Unmanned Aircraft Systems (UAS) Integration in the National Airspace System (NAS) Project

KDP-A for Phase 2 Minimum Operational Performance Standards

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Project Manager

September 13, 2016
KDP-A Overview

• During this review, the Project will address the terms of reference (ToR) intent and demonstrate that we are ready to proceed

• The UAS-NAS Project is requesting approval of the following:
  – Technical Challenges
  – Execution of C2 and ACAS Xu partnerships
  – Pursuit of DAA and IT&E partnership plans
  – Execution of near-term FY17 activities
Outline

• UAS Integration in the NAS (UAS-NAS) Overview
• Technical Challenges and Partnership Plans
• Path forward to KDP-C
• KDP-A Summary
Importance of UAS Integration

• According to recent economic assessments\(^1,^2\), the unmanned aircraft system (UAS) market is one of the fastest growing segments in the aerospace industry
  – Potential for creating over 100,000 jobs by 2025
  – Translating to over $82 billion in total economic impact

• Several civil/commercial markets are poised to take full advantage of the capabilities UAS offer

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<th>Agriculture Monitoring</th>
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• Unfortunately, the UAS market is not able to achieve this level of growth until the barriers and challenges, currently preventing full integration, are addressed
  – Regulations, Policies and Procedures specific to UAS
  – Enabling Technologies and Standards Development
  – Air Traffic Services and NAS Infrastructure
  – Social Considerations (e.g. Privacy, Security, Noise, Trust)

\(^1\) The Economic Impact of UAS Integration in the United States, AUVSI, March 2013
\(^2\) World Civil UAS Market Profile & Forecast, Teal Group, 2016

“For every year integration is delayed, the United States loses more than $10B in potential economic impact ($27.6M per day).” – AUVSI Economic Report 2013
Importance of NASA Involvement with DAA and C2 Technologies

- UAS Integration and Standards Development align with ARMD’s Strategic Plan
- NASA has determined Detect and Avoid (DAA) and Command and Control (C2) are the most significant barriers to UAS integration
- NASA is capable of playing a significant role in addressing UAS airspace integration challenges
  - NASA’s long-standing history assisting the FAA with complex aviation challenges
  - NASA involvement instills confidence in industry standards development activities
- NASA held in high regard by others in UAS community due to our:
  - Prior research and contribution to standards development
  - Existing leadership role in ongoing efforts and working groups
  - Ability to leverage previous assets used for Phase 1 MOPS

Full Integration study identified NASA as being well positioned to Lead the DAA (T02) and C2 (T04) airspace integration challenges

NASA well positioned to lead research addressing most significant barriers, DAA and C2, to UAS integration
Importance of Developing DAA and C2 Standards

- The FAA’s **UAS CONOPS** and **Roadmap** establish the **vision** and define the **path forward** for safely integrating civil UAS operations into the NAS
  - These documents establish the importance of standards development; explicitly DAA and C2 standards
    - **DAA Foundational Challenge**: Sense & Avoid vs. See & Avoid
    - **C2 Foundational Challenge**: Robust and secure communication links

- Standards are essential for multiple stakeholders:
  - Regulators
  - UAS Operators
  - UAS Manufacturers
  - Avionics and Service Providers

- RTCA SC-203 was, and SC-228 now is, chartered by the FAA to establish UAS DAA and C2 Standards

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“Therefore, it is necessary to develop new or revised regulations/procedures and operational concepts, **formulate standards**, and promote technological development that will enable manned and unmanned aircraft to operate cohesively in the same airspace. **Specific technology challenges include two critical functional areas:**

1. **Detect and Avoid (DAA) capability**
2. **Control and Communications (C2) system performance requirements**

- FAA Integration of Civil UAS in the NAS Roadmap, First Edition 2013

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Once the RTCA SC-228 ToR deliverables are approved and their requirements fulfilled, the FAA should be able to eliminate most of the major DAA and C2 barriers for integration.
### Emerging Commercial UAS Operational Environments (OE)

#### I. “Manned like” IFR
UAS will be expected to meet certification standards and operate safely with traditional air traffic and ATM services.  
*(Example Use Case: Communication Relay / Cargo Transport)*

#### II. Tweeners
These UAS will operate at altitudes below critical NAS infrastructure and will need to routinely integrate with both cooperative and non-cooperative aircraft.  
*(Example Use Case: Infrastructure Surveillance)*

#### III. Low Altitude Populated
Must interface with dense controlled air traffic environments as well as operate safely amongst the traffic in uncontrolled airspace.  
*(Example Use Case: Traffic Monitoring / Package Delivery)*

#### IV. Low Altitude Unpopulated
Low risk BVLOS rural operations without aviation services.  
*(Example Use Case: Agriculture)*

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<th>MINIMUM ENROUTE ALTITUDE</th>
<th>Terminal Airspace</th>
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<td>60K’ MSL</td>
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<td>18K’ MSL</td>
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**Non-cooperative Traffic**

**Cooperative Traffic**

**500’ AGL**
C2 Operational Environments

Legend
Current Research Areas (FY14–FY16)
Proposed Research Areas (FY17–FY20)

60K’ MSL

SATCOM
C2 Data Link

18K’ MSL

Communications
Satellite

UAS

Ground
Control Station

SATCOM
Transmitter

60K’ MSL

“Tweener”
UAS

10K’ MSL

SATCOM
C2 Data Link

Terrestrial
C2 Data Link

Terrestrial
C2 Data Link

MINIMUM ENROUTE
ALTITUDE

Network

500’ AGL

CNPC
Ground
Stations

UAS Ground
Control Station

CNPC
Network

UAS Ground
Control Station

Land Line

Terrestrial
C2 Data Link
RTCA SC-228 MOPS Terms of Reference

- RTCA SC-228 Terms of Reference (ToR) defined a path forward to develop Minimum Operational Performance Standards (MOPS)
  - Phase 1 MOPS were addressed by UAS-NAS (FY14 – FY16) Portfolio
  - Phase 2 MOPS included in the original ToR, but had several TBDs
    - ToR development team established to ensure DAA & C2 scope broad enough to fully enable the operating environments relevant UAS were expected to leverage (e.g. Manned Like IFR and Tweeners)

- Phase 2 MOPS ToR Scope
  - C2: Use of SATCOM in multiple bands and terrestrial extensions as a C2 Data Link to support UAS and address networking interoperability standards for both terrestrial and satellite systems
  - DAA: Extended UAS operations in Class D, E, and G, airspace, and applicability to a broad range of civil UAS capable of operations Beyond Visual Line of Sight (BVLOS)

- SC-228 Final Documents

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<th>Phase 2</th>
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<td>DAA MOPS</td>
<td>C2 SATCOM Data Link MOPS (Jul 2019*)</td>
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<tr>
<td>DAA Air to Air Radar MOPS</td>
<td>C2 Terrestrial Data Link MOPS Rev A (Jul 2020)</td>
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* Date under discussion within RTCA SC-228
Goal: Provide research findings, utilizing simulation and flight tests, to support the development and validation of DAA and C2 technologies necessary for integrating Unmanned Aircraft Systems into the National Airspace System.
ARMD Strategic Plan Flow Down to UAS-NAS Project

**AERONAUTICS STRATEGIC THRUST**

Thrust 1: Safe Efficient Growth in Global Operations

Outcome (2015 – 2025): ATM+1
Improved NextGen Operational Performance in Individual Domains, with Some Integration Between Domains

Airspace Operations Performance Enablers

Thrust 6: Assured Autonomy for Aviation Transformation

Outcome (2015 – 2025): Initial Introduction of aviation systems with bounded autonomy, capable of carrying out function-level goals

Implementation and Integration of Autonomous Airspace and Vehicle Systems

Testing and Evaluation of Autonomous Systems

AERONAUTICS OUTCOME

AERONAUTICS Research Theme

AERONAUTICS Overarching Technical Challenge

UAS-NAS Technical Challenges

TC-C2: Command & Control

TC-DAA: Detect and Avoid

TC-ITE: Integrated Test & Evaluation

Primary Mapping

Secondary Mapping

**Thrust 1:**

Outcome (2015 – 2025): ATM+1
Improved NextGen Operational Performance in Individual Domains, with SomeIntegration Between Domains

Airspace Operations Performance Enablers

4B. Select, develop, and implement applications of autonomy that are compatible with existing systems

4C. Develop framework for co-development of policies, standards, and regulations with development and deployment of increasingly autonomous systems

5B. Test, evaluate & demonstrate selected small-scale applications of autonomy

**Thrust 6:**

Outcome (2015 – 2025): Initial Introduction of aviation systems with bounded autonomy, capable of carrying out function-level goals

Implementation and Integration of Autonomous Airspace and Vehicle Systems

Testing and Evaluation of Autonomous Systems

**TC-C2:** Command & Control

**TC-DAA:** Detect and Avoid

**TC-ITE:** Integrated Test & Evaluation
Outline

• UAS Integration in the NAS (UAS-NAS) Overview
• Technical Challenges and Partnership Plans
  – Command and Control (C2)
  – Detect and Avoid (DAA)
  – Integrated Test and Evaluation (IT&E)
• Path forward to KDP-C
• KDP-A Summary
Technical Challenge Background

• Technical Challenge Section Content
  – Technical Challenge Wording
  – Technical Challenge Technologies
    • Related NASA research, State of the art (SOA), and advancement of the SOA through proposed research
  – Technical Challenge Research Summary
    • Proposed research areas and near term activities to be started on or before Oct 1
    • Varying stages of development within the TCs
  – Partnership strategy and plans
    • C2 and IT&E have partnerships ready to execute
    • DAA is working with IT&E to refine requirements and partnership selection paths
  – *Data Deleted*
TC-C2: Command and Control

- **Airspace Operations Performance Enablers**
- **Implementation and Integration of Autonomous Airspace and Vehicle Systems**
- Develop, mature, and provide research findings from analysis, simulations, flight tests, and validation of SC-228 Phase 2 Command and Control (C2) Minimum Operational Performance Standards (MOPS) that will enable Satellite and Terrestrial Communication System Architectures compliant with allocated spectrum requirements.

**Technical Challenge-DAA:** Detect and Avoid (DAA)

**Technical Challenge-C2:** Command and Control (C2)

**Technical Challenge-ITE:** Integrated Test & Evaluation (IT&E)
C2 Overview

State of the Art:
• NASA and partners (i.e. RTCA, Rockwell Collins, etc.) have developed and written standards for a robust and secure terrestrial C2 capability in internationally protected aviation spectrum

• The performance standards development must continue on to fully enable terrestrial architectures, and critical satellite communication technologies

Related NASA Work:
• Developed and flight tested radios (65 mission flights, ~200 hours of data collection, 12 locations)

• Led national and international efforts on Terrestrial C2, and has significant expertise in upcoming SATCOM technologies

TC Advancement:
• A broad set of architectures will be developed and standardized allowing industry to fly their aircraft with well characterized high reliability C2 links
C2 Subproject Structure

Command and Control
<TC-C2>
Subproject Manager (SPM)
Mike Jarrell, GRC
Subproject Technical Leads
Jim Griner, GRC

TWP: Technical Work Package
SP: Schedule Package

TWP: Ku/Ka-Band SATCOM
SP: Ku/Ka-Band Prototype Development
SP: Ku/Ka-Band Prototype Test & Evaluation

TWP: Terrestrial Extension
SP: L/C-Band Prototype Development
SP: L/C-Band Prototype Test & Evaluation

TWP: C-Band SATCOM
SP: C-Band SATCOM

TWP: Integrated Flight Test Support (IT&E TWP)

• TWP: Technical Work Package
• SP: Schedule Package
C2 Technical Plan

TWP: Ku/Ka-Band SATCOM
Develop requirements for a SATCOM link between a UAS and it’s GCS that: supports the UA performance in the NAS, ensures that the pilot maintains a threshold level of control of the aircraft, and is robust to security and technological issues

Near-Term Activities Include:
• Participation in RTCA SC-228 C2 White Paper development, SOA analysis, and Gap Analysis
• Initiate Cooperative Agreement*, Preliminary Design, Lab and Aircraft Test Upgrades, System Architecture Study, Initial System Interface Development

TWP: Terrestrial Extension
Develop requirements for a Terrestrial link, focused on broader flight regimes, that: supports the UA performance in the NAS, ensures the pilot maintains a threshold level of control of the aircraft, and is robust to technological issues

Near-Term Activities Include:
• Establish Cooperative Agreement*, Trade Study, Baseline Specifications, Preliminary Interface Development, Lab and Aircraft Test Gap Analysis

* Partnership Plans will be addressed separately
**TWP: C-Band SATCOM**

Generate design documentation for a C-Band SATCOM system through a series of studies to develop: initial design parameters of airborne and ground station equipment, a preliminary payload design, and assess the feasibility of an operational C-Band satellite-based CNPC system.

Near-Term Activities Include:
- SATCOM Survey, Trade Study, System Design, Cost/Benefit Assessment

**TWP: IT&E Support**

Support the IT&E Technical Challenge for Integrated Flight Tests equipped with equipment developed for Phase 1 C2 MOPS.

Near-Term Activities Include:
- Support TWP Content Decision as required
C2 Data Link
Partnership TWP Planning

- Data Removed
C2 Partnership Strategy

- Data removed
TC-DAA: Detect and Avoid

- Airspace Operations Performance Enablers
- Implementation and Integration of Autonomous Airspace and Vehicle Systems
- Develop, mature, and provide research findings from analysis, simulations, flight tests, and validation of SC-228 Phase 2 Detect and Avoid (DAA) Minimum Operational Performance Standards (MOPS) that will enable a broader range of IFR-like UAS BVLOS Operations by providing technology to safely “See and Avoid” traffic in the NAS.

Technical Challenge-DAA: Detect and Avoid (DAA)

Technical Challenge-C2: Command and Control (C2)

Technical Challenge-ITE: Integrated Test & Evaluation (IT&E)
**State of the Art:**

- NASA and partners (i.e. RTCA, General Atomics, Honeywell, FAA TCAS etc.) have developed and standardized a DAA capability that be leveraged as an alternative means of compliance to “see and avoid”

- Additional DAA performance standards are required to fully enable operational use cases in terminal areas and for a vehicles with lower performance capabilities

**Related NASA Work:**

- NASA has performed simulations, developed and tested a DAA system, led national efforts on DAA, and has significant expertise in upcoming standards for ground and airborne sense and avoid

**TC Advancement:**

- DAA systems developed and standardized that are applicable to broad set of UAS that will fly in the NAS
Detect and Avoid
<TC-DAA>
Subproject Manager (SPM)
Jay Shively, ARC
Subproject Technical Leads
Confesor Santiago, ARC, Tod Lewis, LaRC, TBD, ARC

- TWP: Alternate Surveillance Requirements
- TWP: Well Clear Alerting Requirements
- TWP: ACAS Xu
- TWP: External Collaborations
- TWP: Integrated Events

- SP: TBD
- SP: TBD
- SP: TBD
- SP: TBD
- SP: TBD

- TWP: Technical Work Package
- SP: Schedule Package
TWP: Alternate Surveillance Requirements

Supports the development of MOPS for alternative Phase 1 surveillance systems. The work may include ground-based radar, as well as low-cost, low-power cooperative and non-cooperative sensors, e.g. “mini-ADS-B”, electro-optical, and LIDAR.

Near-Term Activities Include:

• CONOPS development, requirements studies, sensor model integration, and fast-time simulation

TWP: Well Clear/Alerting Requirements

Fast-time simulations and human-in-the-loop simulations to refine the well clear definition and alerting requirements for the operational environments specific to P2 MOPS.

Near-Term Activities Include:

• Develop CONOPS and requirements for well clear interoperability
• Define well clear, algorithms, airspace, aircraft performance, sensor assumptions, etc., leveraging fast-time simulation
DAA Technical Plan

**TWP: ACAS Xu**
Supports the development of minimum operational performance standards for integrated Collision Avoidance (CA; ACAS Xu) and DAA alerting and guidance displays and algorithms

Near-Term Activities Include:
- Interoperability workshop and CONOPS definition for ACAS Xu
- Part Task Sims (i.e. HITLs) planning to assess interoperability and pilot interfaces

**TWP: External Collaborations**
Attend and help lead SC-228 Phase 2 DAA planning, support development of the Phase 2 MOPS deliverables

Near-Term Activities Include:
- Attend and help lead SC-228 Phase 2 DAA planning
- Support development of the white paper for Phase 2

**TWP: Integrated Events**
Utilize the UAS-NAS cross-center research, simulation and flight test capabilities in order to support key verification and validation activities for the Phase 2 DAA MOPS

Near-Term Activities Include:
- Provide high level flight test requirements to IT&E for ACAS Xu, FT5, and FT6
DAA Partnership Strategy
(Joint with IT&E)

- Data Removed
TC-ITE: Integrated Test & Evaluation

- Airspace Operations Performance Enablers
- Testing and Evaluation of Autonomous Systems
- Implement UAS simulation and flight test environments that will enable development, verification and validation of integrated DAA and C2 technologies on UAS
MOPS V&V Contribution by IT&E

• **Verification & Validation (V&V) testing of DAA system**
  – Integrate DAA systems consistent with MOPS development and research activities. Leverage State of the Art UAS, architectures, and sensors to perform flight tests that stress the DAA system and validate necessary research elements.

• **Integrated Testing of DAA and C2 systems**
  – Integrate DAA and C2 technology systems consistent with P1 and P2 MOPS development efforts. Leverage integration and test results to ensure aircraft level functional and operational performance criteria can be met. Leverage Integrated tests to enable UAS operational approval and certification.

RTCA Minimum Operational Performance Standards (MOPS) Drafting Guide

“Aircraft Operational Performance Characteristics: When equipment is designed and manufactured to meet these MOPS, and it is properly installed in an aircraft in accordance with applicable installation and operational approval guidance and regulations, it is expected that all aircraft level functional and operational performance criteria will be met”
IT&E Overview

State of the Art:
- NASA assets such as Ikhana, the LVC-DE, and CNPC radios were built for Phase 1 MOPS. Future systems incorporate technologies developed to support other SAA efforts (e.g. Army GBSAA, industry low-SWaP airborne sensor development)

Related NASA Work:
- The NASA UAS-NAS IT&E subproject played a key role in validating the Phase 1 MOPS through M&S and flight test including ~ 700 DAA system encounters performed

TC Advancement:
- Simulation/flight systems and infrastructure for development, verification and validation of MOPS
- Rigorous NASA safety processes applied against SOA aircraft and technology systems in order to conduct highly complex testing
Integrated Test & Evaluation
<TC-ITE>

Subproject Manager (SPM)
Heather Maliska, AFRC

Subproject Technical Leads
Sam Kim, AFRC, Jim Murphy, ARC

TWP: Integration of Technologies into LVC-DE
- SP: LVC-DE e-Client Integration
- SP: LVC-DE Client Integration
- SP: TBD

TWP: Simulation Planning & Integration
- SP: TBD

TWP: LVC-DE Infrastructure Sustainment
- SP: LVC-DE Improvements
- SP: TBD

TWP: Integrated Flight Test
- SP: ACAS Xu FT2
- SP: No Chase COA
- SP: TBD

- TWP: Technical Work Package
- SP: Schedule Package
TWP: Integration of Technologies into LVC-DE

Development and integration of DAA and C2 technologies, primarily focusing on DAA subproject technologies. Also includes external partner integration and associated cyber security considerations.

Near-Term Activities Include:
- LVC-DE Client Integration - Integrate ACAS into LVC-DE. Update LVC ICD to support ACAS flight messaging
- Systems Engineering - Document LVC system requirements. Develop simulation ConOps

TWP: Simulation Planning & Integration

Support for the planning and conduct of the DAA HITLs, document objectives and requirements, trace system level requirements, and develop V&V test matrix

Near-Term Activities Include:
- Coordinate with DAA to determine plan for Phase 2 simulations
TWP: LVC-DE Infrastructure Sustainment

LVC-DE infrastructure sustainment and continuous improvement. This work includes effort to maintain connectivity to our existing partners and software clients.

Near-Term Activities Include:
- Investigate potential LVC improvements based on simulation and flight lessons learned

TWP: Integrated Flight Test

Integrate the individual technology development simulation and flight test objectives and requirements into executable tests. Conduct flight tests. Collect, archive, and distribute test data.

Near-Term Activities Include:
- FT5 and FT6 Trade Study – Work with DAA to define requirements based on trade study results
- ACAS Xu FT2 – Conduct PDR/CDR. Complete GA and FAA SAA. Begin aircraft modifications
Integrated Flight Test Progression

• The IT&E subproject will perform flight tests leveraging technology progressions to meet project objectives by the final flight test in FY19
  • ACAS Xu Flight Test 2 (FT2)
    – Necessary to ensure timely development of ACAS Xu technology in support of DAA system development
    – Ensures NASA has appropriate Collision Avoidance (CA) hardware, software, and partnerships in place for future flight test efforts
  • NASA Flight Test 5 (FT5) and Flight Test 6 (FT6)
    – Leverages cross subproject DAA and IT&E partnership strategy to progressively test DAA technologies relevant to the project portfolio
    – Developed to further P2 MOPS deliverables according to industry state of the art
    – Implements Program and Project expectations for integrated DAA and C2 flight test executed by IT&E
IT&E ACAS Xu Partnership TWP Planning

Partnership TWPs Titles:
Integration of Technologies into LVC-DE
Integrated Flight Test

ACAS Xu Partnership TWP Attributes:
1. Have detailed technical schedules
2. Well developed partnership planning efforts
3. Leverage P1 MOPS related partnerships or partnership strategies

* Notional Dates for Subproject Formulation
ACAS Xu Partnership Strategy

• Data Removed
FT5 and FT6 Integrated Test Strategy

**Approach to define FT5 and FT6**

- The full trade space of DAA development and Flight Test options will be assessed as part of the Cost, Benefit, Risk assessment to determine the final partnership strategy
  - IT&E is working closely with DAA to evaluate 50+ RFI inputs to select best partners and strategy
- Flight test definition based on the outcome of risk analysis and research requirements for DAA and C2
  - Document DAA research objectives and requirements
  - Build LVC infrastructure
  - Conduct DAA simulation leading to Flight Test

**Integrated Test Strategy**

- Project desires all TCs and technology systems in the Project portfolio have appropriate TC robustness, and are able to be taken to flight
  - Example: Elements for fully integrated flight test include; airspace, full and mid-size UAS, multiple DAA sensor suites (GBSAA and alternative airborne), ACAS Xu, Research Ground Control Station, displays, P2 SATCOM, P2 Terrestrial C2, P1 Terrestrial C2
- The project will assess the options for integrated flight test and incorporate it into KDP-C
  - Anticipate only P1 MOPS DAA and C2 systems will be integrated into testing due to P2 MOPS technology development cycles and project cost/schedule considerations
IT&E Partnership Strategy
(Joint with DAA)

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Path to KDP-C

• **Project Management**
  – Demonstrated rigorous processes in previous Project phases
    • Review/Update Project Processes

• **Partnerships**
  – Execute C2 partnerships
  – Execute ACAS Xu partnerships
  – Develop DAA & ITE partnership plans

• **Technical Portfolio Development**
  – Perform TWP Content Decision Points (Cost/Benefit/Risk)
  – Develop Technical Schedule Packages
    • Update Integrated Master Schedule

• **Other activities occurring in this time frame**
  – Participate in development of Research Transition Teams with FAA
  – Will develop proposals on other potential research activities for consideration at SPMR
  – Will assess our portfolio against the UAS Cohesive Strategy once it’s defined
Outline

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KDP-A Summary

• UAS Integration in the NAS Project has:
  – Developed Technical Challenges that are crucial to UAS integration, aligned with NASA’s Strategic Plan and Thrusts, and support FAA standards development
  – Demonstrated rigorous project management processes through the execution of previous phases
  – Defined Partnership Plans
  – Established path to KDP-C

• Request approval of Technical Challenges, execution of partnerships and plans, and execution of near-term FY17 activities

Project is ready to proceed towards KDP-C
Backup
Developing the Project

There is an increasing need to fly UAS in the NAS to perform missions of vital importance to National Security and Defense, Emergency Management, and Science. There is also an emerging need to enable commercial applications such as cargo transport (e.g. FedEx).

Project Focus: Unencumbered NAS Access for Civil/Commercial UAS

Provide research findings, utilizing simulation and flight tests, to support the development and validation of DAA and C2 technologies necessary for integrating Unmanned Aircraft Systems into the National Airspace System.
## UAS-NAS Project Lifecycle

**Timeframe for impact: 2015 - 2025**

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<th>Project Phase 1 [FY11 - FY13]</th>
<th>Phase 1 MOPS [FY14 - FY16]</th>
<th>Phase 2 MOPS [FY17 - FY20]</th>
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<td>Early investment Activities</td>
<td>Project Start May 2011</td>
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<td>KDP-C</td>
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<td>Formulation</td>
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<td>External Input</td>
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<td>Flight Validated Research Findings to Inform Federal Aviation Administration (FAA) Decision Making</td>
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<td>Technology Development to Address Technical Challenges</td>
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**Key Decision Points**
- MOPS Release
- P1 MOPS Closeout

**Technical input from** Project technical elements, NASA Research Announcements, Industry, Academia, Other Government Agencies, Project Annual Reviews, ARMD UAS Cohesive Strategy
RTCA SC-228 Terms of Reference (ToR) has defined a path forward to develop Minimum Operational Performance Standards (MOPS)

- **Phase 1 MOPS are addressed by UAS-NAS**
  - Current (FY14 – FY16) Portfolio
    - Command and Control (C2) Data Link MOPS – Performance Standards for the C2 Data Link using L-Band Terrestrial and C-Band Terrestrial data links
    - Detect and Avoid (DAA) MOPS – Performance standards for transitioning of a UAS to and from Class A or special use airspace, traversing Class D and E, and perhaps Class G airspace

- **SC-228 Deliverables**
  - C2 & DAA White Papers (Dec 2013) - Assumptions, approach, and core requirements for UAS DAA and C2 Equipment
  - C2 & DAA MOPS for Verification and Validation (July 2015) – Preliminary MOPS Including recommendations for a Verification and Validation test program
  - C2 & DAA MOPS (July 2016) – Final MOPS
FAA Designated Airspace Classes

**CLASS A**
- Commercial Transport Aircraft
- Under ATC Control
- IFR Required

**CLASS B**
- Nontowered Airport
- 700 AGL

**CLASS C**
- ORF Type Airport
- 1200 AGL

**CLASS D**
- Other Towered Airports

**CLASS E**
- LAX Type Airport
- 14,500 MSL

**CLASS F**
- General Aviation Aircraft

**CLASS E & G**
- General Aviation Aircraft

**FL 600 MSL 18,000**
UAS Integration in the NAS Project
Phase 1 MOPS Value Proposition Flow Diagram

**NASA UAS-NAS Project Activities**

**C2 Performance Standards**
- Develop C2 Prototype System
- Conduct C2 Flight Test and MS&A (Data Link, CNPC Spectrum, CNPC Security, LOS, BLOS, ATC Interoperability)
- Develop C2 Requirements
- C2 Performance Requirements to inform C2 MOPS

**SAA Performance Standards**
- Develop SAA Performance Testbed
- Conduct SAA Flight Test and MS&A (Performance Trade-offs, Interoperability, Self Separation, CONOPs, Well Clear, Collision Avoidance)
- Develop SAA Performance & Interoperability Requirements
- SAA Performance Requirements to inform MOPS

**Human Systems Integration**
- Develop Prototype GCS
- Conduct Human Factors (HF) Flight Test and MS&A (Contingency Management, Pilot Response, Autonomy, Displays)
- Develop HF Guidelines for SAA, C2 & GCS
- HF Performance Requirements to Inform MOPS and HF Guidelines

**Integrated Test & Evaluation**
- Develop LVC Test Infrastructure
- Conduct TC Specific Testing
- Conduct IHITL, Conduct SAA Initial Flight Test Scenarios, Conduct FT3 Test Scenarios, Conduct FT4 Test Scenarios
- Test Data for MOPS Development

**Key Products**
- C2 MOPS
- SAA MOPS
- DAA MOPS
- C2 Technical Standard Order (TSO)
- DAA Technical Standard Order (TSO)
- RADAR Technical Standard Order (TSO)

**Resultant Outcomes**
- Re-usable Test Infrastructure
- C2 Technical Standard Order (TSO)
- DAA Technical Standard Order (TSO)
- RADAR Technical Standard Order (TSO)
Fundamental TC Composition

- Data Removed
• Data Removed
C2 P2 MOPS Content Descriptions

• **C2 Data Link MASPS, SATCOM** (Oct 2017)
  – This MASPS will provide system performance requirements for SATCOM based C2. This material is specifically intended for delivery to ICAO to support their development of Standards and Recommended Practices (SARP) in preparation for World Radio Conference 2019.

• **C2 Data Link MOPS, SATCOM** (Jul 2019*)
  – This MOPS will provide system performance requirements for Ka/Ku technology based SATCOM based C2. This document is anticipated to lead to TSO for new functions of existing SATCOM terminals.

• **C2 Data Link MASPS, Network** (Jan 2019)
  – This MASPS will provide system level performance standards for multiple access network C2 applicable to both SATCOM and terrestrial based systems.
  – Provide multiple access techniques, augmenting the initial point-to-point architecture.

• **C2 Data Link MOPS, Terrestrial, Rev A** (Jul 2020)
  – This revision to the C2 Data Link MOPS (Terrestrial) will address: 1) any required updates resulting from ongoing TACAN/DME compatibility testing, 2) any required updates to harmonized shared use of C band between terrestrial and SATCOM systems, 3) any required updates to augment the original point-to-point MOPS description to include multiple access techniques and 4) any other updates to clarify or correct shortcomings identified while the document is open for changes.

• Other specific considerations for White Paper Development
  – C-Band SATCOM inclusion is time dependent
  – Architectures considered include: multiple aircraft communicating through a common ground or satellite transmitter, and single aircraft transitioning through a series of towers
  – Concept of operations and operating environment description for smaller UAS operating at lower altitudes

• Date under discussion within RTCA SC-228 leadership and WGs
• Note: All content per August 2016 Draft SC-228 ToR
C2 Overview

State of the Art:
- There are no civil SATCOM systems that meet initial RTCA C2 requirements established by SC-203
- RTCA SC-228 developed the Phase 1 MOPS which establishes C2 standards for a limited environment
  - Terrestrial C2 architecture only
  - Higher altitude coverage expected for “larger” UAS operations
  - Lower-density operations than expected for “mid-sized” UAS

Remaining Challenge/Barrier/Gap:
- An appropriate C2 link that supports the required performance needs of a broad range of UAS platforms
  - Ensures the pilot can maintain a threshold level of aircraft control
  - Robust to both environmental and technological issues
- Sufficient bandwidth efficiency to meet the anticipated UAS density levels
- Maturation of C2 terrestrial and SATCOM technologies

Related NASA Work:
- Performed/supported spectrum studies used for establishing Ku & Ka-Band designations and C-Band SATCOM allocation at WRC-12 & 15
- Developed multiple generations of a CNPC terrestrial radio evaluation system through a NASA/Industry cooperative agreement
- Leadership of the RTCA SC-228 C2 (WG Security and V&V subgroups) and significant contributions to the Phase 1 Terrestrial C2 MOPS
- NASA developed NAS-wide communications simulation model

NASA’s Unique Positioning:
- Terrestrial and SATCOM C2 Subject Matter Expertise and familiarity with the key issues
- Recognized leader of ongoing efforts and working groups (e.g. WRC, ITU, SC-228)
- Instills confidence in industry that standards will be accepted by the regulator
- Able to leverage previous hardware and software investments as well as M&S and flight test assets used for Phase 1 MOPS
C2 Overview

Objectives:
• Develop data and rationale to acquire UAS frequency spectrum allocations for SATCOM
• Develop and validate UAS control and communications data links for MOPS in compliance with proposed international/national regulations, standards, and practices
• Perform analysis and propose security recommendations for civil UAS control communications
• Perform simulations studying link scalability, capacity testing, and interoperability testing

Key Activities:
• Develop Ku & Ka SATCOM prototype radio systems through a NASA/Industry cost sharing cooperative agreement
• Develop the Initial design parameters for a C-band SATCOM CNPC system
• Develop a C & L-Band terrestrial extension CNPC prototype radio systems through a NASA/Industry cost sharing cooperative agreement
• All prototype systems will be flight tested in a relevant environment

TC Advancement:
• Valuable research findings to SC-228 for Phase 2 C2 MOPS development
• Substantiated UAS frequency spectrum allocations for SATCOM
• Proven terrestrial C & L-band architecture applicable to a broader set of UAS
• Validated Terrestrial Extension and SATCOM C2 Standards
• **Ground-based Primary Radar MOPS and DAA MOPS Rev A (Sep 2019)**
  – MOPS for a ground-based primary radar to support the Phase 2 DAA MOPS
  – Geographically limited operations and operations within a terminal environment should be considered to include; Class D airspace, towered airfields within Class E airspace, non-towered airfields within Class E airspace, non-towered airfields within Class G airspace, and off-airfield launch and recovery sites within Class G airspace

• **Non-Cooperative Sensor MOPS and DAA MOPS Rev B (Sep 2020)**
  – MOPS for an alternative sensor to detect and track non-cooperative aircraft in support of the Phase 2 DAA MOPS
  – Technologies to enable UAS with less available Size, Weight, and Power (SWaP) should be considered. It is expected that this will lead to the development of a MOPS for a non-cooperative sensor

• **Other specific considerations for White Paper Development**
  – A collision avoidance capability that operates in the absence of a C2 Datalink
  – Elaborate potential Visual Operations that could be enabled with a Phase II DAA Capability
  – Operations in other classes of airspace (e.g. Classes B and C)
  – Very Low Level (VLL) operations, which includes extended operations below 500 ft AGL, are not within the scope of Phase Two DAA MOPS
  – Ground operations by UAS are not in scope of Phase Two DAA MOPS

• **Note:** All content per August 2016 Draft SC-228 ToR
DAA Overview

State of the Art:

- A significant amount of DAA research has been conducted by the UAS community over the past several years. Centered on:
  - Government research efforts
  - Industry IRAD funded prototype systems
- RTCA SC-228 developed the Phase 1 MOPS which establishes DAA standards for a limited environment
  - Transition through Class E to Class A
  - Onboard radars as non-cooperative sensors

Remaining Challenge/Barrier/Gap:

- DAA Standards, CONOPs and Use Cases for UAS operations within all remaining classes of airspace (B, C, D, E, G)
- DAA technologies and standards for use on a broad range of UAS platforms
- DAA Standards for low-SWaP alternative sensors and GBSAA
- DAA technologies and avoidance algorithm maturation to more broadly applicable environments

Related NASA Work:

- The NASA UAS-NAS DAA subproject played a key role in the development of the Phase 1 MOPS
- Worked in close coordination with the Science and Research Panel (SARP) to develop the Well Clear Definition
- Developed and evaluated two DAA algorithms using M&S and flight test
- Developed alerts and guidance consistent with existing collision avoidance systems (e.g., TCAS)

NASA’s Unique Positioning:

- Broad DAA Subject Matter Expertise and capabilities; Familiarity with the issues of a difficult problem for the community to solve
  - Able to leverage previous investments such as algorithms, simulation environments, and flight test assets
- Instills confidence in industry that standards will be accepted by the regulator
- Recognized leader in ongoing efforts and working groups (e.g. FAA, SARP, SC-228)
DAA Overview

Objectives:
• Evaluation and Integration alternative airborne sensors
• Support SC-228 and Enable UAS Terminal and/or BVLOS ops for UAS with lower available SWaP (including well clear definitions)
• Rules/logic for ACAS Xu interoperability
• Procedures for safe and efficient UAS Operations
• Evaluate requirements and implications of autonomous DAA with MOPS

Key Activities:
• Conduct engineering analysis
• Perform fast time simulations
• Perform Human in the Loop (HITL) simulations
• Perform flight tests to V&V DAA requirements and Standards

TC Advancement:
• Valuable research findings to SC-228 for Phase 2 MOPS development
• FAA policy/guidance finalization for DAA
• Broadly applicable well clear definition(s) and ATM interoperability
• Safe and efficient unsegregated terminal area operations for UAS
• Low SWaP DAA system definition, testing and validation
State of the Art:
- LVC-DE environment built for phase 1 MOPS
- NASA Ikhana equipped with prototype DAA system and used in multiple flight tests
- Phase 1 C2 prototype system flight tested and available through GRC
- Data from LVC-DE & flight tests used to help V&V Phase 1 MOPs
- Army GBSAA radar based on dedicated ground observer architecture
- Industry low-SWaP airborne sensors, and ground sensors developed with significant industry IRAD being invested

Remaining Challenge/Barrier/Gap:
- Existing Phase 1 MOPS are not intended for operations within terminal areas or for UAS with lower available SWaP
- GBSAA and Low-SWaP airborne sensors have not been integrated into DAA or C2 architectures
- DAA performance specs not yet developed or validated for use on a broad range of UAS platforms
- Automatic Collision Avoidance systems for UAS do not have standards
- Integration of DAA and C2 on board UAS has not been complete, and methods operational approvals of systems have not been developed

Related NASA Work:
- The NASA UAS-NAS IT&E subproject played a key role in validating the Phase 1 MOPS through M&S and flight test
  - Phase 1 MOPS Verification Procedures defined
  - Phase 1 MOPS Validation Flight Tests
- Executed integration and flight tests for P1 DAA MOPS
  - ~320 DAA V&V encounters performed

NASA’s Unique Positioning:
- Flight Test required for V&V and performance standards is challenging and high risk
  - Able to leverage previous investments such as, LVC-DE, flight test assets, FT3 & FT4 risk reduction & DAA flight test operation experience.
- Instills confidence in industry that standards will be accepted by the regulator
- Recognized leader in ongoing efforts and working groups (e.g. FAA, SARP, SC-228)
**IT&E Overview**

### Objectives:
- Design, document, develop, implement, operate, and maintain a LVC-DE for simulation and flight test
- Simulation planning, conduct, data distribution, and reporting
- Plan, conduct, distribute data, and report on flight tests, including; Collision Avoidance flight tests, DAA focused flight tests, and integrated DAA and C2 flight tests

### Key Activities:
- Employing system engineering principles define:
  - LVC-DE infrastructure design requirements
  - Simulation experiment requirements
  - Flight test requirements
  - Data and data distribution requirements
- Develop and document partnerships
- Support multiple DAA simulations
- Collaborate with ACAS Xu partners to plan and conduct ACAS Xu FT2
- Conduct a series of flight tests in support of MOPS development, verification and validation

### TC Advancement:
- Simulation/flight systems and infrastructure for development, verification and validation of MOPS
- Rigorous NASA safety processes applied against SOA aircraft and technology systems in order to conduct highly complex testing
Path to KDP-C Backup Slides
### Overview Schedule to KDP-C

<table>
<thead>
<tr>
<th>Q2 FY16</th>
<th>Q3 FY16</th>
<th>Q4 FY16</th>
<th>Q1 FY17</th>
<th>Q2 FY17</th>
<th>Q3 FY17</th>
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<td><strong>Programmatics Refined</strong></td>
<td><strong>Technical Portfolio Development (Cost-Benefit-Risk Assessment)</strong></td>
<td><strong>Cost/Schedule/Risk</strong></td>
<td><strong>Partnership Development</strong></td>
<td><strong>Technical Portfolio Development (Cost-Benefit-Risk Assessment)</strong></td>
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<td><strong>Project Org Decisions</strong></td>
<td><strong>PPBE18</strong></td>
<td><strong>PPBE18</strong></td>
<td><strong>PPBE18</strong></td>
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<td><strong>Initial SPs Complete</strong></td>
<td><strong>Next Phase Risks/IMS Framework Defined</strong></td>
<td><strong>TC Tollgate Pre-Briefing</strong></td>
<td><strong>TC Tollgate Review (9/13)</strong></td>
<td><strong>KDP-C Pre-Briefings</strong></td>
<td><strong>KDP-C Portfolio Baselined</strong></td>
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<td><strong>PPBE18 Processes Updated</strong></td>
<td><strong>TCs/TWP Defined</strong></td>
<td><strong>IMS/Risks/Budget Distribution Finalized</strong></td>
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Project Processes

• Change Management
  – Standard process utilizing Change Requests (CR) to manage changes to the following elements:
    • L1 and L2 Milestones
    • Project Goals, Objectives, and Technical Challenges
    • Technical Baseline, i.e. SP objective, approach, deliverables
    • Project Requirements
    • Budget

• Risk Management
  – Utilizes a Continuous Risk Management (CRM) process to identify, analyze, plan, track, and control risks
    • Risk Workshops and Risk Review meetings conducted monthly
    • Risks are communicated in ISRP UAS-NAS Risk Review Board, AFRC & Partner Center CMCs

• Resource Management
  – TWP, Budget roll up, and travel spreadsheets used in conjunction with standard tools (PMT, Business Warehouse, and SAP) to generate phasing plans and monitor status

• Management Review Board (MRB)
  – Monthly meeting where CRs and Risks are assessed/approved and resource status and schedule status are presented
Project Processes
Schedule Management Flow

- Project weekly status is the primary means of information flow, schedule status, and updates.
- Schedule Packages and Milestones are the primary means of reporting at the project weekly status.
- The version controlled IMS contains change managed Milestones.
- Schedule management process is formally documented in the SMP.
<table>
<thead>
<tr>
<th>Acronym</th>
<th>Description</th>
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<tr>
<td>ACAS</td>
<td>Airborne Collision Avoidance System</td>
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<td>ACAS Xu</td>
<td>Airborne Collision Avoidance System for Unmanned Aircraft Systems</td>
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<td>ACES</td>
<td>Airspace Concept Evaluation System</td>
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<td>ACSS</td>
<td>Aviation Communication &amp; Surveillance Systems</td>
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<td>ADS-B</td>
<td>Automatic Dependent Surveillance - Broadcast</td>
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<td>AFLCMC</td>
<td>Air Force Life Cycle Management Center</td>
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<td>AFRC</td>
<td>Armstrong Flight Research Center</td>
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<td>Above Ground Level</td>
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<td>Air Traffic Organization-FAA Organization or Authority to Operate</td>
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<td>BLOS</td>
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<td>AUVSI</td>
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<td>Control and Non-Payload Communications</td>
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<td>COA</td>
<td>Certificate of Authorization or Waiver</td>
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<td>Concept of Operations</td>
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<td>CPDS</td>
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<td>CR</td>
<td>Change Request or Continuing Resolution</td>
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<td>Continuous Risk Management</td>
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<td>DAA</td>
<td>Detect and Avoid</td>
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<td>F2F</td>
<td>Face to Face</td>
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<td>Acronyms</td>
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<td>HALE</td>
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<td>ICD</td>
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<td>IRAD</td>
<td>Internal Research and Development Program</td>
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<td>IT&amp;E</td>
<td>Integrated Test and Evaluation</td>
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<td>ITU</td>
<td>International Telecommunication Union</td>
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## Acronyms

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<tr>
<th>Acronym</th>
<th>Description</th>
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<tr>
<td>ITU-R</td>
<td>International Telecommunication Union-Radiocommunication</td>
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<tr>
<td>JADEM</td>
<td>Java Architecture for Detect and Avoid Extensibility and Modeling</td>
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<tr>
<td>JOFOC</td>
<td>Justification of Other than Full and Open Competition</td>
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<tr>
<td>KDP</td>
<td>Key Decision Point</td>
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<td>L1</td>
<td>Level 1</td>
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<td>L2</td>
<td>Level 2</td>
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<td>LaRC</td>
<td>Langley Research Center</td>
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<td>LIDAR</td>
<td>Light Imaging, Detection, And Ranging</td>
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<td>LAX</td>
<td>Los Angeles International Airport</td>
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<td>LOS</td>
<td>Line of Sight or Loss of Separation</td>
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<td>Live Virtual Constructive</td>
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<td>LVC-DE</td>
<td>Live Virtual Constructive- Distributed Environment</td>
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<td>Live Virtual Integrated System</td>
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<td>M&amp;S</td>
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<td>MS&amp;A</td>
<td>Modeling, Simulation and Analysis</td>
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<td>MASPS</td>
<td>Minimum Aviation System Performance Standards</td>
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<td>MIT-LL</td>
<td>Massachusetts Institute of Technology Lincoln Labs</td>
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<td>Memorandum of Agreement</td>
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<td>Minimum Operational Performance Standards</td>
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<td>Management Review Board</td>
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<td>Description</td>
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<td>NAS</td>
<td>National Airspace System</td>
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<td>Next Generation</td>
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<td>NSPIRES</td>
<td>NASA Solicitation and Proposal Integrated Review and Evaluation System</td>
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<td>Project Management Tool</td>
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<td>PPBE</td>
<td>Planning, Programming, Budgeting, and Execution</td>
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<td>RFI</td>
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<td>Request for Proposal</td>
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<td>SAA</td>
<td>Space Act Agreement or Sense and Avoid or See and Avoid</td>
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<td>Systems Applications and Products</td>
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<td>Schedule Management Plan</td>
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<td>State of Art</td>
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<td>SOW</td>
<td>Statement of Work</td>
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<td>Strategic Portfolio Management Review</td>
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<td>Software</td>
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<td>SWaP</td>
<td>Size, Weight and Power</td>
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<td>Tactical Air Navigation System</td>
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<td>TBD</td>
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<td>Test Conductor/Technical Challenge</td>
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<td>Traffic Alert and Collision Avoidance System</td>
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<td>VLL</td>
<td>Very Low Level</td>
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