Development of an Airspace Simulation and Modeling Tool for Enhanced Spectrum Management

23rd Integrated Communications, Navigation, and Surveillance Conference

April 18-20, 2023

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Motivation: New Airspace Concepts (AAM/UAM)

Increasingly dense airspace with more complex airspace operations

- **Aviation spectrum is a limited resource and used inefficiently**
- **New airspace concepts are envisioned, such as AAM/UAM**
  - Results in an increasingly dense airspace with more complex airspace operations
  - Requires enhanced connectivity between air and ground assets for increased situational awareness
- **Enhanced connectivity and increased complex operations will require greater CNS service demands**
- **Current spectrum management approach may not be sufficient**
  - New approaches need to be investigated for enhanced spectrum usage efficiency to support future airspace operations

Concept: Autonomous Spectrum Allocation

Overview and approach to implement new concept for aviation spectrum management

- **Investigate concepts and technologies to modernize aviation spectrum management**
  - Leverage advancements in wireless communications, artificial intelligence, machine learning, and other concepts/technologies
- **Implement dynamic (i.e., "intelligent") assignment of resources (e.g., spectrum) based on current and predicted airspace state**
  - State of airspace: locations of aircraft and relative proximity (i.e., surveillance), weather occurrences, airspace restrictions
  - Predictions: aircraft 4D trajectory, communications demands
- **Desired result of this new concept:**
  - Improve spectrum utilization efficiency and facilitate enhanced airspace capacity
  - Significantly improve safety and efficiency of future airspace operations
  - Enable future operational concepts, such as UAM/AAM

Autonomous Spectrum: Research Focus Areas

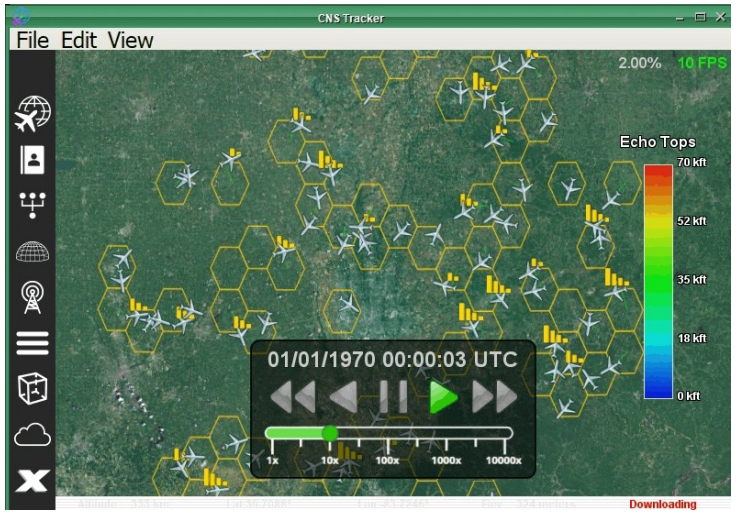
Research is being conducted via three inter-related research areas

- **Prediction Methods**
  - Determine where and when resources (i.e., spectrum) will be required
  - Can be used to inform resource allocation algorithms to aid in determining optimal assignments
  - Two focus areas: aircraft 4D trajectory, and communications demand
- **Dynamic Resource Allocation (RA)**
  - Given a pool of available resources, the RA algorithm assigns resources based on airspace state and prediction inputs
  - Envision the airspace is comprised of multiple coordinated algorithms
- **Use Case Evaluation**
  - Evaluate performance of prediction and RA in realistic airspace scenarios (e.g., AAM)
  - Determine benefits of learning-based solutions vs. non-learning based solutions
  - Develop a custom modeling and simulation tool to assist in the use case evaluation

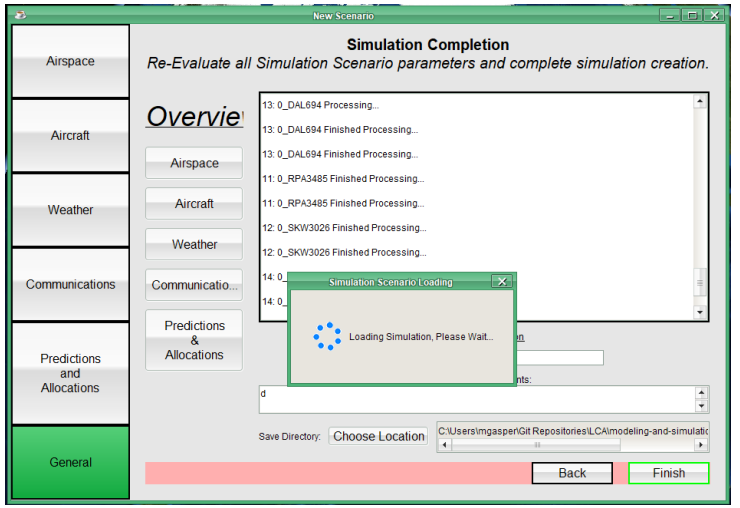
Use Case Evaluation

Advanced Custom Computational Tool to Evaluate Future CNS Designs

- **Challenge**
  - Need for new computational tools to assess new CNS system designs in realistic use cases for future airspace operations
- **Proposed Solution**
  - Develop new, custom computational tool capability to validate performance of advanced CNS concepts for future airspace scenarios
  - Incremental capability development for CNS simulations using open-source software visualization framework
- **Benefits**
  - Performance evaluation of advanced algorithms and methods
  - Custom solutions tailored to specific scenarios / needs
  - Rapid prototyping of large-scale scenarios that cannot be easily done with COTS tools



Simulation Visualization

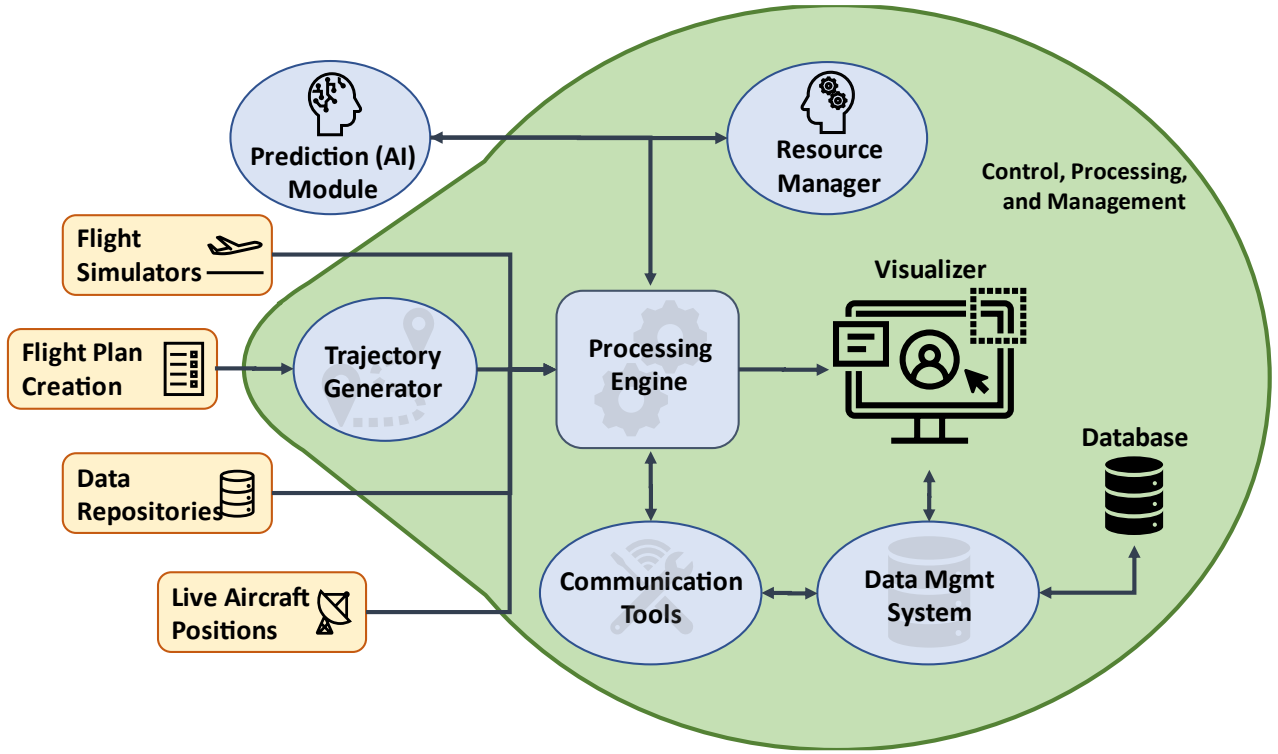


Scenario Developer User Interface

CNS Advanced Modeling Tool

Evaluation of proposed concepts via a custom modeling and simulation tool

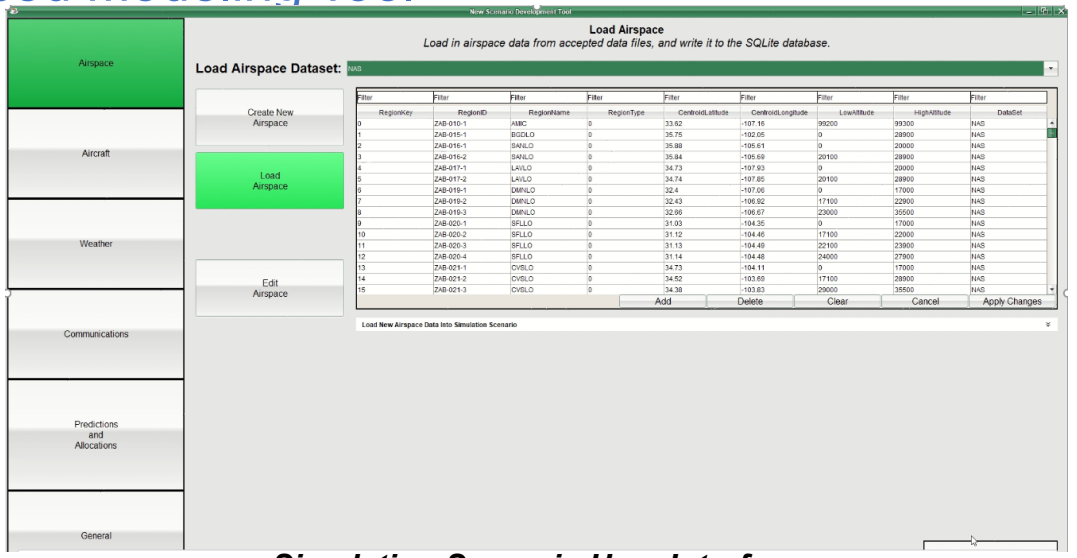
- **Toolset Architecture – Modular Design**
  - Visualization, i.e., user interface
  - Processing engine
  - Communication tools
  - Data management system
  - External interfaces
- **Features**
  - Simulation Scenario Development
  - Custom Airspace Builder
  - Aircraft Communications Analysis
  - Aircraft 4D Flight Track Generation
  - External Interface for Advanced Algorithms



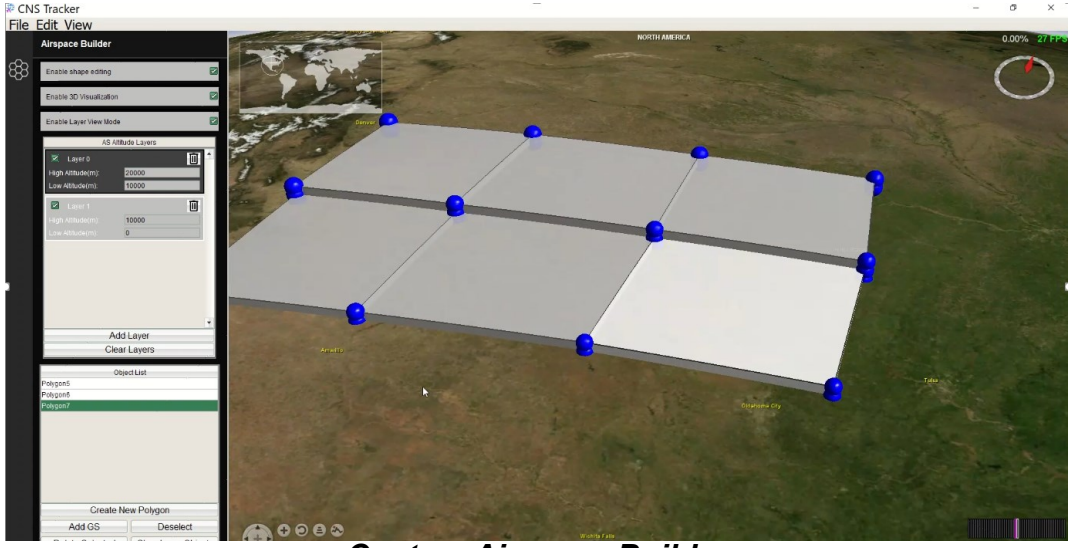
Overview of Toolset Features (1 of 3)

Description of features and capabilities of the CNS Advanced Modeling Tool

- **Simulation Scenario Developer**
  - Configure airspace sectors
  - Generate aircraft trajectories
  - Configuration communications link parameters
  - Generate weather effects
  - Interface with external modules for advanced algorithms
  - Configure simulation metrics and view simulation results
- **Custom Airspace Builder**
  - Create and manipulate custom airspace volumes
  - Manage altitude layers of airspace volumes
  - Create ground stations and associate to airspace volumes



Simulation Scenario User Interface

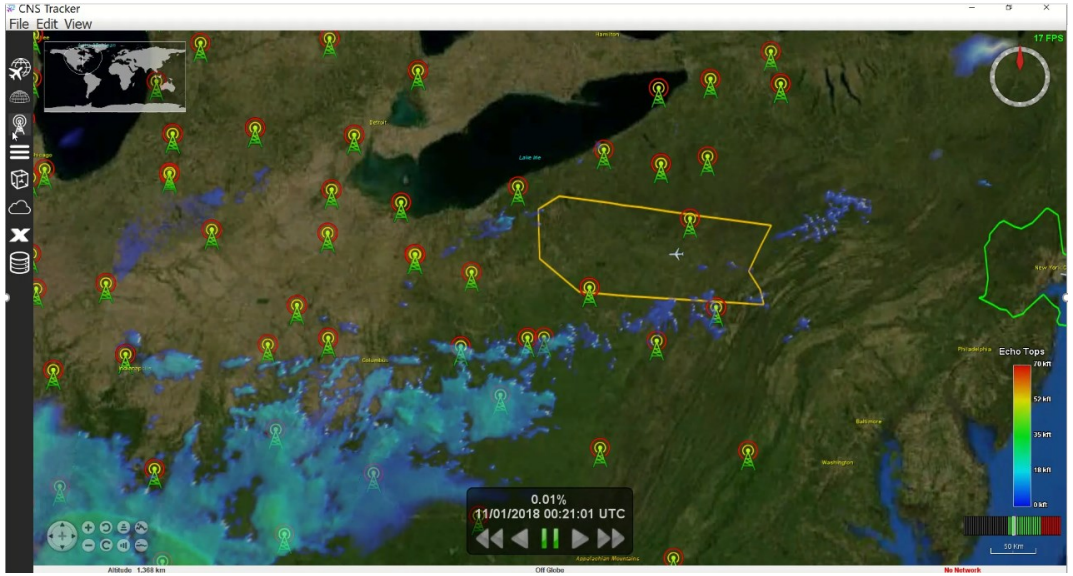


Custom Airspace Builder

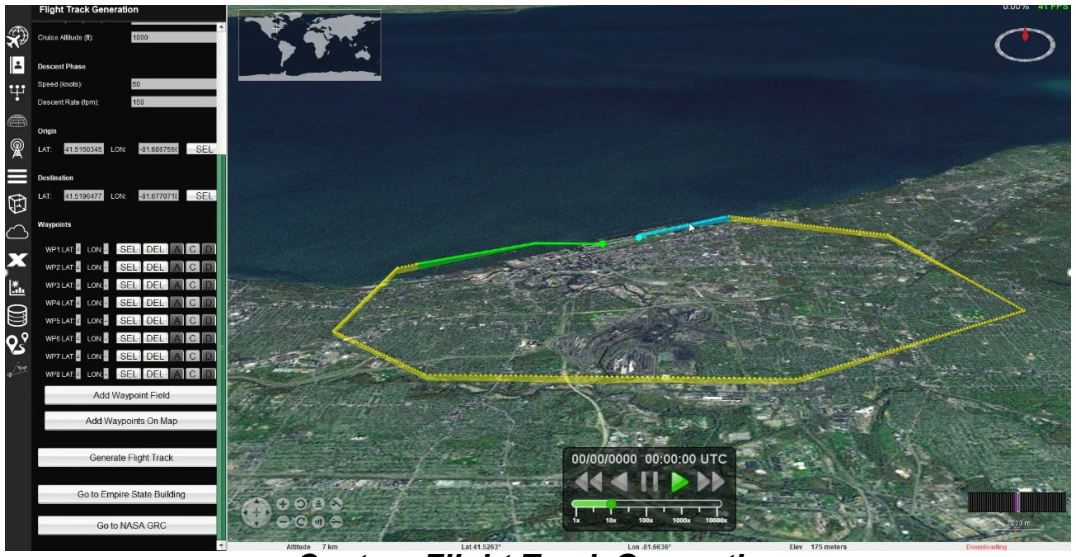
Overview of Toolset Features (2 of 3)

Description of features and capabilities of the CNS Advanced Modeling Tool

- **Aircraft Communications Analysis**
  - Link budget analysis and interference evaluation (co-channel and adjacent channel)
  - Line-of-sight evaluation using terrain data and geographic databases (e.g., OpenStreetMap)
  - Antenna radiation patterns and directivity
- **Aircraft 4D Flight Track Generation**
  - Custom flight tracks via graphical user interface
  - Import flight tracks from historical databases, such as Sherlock Data Warehouse
  - Generate flight tracks via external interface with flight simulators (e.g., X-Plane)
  - Import live aircraft tracks from FAA SWIM feed
  - Generate flight tracks from flight plans (in work)



Aircraft Communication Analysis

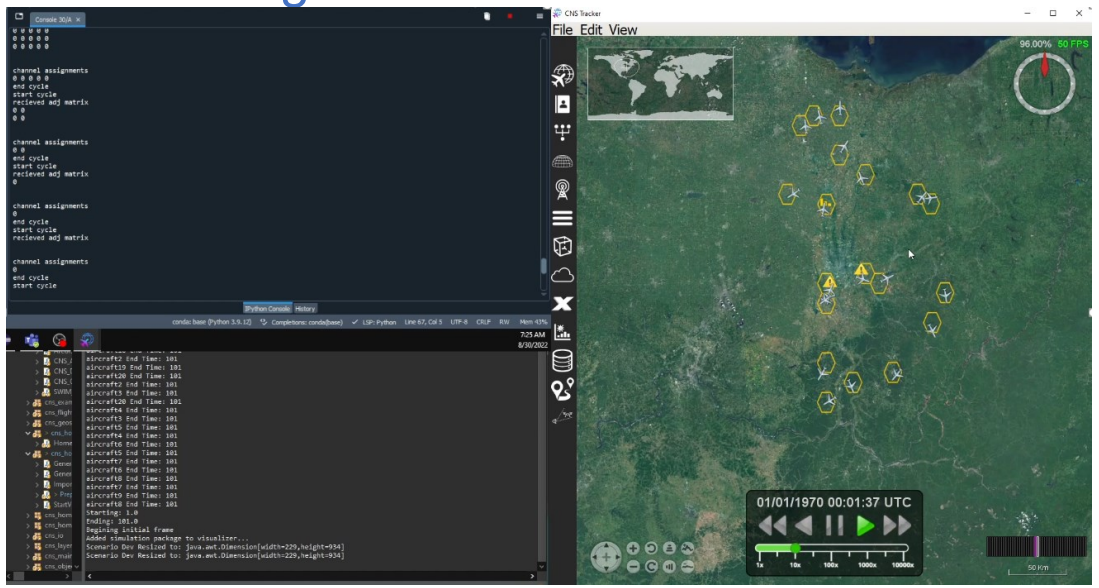


Custom Flight Track Generation

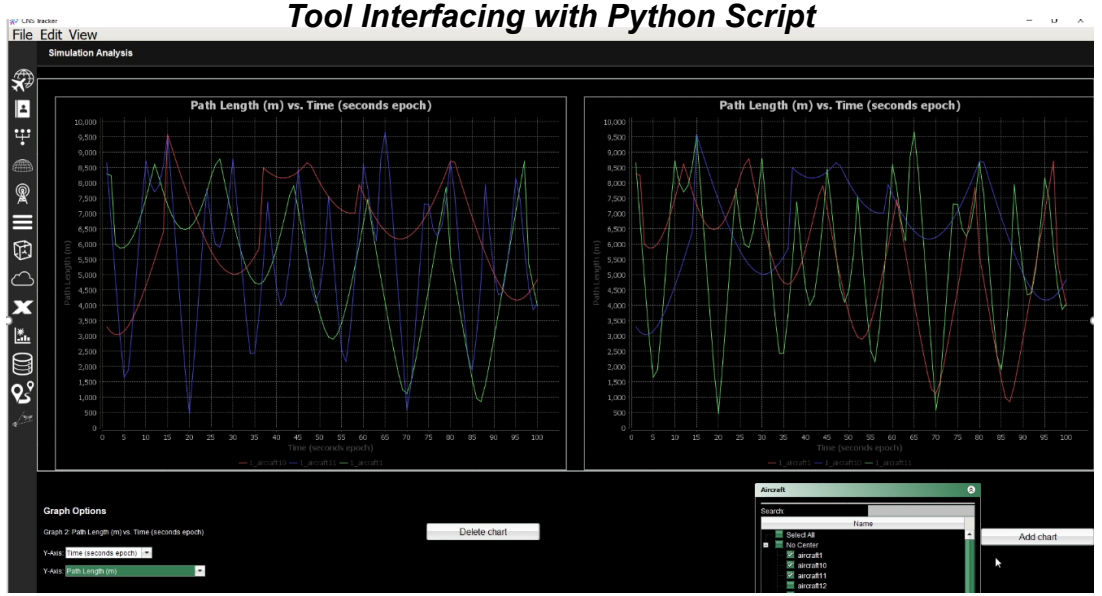
Overview of Toolset Features (3 of 3)

Description of features and capabilities of the CNS Advanced Modeling Tool

- **External Interface for Advanced Algorithms**
  - Socket connection via TCP to external software (e.g., Python) to execute advanced algorithms
  - CNS Tool provides airspace data to Python algorithms
  - Python algorithms determine optimal resource assignments
- **Simulation Results Analysis**
  - Plot data sets from simulation results
  - Display multiple plots
  - Examine individual aircraft results within the tool and compare to other aircraft
  - Analyze potential failing configurations



Tool Interfacing with Python Script

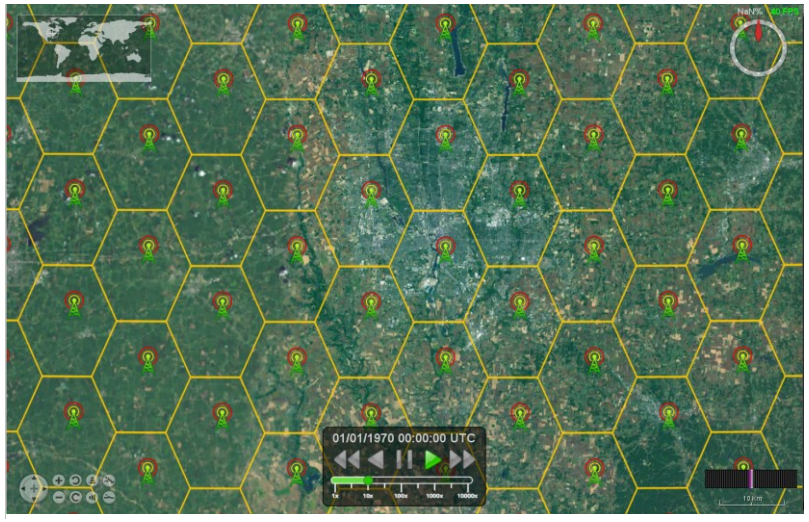


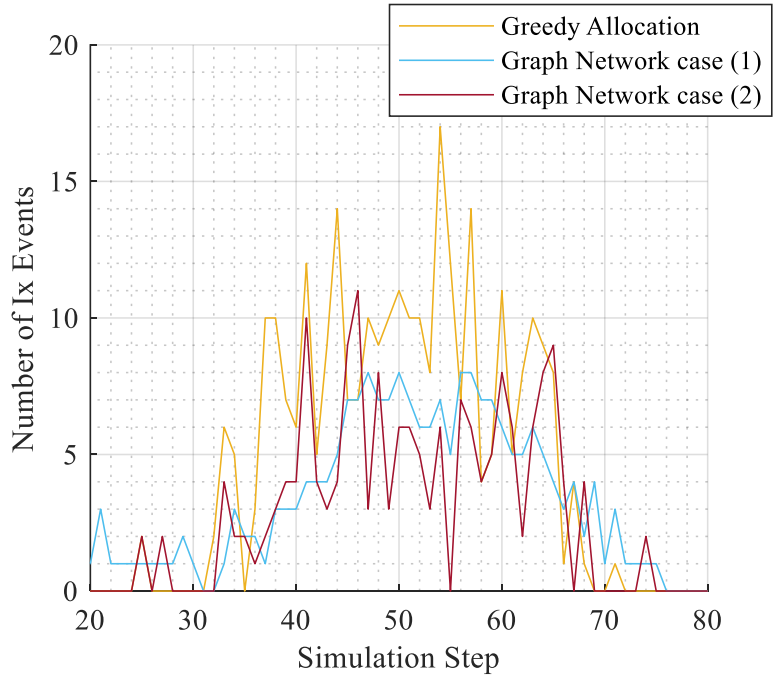
Simulation Results Analysis

Application of Toolset

Evaluation of spectrum allocation methods using the modeling and simulation tool

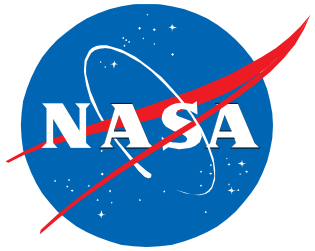
- **Simulation parameters:**
  - Airspace volumes and aircraft tracks
  - Communications link parameters (e.g., power and gain)
  - Number of available communication channels (e.g., 10, 20, ... 60)
- **Performance Examination:**
  - Dynamic resource allocation (i.e., channel assignment) via external Python algorithms
  - Resource allocation methods:
    - Greedy: unoptimized, i.e., first come, first serve
    - Graph neural networks
  - Performance metrics:
    - Number of interference events: D/U ratio < 14 dB
    - Number of channels utilized





Conclusions and Next Steps

- **Need to address spectrum depletion in aviation**
  - Investigate new approaches for dynamic spectrum management
  - Develop advanced algorithms to improve spectrum utilization efficiency
  - Evaluate performance of new methods via custom modeling and simulation tool
- **Next steps**
  - Continue to refine and enhance the functionality of the CNS Advanced Modeling Tool
  - Introduce new capabilities for advanced CNS performance analysis
  - Define use cases relevant for future concepts such as UAM/AAM
  - Continue to refine dynamic resource allocation algorithms
  - Define performance metrics for comparison of methods
  - Evaluate performance of learning and non-learning-based methods for defined use cases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