronautics** | **$690.0** | **$725.0** | **$666.9** | **$673.6** | **$680.3** | **$587.1** | **$587.0** |
| Airspace Operations and Safety | 118.7 | | 121.2 | 130.6 | 133.5 | 136.2 | 138.9 |
| Advanced Air Vehicles | 237.7 | | 188.1 | 203.3 | 212.2 | 219.3 | 224.2 |
| Integrated Aviation Systems | 221.5 | | 233.2 | 209.4 | 202.2 | 97.1 | 87.2 |
| Transformative Aeronautics Concepts | 112.2 | | 124.4 | 130.3 | 132.3 | 134.6 | 136.7 |

*FY 2018 reflects funding amounts specified in Public Law 115-41, Consolidated Appropriations Act, 2018, as adjusted by NASA's FY 2018 Operating Plan.*

*FY 2019 reflects funding as enacted under Public Law 116-06..*

Beginning in FY 2020, Aeronautics budget no longer includes the Aeronautics Evaluation and Test Capabilities (AETC) project of approximately $56M. AETC was transferred to the Safety Security and Mission Support account.

# Acronyms

- AATT – Advanced Air Transport Technology Project
- AAVP – Advanced Air Vehicles Program
- A/C - Aircraft
- AETC - Aeroscience Evaluation and Test Capabilities
- ARMD – Aeronautics Research Mission Directorate
- DoD – Department of Defense
- EAP – Electrified Aircraft Propulsion
- EMI – Electro-Magnetic Interference
- FAA – Federal Aviation Agency
- HALE – High Altitude Long Endurance
- IASP – Integrated Aviation Systems Program
- LBFD – Low Boom Flight Demonstrator
- MVP – Minimum Viable Product
- MW - Megawatt
- NAC – NASA Advisory Council
- OGA – Other Government Agencies
- RJ – Regional Jet
- RVLT – Revolutionary Vertical Lift Technology
- TCL – Technology Capability Level
- TRACON – Terminal Radar Approach Control Facilities
- TRL – Technology Readiness Level
- UAM – Urban Air Mobility
- UAS - Unmanned Aircraft Systems
- UAV – Unmanned Air Vehicle
- UEST – Ultra Efficient Subsonic Technology
- UTM – Unmanned Aircraft Systems (UAS) Traffic Management