National Aeronautics and Space Administration

ARMD Strategic Thrust 6:
Assured Autonomy for Aviation Transformation

Roadmap, Part 3: Candidate Mission Products and Community Feedback

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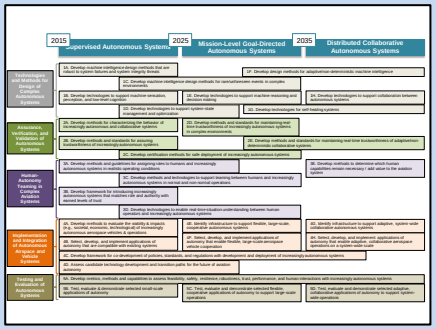
August 2, 2016

Roadmap Elements

Three parallel and interdependent elements to achieve the Vision

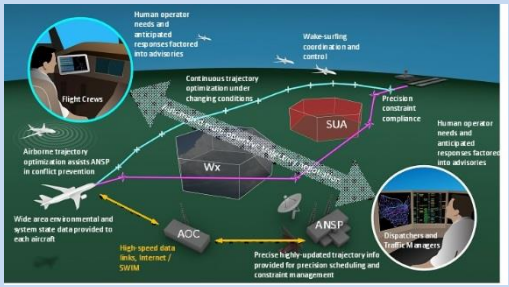


Research Challenges

Technical activities to achieve knowledge breakthroughs and advance aviation autonomy capabilities

Advancement Strategies

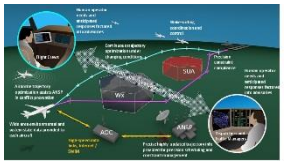
Approaches employed by NASA to achieve aviation autonomy objectives



Mission Products

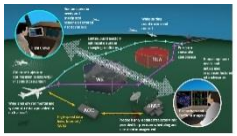
Targeted NASA and community capabilities that facilitate a viable path toward mature and widespread aviation autonomy

Vision



Candidate Mission Products

- Candidate Mission Products: targeted capabilities to be achieved in Epoch 1 (2015-2025)
  - Described in terms of a specific products achievable by 2025
  - Provide focus for research and technology development
  - Research Themes will apply theme-specific R&D to each mission product
  - Provide near-term benefits as well as advancement paths toward ultimate objectives
- Mission Product selection
  - Identified 17 candidate Mission Products based on 2025 Vision, utilizing Advancement Strategies
  - Refinement and down-selection will be based on:
    - NASA/community partnership dialogue (in progress)
    - NASA goals and resources
    - Partnership potential



Candidate Mission Products (1 of 3)

1. **Autonomy-Enabled Airborne Public Safety Services**

   Goal: Use autonomy technologies to improve safety and effectiveness of airborne public safety operations

   2025 Product: Autonomy-augmented airborne medical services

2. **Autonomy-Enabled UAS for Earth Science**

   Goal: Advance practical civil applications of collaborative UAS swarms

   2025 Product: Brassboard capability to support multi-UAS NASA Earth Science missions

3. **UAS Traffic Management and Operations**

   Goal: Safely enable large-scale UAS operations and provide a blueprint for autonomy-centric redesign of the National Airspace System

   2025 Product: Autonomy-based concept and technologies for beyond-visual-line-of-sight civil operations of small UAS

4. **Autonomous Airport Surface Operations**

   Goal: Establish a foundation for in-flight multivehicle collaborative autonomy using ground systems to enable optimal airport surface operations

   2025 Product: Demonstrate an integrated multi-agent autonomous airport ground operations using initial collaborative autonomy and sensor technologies

5. **Autonomy-Enabled Air Traffic Management**

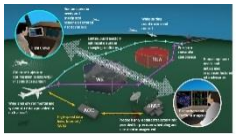
   Goal: Advance development of large-scale autonomous decision systems that require integration of complex constraints and multi-agent coordination, through direct operational experience

   2025 Product: Develop a human-supervised autonomous traffic flow management capability based on large data systems and data analytics

6. **Collaborative In-Flight Optimization for Transport Aircraft**

   Goal: Advance collaborative autonomous air/ground traffic management concepts and technologies and provide an autonomy modernization path for existing IFR operations

   2025 Product: Operational initial autonomy technologies applied to commercial aviation to facilitate in-flight trajectory optimization, trajectory negotiation, and vehicle teaming



Candidate Mission Products (2 of 3)

7. **Autonomy-Enabled Flight Crew Performance in Complex Environments**

   Goal: Achieve optimal flight performance, pilot training, and operational resilience through human/cockpit systems that employ the specialized skills of operators and machine systems working as an optimized team

   2025 Product: Cockpit technology prototypes and guidelines for autonomy-enhanced flight systems, teamed human/machine decision making, and human/autonomy interfaces to enable transformational operations and mobility

8. **Autonomy-Enhanced Vehicle Safety**

   Goal: Make flight vehicles situationally aware of their internal states so they are able to assume an independent role in safety assurance

   2025 Product: Vehicle intelligence technologies that assess vehicle safety state, targeting high risk scenarios

9. **Resilient, Trusted Autonomous Vehicle Systems**

   Goal: Achieve safe and reliable operations for autonomous aircraft by integration of resilient vehicle technologies

   2025 Product: A prototype scaled vehicle that demonstrates refuse-to-crash operation in selected off-nominal conditions through resilient design approaches, ability to deal with uncertainties, and appropriate response to off-nominal conditions

10. **Inflight Vehicle Performance Optimization**

    Goal: Optimize vehicle performance and efficiency through automated and autonomous systems that determine the vehicle state and adaptively reconfigure

    2025 Product: Demonstration of improved vehicle efficiency with less environmental impact through intelligent feedback between internal state monitoring and adjustment of vehicle parameters

11. **Complex Decision-Making UAS**

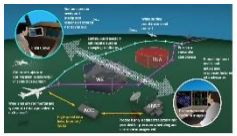
    Goal: Develop autonomous vehicles with reasoning and decision making capabilities to independently and reliably make safety-related decisions in complex, uncertain environments

    2025 Product: Demonstration of UAS that identifies loss of control in selected multiple simultaneous simulated faults and makes a decision to crash in a manner that does not impact property/personnel

12. **Fully Autonomous Transport Aircraft**

    Goal: Understand CONOPS, technologies, and system requirements necessary for design, development, and operations of practical fully autonomous transport class civil aircraft

    2025 Product: Design and demonstrate a fully autonomous aircraft to understand the full potential and costs of autonomy technology for transport class civil aircraft



Candidate Mission Products (3 of 3)

13. **Mission-Adaptive, Eco-Friendly Autonomous Vertical Lift Vehicles**

    Goal: Design small-scale vertical lift vehicles to be safe, reliable, and eco-friendly through the application of autonomy technologies, and rapidly advance the state of maturity for autonomy technologies that improve vehicle design and vehicle operational safety and efficiency

    2025 Product: A small-scale autonomous UAV with reliability and performance enhanced and environmental impacts reduced through use of autonomy-enabled design tools, and operational safety and utility improved through mission-adaptive health state awareness and prediction technologies

14. **Infrastructure for Experimentation, Evaluation, and Testing of Autonomous Systems**

    Goal: Enable researchers in academia, industry, and government laboratories to provide consistent benchmarked experimental and evaluation data on autonomous system through well established methods, tools, and infrastructure

    2025 Product: Flexible infrastructure for experimentation, evaluation, and testing of autonomous systems and multi-agent collaborations

15. **Initial Certification Standards for Autonomous Systems**

    Goal: Enable certification of autonomous aviation systems and provide verification and validation (V&V) techniques to support certification

    2025 Product: Initial certification standards for *runtime assurance* and *continuous certification* approaches to V&V of autonomous systems, obtained by brokering consensus between regulators and industry.

16. **Vehicle Structural Health for Maintenance and Safety**

    Goal: Integrate distributed structural sensor network data with models of individual vehicles to determine the structural health and impose necessary constraints on performance or mission

    2025 Product: Digital Twin for autonomous sustainment/maintenance and real-time structural safety in flight vehicles

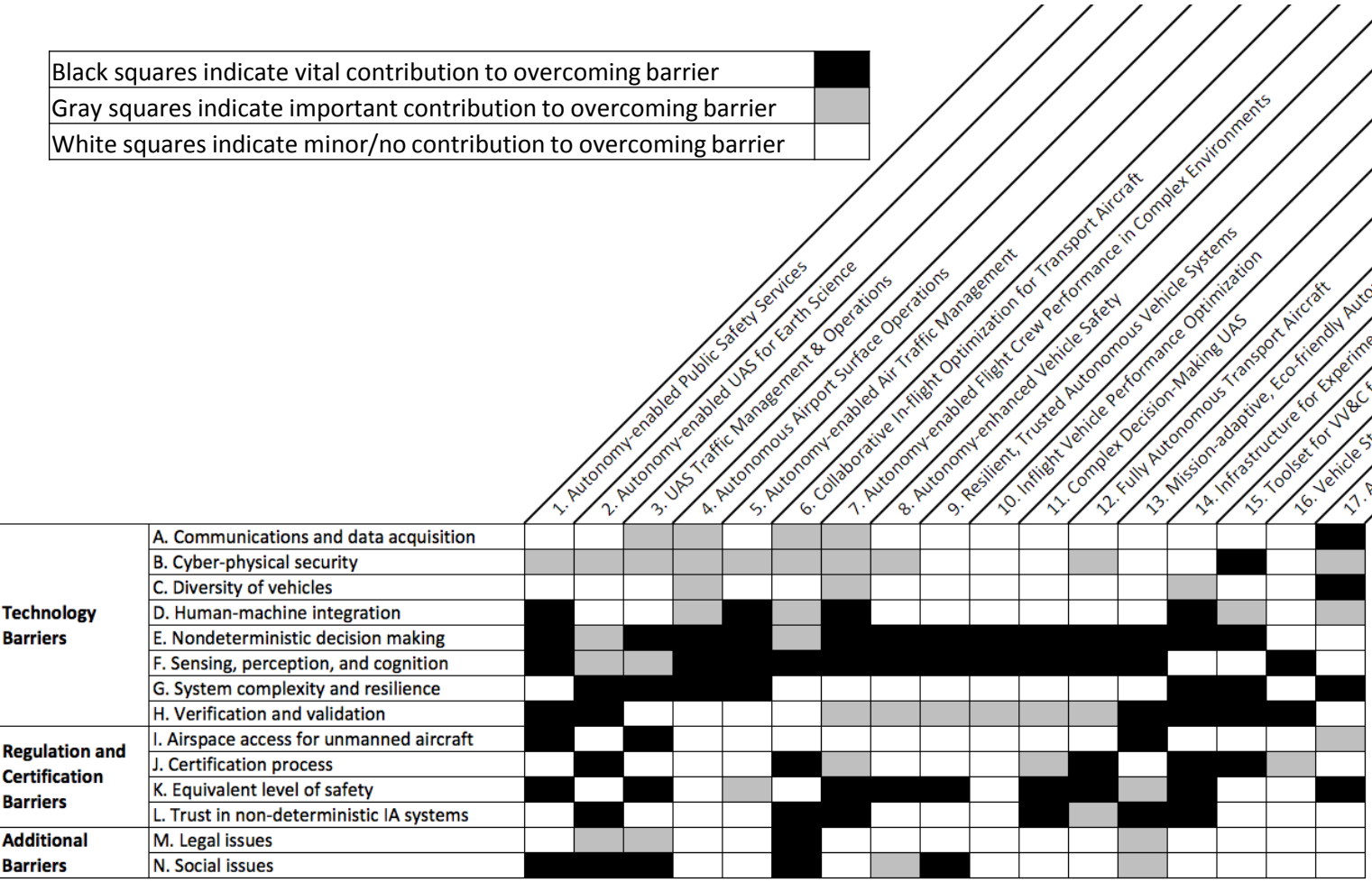
17. **Autonomy-Enabled Concepts for Achieving the ATM+3 Vision**

    Goal: Advance autonomy technologies to enable future National Airspace System densities, diversities, efficiencies

    2025 Product: Stakeholder-vetted autonomy-enabled integrated air/ground concept alternatives that will enable millions of manned and unmanned platforms to operate in U.S. airspace in a safe and efficient manner

Mapping of Mission Products to NRC Barriers

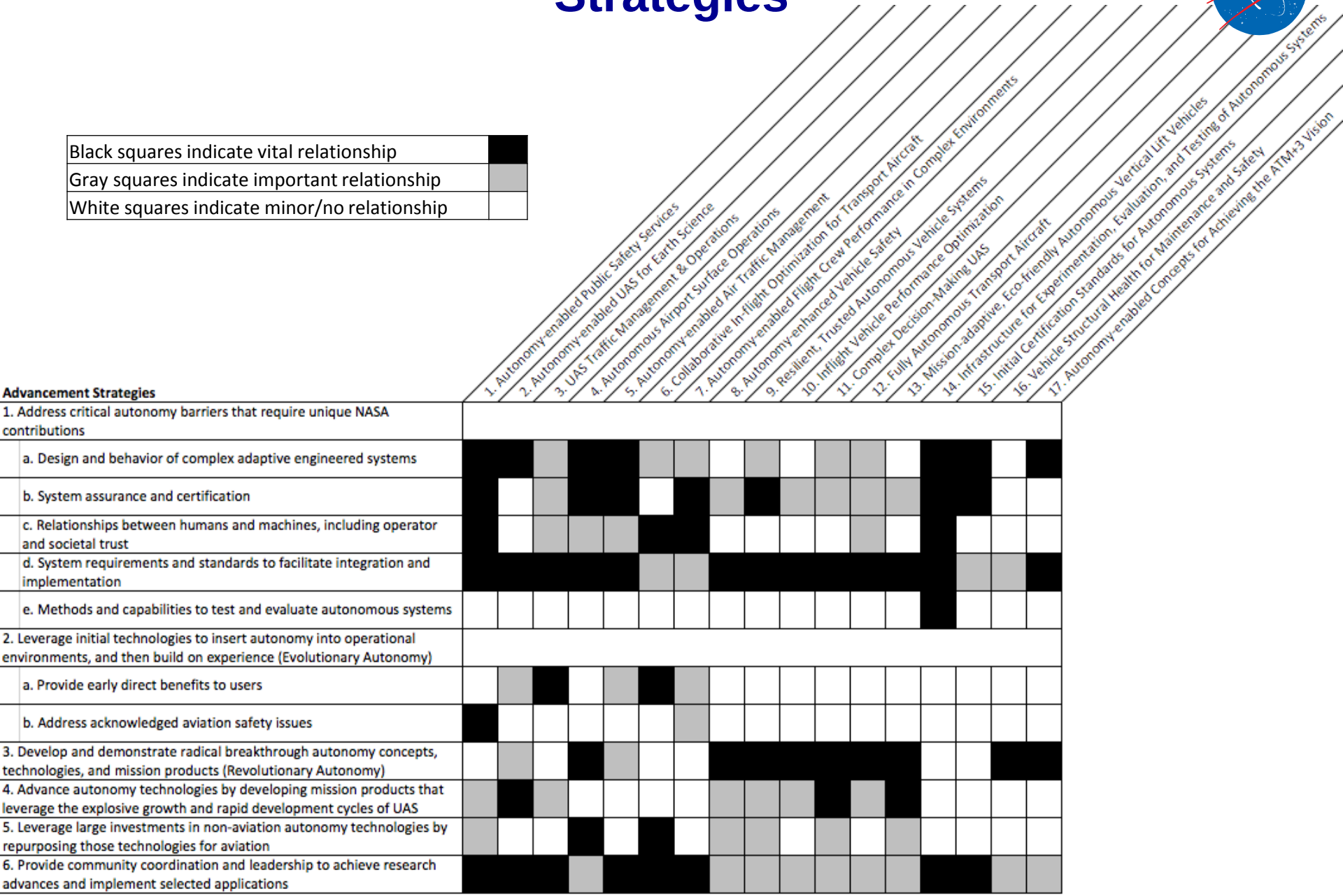
Black squares indicate vital contribution to overcoming barrier	
Gray squares indicate important contribution to overcoming barrier	
White squares indicate minor/no contribution to overcoming barrier	



Barrier ID	Comments
A	Hi-bandwidth communications and data exchange barriers are addressed in Strategic Thrust 1. MPs indicated provide applications to focus R&D.
B	Cyber-physical security barriers are addressed in Strategic Thrust 1. MPs indicated provide applications to focus R&D.
C	Backward-compatibility with legacy systems is a requirement for the MPs indicated.
G	Barrier emphasis is complexity and resiliency of large-scale highly distributed systems employing IA
J	MPs indicated have a goal to support advancement of the certification process for IA systems.
K	MPs indicated have a goal to support R&D of a regulatory framework for safety of systems that employ IA.
L	MPs indicated are designed to contribute to trust through evidential / experiential strategies.
M	MPs indicated contribute to public policy development through evidential / experiential strategies.
N	MPs indicated contribute to public acceptance by providing clear safety or public service benefits.

Mapping of Mission Products to Advancement Strategies

Black squares indicate vital relationship	
Gray squares indicate important relationship	
White squares indicate minor/no relationship	



Community Outreach and Feedback

Public presentations and interactions include

- AIAA Demand for Unmanned Symposium
- AIAA Aviation 2016 Community Forum event (poster session)
- Interactive Webinar, June 28
- Roadmap available for download at NASA Aeronautics website
  http://www.aeronautics.nasa.gov/strategic-plan.htm
- NASA Thrust 6 website, containing webinar video and on-line survey
  https://nari.arc.nasa.gov/thrust6
- Thrust 6 email address to receive feedback
  NASA-ARMD-Autonomy@mail.nasa.gov

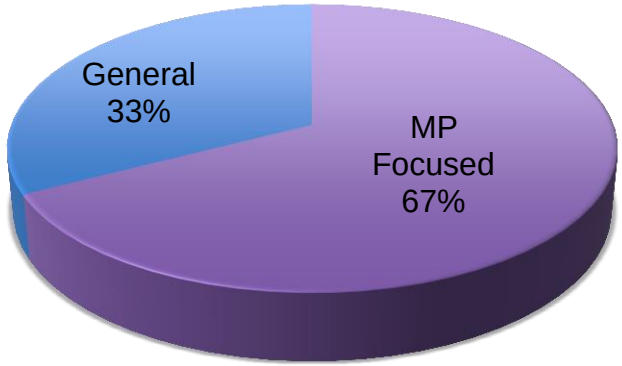
Community Feedback: Collection Methodology

Community feedback was collected primarily through

- Community forum survey form
- Online survey form
- Email freeform feedback

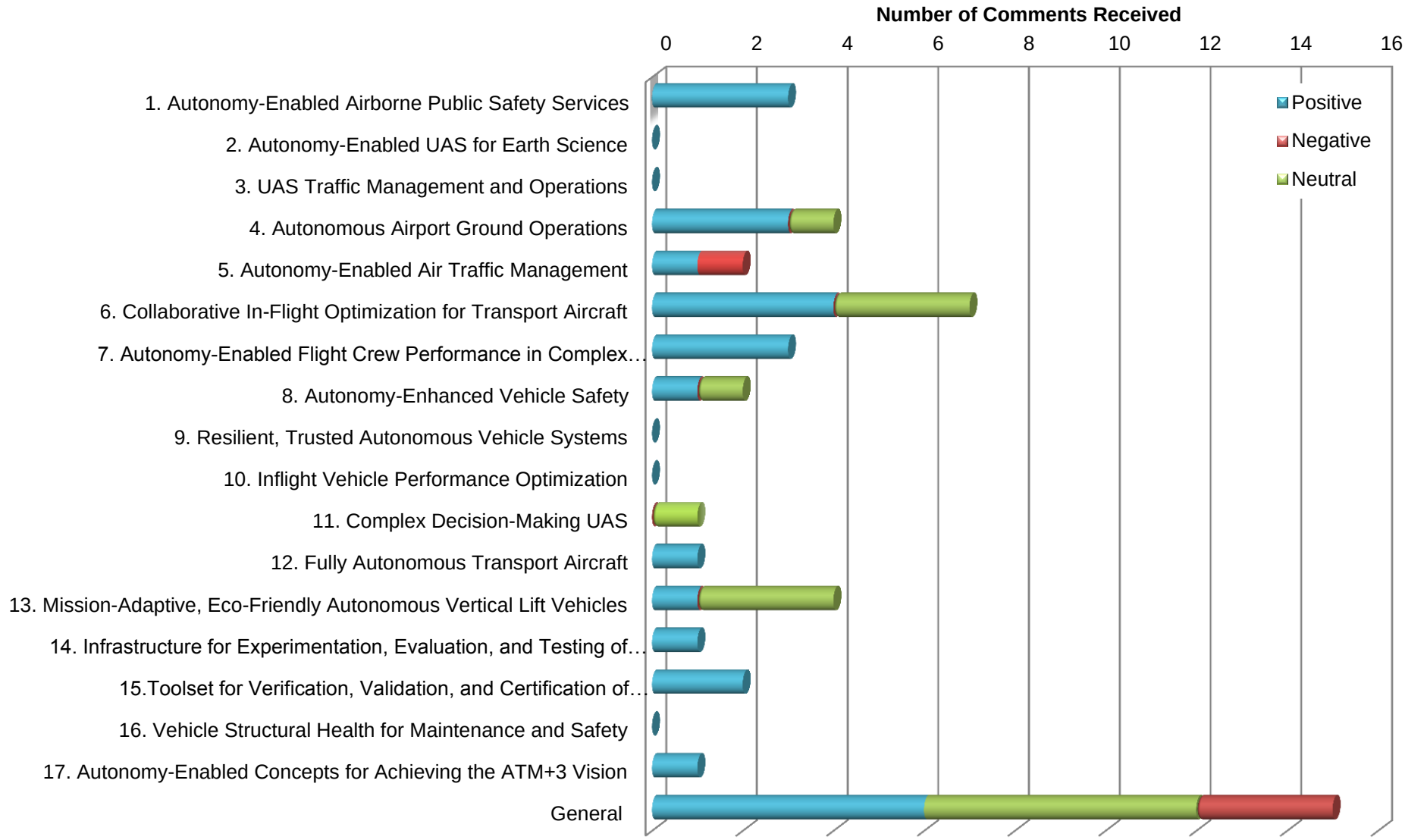
The survey form asked questions across 5 categories ranging from changes to the mission product, whether the MP should be considered a NASA priority, the role of NASA in achieving the objective of the MP, and the ability of achieving the goal in a 10 year time frame.

Collected 46 unique feedback responses that ranged from detailed comments for individual mission products, short suggestions, and general comments regarding the roadmap as a whole.



Due to the small sample size, no real statistically significant criteria could be evaluated from the feedback collected. The number of comments for each mission product were tallied and a general valence (positive, negative, neutral) for each comment was also assessed.

Breakdown of Comments Provided



General Feedback: Summary of Comments

General comments included broad suggestions as well as recommendations of organizations/individuals to interface with; in particular, comments included the following recommendations:

- Explicitly address cyber security
- Demonstrate pathways to certification
- Significant research investment is required

Comments reflect a broad diversity of opinion regarding vision and NASA emphasis. Some highlights:

- A focus on exposing the general public to the potential benefits of increased autonomy in aviation could be beneficial to the overall mission.
- There are a lot of fundamental assumptions in this roadmap that are not substantiated. Particularly, distributed collaborated autonomy as the 3rd big stage … this is not how the rest of the industry appears to be going.
- Mission products are too narrowly defined. They are too vehicle centric. … I encourage that a stronger consideration must be given to integrated air/ground platforms and airspace operations.
- The scope is so broad now that it can support nearly any form of autonomy research and runs the risk of doing lots of great work that doesn't patch together to solve specific problems.
- I suggest putting more emphasis on the pilot in the near term to speed transition to practice.
- Various stakeholders will build vehicle technologies but airspace operations is something no one company can solve.
- Keep in mind and address training/education for operational activities.

Summary and Concluding Remarks

- NASA ARMD is developing a roadmap to guide activities for Aeronautics Strategic Thrust 6: Assured Autonomy for Aviation Transformation.
- Major elements of the roadmap are Advancement Strategies, Research Challenges, and Mission Products with outcomes that produce defined capabilities and benefits.
- Due to the game-changing potential and fast-moving nature of autonomous systems, candidate Mission Products are focused primarily on Outcome 1 (2025), with an eye on advancement toward ultimate capabilities.
- Active outreach to the aviation community is in progress. Initial feedback is largely positive or neutral. All feedback is considered and addressed.
- Roadmap will serve as a guide to inform NASA programmatic commitments. Execution will rely on collaborative partnerships to strategically leverage efforts and resources.
- Roadmap will evolve based on continued engagement with the aviation community.
- Initial roadmap will be finalized in September 2016.

Backup

Mapping of Mission Products to Aviation System Components

Black squares indicate primary component
Gray squares indicate important component
White squares indicate minor/no component

Aviation System Components	1. Autonomy-enabled Public Safety Services	2. Autonomy-enabled UAS for Earth Science	3. UAS Traffic Management & Operations	4. Autonomous Airport Surface Operations	5. Autonomy-enabled Air Traffic Management	6. Collaborative In-flight Optimization for Transport Aircraft	7. Autonomy-enabled Flight Crew Performance in Complex Environments	8. Autonomy-enhanced Vehicle Safety	9. Resilient, Trusted Autonomous Vehicle Systems	10. Inflight Vehicle Performance Optimization	11. Complex Decision-Making UAS	12. Fully Autonomous Transport Aircraft	13. Mission-adaptive, Eco-friendly Autonomous Vertical Lift Vehicles	14. Infrastructure for Experimentation, Evaluation, and Testing of Autonomous Systems	15. Initial Certification Standards for Autonomous Systems	16. Vehicle Structural Health for Maintenance and Safety	17. Autonomy-enabled Concepts for Achieving the ATM+3 Vision
Airspace System																	
Air Traffic Control Systems and Ops																	
Airspace Resource Management Systems and Ops																	
National Airspace System Management Systems and Ops																	
Airport Systems and Ops																	
Vehicles																	
Unpiloted Aerial Vehicle Systems and Ops																	
Piloted Vehicle Systems and Ops - Scheduled																	
Piloted Vehicle Systems and Ops - On Demand																	
Ground Vehicle Systems and Ops																	
People																	
Air Traffic Controllers and Managers																	
Pilots																	
Operators and Suppliers																	

Mapping of Mission Products to Autonomy Attributes

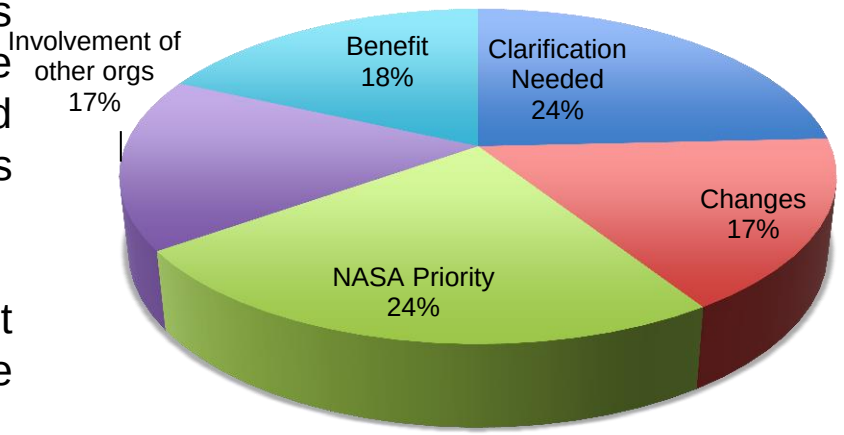
L	Low
M	Moderate
H	High
NA	Not Applicable

Autonomy Attributes	1. Autonomy-enabled Public Safety Services	2. Autonomy-enabled UAS for Earth Science	3. UAS Traffic Management & Operations	4. Autonomous Airport Surface Operations	5. Autonomy-enabled Air Traffic Management	6. Collaborative In-flight Optimization for Transport Aircraft	7. Autonomy-enabled Flight Crew Performance in Complex Environments	8. Autonomy-enhanced Vehicle Safety	9. Resilient, Trusted Autonomous Vehicle Systems	10. Inflight Vehicle Performance Optimization	11. Complex Decision-Making UAS	12. Fully Autonomous Transport Aircraft	13. Mission-adaptive, Eco-friendly Autonomous Vertical Lift Vehicles	14. Infrastructure for Experimentation, Evaluation, and Testing of Autonomous Systems	15. Initial Certification Standards for Autonomous Systems	16. Vehicle Structural Health for Maintenance and Safety	17. Autonomy-enabled Concepts for Achieving the ATM+3 Vision
Goal Specification Level	M	H	L	L	L	L	M	L	H	L	M	M	M	NA	NA	L	M
Human Supervision Level	H	L	M	H	M	H	H	L	L	L	L	L	L	NA	NA	L	L
World View	H	H	H	M	H	H	L	H	M	L	H	H	M	H	NA	H	H
System Scale	M	M	H	M	H	M	L	M	L	L	L	L	L	H	L	L	H
Distribution / Collaboration / Data Analytics Level	M	H	M	L	M	H	L	M	L	M	L	L	L	H	L	H	H

MP Focused Analysis of Feedback

Of the mission product focused comments the following pie chart indicates the percentage of comments directed toward toward the criteria detailed on a previous slide.

It should be noted that each distinct comment may have indicated multiple criteria.



Of the mission products that received comments the following were explicitly stated as those that should be considered a high priority for NASA:

- MP 1. Autonomy-Enabled Airborne Public Safety Services
- MP 4 & 5. Autonomous Airport Ground Operations and Autonomy-Enabled Air Traffic Management
- MP 6. Collaborative In-Flight Optimization for Transport Aircraft
- MP 7. Autonomy-Enabled Flight Crew Performance in Complex Environments
- MP 8 & 10. Autonomy-Enhanced Vehicle Safety and Inflight Vehicle Performance Optimization
- MP 15.Toolset for Verification, Validation, and Certification of Autonomous Systems
- MP 17. Autonomy-Enabled Concepts for Achieving the ATM+3 Vision

MP Feedback: Common Criteria Used for Evaluation

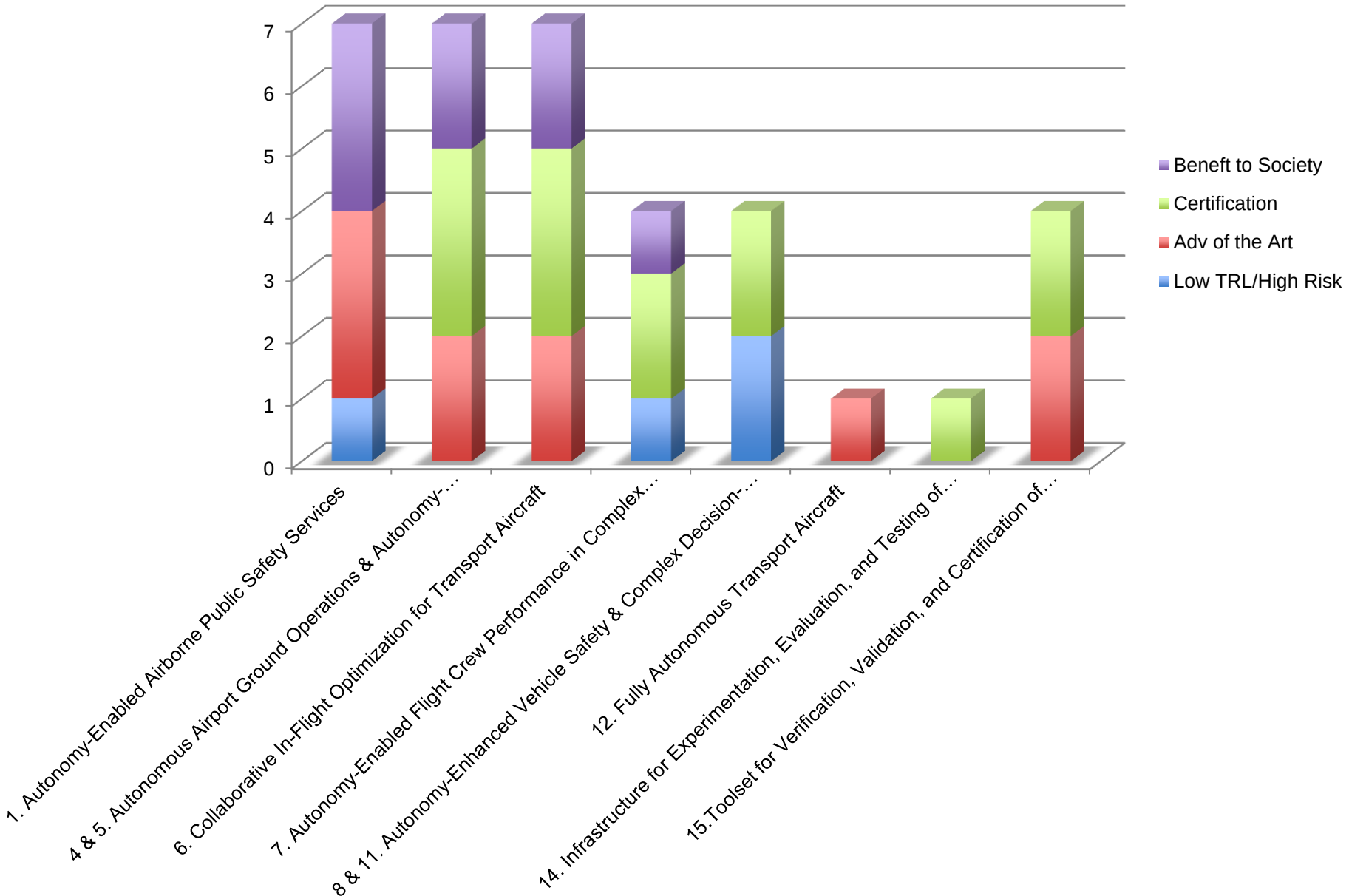
Due to the small sample size of the comments collected the MP feedback was analyzed to determine if certain criteria were commonly used by the community

The analysis of the feedback revealed the following criteria were stated when positively reviewing a MP:

- Low TRL/high risk
- Advancement of the art
- Certification
- Measurable benefit to society

Each individual comment was analyzed and a single point was assigned to each of the above criteria if they were indicated

MP Feedback: Common Criteria Used for Evaluation



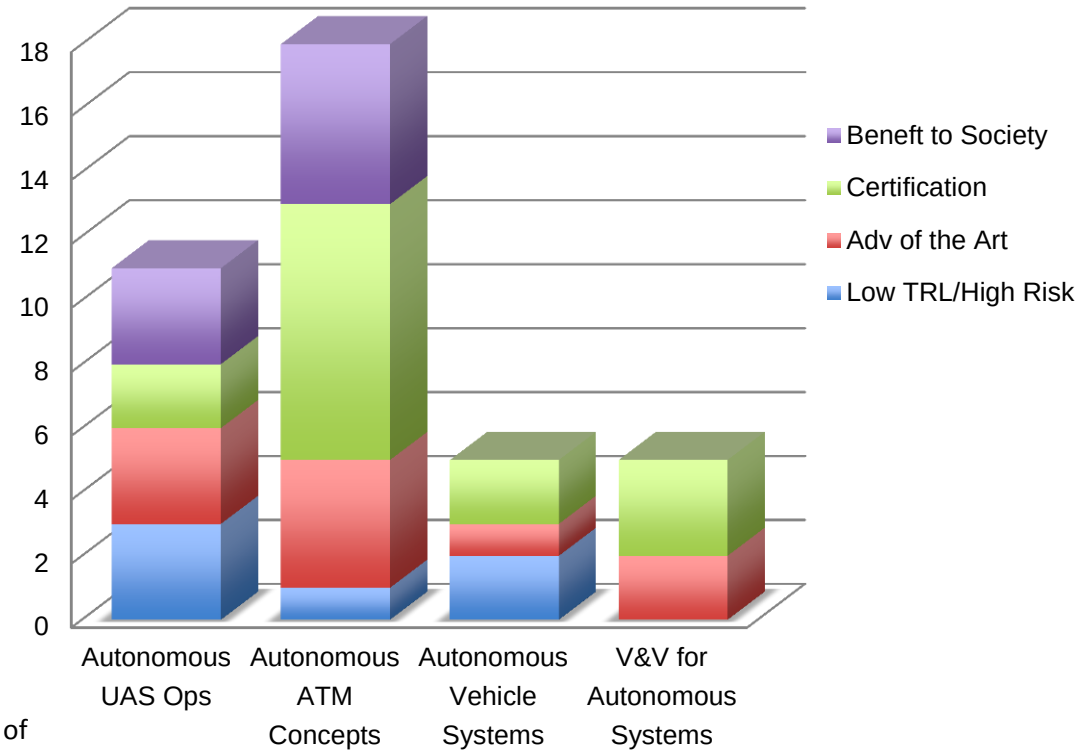
Comments Organized based on clusters of MPs

Autonomous UAS Ops
1. Autonomy-Enabled Airborne Public Safety Services
2. Autonomy-Enabled UAS for Earth Science
3. UAS Traffic Management and Operations
11. Complex Decision-Making UAS

Autonomous ATM Concepts
4. Autonomous Airport Ground Operations
5. Autonomy-Enabled Air Traffic Management
6. Collaborative In-Flight Optimization for Transport Aircraft
7. Autonomy-Enabled Flight Crew Performance in Complex Environments
17. Autonomy Enabled Vision for ATM+3

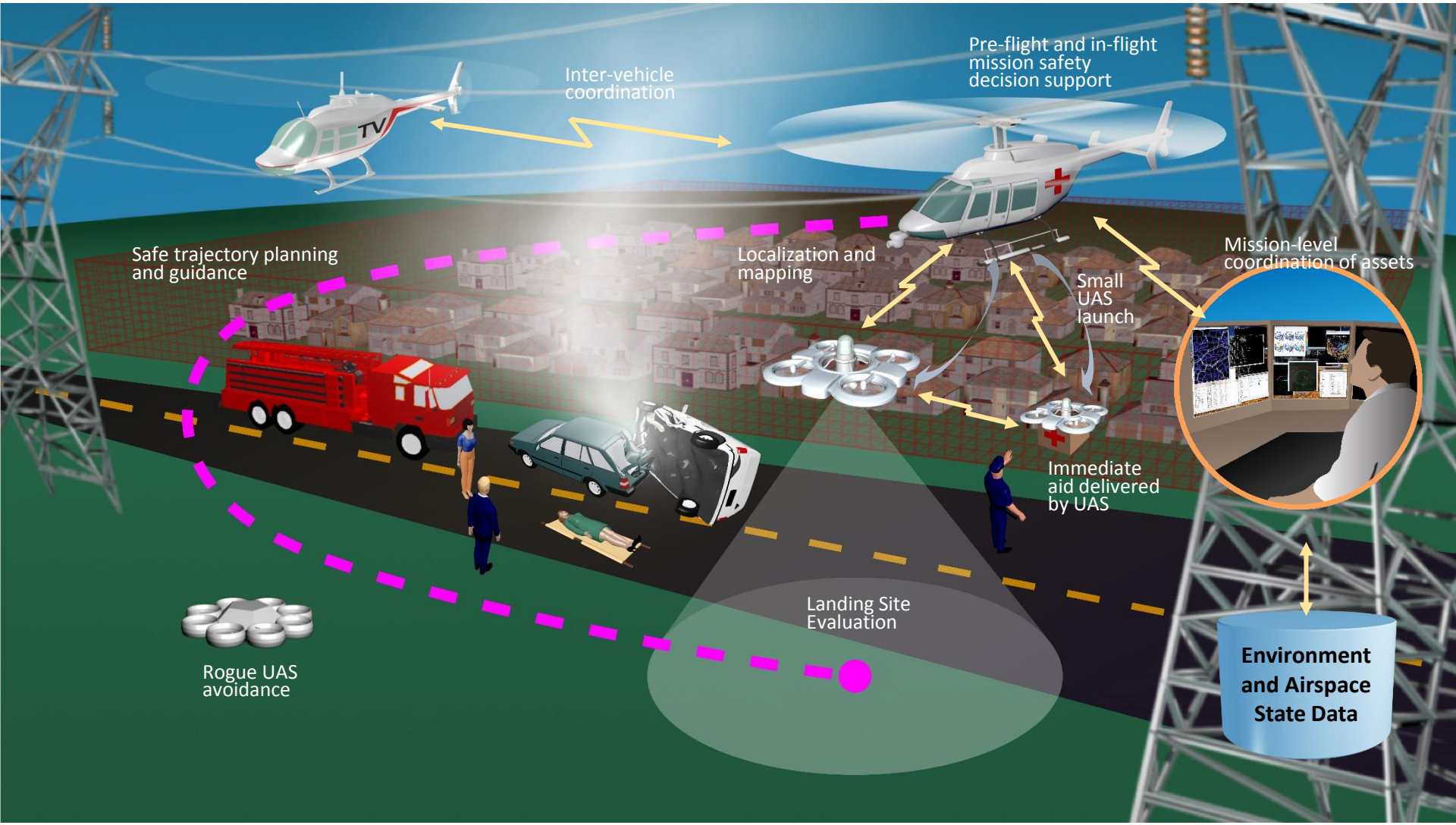
Autonomous Vehicle Systems
8. Autonomy-Enhanced Vehicle Safety
9. Resilient, Trusted Autonomous Vehicle Systems
10. Inflight Vehicle Performance Optimization
12. Fully Autonomous Transport Aircraft
13. Mission-Adaptive, Eco-Friendly Autonomous Vertical Lift Vehicles

V&V for Autonomous Systems
14. Infrastructure for Experimentation, Evaluation, and Testing of Autonomous Systems
15.Toolset for Verification, Validation, and Certification of Autonomous Systems
16. Vehicle Structural Health for Maintenance and Safety



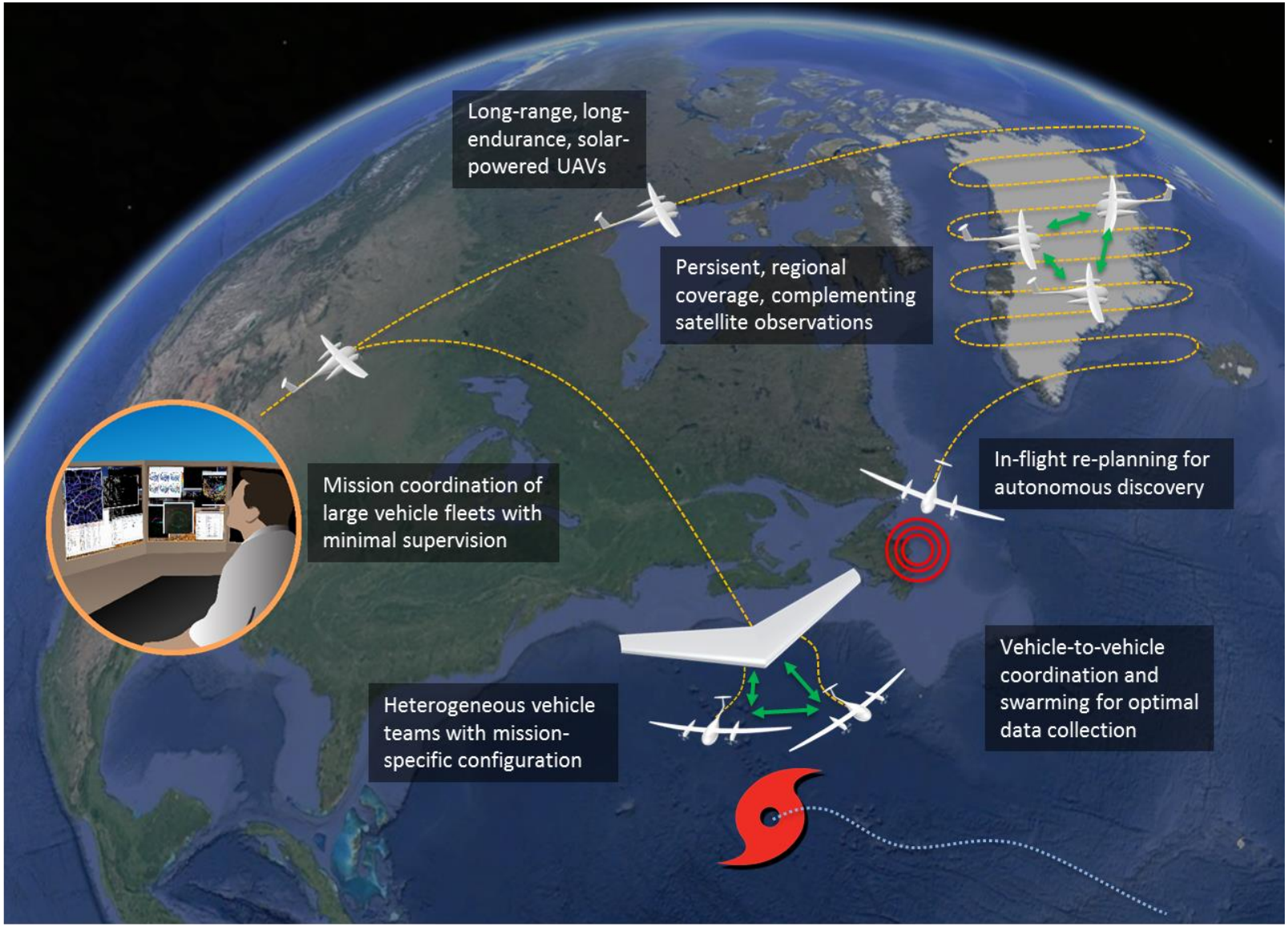
Autonomy-Enabled Airborne Public Safety Services

Operational View



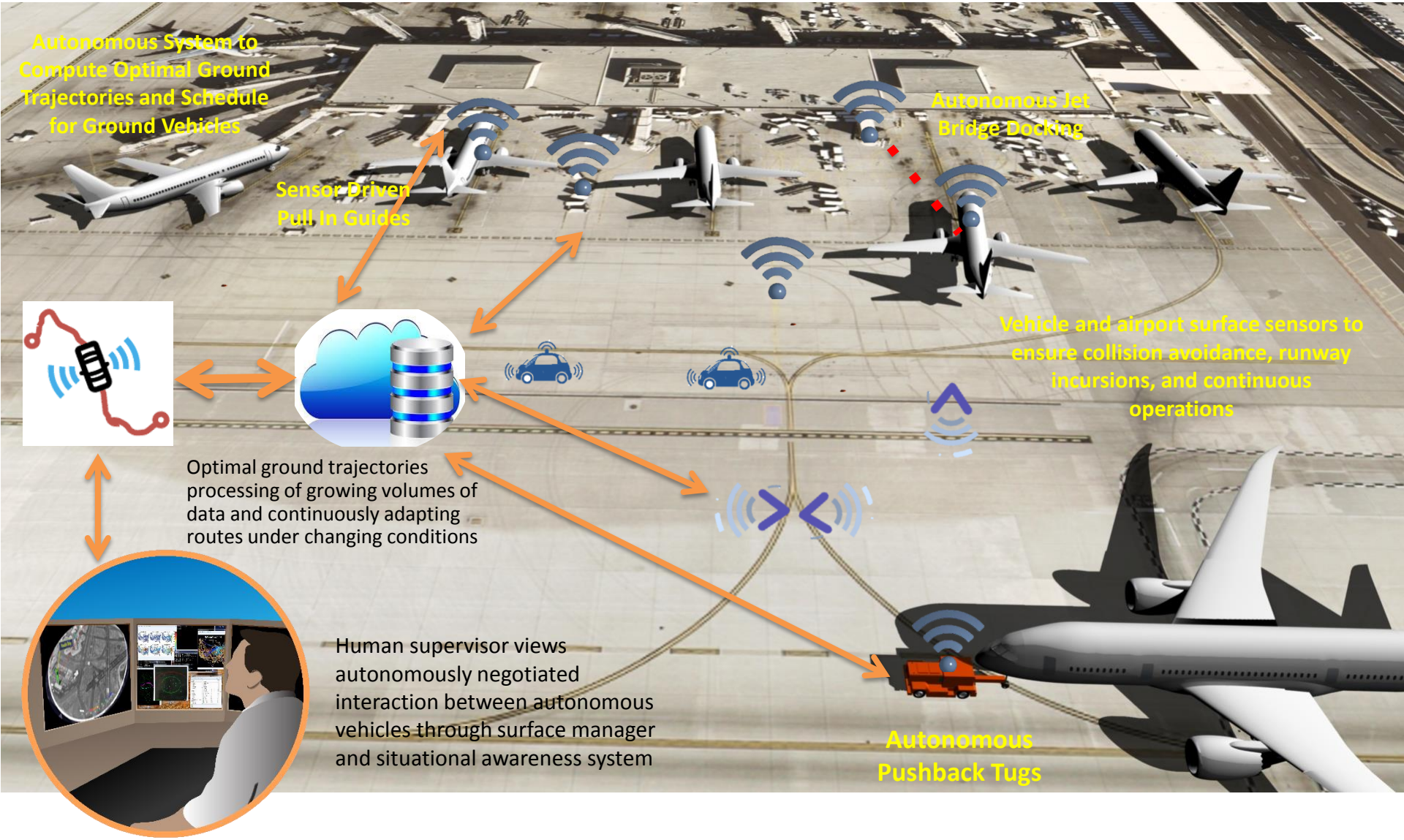
Autonomy-Enabled UAS for Earth Science

Operational View



Autonomous Airport Surface Operations

Operational View

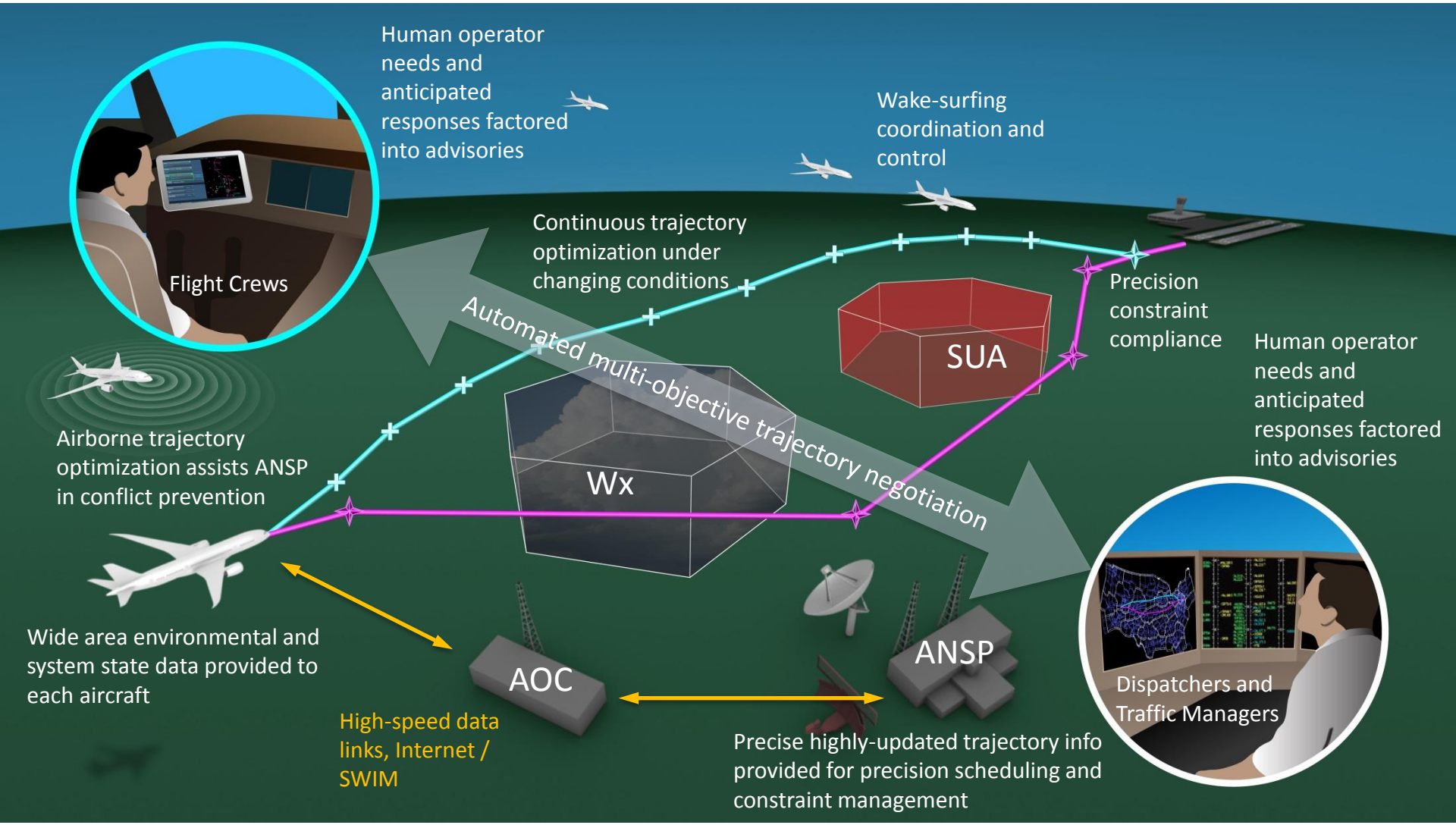


Autonomy-Enabled Air Traffic Management

Operational View

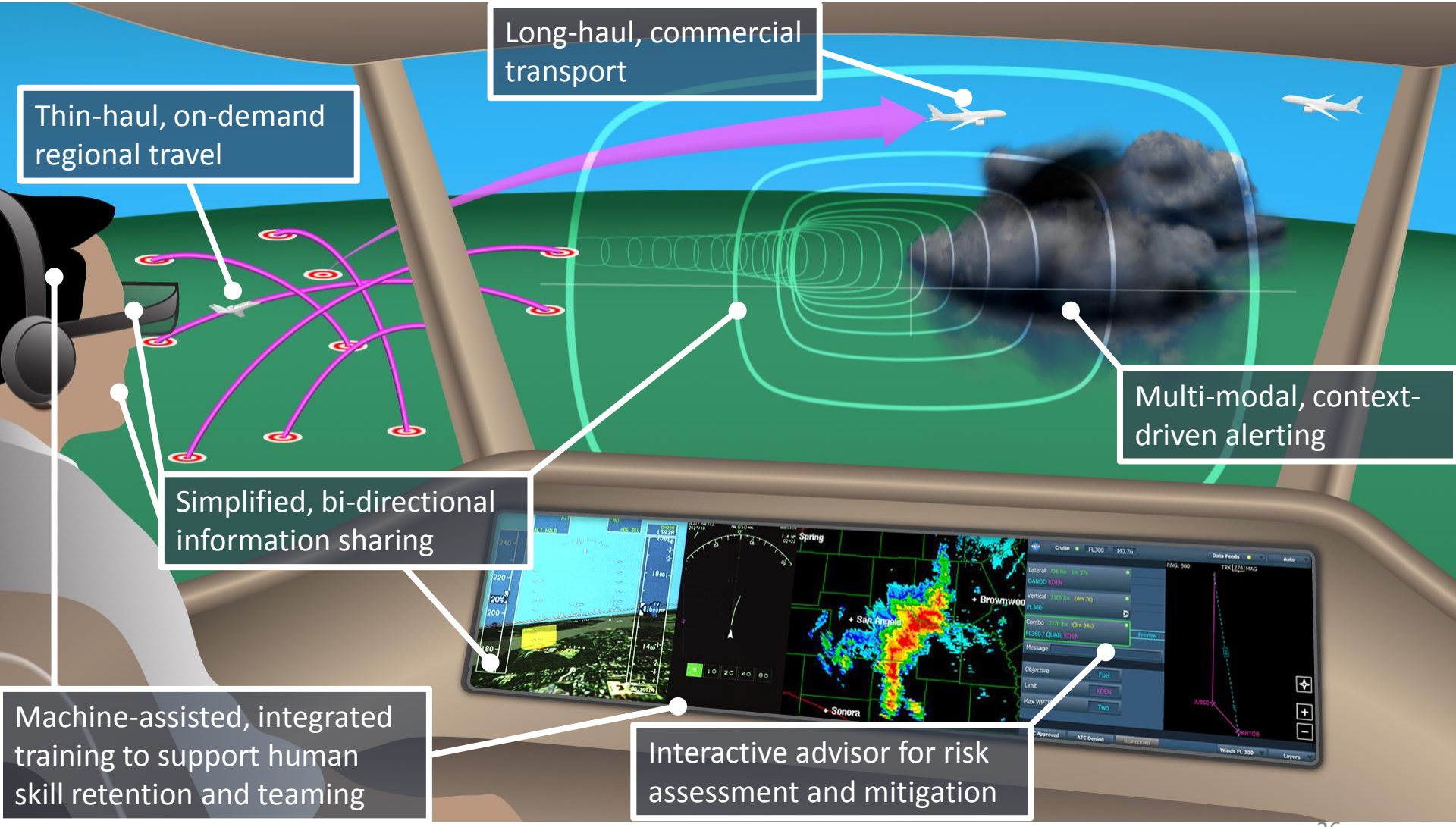
Collaborative In-Flight Optimization for Transport Aircraft

Operational View



Autonomy-Enabled Flight Crew Performance in Complex Environments

Operational View



Fully Autonomous Transport Aircraft

Operational View