National Aeronautics and Space Administration

NASA Advisory Council Aeronautics Committee Report

Ms. Marion Blakey
Chair
NASA Headquarters
April 1, 2016

Aeronautics Committee Membership

- Ms. Marion Blakey, Chair*, Rolls Royce North America*
- Mr. John Borghese, Vice Chair*, Rockwell Collins*
- Dr. Missy Cummings*, Duke University*
- Dr. John Paul Clarke, *Georgia Institute of Technology*
- Dr. Michael Francis, *United Technologies*
- Mr. Stephen Morford, *Pratt and Whitney*
- Dr. Lui Sha, *University of Illinois*
- Dr. Karen Thole, *Pennsylvania State University*
- Mr. Tommie Wood, *Bell Helicopter*
- *Dr. David Vos, Google [X] **

** New Member*

Areas of Interest Explored at Current Meeting

Topics covered at the Aeronautics Committee Meeting held on March 23, 2016 at NASA Headquarters:

- ARMD 10-year Investment Strategy*
- Overall Thrust Roadmaps Overview*
- NASA/USAF ERC Collaboration
- Hypersonics Research Strategy
- Work Plan and Schedule Discussion

* These topics have related findings provided by the Aeronautics Committee

Global Growth in Aviation: Opportunities and Challenges

Global Air Passengers by Region (% of Total)

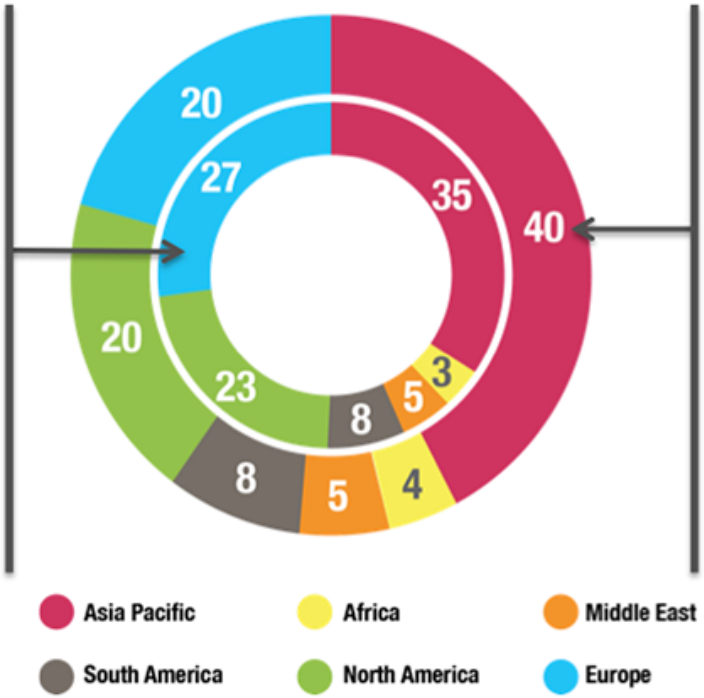
2014 Global Aviation Industry

3.3B Passenger Trips

North America and Europe combined is half of all Passenger Trips

58M Jobs

$2.4T GDP



2034 Global Aviation Industry, est.

7B Passenger Trips

Asia-Pacific Passenger Trips equal to North America and Europe combined

105M Jobs

$6T GDP

Over 36,000 New Aircraft required (replacement and growth) over the 20 year period ($4-$5T value)

Sources: International Air Transport Association, Air Transport Action Group, Boeing

Major Opportunities / Growing Challenges

Competitiveness—New state backed entrants, e.g., COMAC (China); Growing global R&D

Environment—Very ambitious industry sustainability goals; Large technology advances needed

Mobility—More speed to connect the worlds' major cities; Opportunity for commercial supersonic flight

U.S. Technological Leadership Required!

ARMD 10-year Investment Strategy

NASA Aeronautics Ready for Flight

Accomplishments and Planning

NASA Aero Vision and Strategy Established

Roadmaps Completed

2008-2013	2014/15	2016/17	2018-2026

N+3 Subsonic & Supersonic Concept/ Technology Studies

Ground Testing of N+3 configurations and technologies

LBFD PDR Completed

UEST PDR Completed

N+2 Environmentally Responsible Aviation (ERA) Project Initiated

8 Integrated Tech Demos Completed, Tech transitioned to industry. HWB ready for Flight Dem/Val.

Ready for X-Plane Integration & Demonstration

NASA FAA NextGen Research Transition Teams (RTTs) Initiated

Technology Transitions to FAA: MSP, EDA, PDRC, TSAS

ATD-1 Completed and transferred to FAA

ATD-2, 3 Completed & Transferred to FAA

Ready for NextGen TBO Integration & Demonstration

FY 2017 Budget

$ Millions	FY 2015	Enacted FY 2016	FY 2017	FY 2018	FY 2019	FY 2020	FY 2021	FY 2022	FY 2023	FY 2024	FY 2025	FY 2026
Aeronautics	**$642.0**	**$640.0**	**$790.4**	**$846.4**	**$1,060.1**	**$1,173.3**	**$1,286.9**	**$1,294.2**	**$1,307.6**	**$1,218.1**	**$829.7**	**$839.5**
Airspace Operations and Safety	154.0		159.4	159.2	176.2	189.1	221.5	198.7	200.9	193.2	175.5	167.8
Advanced Air Vehicles	240.6		298.6	277.4	308.8	311.6	312.6	321.3	315.0	318.9	317.7	326.7
Integrated Aviation Systems	150.0		210.0	255.4	381.4	493.0	556.7	591.5	612.2	525.0	203.8	210.6
Transformative Aeronautics Concepts	97.4		122.3	154.4	193.8	179.7	196.2	182.8	179.4	181.0	132.7	134.4

Aeronautics budget includes paid-for 10-year mandatory funding from the Administration's 21st Century Clean Transportation Plan.

Mandatory Budget Authority $ Millions	FY 2017	FY 2018	FY 2019	FY 2020	FY 2021	Outyears
21st Century Clean Transportation Plan	**100**	**200**	**400**	**500**	**600**	**1900**
Airspace Operations and Safety	*18*	*20*	*35*	*45*	*75*	*170*
Advanced Air Vehicles	*30*	*41*	*79*	*80*	*65*	*305*
Integrated Aviation Systems	*37*	*84*	*196*	*300*	*370*	*1170*
Transformative Aeronautics Concepts	*15*	*55*	*90*	*75*	*90*	*255*
Low Boom Flight Demonstrator	**56**					
Integrated Aviation Systems	*56*					

ARMD 10-year Investment Strategy

Ten Year Investment Plan—FY 2017 Budget Accelerates Key Components of NASA Aeronautics Plan

Fund the Next Major Steps to Efficient, Clean and Fast Air Transportation Mobility

New Aviation Horizons

Start a continuing series of experimental aircraft to demonstrate and validate high impact concepts and technologies. Five major demonstrations over the next 10+ years in the areas of Ultra-Efficiency, Hybrid-Electric Propulsion, and Low Noise Supersonic Flight

Major New Initiative within IASP

Enabling Tools & Technologies

Major series of ground experiments to ready key technologies for flight

Research and ground demonstration for an advanced small engine core for very high bypass engines and as a hybrid-electric propulsion enabler

Development of next generation physics-based models needed to design advanced configurations

Increases to AAVP and TACP

Revolutionizing Operational Efficiency

Accelerate demonstration of full gate-to-gate Trajectory Based Operations

Increase to AOSP

Fostering Advanced Concepts & Future Workforce

Increased investment in new innovation through the NASA workforce and Universities

Leverage Non-Traditional Technology Advances

Pursue challenge prizes in areas such as energy storage, high power electric motors, advanced networking and autonomy

Increase to TACP

UAS

Strong continued research leadership in enabling UAS integration into the National Airspace. Extending the UAS in the NAS project for an additional 4 years

Hypersonics

Increased investment to ensure a strong National fundamental research capability

Increases to IASP and AAVP

Build off of major current developments and accomplishments

Continue to incentivize new innovation

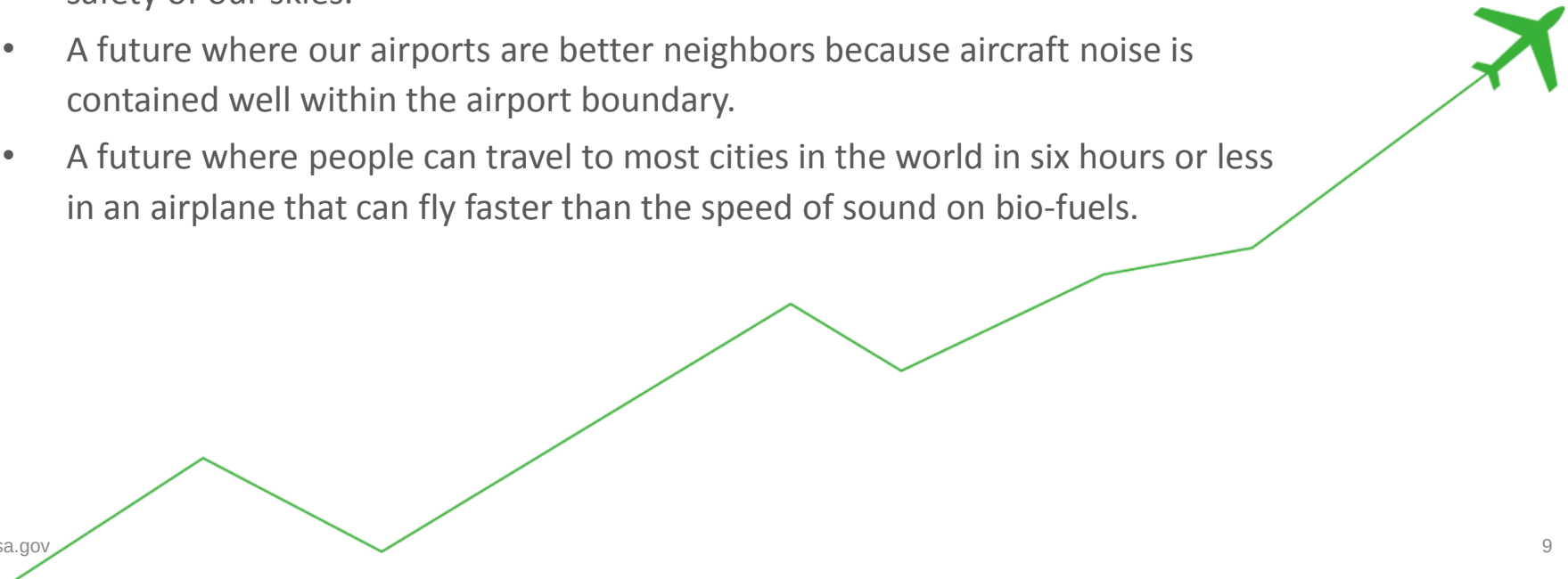
New Aviation Horizons

- Validated ability for U.S. Industry to Build Transformative Aircraft that use 50% less energy and contain noise within the airport boundary.
- Enables global standards and validated ability for industry to produce and operate commercial low noise supersonic aircraft
- Validated Hybrid Electric Propulsion (HEP) Concepts, Technologies and Integration for U.S. Industry to Lead the Clean Propulsion Revolution

New Era For NASA Aeronautics

Investing In Our Future - Investments in NASA's cutting edge aeronautics research today are investments in a cleaner, safer, quieter and faster tomorrow for American aviation:

- A future where Americans are working in stable, well-paying jobs.
- A future where we fly on aircraft that consume half as much fuel and generate only one quarter of current emissions.
- A future where flight is fueled by greener energy sources.
- A future where our air transportation system is able to absorb nearly four billion more passengers over the next 20 years without compromising the safety of our skies.
- A future where our airports are better neighbors because aircraft noise is contained well within the airport boundary.
- A future where people can travel to most cities in the world in six hours or less in an airplane that can fly faster than the speed of sound on bio-fuels.

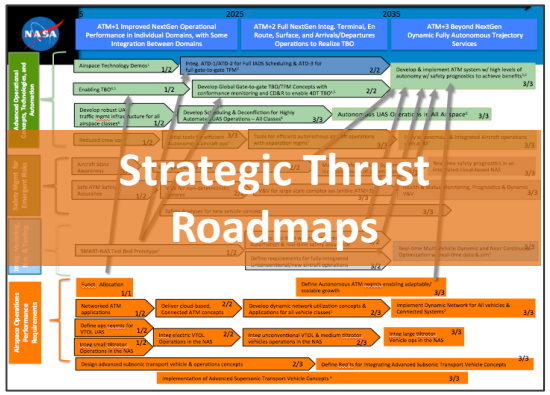


Committee Finding for ARMD AA on 10-year Investment Strategy

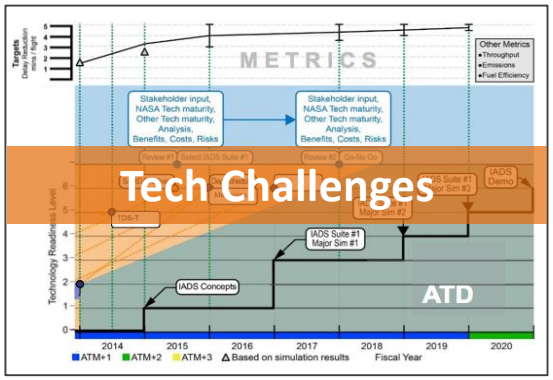
1. The Committee endorsed the 10-year strategy that ARMD has established. The Committee finds that ARMD needs to be sure to focus on a goal setting strategy that makes aviation safe for the environment.
2. The Committee was excited about the X-planes initiative for its technology significance and inspirational value for future generations. The Committee feels that it is an opportunity for the younger community to get excited about aeronautics and commended ARMD for the strategy. (The younger community includes not only the NASA younger generation of employees but the universities and the overall younger community through STEM to be inspired to pursue the aeronautics research fields.)

ARMD Strategic Portfolio Model

SIP Outcomes Drives Top-Down Planning



Roadmaps Provide Guidance for Project / Center Innovation and Planning



Partnerships & Performance Create a Feedback Loop

6 Strategic Thrusts

Safe, Efficient Growth in Global Operations
Enable full NextGen and develop technologies to substantially reduce aircraft safety risks

Innovation in Commercial Supersonic Aircraft
Achieve a low-boom standard

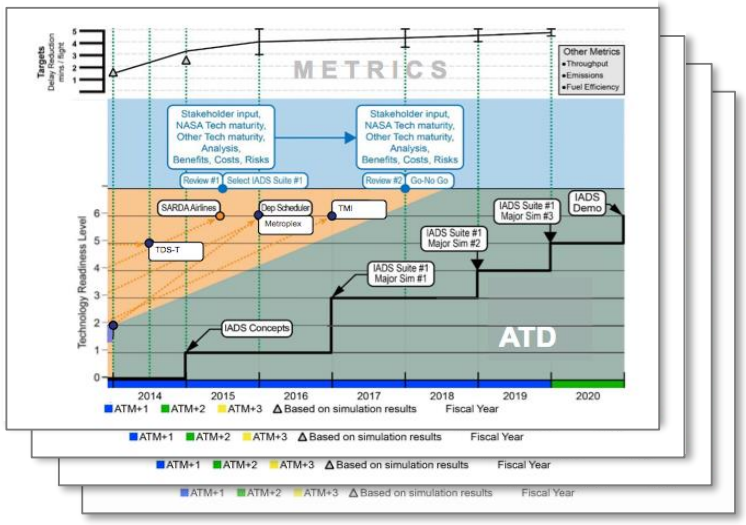
Ultra-Efficient Commercial Vehicles
Pioneer technologies for big leaps in efficiency and environmental performance

Transition to Low-Carbon Propulsion
Characterize drop-in alternative fuels and pioneer low-carbon propulsion technology

Real-Time System-Wide Safety Assurance
Develop an integrated prototype of a real-time safety monitoring and assurance system

Assured Autonomy for Aviation Transformation
Develop high impact aviation autonomy applications

Portfolio Elements



Technical Challenges, as derived from the SIP and Strategic Thrust Roadmaps, are the primary Portfolio Elements for ARMD

Technical Challenges have specific and track-able value propositions to enable benefit in the aviation system

- In addition, there are some key additional portfolio elements
  - Emerging Technical Challenges – Exploratory Research to define and enable future technical challenges aligned to the Strategic Thrust Roadmaps
  - CAS / LEARN Initiatives – Multi-Discipline and Convergent “Fast Feasibility” efforts to challenge conventional thinking and define potentially new, transformative pathways
  - Transformative Tools and Technologies – Supports single discipline advancements and development of revolutionary physics-based tools. Utilizes community-based vision at a discipline level to define pathway – e.g., CFD 2030

ARMD Roadmaps

ARMD's Aeronautical Research Taxonomy

Strategic Thrust 1
Safe, Efficient Growth in Global Operations

Strategic Thrust 2
Innovation in Commercial Supersonic Aircraft

Strategic Thrust 3
Ultra-Efficient Commercial Vehicles

Strategic Thrust 4
Transition to Low-Carbon Propulsion

Strategic Thrust 5
Real-Time System-Wide Safety Assurance

Strategic Thrust 6
Assured Autonomy for Aviation Transformation

Community Outcomes and Vision & Strategy
Near Term: 2015-2025
Mid Term: 2025-2035
Far Term: Beyond 2035

Benefits, Capabilities (Expanded Outcomes)

Research Themes
Long-Term Research Areas that will enable the outcomes (most outcomes encompass multiple research themes)

Roadmap and Overarching Technical Challenges
Specific measurable research commitments within the research themes (most research themes encompasses several technical challenges (TC); each ARMD program project list the TC's for which they are responsible.

NASA Contribution to Community Outcomes

Size/Complexity connection to Lead Times/Development Cycles

COMMUNITY OUTCOMES

SYSTEM VEHICLE SIZE/COMPLEXITY

Large Fixed Wing, 5-7 years
1-2 opportunities

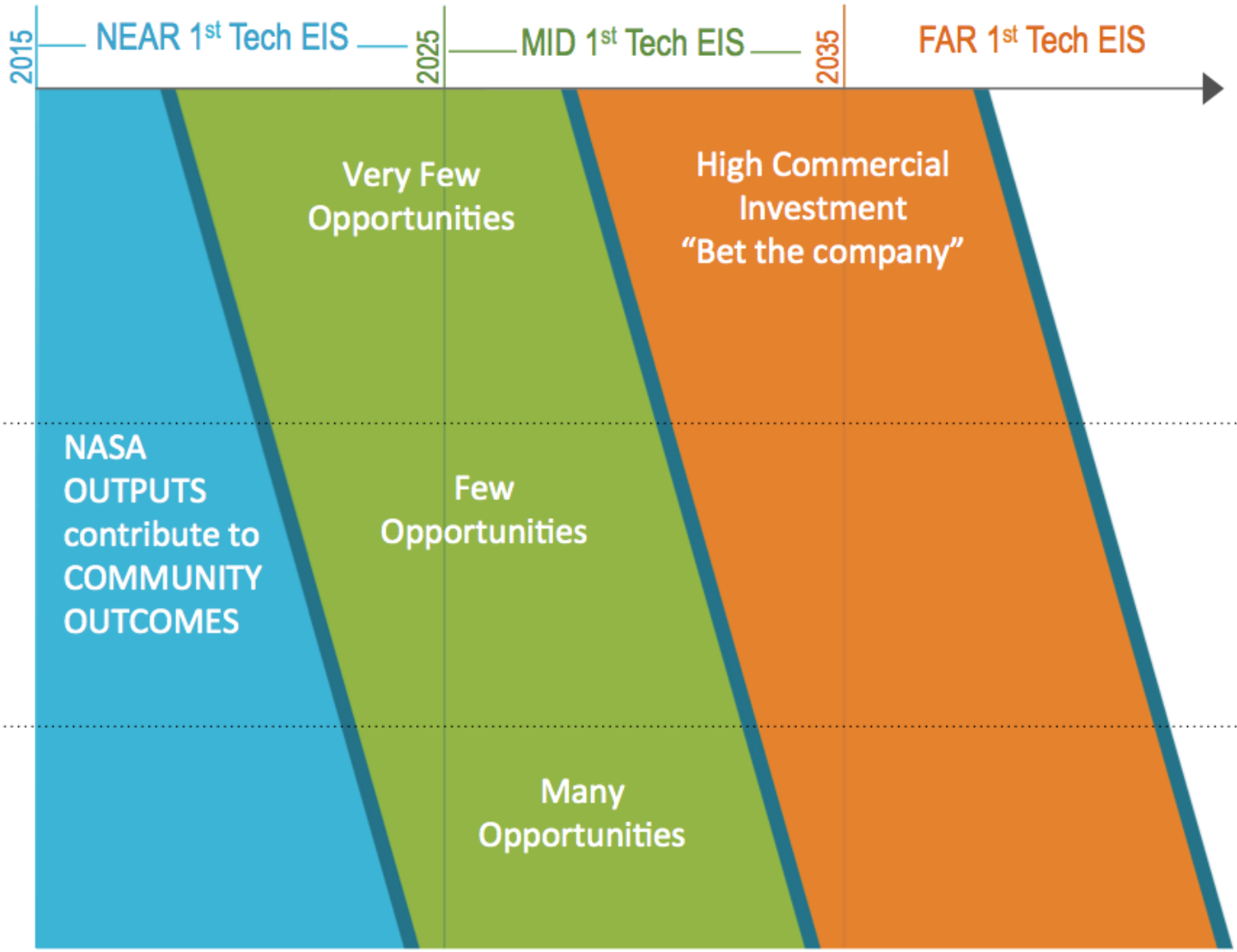
Complex National System,
(ERAM datacom) 5-15 years
1 opportunity

Large Vertical Lift, 3-5 years
2-3 opportunities

Complex Single Domain System
ATD-1, 5-10 years
3-5 opportunities

Small VL/FW, 1-2 years
Many opportunities

Targeted system improvements
DWR, 3-5 years
many opportunities



Planning Priorities

- **Thrust 1 – Safe, Efficient Growth in Global Operations**
  - Transition from Terminal Area optimization to Gate-to Gate TBO

- **Thrust 2 – Innovation in Commercial Supersonic Aircraft**
  - Initiate Low Boom Flight Demonstrator Project

- **Thrust 3 – Ultra Efficient Commercial Vehicles**
  - Initiate planning for Flight Demonstration of N+2 / N+3 configurations and technologies
  - Develop plans for research and ground demonstration of small core engine technologies
  - Develop plans for research and technology development for flex fuel combustors that operate at higher alternative fuel fractions. In addition, planning should anticipate supporting the community with additional alternative fuel characterization tests
  - Develop plans to fully implement CFD 2030

Planning Priorities

- **Thrust 4 – Transition to Low Carbon Propulsion**
  - Develop baseline plans for hybrid-electric propulsion research and development, consistent with Thrust 4 roadmapping, including technical challenges that utilize research results from small-scale demos, such as SCEPTOR

- **Thrust 5 - Real-Time System-Wide Safety Assurance**
  - Develop a comprehensive assessment of ARMD's Verification and Validation (V&V) efforts
  - Develop initial, focused TCs and funding requirements to implement the Thrust 5 roadmap

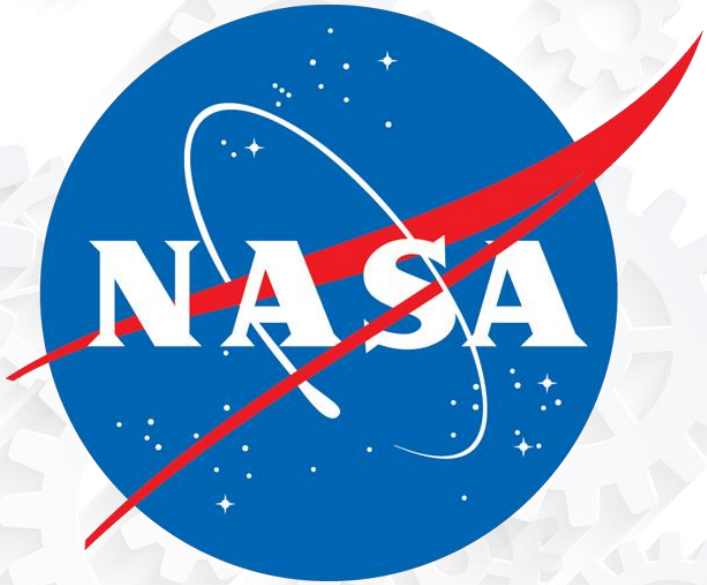
- **Thrust 6 - Assured Autonomy for Aviation Transformation**
  - Develop a cohesive framework and strategy for achieving full integration of UAS into the NAS (AOSP & IASP)
  - Develop initial, focused TCs and funding requirements (beyond current funded UAS TCs) to implement the Thrust 6 roadmap

Committee Finding for ARMD AA on ARMD Strategic Planning

The Committee believes that UTM is a potential test bed for capability prototyping to be an integrating force and potentially revolutionize the ATM for the benefit of the aviation industry. The Committee found that it has potential to be a contributing factor to NextGen.

Air Force and NASA

U.S. AIR FORCE



A rich history of collaboration and partnerships

NASA/Air Force Executive Research Committee Summary

- ERC Meeting held on 2/19/16 at NASA Headquarters.
- Dr. Jaiwon Shin and Dr. David Walker are the committee co-chairs.
- Based on the feedback received during the meeting, we expect to continue holding these meetings bi-annually.
- The purpose of the meeting was to explore collaboration opportunities between NASA and the Air Force and potentially expand our partnership engagement with them.
- One of the main topics was Hypersonics in light of NASA's increased budget request in this research area.
- The other topic areas discussed were: Vehicles, Facilities, Cybersecurity, Autonomy and UAS.

U.S. AIR FORCE

NASA/USAF ERC Collaboration

Areas of Collaboration

AUTONOMY / UAS	VEHICLE	FACILITIES	HYPERSONICS	AIRSPACE OPERATIONS	OTHER FORUMS TO COORDINATE
Detect & Avoid Technology Develop.	DoD Community of Interest (COI) Process	MOU between AFRC and Air Force Flight Test Center and Air Force Propulsion Directorate for Alliance Operations	Joint Technology Office for Hypersonics (JTOH)	Early Discussion with Air Mobility Command	Commercial Aviation Alternative Fuels Initiative (CAAFI) (Fuel Cert. and Qualification, Environment, Business, and R&D)
FAA UAS Aviation Rulemaking Committee (ARC)	Fixed Wing Executive Council	National Partnership for Aeronautical Testing (NPAT) Council		NextGen Interagency Planning Office (IPO)	Federal Alternative Jet Fuel Strategy document
Jointly Optimal Collision Avoidance	Fixed Wing Vehicle ExCom	Range Commanders Council–Telemetry Group, Optical Systems Group, Range Safety Group, and Frequency Management Group			Independent Research and Development (IRAD) reviews
OSD SAA Science and Research Panel (SARP)	Future Vertical Lift Executive Steering Group				NASA/AF Executive Research Committee
Radio Tech Commission for Aero. (RTCA) Special Committee 228 Min. Perform. Standards for UAS	National Composites Strategy				
UAS Aviation Rulemaking Comm.	Versatile Affordable Advanced Turbine Engine (VAATE) Steering Committee				
UAS-NAS Project simulation & flight support					
UAS ExCom SSG and UAS Working Groups					
Vigilant Spirit Control Station Dev.					

Individual agreements development for specific technology collaborations

- FAST-MAC Testing in National Transonic Facility (NTF)
- Vehicle Integrated Propulsion Research (VIPR)

Key Discussion Points

- The ERC is intended to provide a forum for senior level dialogue about priority research activities and identify any areas where additional or new coordination is necessary, and not to duplicate existing efforts.
- The co-chairs (Shin and Walker) will make formal decisions or assign actions resulting from ERC meetings, based on input from the ERC members.
- To ensure future meetings can inform development of budget and strategic investment decisions, both parties (AFRL/NASA) agreed to develop an ERC meeting schedule taking into account each other budget preparation timeline.
- AF and NASA will develop a collaborative hypersonic technology roadmap to document alignment and commitment to collaboration

2 Major Areas of NASA Hypersonic Competencies & Capabilities

Air-breathing: Enabling Potential Future Responsive Space Access

- On Demand Access To Low Earth Orbit
- Reusable First Stage
- Lower Cost To Orbit
- One or Two Stage to orbit

NASA Aeronautics Focus

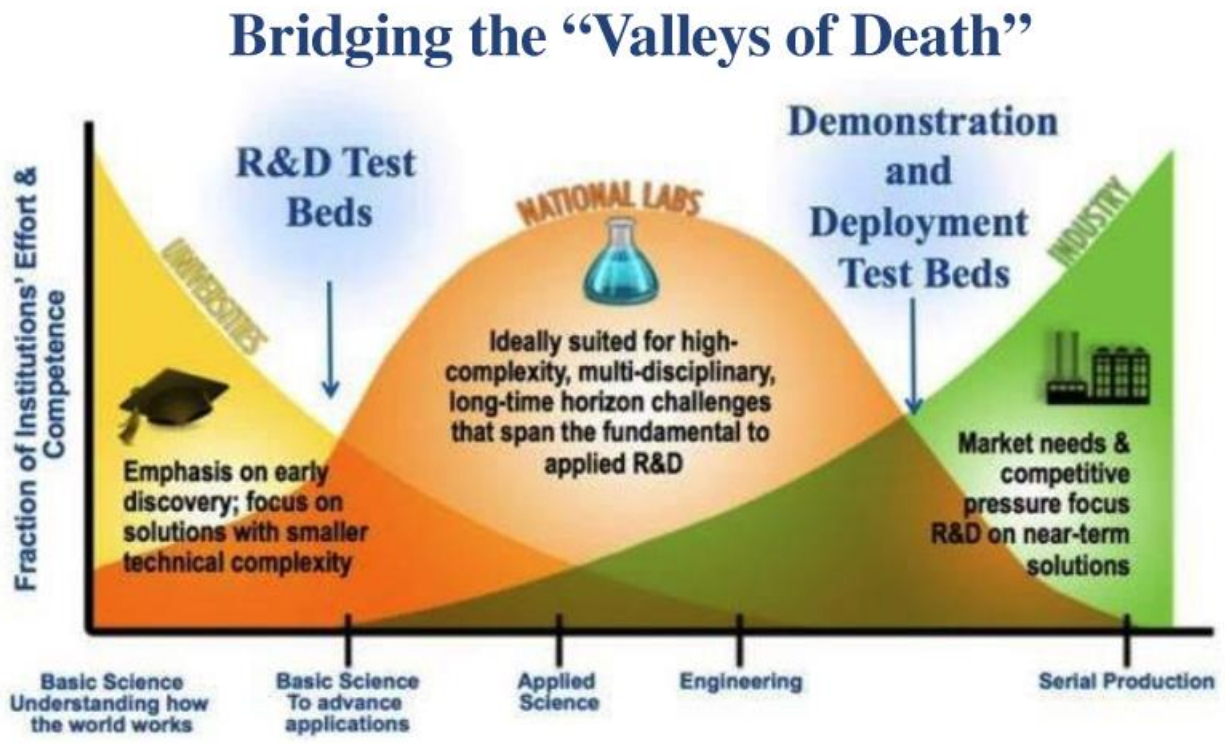
Entry, Decent and Landing (EDL): Required for Atmospheric Reentry

- Reentry of Crew Vehicles to Earth's Atmosphere
- Entry, Descent and Landing on other bodies

NASA Space Technology Focus

Strategic Assumptions

- Our strength (unique integrated capability: SA-Analytical / Computational, Experimental) is mid-TRL, bridging valley of death
- Strategic focus on fundamental research, capability development and student development
- Systems Analysis technology trades drive priorities
- Expertise to identify emerging technologies that are ready for mid-TRL investment
- Critical to see TRL advancement through to flight-test demo
  (National Enterprise / partnerships essential)



FY 2017 Budget Guidance

- **Hypersonic Technologies Project**
  - With the request, NASA will also establish the Hypersonics Technology Project. NASA will balance investments that support and leverage the work of the Department of Defense (DoD) with investments in fundamental hypersonics research.
  - The project objective is to advance and utilize analytical tools, test techniques and capabilities, and critical technologies to ensure U.S. supremacy in hypersonics for future national needs.
  - The project will work with the DoD to develop a National Hypersonic Strategy (requested by OMB and OSTP). NASA's investment will be informed by and aligned to the National Strategy.

Increases investment in fundamental hypersonics research to support and leverage the work of the Department of Defense (DoD).

2016 Work Plan

1. Review the ARMD ten year investment strategy and discuss changes based on the FY17 President's budget. (March)
2. Review the overall Thrust roadmaps and provide feedback. (March, November)
3. Review the NASA – USAF collaboration efforts through the context of the Executive Research Committee (ERC). (March)
4. Review the Hypersonic research strategy at the $25M a year funding level and provide feedback on the technical content and partnering approach. (March)
5. Provide feedback on the NRC Low Carbon (Thrust 4) study and provide recommendations on how this report should influence the ARMD portfolio. (July)
6. Review the New Aviation Horizons formulation plan with a focus on the Low Boom Flight Demonstrator planning. (July)
7. Review the ARMD integrated strategy for UAS (including UTM) research. (July)
8. Review the formulation and execution activities of both the Advanced Composites and the System-wide Safety Assurance projects. (November)
9. Review ARMD autonomy research strategy. (November)
10. Review CFD Vision 2030 implementation plan and synergy with the new funding model for key facilities to maintain aeroscience technical capability. (November)