Initial Study of Tailored Trajectory Management for Multi-Vehicle Uncrewed Regional Air Cargo Operations
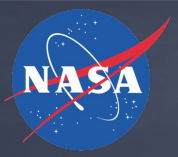
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Authors: David Thipphavong, Todd Lauderdale, Bob Windhorst, Heather Arneson, Husni Idris, Richard Coppenbarger, Jordan Sakakeeny, Nadezhda Dimitrova, Vishwanath Bulusu, Gano Chatterji, Arwa Aweiss
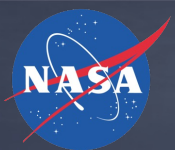
Outline

- Introduction

- Test Apparatus

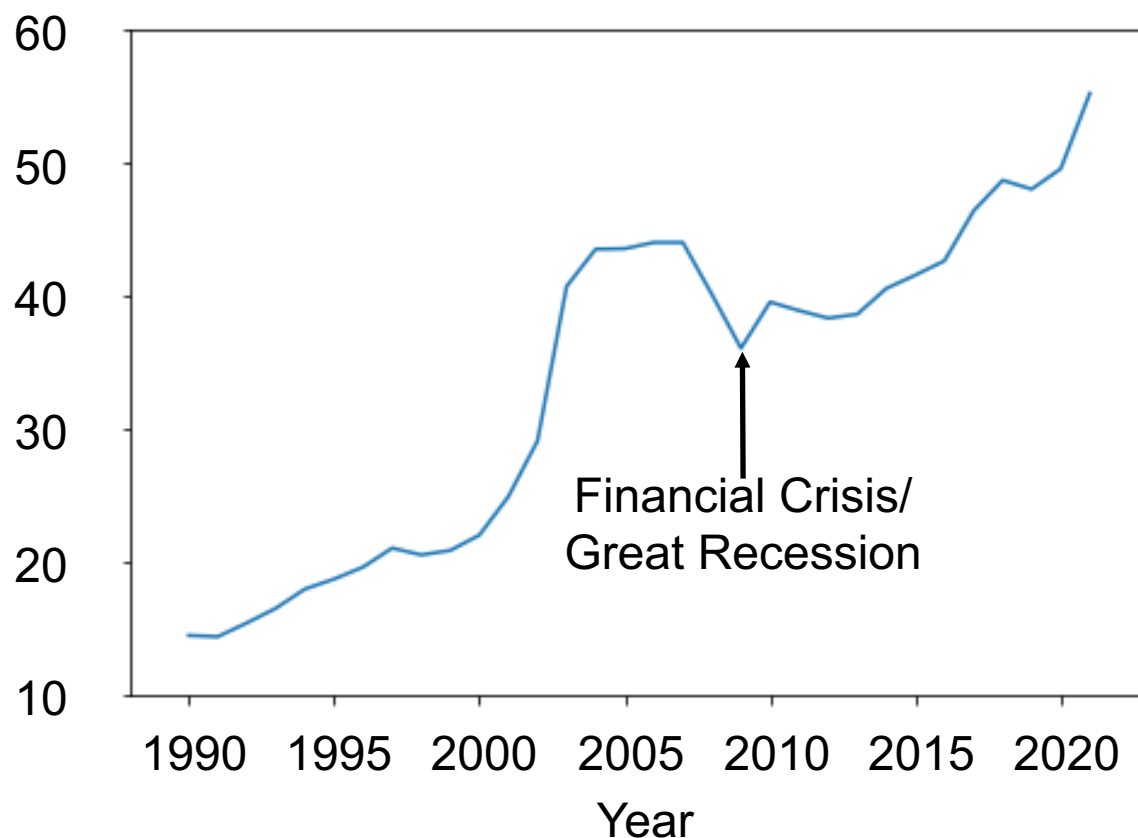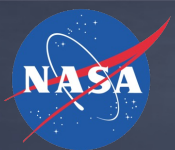- Methodology

- Results

- Summary and Future Work

Introduction

- Demand for air cargo transportation has **grown** over the past decade

- Industry is seeking to utilize **remotely-piloted** mid-sized and **large uncrewed aircraft (UA)**
 - For air cargo operations
  - In 1:1 and m:N operations (m < N)

Annual Air Cargo (billions of lbs)

Financial Crisis/ Great Recession

Year

- **Multi-vehicle** UA **regional air cargo operations** will need to be integrated into the increasingly complex airspace envisioned in the
  - FAA's **Info-Centric NAS** 2035 vision and initial concept of operations
  - NASA's **Sky for All** 2050 vision

- Operating UA under **present-day IFR**
  - Requires communicating with and responding to ATC by voice
  - Could lead to **excessive workload** when managing multiple UAs when communicating concurrently
    - With different air traffic controllers
   - On different radio frequencies
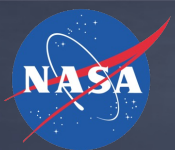
Research Goals

Evaluate the extent to which a UA operator Tailored Trajectory Management (TTM) capability can proactively

- **Detect conflicts prior** to ATC performing conflict resolution
- **Reduce peaks** in UA operator **workload**

- **Detect** and **resolve** conflicts prior to ATC
  - Time horizon up to about 20 minutes
  - Changes to flight route, speed, and/or altitude profile
  - **Tailored** to the **performance** of individual flights

- Extension of **Tailored Arrival Management** that was evaluated with Boeing in 2020 ecoDemonstrator activities

- **TTM**, combined with **data-link communications** and **automatic flight control**, can facilitate **m:N** and **fully autonomous** operations
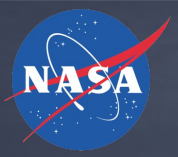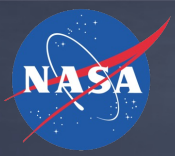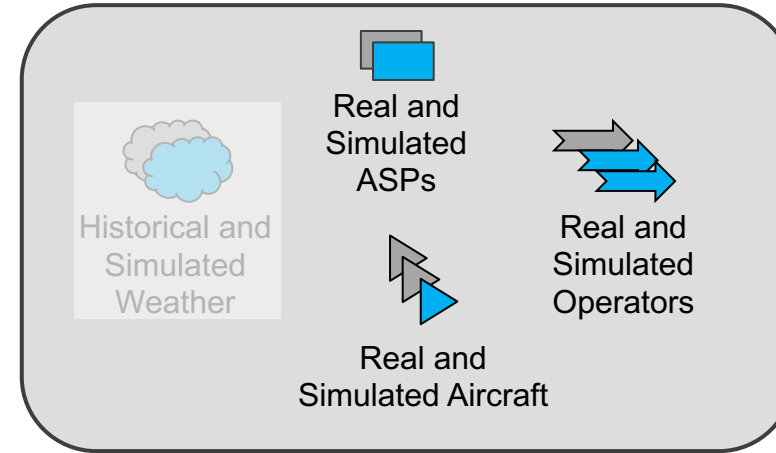
Test Apparatus
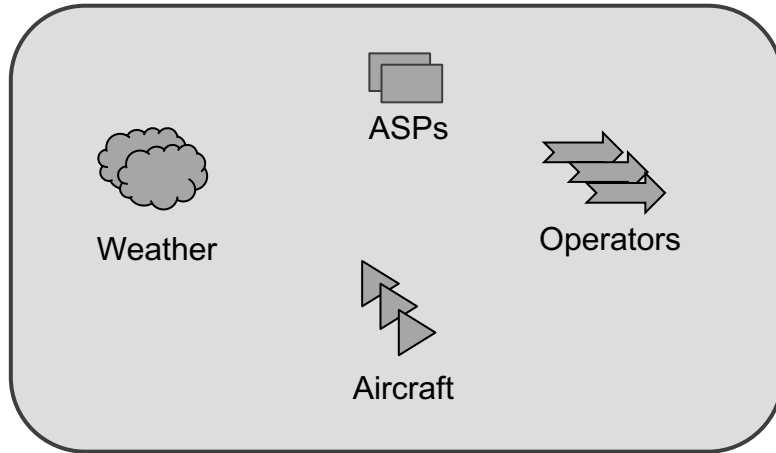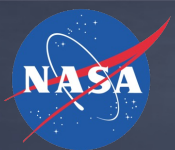
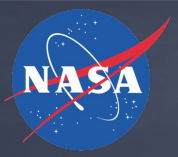Current NAS   NAS Digital Twin

National Airspace System (NAS) Digital Twin provides a **Live, Virtual, Constructive (LVC)** environment to

- Explore potential changes to the NAS

- Uncover unintended consequences and risks of introducing new technologies and concepts

- Verify and validate new algorithms

Autoresolver

- **Autoresolver (AR)** is the **Tailored Trajectory Management (TTM**) solution engine that
  - Detects conflicts
  - Develops coordinated and comprehensive closed-form trajectory-based resolutions
  - Closed form: comprised of maneuvering the flight from its original plan and returning it back

- AR is composed of **integrated algorithms** for
  - Pre-departure scheduling
  - Air traffic separation
  - Arrival merging and spacing
  - Weather avoidance (not utilized in present study)

- AR was **adapted** and **extended** to **model** a UA operator **TTM** capability
  - Only maneuver UA flights to resolve predicted conflicts
  - Resolve primary conflict, even if doing so would cause secondary downstream conflict(s) that require subsequent resolution(s)

Methodology

- **Two-and-a-half hours** during morning rush on a day with **no weather impacts**

- Simulated UA cargo flights
  - **Five** flights into **Fort Worth Alliance** airport (KAFW, Texas)
    - Three flights from **Austin** (KAUS, Texas), followed by
    - One flight from **Lubbock** (KLBB, Texas), followed by
    - One flight from **Wichita** (KICT, Kansas)
  - Based on recorded **Cessna 208 Caravan** (C208) flights
  - Arriving at KAFW at intervals of about 20 minutes

- Background traffic
  - Played back recorded **IFR** and **VFR** track data
  - Autoresolver maneuvered simulated UA flights to maintain separation from background traffic

Simulated UA Flight Routes
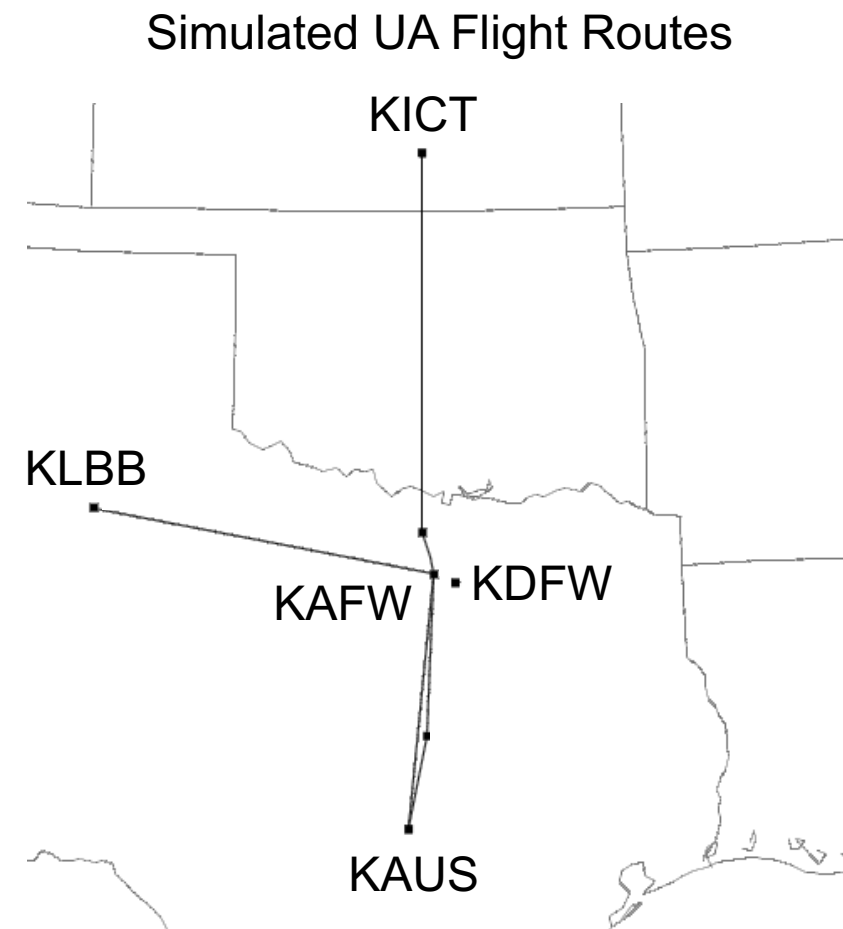
- Four instances of Autoresolver that model
  1. ATC in D10 TRACON airspace
  2. ATC in Center airspace
  3. UA operator with TTM capability for D10 TRACON airspace
  4. UA operator with TTM capability for Center airspace

- No trajectory uncertainties
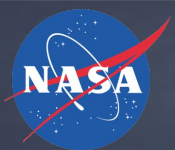- No simulated winds
- No simulated weather

Experiment

- One baseline simulation
  - Models current air traffic operations
  - Does **not** include a UA operator TTM capability

Baseline Simulation Configuration

ATC TRACON AR
Detection and resolution

ATC Center AR
Detection and resolution

- One baseline simulation
  - Models current air traffic operations
  - Does not include a UA operator TTM capability

- **Four test simulations**
  - Models **UA operator with a TTM capability**
  - **Proactively** detects conflicts and develops resolutions to request of ATC to preclude instances of multiple concurrent conflicts
  - Set different configuration parameters to evaluate performance tradeoffs (more details on next slides)

Baseline Simulation Configuration

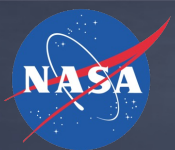| |
| --- |
| ATC TRACON AR Detection and resolution |
| ATC Center AR Detection and resolution |

Test Simulation Configuration

ATC TRACON AR Detection only
ATC Center AR Detection only
UA Operator TRACON AR with TTM Detection and resolution
UA Operator Center AR with TTM Detection and resolution

Baseline Simulation

	Horizontal Separation for Detection [nmi]	Horizontal Separation for Resolution [nmi]	Vertical Separation for Detection [ft]	Vertical Separation for Resolution [ft]	Time to LOS to Start Conflict Resolution Process [minutes]	Required Conflict-Free Duration for Conflict Resolutions [minutes]
ATC TRACON AR	3.0	4.0	1000	1000	8	10
ATC Center AR	5.0	7.0	1000	1000	8	12

- Conflict Detection
  - **ATC TRACON AR** identifies conflicts with less than 3.0 nmi of HorzSep and less than 1000 ft of VertSep
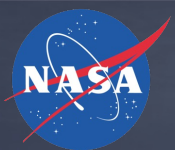 - **ATC Center AR** identifies conflicts with less than 5.0 nmi of HorzSep and less than 1000 ft of VertSep
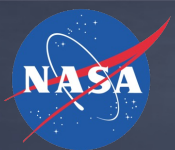
Baseline Simulation

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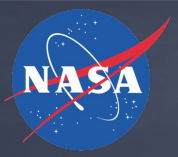 - **ATC Center AR** identifies conflicts with less than 5.0 nmi of HorzSep and less than 1000 ft of VertSep

- Conflict Resolution
  - When time to **LOS** was **8 minutes or less**, ATC TRACON AR develops conflict resolutions for simulated UA flights to maintain at least 4.0 nmi of HorzSep and/or at least 1000 ft of VertSep for at least 10 minutes
  - ATC Center AR did so for simulated UA flights to maintain at least 7.0 nmi of HorzSep and/or at least 1000 ft for at least 12 minutes
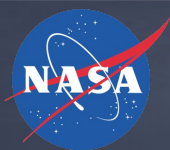
Test Simulations

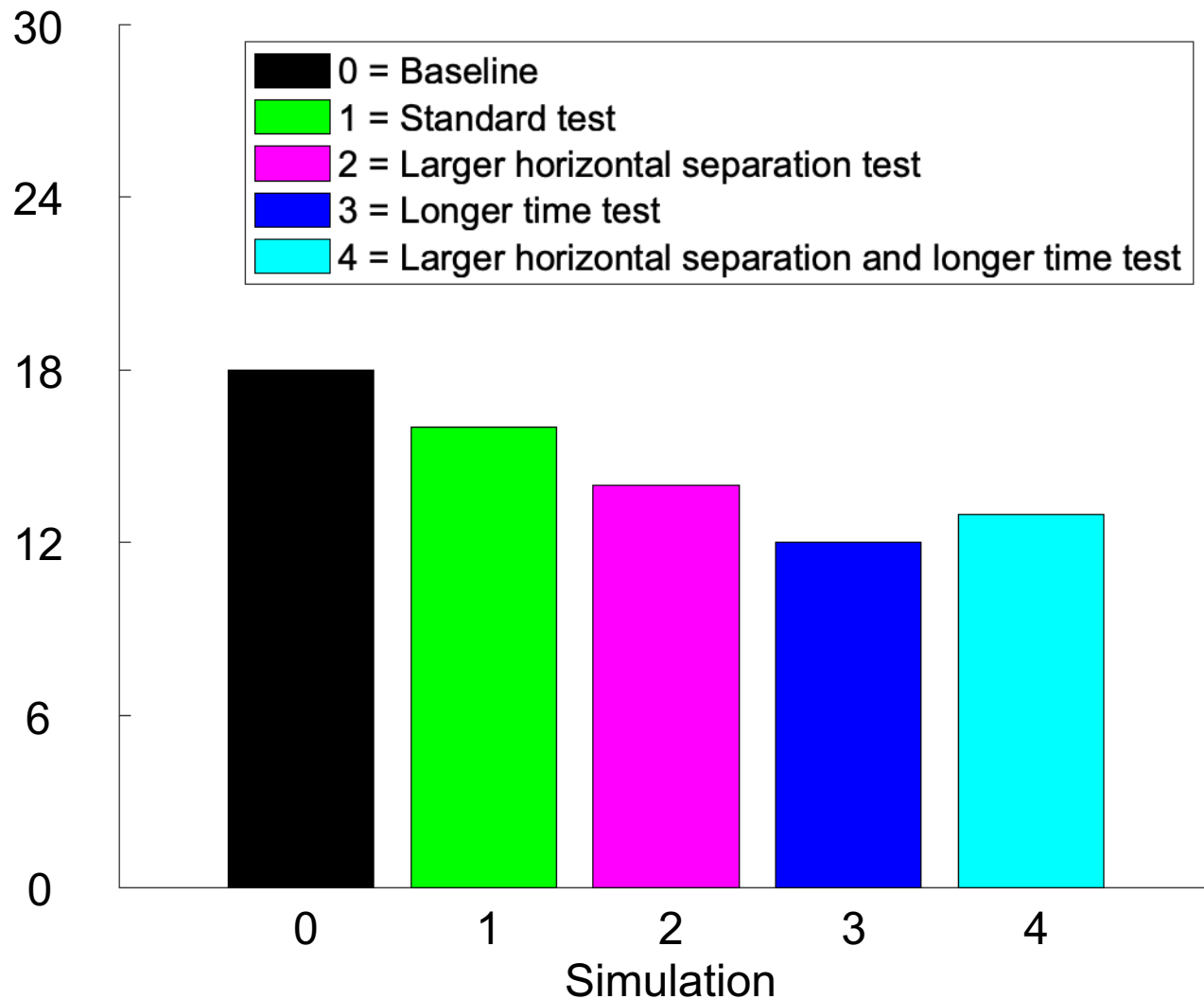|	Test Simulation	Horizontal Separation for Detection [nmi]	Horizontal Separation for Resolution [nmi]	Vertical Separation for Detection [ft]	Vertical Separation for Resolution [ft]	Time to LOS to Start Conflict Resolution Process [minutes]	Required Conflict-Free Duration for Conflict Resolutions [minutes]
ATC TRACON AR	All	3.0	N/A	1000	N/A	N/A	N/A
ATC Center AR	All	5.0	N/A	1000	N/A	N/A	N/A
UA Operator TRACON AR	All Test	3.0	4.0	1000	1000	10	12
UA Operator Center AR	Standard	5.0	7.0	1000	1000	12	16
UA Operator Center AR	Larger Horizontal Separation	7.0	9.0	1000	1000	12	16
UA Operator Center AR	Longer Time	5.0	7.0	1000	1000	16	20
UA Operator Center AR	Longer Horizontal Separation and Longer Time	7.0	9.0	1000	1000	16	20

Results

Number of Conflicts

Legend:
- 0 = Baseline (black)
- 1 = Standard test (green)
- 2 = Larger horizontal separation test (magenta)
- 3 = Longer time test (blue)
- 4 = Larger horizontal separation and longer time test (cyan)

X-axis: Simulation (0, 1, 2, 3, 4)
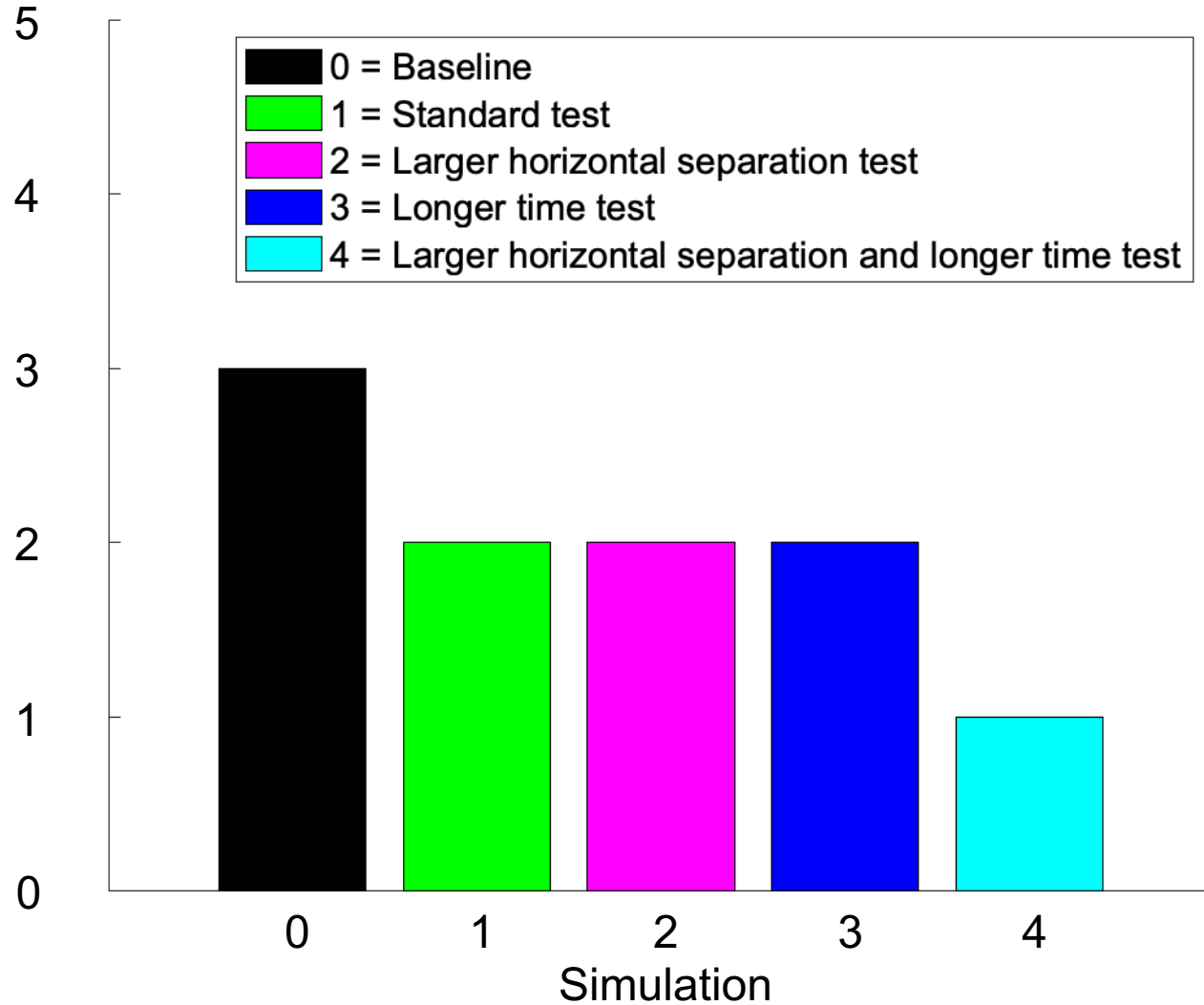Y-axis: 0, 6, 12, 18, 24, 30

- **Decreased** between
  - Baseline simulation of current operations (black bar)
  - Four test simulations with UA operator TTM capability (green, magenta, blue, and cyan bars)

- Utilizing both larger horizontal separation and longer time parameters (cyan bar) made it **more challenging** for TTM capability to find conflict-free maneuvers

Conflict detection and resolution parameters need to be tailored to the operating environment

Number of Conflicts

Legend:
- 0 = Baseline (black)
- 1 = Standard test (green)
- 2 = Larger horizontal separation test (magenta)
- 3 = Longer time test (blue)
- 4 = Larger horizontal separation and longer time test (cyan)

X-axis: Simulation (0, 1, 2, 3, 4)

- **Decreased** from three to two between baseline simulation and standard, larger horizontal separation, and longer time test simulations

- **Decreased** by one additional instance when both larger horizontal separation and longer time parameters were utilized

TTM capability can proactively preclude instances of concurrent communications with ATC during which UA operator workload could spike
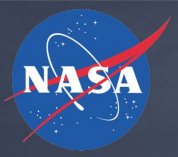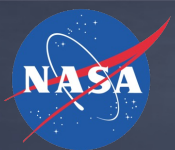
Number of Conflicts
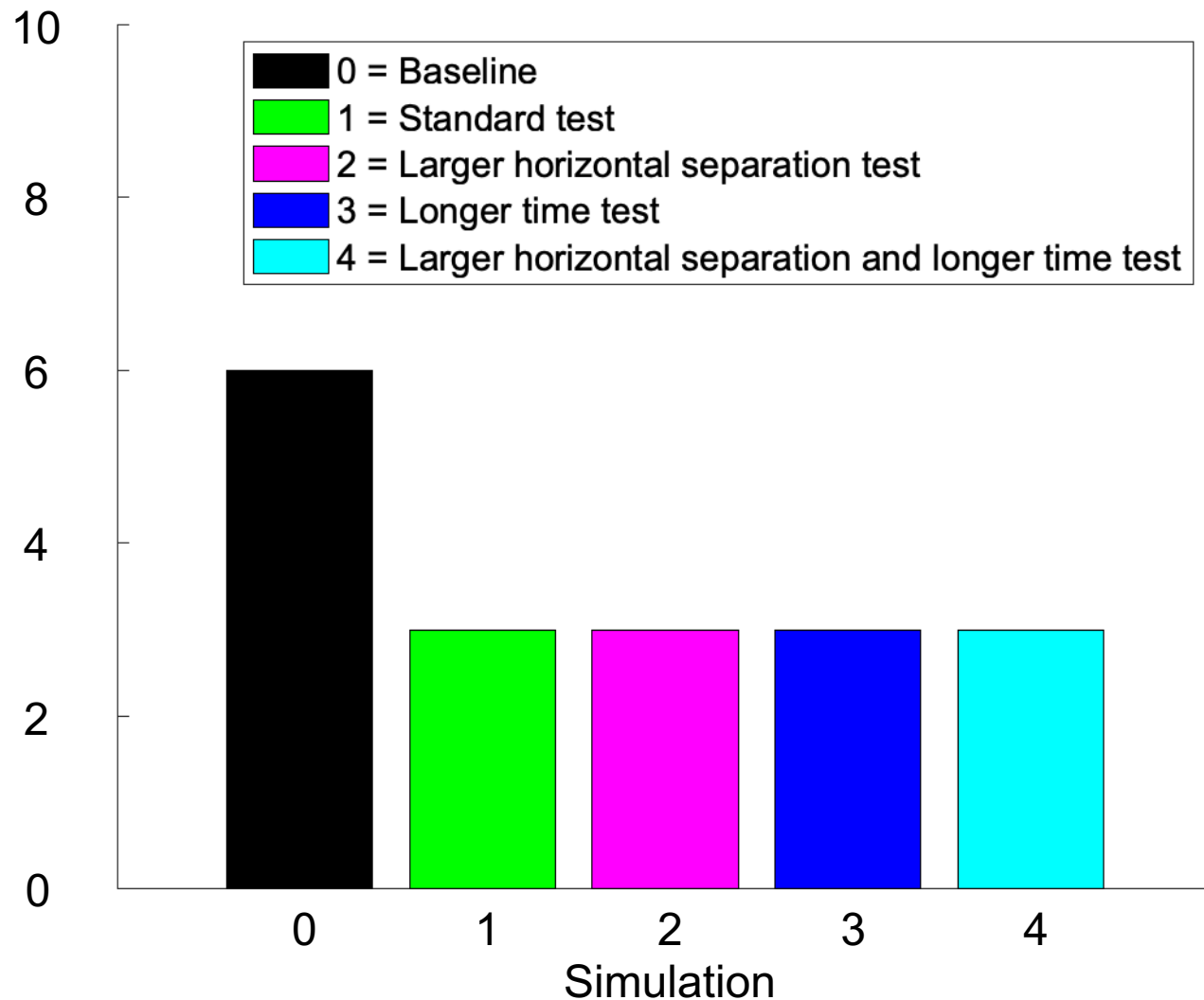
- **Decreased** from six to three between baseline simulation and test simulations

TTM capability can proactively detect conflicts and develop resolutions upstream to reduce the complexity of conflict situations downstream
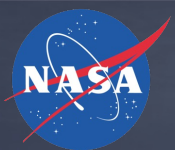
Summary and Future Work

- **Significant challenges** must be overcome to conduct remotely piloted UA regional air cargo operations **at scale**

- One major potential safety challenge is **excessive UA operator workload** that
  - Could occur when a UA operator managing multiple UA must communicate concurrently with different air traffic controllers on different radio frequencies
 - Could lead to missed communications and delays in maneuvering UA

Tailored Trajectory Management capability for UA operators can **preclude** events that could spike UA operator workload

Potential Extensions to Current Study

- Model and develop mitigation solutions for VFR trajectory uncertainties

- Additional days and time periods

- More UA flights and UA operators at KAFW based on historical operations

- Additional airspaces and airports (e.g., Visalia airport in California and Ontario airport in California)

- Complementary HITL simulations towards ensuring UA operator and ATC acceptability and interoperability
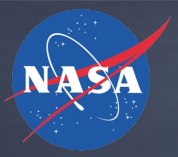
Questions, Comments, Feedback

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