National Aeronautics and Space Administration

# Airspace Operations and Safety Program (AOSP)

# Safe Autonomous System Operations (SASO) Project

## Deep Dive
## Presentation for ARTR
## August 2, 2016

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**Note: This is a current project of record under AOSP. TACP will plan a new project in FY17.**

# Outline

- Main Message
- Autonomy for Airspace operations
- Safe Autonomous System Operations: Project Goals
- Selected initial autonomy applications
- Concluding Remarks

# Main Message

- **System View**: Air and ground integrated autonomous capabilities are essential to enable significant improvements in performance of National Airspace System (NAS) operations
  - Enabling future aviation: Air/ground integration is key
  - UTM is beginning but not nearly enough
  - Autonomicity: self-management

- **Task and functional View**: Targeted opportunities for autonomy exist within vehicle and airspace domain
  - Health, status, diagnosis, prognosis, advisory, and mitigation (domain: cockpit, airport, etc.)
  - Autonomy: Self-governance

# Autonomy for Airspace Operations

**Thesis: Current human-centric architectures, concepts, and technologies are not scalable**

**Problem: Higher levels of automation still require human intervention limiting scalability and precision and won't be adequate for complex, dynamic, unforeseen situations**

**Hypothesis: Systems have to evolve beyond original programmed set of procedures, move towards independent/augmented intelligence, and they have to "learn"**

**Need: Future densities, diversity, business models, safety, affordability, predictability**

- Augmented Intelligence (to extend human effectiveness),
- Connected systems,
- Independent individually optimized decisions but consistent in maintaining entire system effectiveness
- Air platforms and supporting ground-based capabilities integration is essential

**Why NASA: We understand push of technology, pull of future needs, develop complex systems, can help bridge the gap between technology to acceptance, world-class ATM expertise, sustained impact, and can balance disruptive/revolutionary and evolutionary methods**

**FAA's charter is safe operations, industry's charter is serve customers, and NASA's charter is enable future**

# Towards Autonomy

| Better Information | Decision Support Tools | More automation and integration | Autonomy/Autonomicity |
|---|---|---|---|
| Human Dominated | Human Centric | Manage by Exception | Increasingly autonomous |
| **ATM** | **ATM+1** | **ATM+2** | **ATM+3** |
| • Mechanical aircraft<br>• Miles-in-trail | • Time based management<br>• Glass cockpit | • Flight service station<br>• Full TBO | • Architecture<br>• Targeted capabilities |
| Radar | Ground-based systems | ADS-B, Data comm, and Air/ground systems | Machine intelligence |

- Develop concepts, algorithms, technologies, and architecture(s) towards ATM+3
- Validate key "phase transition" technologies are feasible, safe and can be assured
- Analyze benefits and ensure overall autonomy architecture compatibility
- Fully develop, validate and migrate towards architecture that support safe autonomous operations
- Transition safe and beneficial technologies to stakeholders for operational use

# SASO Mission and Goals

## Mission

Define and safely enable all future airspace operations (ATM+3) by justifiable and optimal autonomy for advanced air and ground capabilities

## Goals

- Increase **mobility** of passengers, goods, and services
- Allow **diverse** vehicle mix and airspace uses (e.g., air travel, wind turbines, commercial space launches)
- **Safely** enable **scalability** to accommodate future demand
- Accommodate a variety of **business models** (e.g., hub-and-spoke, point-to-point, air taxi, sharing)
- Maintain highly efficient, predictable, agile, scalable, safe, and **affordable** airspace operations system
- Maintain global **competitiveness** and domestic viability by innovation in technology and business models to manage airspace operations

## *Auto* Characteristics

**Automation, Autonomy (Self-governance), Autonomicity (Self-management):** Self-configuration, self-optimization, self-protection, and self-healing

# Stages of Traffic Management: Requirements are Different

1920, Photo Collection, Los Angeles Public Library


# What is UAS Traffic Management (UTM)?

**Research Platform that**

(1) Gives situational awareness of all airspace constraints and info about other operations to UAS operators, support service suppliers, and regulators
(2) Allows to exchange data among UAS operators as well as regulator
(3) Allows UAS operators to submit flight plans to execute a specific mission in low-altitude airspace, and
(4) Determines how to safely enable such single or multiple UAS operations either within visual line of sight or beyond visual line of sight

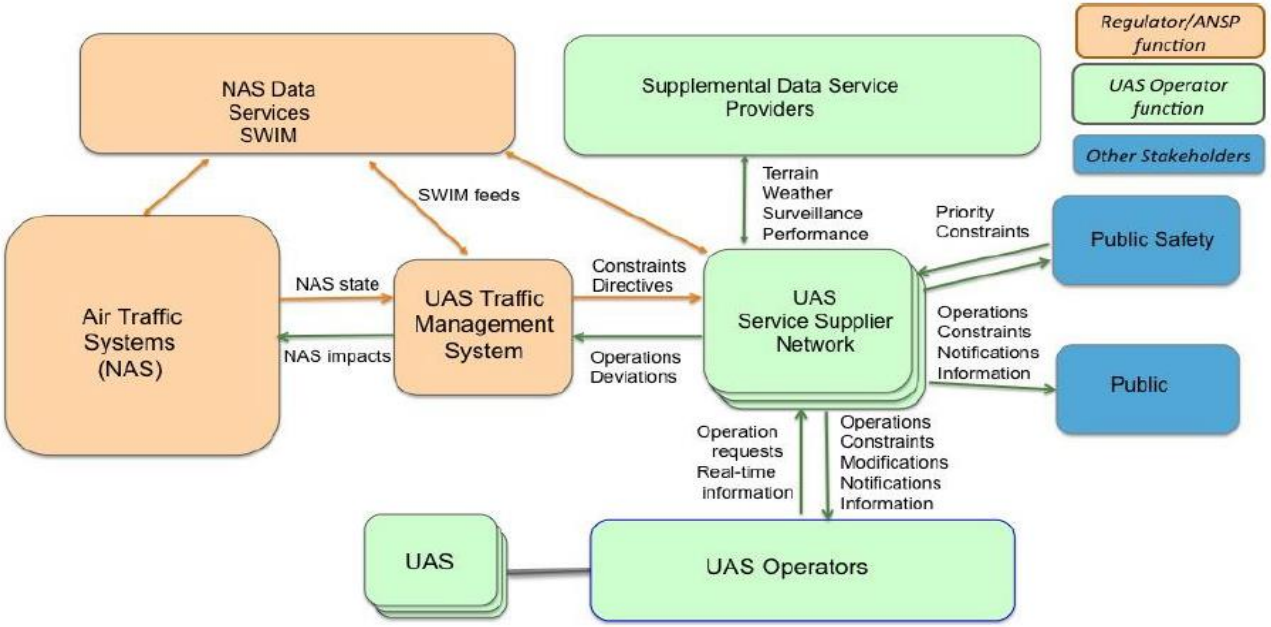
**Product:** Validated airspace operations requirements: roles/responsibilities; federated, networked, and interoperable data exchange; information architecture; and air/ground integrated concept of operation

- Airspace configuration (static and dynamic geo-fencing)
- Weather and wind (actual and predicted)
- Demand/capacity imbalance management
- 3D maps
- Track and locate
- Conflict (V2V, sense and avoid) and hazard avoidance
- Last and first 50 feet operation
- Contingency management

# UAS Traffic Management

*In close collaboration with the FAA, industry, and academia*

- 2.6M commercial small UAS are expected by 2020: Need a way to manage beyond visual line of sight UAS operations in the low-altitude airspace
- UTM is an instantiation of air/ground integrated increasingly autonomous system – in lower and/or uncontrolled airspace
- Cloud-based, connected, federated system
  - Flexibility where possible, structure where necessary
  - Risk and performance based
- Defined roles/responsibilities: UAS operator, UAS support service supplier, and regulator (implications on who pays)



# UTM Research Technical Capability Level

**Each capability is targeted to type of application, geographical area and uses risk-based approach for performance needs**

## Capability 1

- Notification of airspace use
- Over unpopulated land or water
- Minimal general aviation traffic in area
- Contingencies handled by UAS pilot
- Enable agriculture, firefighting, infrastructure monitoring

## Capability 3

- Beyond visual line of sight
- Over moderately populated land
- Some interaction with manned aircraft
- Tracking, V2V, V2UTM and internet connected
- Public safety, limited package delivery

## Capability 2

- Beyond visual line-of-sight
- Tracking and low density operations
- Sparsely populated areas
- Procedures and "rules-of-the road"
- Longer range applications

## Capability 4

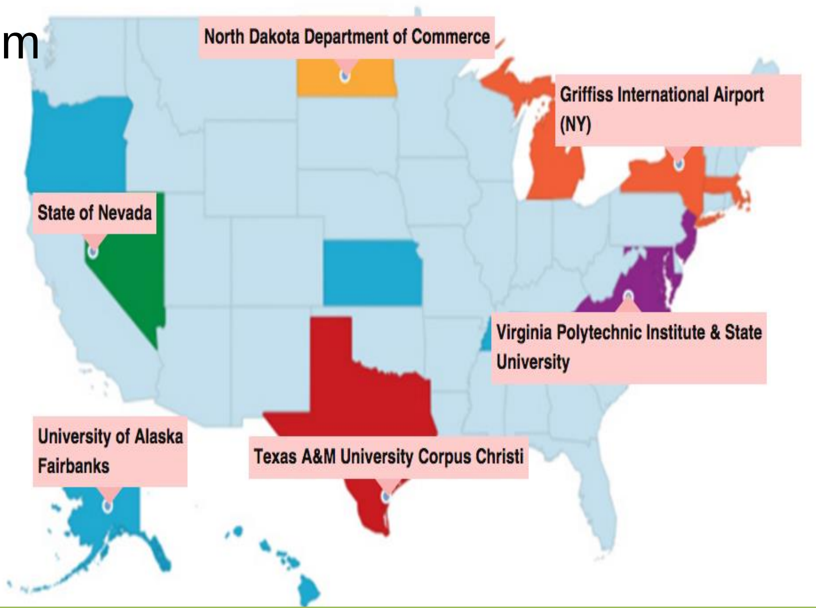
- Beyond visual line of sight
- Urban environments, higher density
- Autonomous V2V, internet connected
- Large-scale contingencies mitigation
- News gathering, deliveries, personal use

# Vehicle Technologies

- Low Size, Weight, Power, and cost – Sense and avoid
  - Detection of obstacles such as wires as well as other moving objects (V2V)
- Tracking: Cell phone, ADS-B, satellite, and psuedolites
- Reliable control system that will not cross static and dynamic geo-fences:
- Safe landing under failure
- Long endurance (45 min current battery life)
- Cyber secure/spoof free vehicles
- Graceful landing in case of failure with low kinetic energy – safe flying around people
- Ultra-low noise from vehicles
- Last/first 50 feet safe autonomous operation
- Certification approaches

# Successful Initial National Safe UAS Integration Campaign

**What:** Demonstrated management of geographically diverse operations, 4 vehicles from each site flown simultaneously under UTM
**Where:** All 6 FAA UAS Test Sites
**Who:** NASA, Test Sites, support contractors
**When:** 19 April 2016
***24 live vehicles, over 100 live plus simulated flights***




Received positive feedback from the FAA Test Sites on the UTM concepts, technologies and operations


API based model worked well – enabled operator flexibility, exchanged information, and maintained safe operations

**National Campaign Statistics:**

- 3 Hours
- 102 real, distinct flights
- 67 simulated operations injected
- About 31 hours of flight time
- 281.8 nmi flown

# UTM Main Lesson

- In order to safely enable large-scale autonomous vehicles, increasingly autonomous UAS traffic management system (vehicle as well as ground/cloud) instantiation is needed one that does not require continuous human oversight for every vehicle and every position update

- It is a beginning, UTM only refers to a small portion of airspace

# Safe and Efficient Crew Autonomy Teaming

## Background

- Fatigue rules prevent full stage length utilization of B777 type aircraft, unless multiple crews are on-board
- International competitiveness in crew costs, but pilots frequently intervene in emergency and off-nominal conditions
- Accident statistics cite the flight crew as a primary contributor in over 60% of accidents involving transport category airplanes
- Yet, a well-trained and well-qualified pilot is acknowledged as the critical center point of aircraft systems safety
- Emergence of small personal aircraft

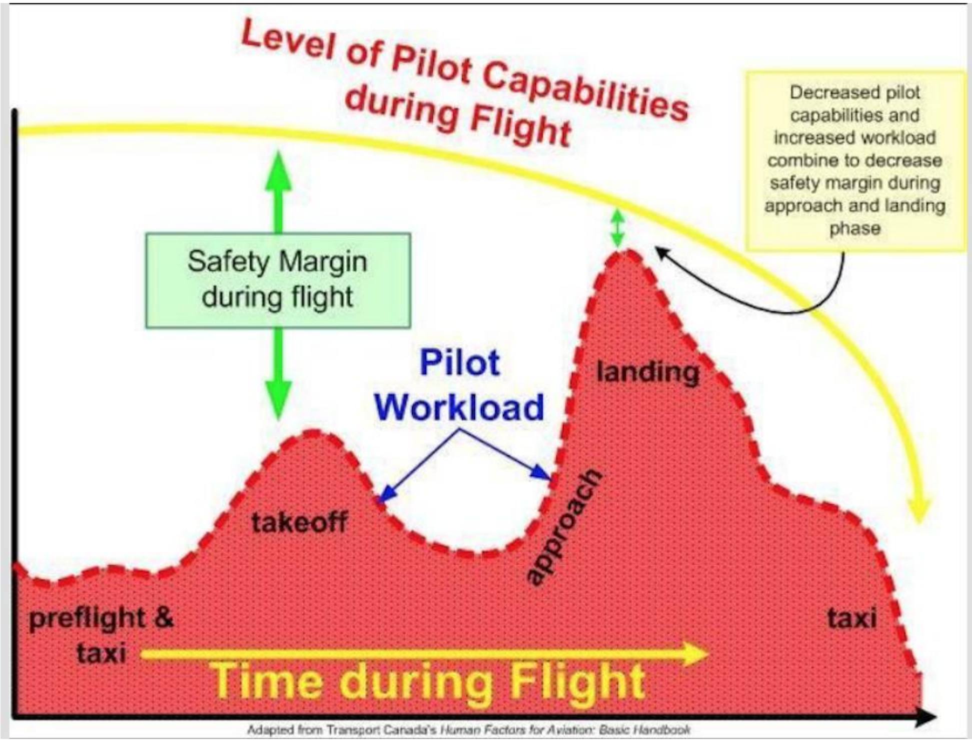
## Goal

- Develop air and ground autonomy technologies that will help manage complex nominal and off-nominal situations with crew-autonomy teaming

## Rationale

- If autonomy does not support off-nominal conditions, it is unlikely we can get to reduced crew operations, single pilot operations, or no pilot operations

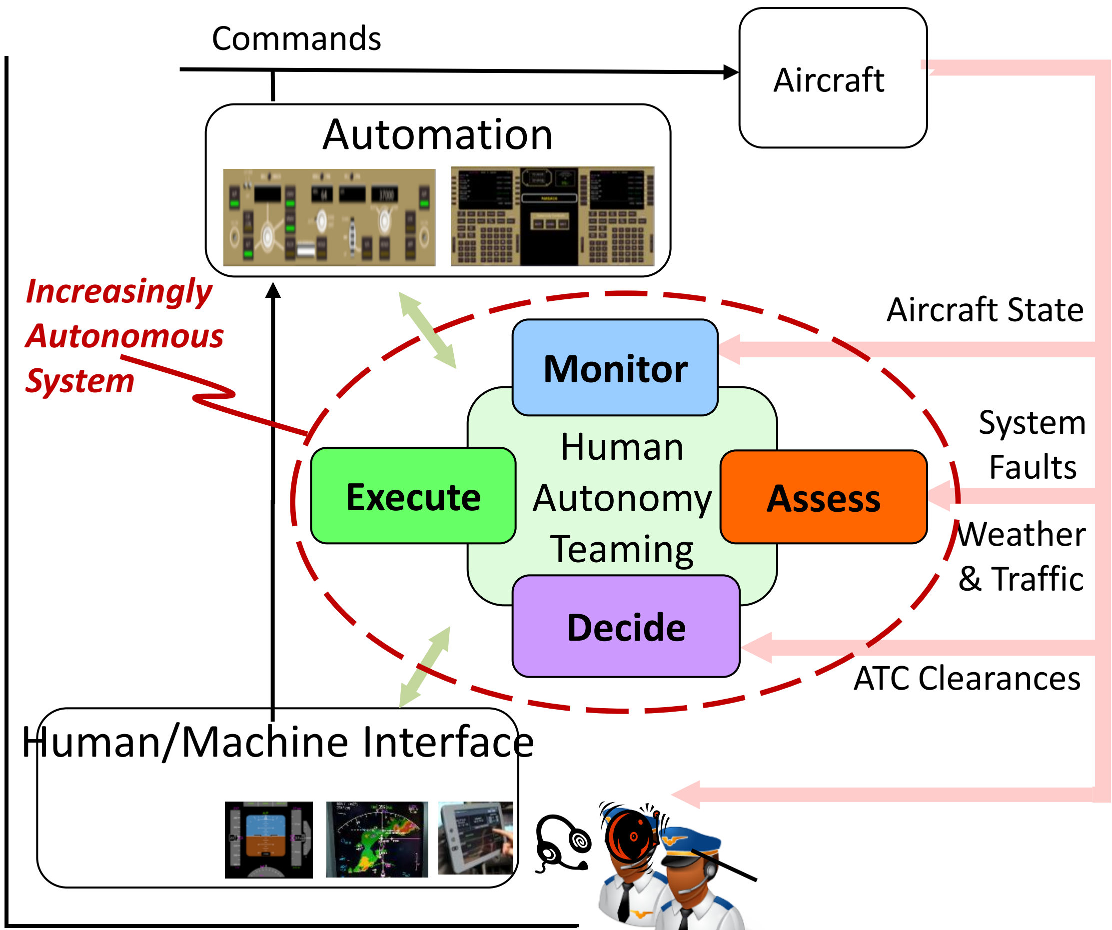
# Safe and Efficient Crew Autonomy Teaming




- Missing a slowly developing adverse condition due to loss of vigilance, alertness, or pilot incapacitation
- Overwhelming workload associated with a complex failure or cascading set of failures, where the priority of pilot actions is not clear

# Human-Autonomy Teaming

Crew-autonomy teaming entails on and off-board increasingly autonomous monitoring, detection, prognosis, and mitigation capabilities that will learn over time to manage off-nominal conditions




Metrics: Reduced training time, time to detect, and/or resolve safety critical situation

# Operational Conditions (together with Boeing)

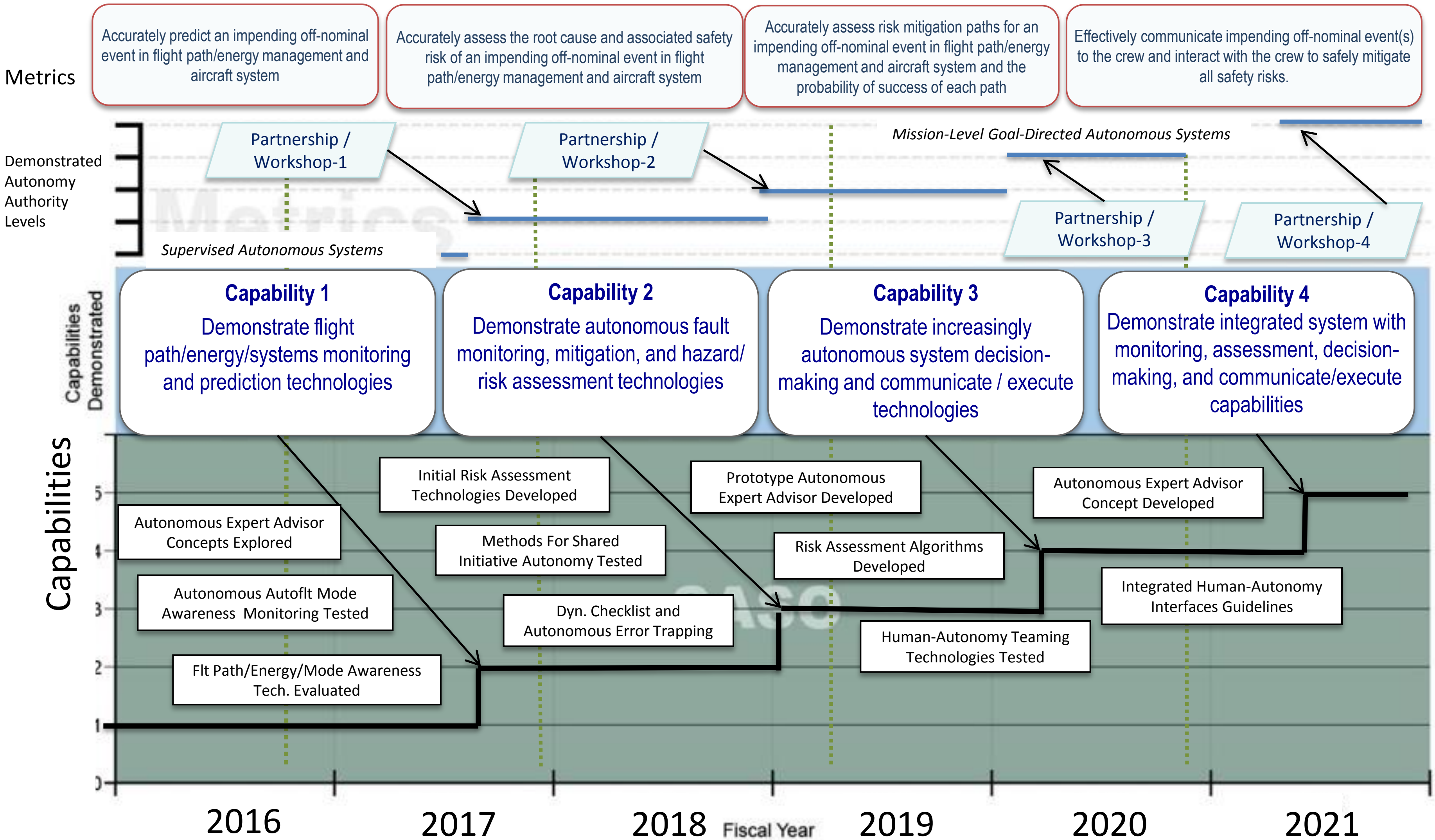
- Many alerts occur during an off-nominal situation – cause and effect relationship and prioritization of tasks is critical for safety of flight
  - Un-commanded roll,  loss of airspeed, stall and energy management
  - Bird strikes
  - Terminal operations – including self-separation
  - Alternate airport selection
- Deploy resources dynamically from ground-based, cloud-based, or other means to support flight operation as needed

# Safe and Efficient Crew Autonomy Teaming

- Products
  - Monitor of sub-system and their performance – Pilot assistant
  - Data analytics for anomaly detection – Classical algorithms
  - Deep learning for cause and effect – Self-learning
  - Advisory for priority actions – Pilot advisor
- Challenges
  - Certification and acceptance
- Partnerships
  - Boeing, Fed Ex, AFRL, DoD/AMC, IBM, and FAA

Metrics: Reduced training time, time to detect, and/or resolve safety critical situation

# Research Roadmap




***SECAT: Safe & Efficient Crew-Autonomy Teaming Technologies:***

*Develop and demonstrate the feasibility of improving aviation safety and efficiency during nominal and off-nominal operations by increasingly autonomous systems concepts, technologies, and procedures*

# Emerging Opportunities

- Airport: integrated autonomous operations from scheduling to aircraft movement management
  - Some dull, dirty, and dangerous tasks can be eliminated
- Traffic flow management – strategic nature offers opportunities to try autonomy – particularly learning systems
- Airline operations center – Data driven decision making – appealing for learning systems
- Simplified vehicle operations – key to personal mobility without extensive training and licensing requirements

# Cross Cutting

- V&V Methods for Autonomous Systems (will continue under new project)
  - Formal methods analysis has discovered a software error in ADS-B logic
  - ACAS-X verification which is based on partially observable
  - Developing class of methods for non-deterministic approaches which are likely to be part of autonomy

- Ab Initio/Clean Sheet Airspace Design
  - Developing concepts, algorithms for cooperative autonomous operations in terminal operations

# Project R&D and NRC Recommendations

| ARMD TC | TC | NRC Recommendations |
|---|---|---|
| 9 | UAS Traffic Management | • Airspace access for Unmanned Aircraft<br>• Stds and processes for V&V and Safety Assurance<br>• Modeling and Simulation with virtual airspace components for UTM Testing<br>• Methods for certification through bounding behavior of autonomous system |
| 10 | Safe and Efficient Crew Autonomy Teaming | • Operation without continuous human oversight<br>• Humans and machines working together in new and different ways that have not yet been identified.<br>• Creating the ability of IAS to operate independently of human operators<br>• Regulation and Certification barriers |
| Cross-cutting | V&V of Autonomous Systems | • Assurance that adaptive and non-deterministic autonomous systems are safe and reliable<br>• Coupling of formal methods and machine intelligence for real-time safety assurance |
| Cross-cutting | Ab Initio / Clean Sheet Airspace Design | • Integrated air/ground operation in new airspace concept - manned, unmanned a/c, and IA systems operating safely in same airspace |

# Concluding Thoughts

- Could we and should we consider autonomy, or autonomicity?
- Integrated air-ground autonomous operations is key – otherwise we will not realize full NAS-level benefit
- UAS Traffic Management “construct” – potential to make larger impact as it covers air/ground integrated operation
- Safe Efficient Crew Autonomy Teaming may lead to single or no pilot operations
- Newer V&V methods are needed – research to continue
- Task/function level autonomy opportunities exist, benefit cases are essential
- Continue air/ground integrated increasingly autonomous concepts to enable future

**Questions?**

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# Creating digital, flexible, virtual infrastructure

# Technical Challenge

- Safe and Efficient Crew-Autonomy Teaming (SECAT)
  - Develop and demonstrate the feasibility of improving aviation safety and efficiency during nominal and off-nominal operations by increasingly autonomous systems concepts, technologies, and procedures
- The Problem:
  - We are confronting human performance limits in safety, mobility, and efficiency
    - A problem that exists today and is trending to degrade further without intervention.
      - *Natural human capacities are becoming increasingly mismatched to the enormous data volumes, processing capabilities, and decision speeds demanded in today's aviation environment.**
  - Autonomy is uniquely suited to solve this problem:
    - *Intelligent machines seamlessly integrated with humans – whereby performance of the combined system is significantly greater than the individual components*
  - However, significant technological and regulatory/certification barriers exists to adoption of Autonomy and Increasingly Autonomous System in aviation
    - Foster acceptance of autonomy and autonomous systems by solving problems for which current-day technology has proven inadequate

26

**USAF Technology Horizons, "A Vision for Air Force Science & Technology During 2010-2030"*

# Approach

- Tech Challenge: Develop and demonstrate the feasibility of improving aviation safety and efficiency during nominal and off-nominal operations by increasingly autonomous systems concepts, technologies, and procedures

- Human-Autonomy Teaming
  - Bi-Directional Communication
  - Common Knowledge
  - Shared Initiative
  - Trust

***Emphasizing This Aspect of Problem:***

***> Area of In-House Expertise***
***> Minimal Overlap with other Gov't Agency Efforts***
***> Significant benefit if successful***
***> Significant Knowledge Gaps***

- *Sub-Challenge:*
  *Create bi-directional communication technologies for optimal roles and teaming*
  - *Making adaptive (unpredictable) autonomous behavior predictable*

# Technology Development Approach

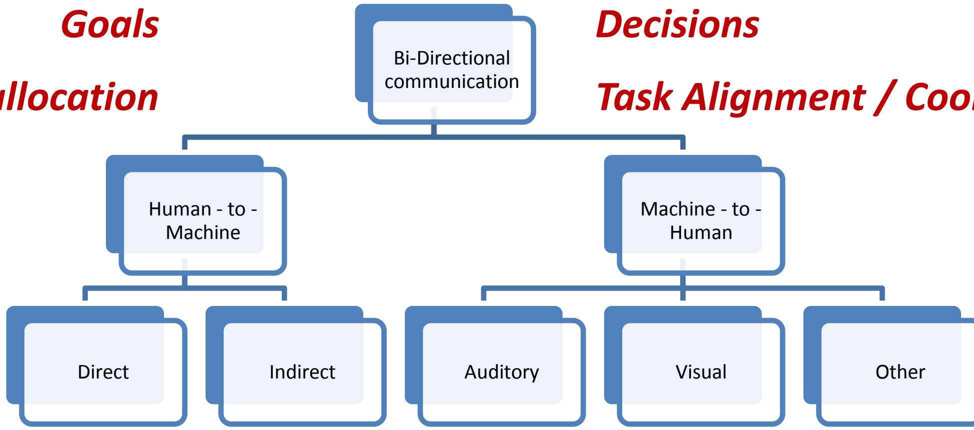
*Create bi-directional communication technologies that make adaptive (unpredictable) autonomous systems behavior predictable*

***Goals***

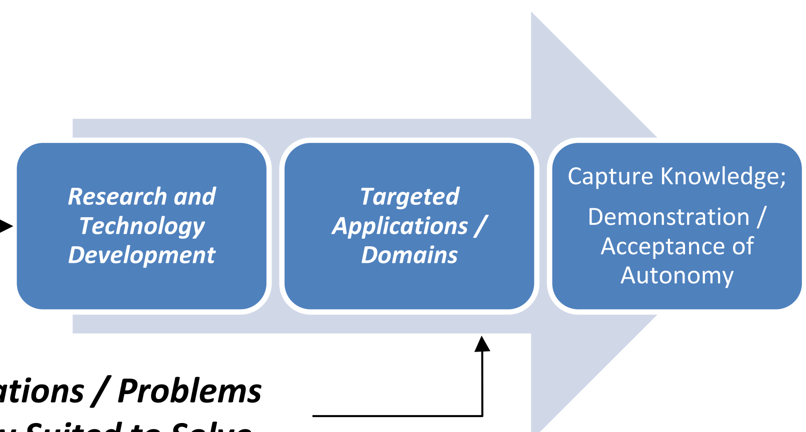
***Function Allocation / Re-allocation***

***Decisions***

***Task Alignment / Coordination***




- ***IAS HAT Technology Knowledge Gaps;***
- ***State-of-Art Deficiencies***
- ***NASA Unique Talents / Niche***




***3 Challenge Problems Identified to Date***

***Operational Limitations / Problems For Which IAS Ideally Suited to Solve.***

# Traffic Surveillance by IAS (TSIAS)

## Application

- Problem Statement:
  - As traffic volume increases and the time / space margins are reduced in the Terminal Area for increased capacity, traffic awareness becomes critical
  - Delegated separation concepts of operation proposed for flights to tactically manage arrivals and departures
- Objectives:
  - A high precision, low false alarm, redundant or uncooperative vehicle tracking and identification method via IAS is needed.
    - Improved traffic surveillance precision over ADS-B
    - Traffic surveillance of non-transponding vehicles (UAVs, etc.)
    - Identification of vehicles (B737, A321, C172, etc.)
    - *Detect, Sense-and-avoid for manned aircraft; Delegated Separation*

## Technologies

- *Challenge: Human Interaction with Autonomous Sensor(s) / Network*
  - Creating Optimal IAS Team - Balancing Strengths, Offsetting Weakness of Human-Machine Perception, Learning, Task / Goal Direction
- Traffic Surveillance by IAS (TSIAS):
  - Create Next Generation Image Object Detection (IOD) System:
    - *H2A Direct Comm*: Create new method of human (soft-data) and machine (hard-data) fusion / learning via Bayesian framework
    - *Algorithms*: Create high acuity, multi-camera IOD and tracking system
    - *Algorithms*: Evaluate use of convolution neural nets to perform real-time aircraft / vehicle identification from in-flight video. (Eliminate range ambiguity in IOD)
- Augmented Reality
  - *A2H Visual Comm*: Assess benefit of spatially-referenced display info to convey IAS outcome

# Monitoring Automation / Auto-flight by Autonomy

## Application

- Problem Statement:
  - Pilots are increasingly using automated systems
  - Auto-flight reqr'd for some operations (e.g., RNP) and more be more dependent for Trajectory-based flight operations (TBO).
  - However, the automation is not without fault / failure; pilots are not naturally good monitors of automation
- Objectives:
  - Improve the effectiveness / reduce the workload with auto-flt / information automation understanding & monitoring by continuously monitor parameters critical to flight safety (e.g., flight path, energy, systems, weather, etc.) and operating by Increasingly Autonomous systems
  - *Autonomy to solve current-day automation failings*

## Technologies

- *Challenge: Supervised Human Attention and Understanding*
- Monitoring Automation By Autonomy (MABA):
  - Create IAS to Monitor / Modulate Human-Autonomy Supervision of automated flight (auto-flight and information)
    - *Algorithms*: methods for machine perception, comprehension, and projection of energy, attitude, system status
    - *Algorithms*: root cause analysis of non-normals; Autonomous Comm. Error Checking
  - *H2A Direct Comm:*
    - Assess if speech can be reliable autonomy communication modality
    - Aviation-tailored hierarchical vs. natural language (e.g., IBM Watson, Faceboot Bot, Google SyntaxNet)
    - Speech as a cognitive indicator
  - *H2A Indirect Comm:*
    - Goal: Physiological Markers and Autonomy for Human Understanding / Comprehension
    - *Algorithms*: Big Data analysis to extract reliable, accurate human physical, cognitive states; identify "wearables" technologies.

# Intelligent Party-Line for Data Comm

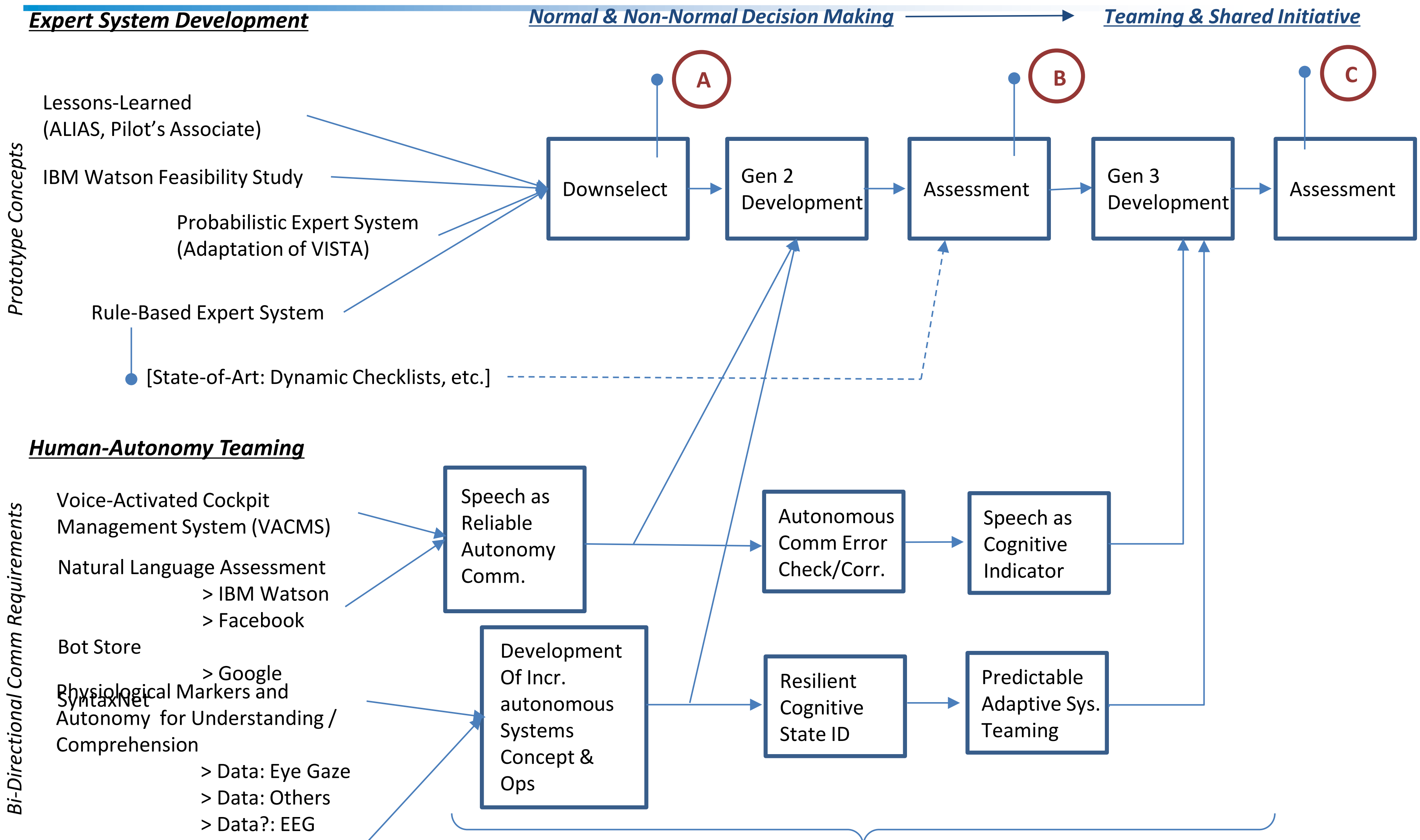
## *Application*

- Problem Statement:
  - Controller-pilot data link capability is becoming a reality (i.e., Data Comm)
  - Data Comm offloads radio frequency congestion esp. as traffic volume increases; allows direct digital up-link of routing et al
  - Unfortunately, loss of 'party-line' information and error-checking by read-back over radio is safety-critical
- Objectives:
  - Apply Increasingly Autonomous Systems technologies to create an "Intelligent Party-line"
    - Provides display of traffic and messaging that is 'relevant' or important to flight crew.
    - Filters out non-relevant traffic and information from flight deck display (aural and visual)
    - *How to keep human informed, and in-the-loop during machine-to-machine networking*

## *Technologies*

- *Challenge*: *Creating Transparent, Reliable Adaptive IAS*
- Traffic / Data comm Manager (TDM):
  - Use IAS to Identify "Relevant" Traffic
    - *Algorithms*: Evaluating K-Means Clustering and Supervised Learning Neural Net for Robustness
    - *H2A Indirect Comm*: Assess capabilities of speech-to-text of conversational cockpit audio to identify relevancy markers
    - *H2A Direct Comm*: Evaluate flight path & path intent information to identify relevancy markers
- Augmented Reality
  - *A2H Visual Comm*: Assess benefit of spatially-referenced display info to convey IAS outcome
- Audio Encoding
  - *A2H Audio Comm*: Assess benefit of encoded audio information to convey IAS outcome
    - 3D Spatial Audio for spatial location of relevant info.
    - Message coding for classification / type ID of TDM process.

# Increasingly Autonomous Pilot Advisory System




- ***Roles/responsibilities between autonomy and pilots***
- ***Human-Autonomy Teaming Technologies Developed***
- ***Bi-Directional communication methods created/tested***

# Increasingly Autonomous Systems under nominal, and off-nominal conditions

***Goal: IAS to improve / enable safe and efficient current-day and NextGen automation-based operations***

*IAS for Automation Awareness*

> improve the effectiveness / reduce the workload with auto-flt / information automation understanding & monitoring (Current day safety)

Auto-flt Autonomous Informational Concept

Task Engagement & Understanding Measures

Autonomous Information Automation Agent

Shared Initiative Auto-flight

Autonomous Auto-flt /Info Awareness

*Traffic and Data Comm. Manager (TDM)*

> Traffic and intent awareness for human participants without workload increases during NextGen+3 traffic loads (NextGen Enabling Tech.)

Machine Learning Alg. for Traffic Relevance

Integration with Intent / Messaging

Integration with Spatial Audio

Head-Worn Displays > Augmented Reality > Spatially Integrated Information

Audio Encoding

*Traffic Surveillance via IAS (TSIAS)*

> High precision, low false alarm ,redundant or uncooperative vehicle tracking and identification method via IAS (Delegated Separation E.T.)

Multi-Camera Image Object Detection and Tracking System

Develop Bayesian Fusion / Learning from Human Input System

Integration & Test, Gen 1

Object Identification by Convolution Neural Net

Integration & Test, Gen 2

## *Capabilities*

A B C

**1) Non-normal and Information Automation Expert Decision Support Systems – probabilistic expert system to create flight deck-based advisory and decision support system for information management and for off-nominal/non-normal operations procedures**

**2) Autonomous, dynamic integrated information and Expert management System**

**3) Increasingly Autonomous System (IAS) for Traffic Surveillance in Terminal Area – IAS to create accurate, high precision, redundant or uncooperative vehicle tracking and identification method; delegated separation enabling technology**

**4) 1stGen Bi-Directional IAS Comm System - Technologies to create intuitive communication, goal/direction, and status awareness system for both machine and human to achieve teaming; enabling technology element for RNAV-/RNP-based trajectory-based**

(Partial Listing)

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(Partial Listing)

# Roles and responsibilities

- UAS Support Supplier Services or UAS operator
  - Authentication and authorization
  - Track and locate
  - 3D maps
  - Weather – actual and prediction
  - Flight planning
  - V2V
  - Contingency management
  - Others…
- Data exchange content, format, protocols, and application protocol interfaces (APIs) – initial definition done, now group validation, and testing next steps