Integrated Command and Control Toolset for Global Aerospace Operations

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INTEGRATED COMMAND AND CONTROL TOOLSET FOR GLOBAL AEROSPACE OPERATIONS

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ABSTRACT

Reusable launch vehicles present a series of unique problems in the management of the national and global air space. Commercial and military spaceports that support RLV's will be built inland, forcing vehicles launched from these spaceports to fly over populated areas and through commercial airways to reach orbit. Integrated command and control tools are required to manage these new dynamic spaceways that safely accommodate standard air transportation, RLV's, expendable ELV's, and military SOV's. These tools need to address both the mission planning phase and real time operations associated with these vehicles and assorted mission classes to enable class-specific goals like rapid turnaround for military sorties.

Under a NASA-sponsored phase 2 small business innovation research project, Command and Control Technologies Corp. is building a path finding solution for aerospace traffic management that integrates both RLV operations and conventional aircraft operations. It may also be adapted to military aircraft operations. Major features include:

- Aerospace Mission Planning
- Safety/Risk Planning
- Aerospace Traffic Control

It will also support collaborative operations for the following major stakeholders:

- Aerospace Traffic Management Organization
- Space Carrier Organizations
- Spaceport Organization

The major result of this research is expected to be the translation of real-time RLV and air traffic data acquired from multiple sources into a single, collaborative, environment distributed over standard network architectures that presents a common operating picture for civil and military space operations. This presentation will summarize the research findings to-date and outline the final steps and challenges of creating an integrated command and control infrastructure for future spaceways.

INTRODUCTION

Air traffic is growing worldwide. According to the FAA Office of Aviation Policy and Plans forecasts, the number of aircraft handled by Air Route Traffic Control Centers (ARTCC) will increase from 47 million to 61 million in the next decade.[1] Concurrently, it is foreseen that the next generation of Reusable Launch Vehicles (RLV's) will promote a significant increase in the commercial space transportation industry, taking not only cargo and science to space, but also manned commercial missions. These commercial ventures are expected to far exceed the government/military space industry market share.

Additionally, these new RLV's are expected to be more "aircraft like" in their appearance and operations, yielding faster turnarounds and more standardized operations. The combined growth of traditional aviation activities and commercial RLV airspace usage promotes the need for an Integrated National Airspace System that incorporates the airspace requirements of RLV's, and minimizes the impact of the RLV flight profile on traditional air traffic. This need is being addressed within the FAA and is evidenced by their *Combined Concept:* National Airspace System Concept of Operations, Version 1.0, Rev 0.4a.

BACKGROUND

Traditionally, a space launch's impact on commercial air traffic has not been part of the mission planning analysis. NOTAM (Notice to Airmen) are simply issued to grant exclusive use of Special Use Airspace (SUA) to the space operations and unrelated aircraft are prohibited from entering the airspace. The impact to other NAS users depends on the size of the SUA, the time of day, and the duration that the airspace reservation is in effect.

This preferential treatment stemmed mainly from the fact that the majority of the launches have been government/ "national-priority" missions and launch operations occurred relatively infrequently. Additionally, spaceports have typically been located on the coast and launches have occurred over water near minimum NAS "population". However, with the advent of commercial space traffic competing with commercial air traffic, and the addition of numerous land-locked spaceports, the concept that space transportation operations take precedence over air traffic operations will no longer be appropriate. Fair business practices dictate that policies and tools that ensure equitable air and space traffic management decisions are required.

Relative to policy changes, the Federal Aviation Administration (FAA) published their Concept of Operations for Commercial Space Transportation in the National Airspace System, Version 1.1, dated January 14, 2000[2]. This document highlights the requirement for a "re-examination of current technology and methodology used for managing the National Airspace System (NAS)." The FAA has embraced the future in this document and called to action the stakeholders, stating:

> *"… this Concept of Operations for Commercial Space Transportation in the NAS in 2005 has been developed by the FAA Administrator for Commercial Space Transportation (AST) in anticipation of the evolution of a NAS environment in the 21st century that fully integrates commercial space operations."*[3]

The *Concept of Operations for an Integrated National Airspace Control System* reflects the general approach outlined in both the AST Concept of Operations, and the FAA *Combined Concept;* however, it mainly focuses on a path-finding solution to an integrated aerospace traffic management system via the development of an Integrated National Aerospace Control Tool Set (INACTS). The major functions that will be performed using INACTS are highlighted in Figure 1.

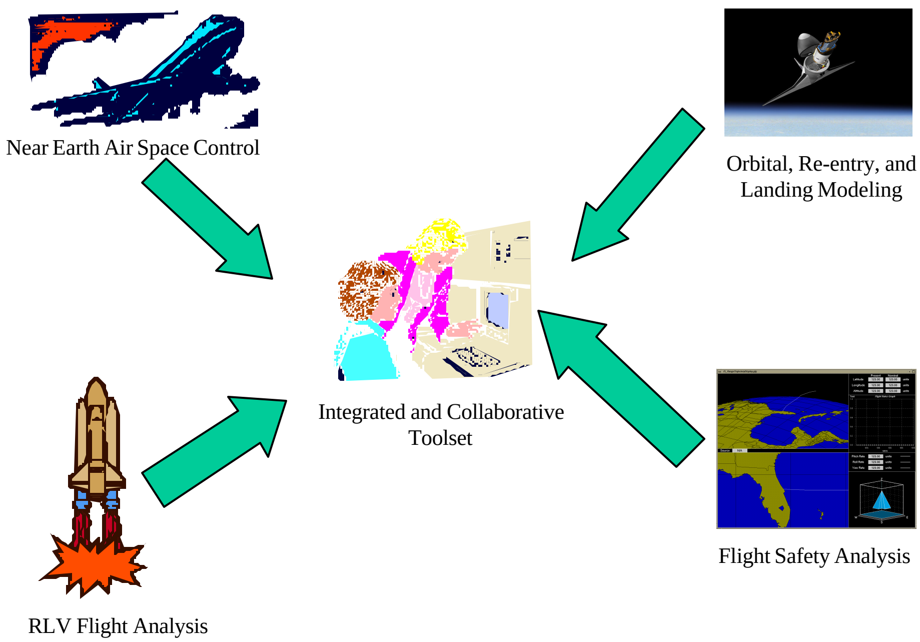

Figure 1. INACTS Functions

The emerging technologies outlined by FAA/AST to integrate space and aviation operations in the NAS that will be addressed by INACTS include:

- Conflict Prediction/Resolution
- Dynamic Airspace Reconfiguration
- Trajectory Modeling
- Simulation
- Information Exchange/CDM Tools
- Decision Support Systems
- System Performance Analysis Tools

OPERATIONS CONCEPT OVERVIEW

Two organizations are the primary users of INACTS. The Air Traffic Management Organization (ATMO) performs the regulatory function of reviewing and approving transition of space vehicles through the controlled airspace. The Space Carrier Organization (SCO), who operates space vehicles for commercial payload customers, plan and execute missions. There are also several secondary users of INACTS. The definition of users presented here is slightly different than the view presented in the Concept of Operations for INACTS. The terminology was refined to match the AST documentation where appropriate. Other minor changes were made to make the user's titles more consistent. Figure 2 depicts the primary INACTS users and the organization they are associated with. They are described in more detail in the following sections.

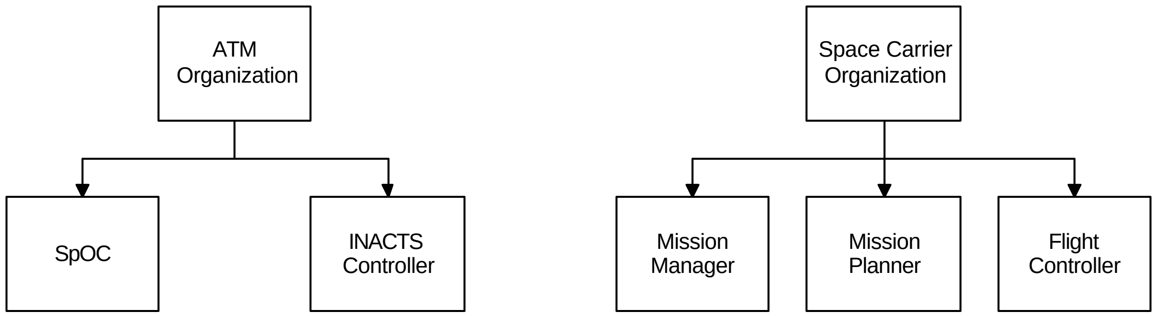

Figure 2. INACTS User Organization Diagram

Air Traffic Management Organization

The ATMO is responsible for air traffic safety. The ATMO also ensures that air traffic flows smoothly and that integration of space traffic into the air traffic system does not adversely affect a significant number of aircraft. The ATMO must strike a balance between the needs of air carriers and space carriers as they compete for the same airspace. The ATMO has roles associated with both planning (review/approval) and execution (traffic management) of space carrier missions.

Space Operations Coordinator

The Space Operations Coordinator (SpOC) helps facilitate the planning process of space missions. The SpOC collaborates with the Mission Planner to define the STC for a particular mission. The SpOC analyzes proposed missions to determine their impact on air-traffic. This is accomplished through the use of a historic air traffic database. By analyzing how a proposed mission would affect historic air traffic, predictions on how it may affect future air traffic could be extrapolated. The SpOC also analyzes proposed missions to determine if they conflict with one another. The SpOC is ultimately responsible for approving or declining the STC associated with a mission based upon the results of the analysis.

INACTS Controller

The INACTS Controller manages air-traffic during mission execution. The INACTS Controller is a specially trained ATC who manages the separation between a defined STC and air traffic. The INACTS Controller communicates with the Flight Controller and ensures that all aircraft are clear of the STC. The INACTS Controller also tries to minimize the effects of the restricted airspace on aircraft. During an abort situation, the INACTS Controller actively manipulates air-traffic to provide for an emergency landing of a space vehicle.

Space Carrier Organization

The SCO parallels today's air carriers. SCO's operate space vehicles for commercial payload customers on a regular/routine schedule. They are familiar with the procedures and policies necessary to plan a mission and transition a space vehicle through controlled air space.

The different roles within the SCO are described below. The three primary role players are Mission Manager, Mission Planner, and Flight Controller.

Mission Manager

Each mission has a manager who oversees the entire mission. The Mission Manager is responsible for ensuring that all phases of the mission complete successfully. The Mission Manager organizes the mission and interacts with the Mission Planner, the Flight Controller, the ATMO, and the payload customer. Ultimately, responsibility of the mission falls to the Mission Manager.

Mission Planner

The Mission Planner is a member of the SCO who is responsible for the planning portions of a mission. The Mission Planner interacts with the Mission Manager, the payload customer, and the SpOC to ensure that a mission is planned correctly. The Mission Planner enters mission parameters into INACTS, possibly performs some preliminary traffic impact estimates, and submits a mission for approval. The Mission Planner represents the interests of the SCO and desires to obtain an approved mission for the lowest cost.

Flight Controller

The Flight Controller is a member of the SCO who is responsible for the actual flight of the mission. The Flight Controller may be an operator on the ground or may be a pilot of a manned RLV. In some cases, the Flight Controller may be represented by multiple individuals. In the case of a piloted vehicle, the Flight Controller actually flies a vehicle. In the case of a ground controller, the Flight Controller may fly the vehicle or may simply monitor the vehicles flight. The Flight Controller interacts with the SCO through the INACTS Controller. The Flight Controller relays updated launch status information to the INACTS Controller.

Secondary Users

INACTS is will not only assist space mission planning and operations, but also be used as a research tool for the next generation air/space traffic control system. INACTS will help facilitate this by providing access to a stored database of missions, including all pertinent mission information. Researchers will be able to use this database of information to perform research on air/space traffic integration. At this time researchers are considered secondary users of INACTS.

SYSTEMS MODES AND STATES

In this section, the different modes and states associated with an INACTS mission are described. The three primary groups of states are first discussed. Figure 3 presents a graphical view of the INACTS timeline. A state diagram is then presented and each state is discussed in more detail.

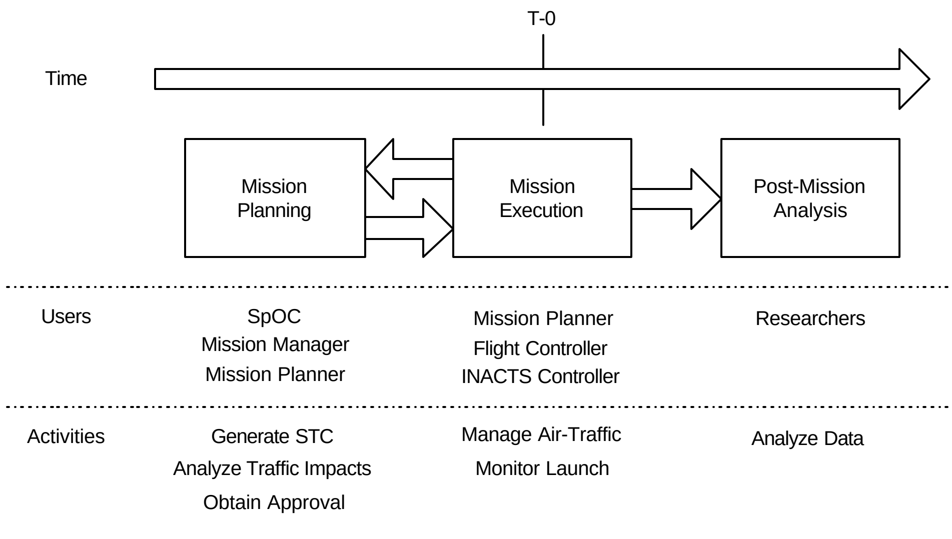

Figure 3. INACTS Timeline

Mission Planning

Mission planning is the time period from mission conception till the mission is declared ready for execution. The goal of mission planning is to produce a valid STC, which ensures public safety, allows the SCO to complete their mission, and minimizes disruption to air-traffic. Mission planning is accomplished through collaboration between the SpOC and the Mission Planner. For a mission to move from mission planning to mission execution, the SpOC must approve the mission.

Each mission may consist of multiple phases. A mission phase is a portion of the mission that needs to be completed before the mission can be completed. A mission may be composed of one or more phases. All of the phases may not execute before a mission is declared complete. Each mission phase has a single trajectory. For example, an ELV may have three mission phases, each representing a vertical ascent, on different days. Each of these phases is a separate launch window. Only one of these phases needs to be completed for the mission to be declared complete. However, each trajectory (and thus each phase) must be analyzed individually. The historic air-traffic analysis may return vastly different results depending upon the day of the week and time of the year. In another example, an RLV may have three mission phases for launch (representing different launch windows) and three mission phases for landing (representing different landing windows). One launch phase and one landing phase must complete for the mission to be declared completed.

Mission Execution

Mission execution is the time period from when a mission phase is declared ready until the mission phase is completed or canceled. Mission execution is the operations portion of the INACTS system. Mission execution is accomplished through collaboration between the INACTS Controller and the Flight Controller. The goal of mission execution is to complete a successful, safe mission while minimizing impacts on air-traffic. Once all necessary phases are complete, the mission can be declared completed.

Post-Mission Analysis

Post-mission analysis occurs after a mission is complete and is in the completed or cancelled states. Post-mission analysis allows researchers to examine how a mission effects air-traffic, compare that to the projected effects, and possibly propose changes to improve the accuracy of the prediction models.

TECHNICAL DESCRIPTION

The completed toolset will address the following requirements and functions:

- Analysis of all aspects of RLV flight including the following:
  - Near Earth airspace modeling and prediction of flight hazards presented by flight through commercial air corridors.
  - Orbital airspace management for the prediction and avoidance of collision with orbiting objects.
  - Abort site selection and modeling for all phases of ascent and re-entry.
  - Integrated range safety analysis functions
- Provide a collaborative environment to allow vehicle, payload, and range operators to interactively build and review flight plans and range safety issues.
- Provide the capability to continually update flight plan, orbital debris, and weather databases via the Internet to ensure proper planning data is being used.
- Provide a reporting function that prints analysis of range safety, trajectory, and related planning data in a format acceptable to regulating organizations such as NASA and the FAA.
- Provide a built in function for submitting flight plans for approval via the Internet.
- Build in What-If capabilities for analysis of off-nominal operations.
- Create the capability for the tool to accept real time feeds of vehicle and air traffic positional data to enable flight day support of the mission operation.
- Provide for the import of real time data including launch site and winds aloft data. Provide the overlay of satellite imagery of the air space in question.
- Provide a post mission analysis function to compare actual performance to predicted performance of the launch vehicle and air space model.

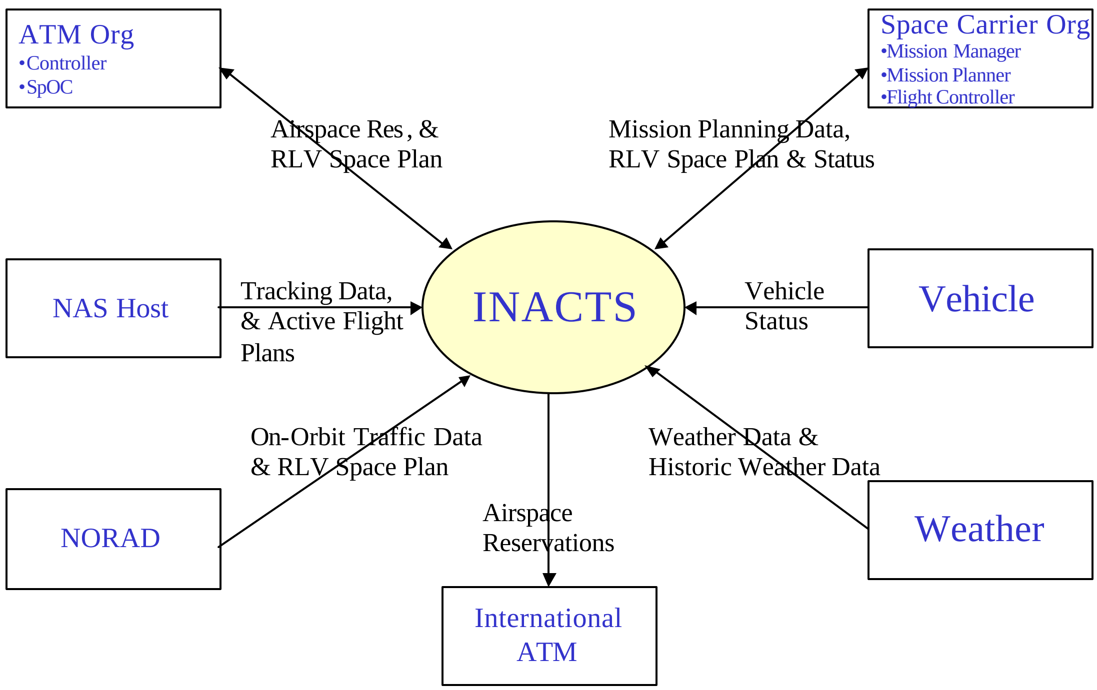

Figure 4. INACTS Context Diagram

The external interfaces that these functions imply are characterized in Figure 4, and Table 1.

External	Interface
Space Carrier - RLV Owner and Mission Manager	▪ Mission Planning Data – The RLV owner and mission manager will provide INACTS with mission planning data. This data will be used to perform mission-planning activities such as launch site selection, abort site selection, safety analysis, etc. ▪ RLV Space Plan – Once the entire mission planning data has been entered, the mission analysis is complete, and the mission plan is finalized, INACTS will generate an RLV Space Plan. The RLV Space Plan will detail all aspects of the vehicles flight, from launch to landing. Special attention will be paid to safety and air-traffic issues. Before a launch can proceed, the proper authorities must approve the RLV Space Plan. INACTS will automatically send the RLV Space Plan to all interested parties.
Space Carrier - Flight Controller	▪ Query Status – The Flight Controller can query INACTS to obtain status information on a variety of topics such as abort site availability, current air traffic, current weather, etc. ▪ Edit Performance Attributes – The Flight Controller will be able to edit the performance attributes used by INACTS to model a vehicle's trajectory during correlated time operations. This will allow the INACTS modeling engine to dynamically adapt to unforeseen circumstances such as physical damage to a vehicle. ▪ Resource Status – INACTS will provide to the Flight Controller status information on a variety of topics such as abort site availability, current weather, etc. ▪ RLVATM Data – INACTS will also be able to provide air traffic management data to the flight controller.
ATM - NATM Interfaces	▪ Proposed RLV Space Plan – Once the RLV mission manager completes a space plan, it is submitted for approval. The proposed RLV Space Plan is reviewed for impact on air traffic and either approved or denied. ▪ Airspace Reservations – INACTS will provide NATM with specific airspace reservation requests based upon approved RLV Space Plans. These airspace reservations will be automatically generated during mission analysis based upon the flight trajectories of the RLV vehicles. ▪ Approval – NATM will provide approval for proposed RLV Space Plans.

External	Interface
	▪ Constraints
ATM - RAPCON	▪ RAPCON Tracking Vector ▪ Resource Status ▪ Airspace Reservation ▪ RLV Space Plan
ATM - CATM	▪ Approved RLV Space Plan ▪ Airspace Reservation ▪ Airspace Sectorization
ATM - SATC	▪ Tracking Data – INACTS provides RLV tracking data to SATC. ▪ RLV Space Plan ▪ Airspace Reservations
ATM - FAA Operations Research	▪ System Analysis Reports – These reports are generated during post-mission analysis. These reports are provided to FAA Operations for analysis. The results of this analysis could impact and improve future operations.
NAS Host	▪ NAS Host Aircraft & Track Data – NAS Host provides tracking data for all aircraft currently flying. This data is used by INACTS to predict conflicts between RLV operations and aircraft. ▪ Active Flight Plans – NAS Host provides active flight plans to the INACTS system. This data is used by INACTS to predict possible, future conflicts between RLV operations and planned aircraft operations.
Weather - WMO	▪ Weather Data – INACTS obtains real-time weather data via this interface.
Weather - Air Situation Display	▪ Historical Weather Data – INACTS needs historic weather data during mission analysis. Historic weather data is used to predict the probability of a mission being delayed due to unfavorable weather conditions during a particular season. ▪ ERAU Historical Air Activity – INACTS needs historic air data during mission analysis. Historic air data is used to predict the affect that an RLV mission will have on air traffic. Historic air traffic is used to attempt to minimize the impact that an RLV flight may have on air activity. ▪ RLV Space Plan
Vehicle	▪ Vehicle Status – During correlated time operations, it is necessary for INACTS to receive information from the vehicle control system. The vehicle control system should provide critical, safety related data to INACTS such as position, velocity, etc …
NORAD	▪ On-Orbit Traffic Data (TLES) – INACTS requires the current set of on orbit traffic data to perform COLA. This data will be retrieved from NORAD. ▪ RLV Space Flight Plan
NOTAM	▪ Airport Status – INACTS will receive NOTAM updates and update its internal database appropriately to reflect the status of airports/spaceports. This will be used during mission-planning and correlated-time operations when choosing landing and abort sites.
TRACON	▪ Aircraft Track Data – TRACON provides INACTS with aircraft track data, which can be integrated onto its display and used to perform conflict detection. ▪ Surveillance
Other Tracking	▪ Other Tracking Data – INACTS has the ability to accept generic tracking data from other sources and integrate this data into its displays and conflict detection routines.
International ATM	▪ Airspace Reservations – INACTS will generate airspace reservations for the international community from the RLV Space Plan.

Table 1. INACTS External Interfaces

The major segments of INACTS are organized as follows and is depicted in Figure 5:

- Aerospace Mission Planner - Provides visual and analytical planning tools for integrating space flight missions in to the NAS.
- Safety Planner – Provides the tools necessary to perform risk analysis, conjunction on launch assessment (COLA) and vehicle licensing.
- Spaceport Planner – Supports the planning process by providing spaceport resource scheduling for ascent, reentry, and abort scenarios. The spaceport also provides support in establishing instrumentation coverage via the instrumentation planner.
- Simulation – Provides time-correlated models that support both mission planning as well as training and demonstration in mission execution mode.
- Real-Time Gateway – Serves as the real-time communication bridge between the various end-items involved in mission execution.
- Mission Execution – Provides decision support functions for the various role players during space flight operations.
- Communications – Peer-to-peer and client-server middle ware that supports transport of semi-static and dynamic mission data across the role players.

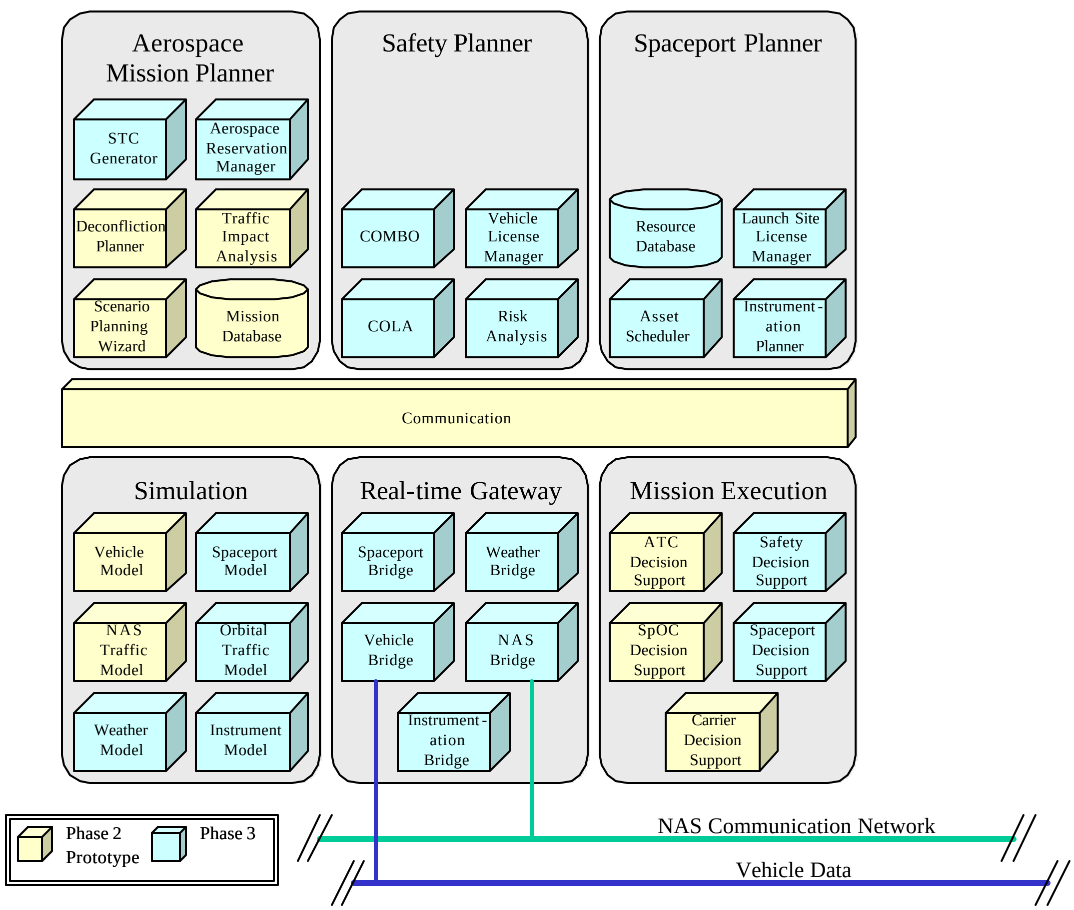

Figure 5. INACTS Functional Architecture

Prototype Research and Development

A large part of the Phase 2 research and development activities have focused on Aerospace Mission Planning and NAS integration. The prototyping work to date has produced a working Aerospace Mission Planner that demonstrates some of the key features of a future integrated aerospace management system. In addition to creating a working prototype a few important artifacts have been produced along the way, such as: Concept of Operations, System Requirements Specification, and Architecture Design.

The prototype includes a planning wizard that automates the creation of missions, phases (launch, reentry, and landing) and associated profiles (Window #1, Window #2, etc.) and abort scenarios. Profiles can be created from scratch or loaded from other modeling tools. We have successfully used trajectory-modeling tools such as Ascent™ from Autometric Corporation that includes a database of current launch vehicles models that can be used to calculate nominal trajectories and instantaneous impact point profiles. Future enhancements will included an integrated trajectory-modeling environment. The planning wizard also assists the INACTS mission planner in creation of the associated Space Transition Corridor (STC).

The mission database is the central repository for all the planning data created using the mission-planning wizard and/or generated from Safety Planning activities (3σ dispersion and risk analysis). Created as an open repository, the mission database stores the mission geometry for analysis and refinement or comparison with other missions.

A key step in determining a space mission plan is evaluating the NAS impact. A prototype Traffic Impact Analysis algorithm has been developed which provides the ability to assess degree of NAS impact for the various mission profile options based on analysis of historical air traffic patterns. This traffic analysis algorithm utilizes the Historical Air Traffic Database, compiled by Embry Riddle Aeronautics University. Queries of prospective missions profiles (STC volumes, date, time, duration, and location) are evaluated against the historical average air traffic pattern for equivalent dates, days of the week, and times. The query produces a net cost (Cost is based on expected rerouted flight miles) impact of the prospective operations. It also provides other metrics and the impacted flight plans for further analysis inside of INACTS.

Once a mission profile has been selected we use a deconfliction planner to reroute flights to avoid the STC. INACTS currently uses a STC conflict resolution algorithm that optionally calculates new paths for conflicting flights to minimize heading changes or net flight path length required to avoid the STC. The algorithm is part of the Future ATM Concept Evaluation Tool (FACET)[4] created by NASA Ames Research Center, and has been integrated as an embedded algorithm inside of INACTS.

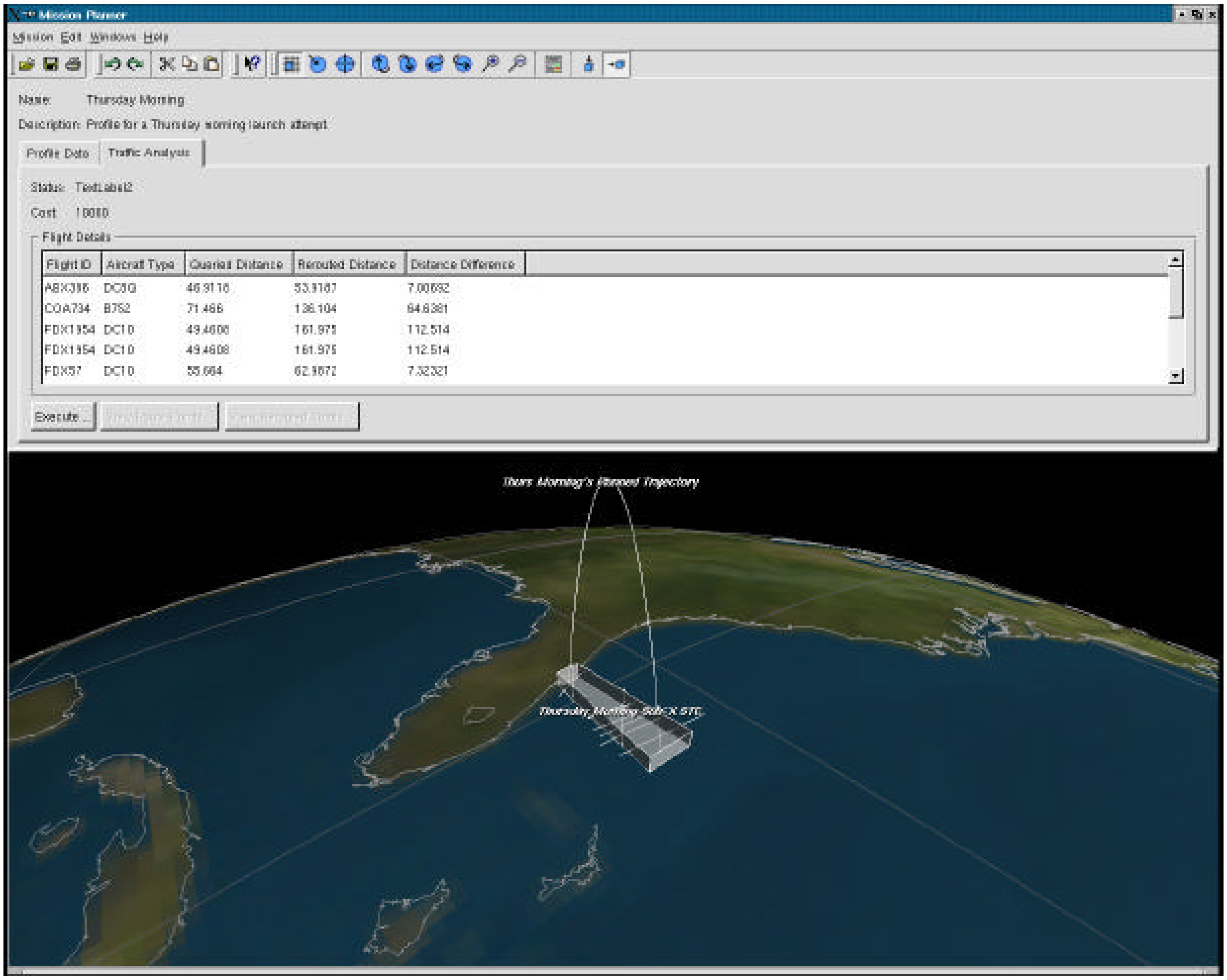

Figure 6. Aerospace Planner Conflict Detection Analysis

Another key part of the prototype has been the creation of a general-purpose visualization environment that allows a planner to dynamically interact with the various mission models and characteristics. INACTS provides a set of dynamic features that allow an operator to render 4D geospatial information including:

- Airspace & Near Earth Geometry
- Geographic Features
- Aircraft & Spacecraft
- Political Maps
- Sector/Center Boundaries
- SUA's
- Flight Plans & Airways
- Information Overlays.

Figure 6 shows an example visualization of a conflict analysis performed for a sub-orbital flight from Canaveral Air Force Station in Central Florida. Figure 7 shows the same mission profile with the deconflicted flight plans.

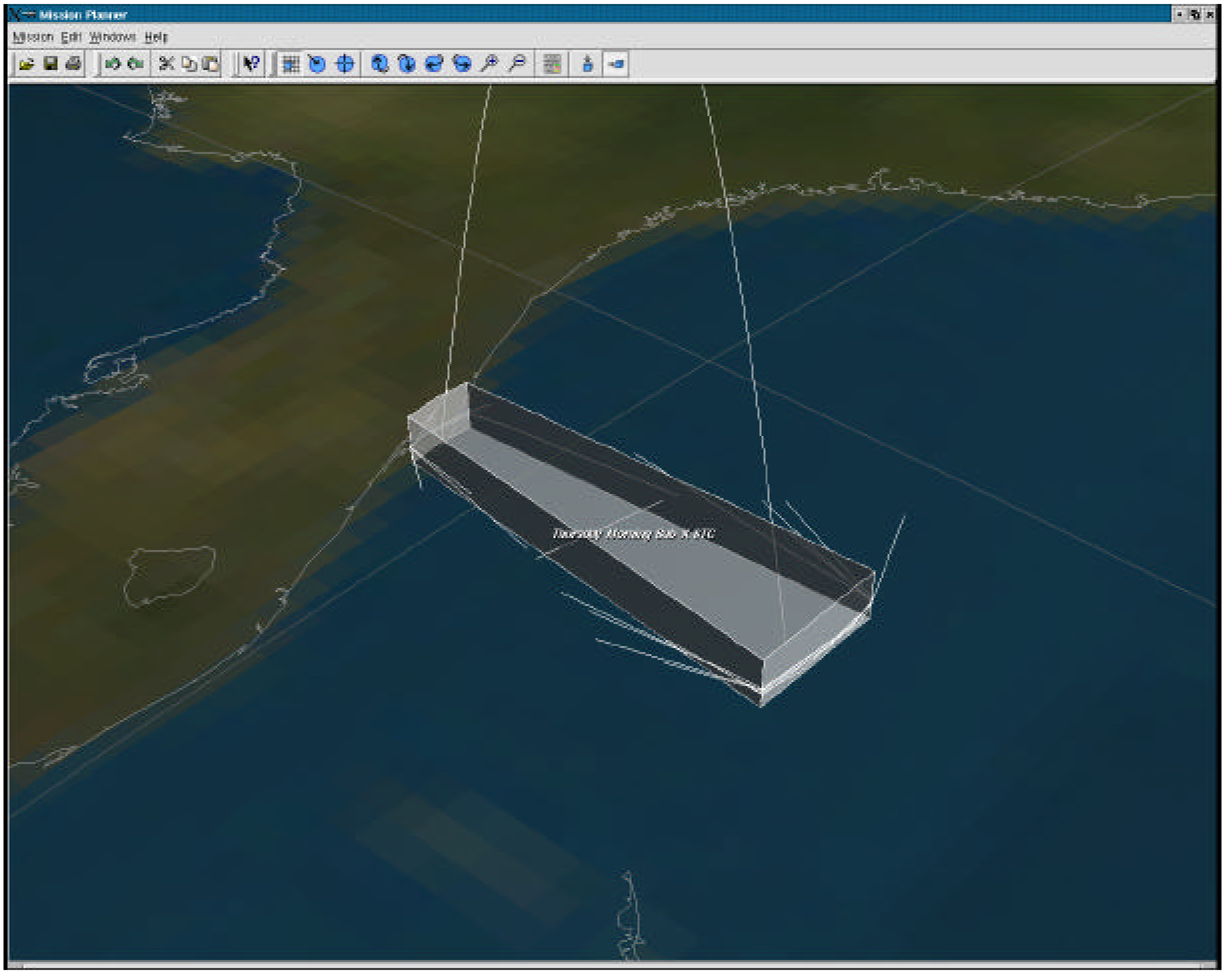

Figure 7. Aerospace Planner Deconfliction

Time correlated modeling features are currently being added to INACTS that will allow planned missions to be simulated within near Earth airspace. The modeling features will allow a mission to be interacted with for refinement of mission characteristics and space controller training. More importantly the simulation environment will allow the integration of future models, such as weather, orbiting traffic, and instrumentation that will further enhance the fidelity of the environmental modeling.

Mission execution will provide a common operating view of the mission to all role players. The plan for INACTS is that the underlying general-purpose visualization tools can be readily adapted to support the various role players. In fact, in many cases the very same visuals presented to mission planners are relevant to the mission controllers with some augmentation for real-time collaboration and situational awareness. Figure 8 shows some examples of the various decision support views to be supported by INACTS.

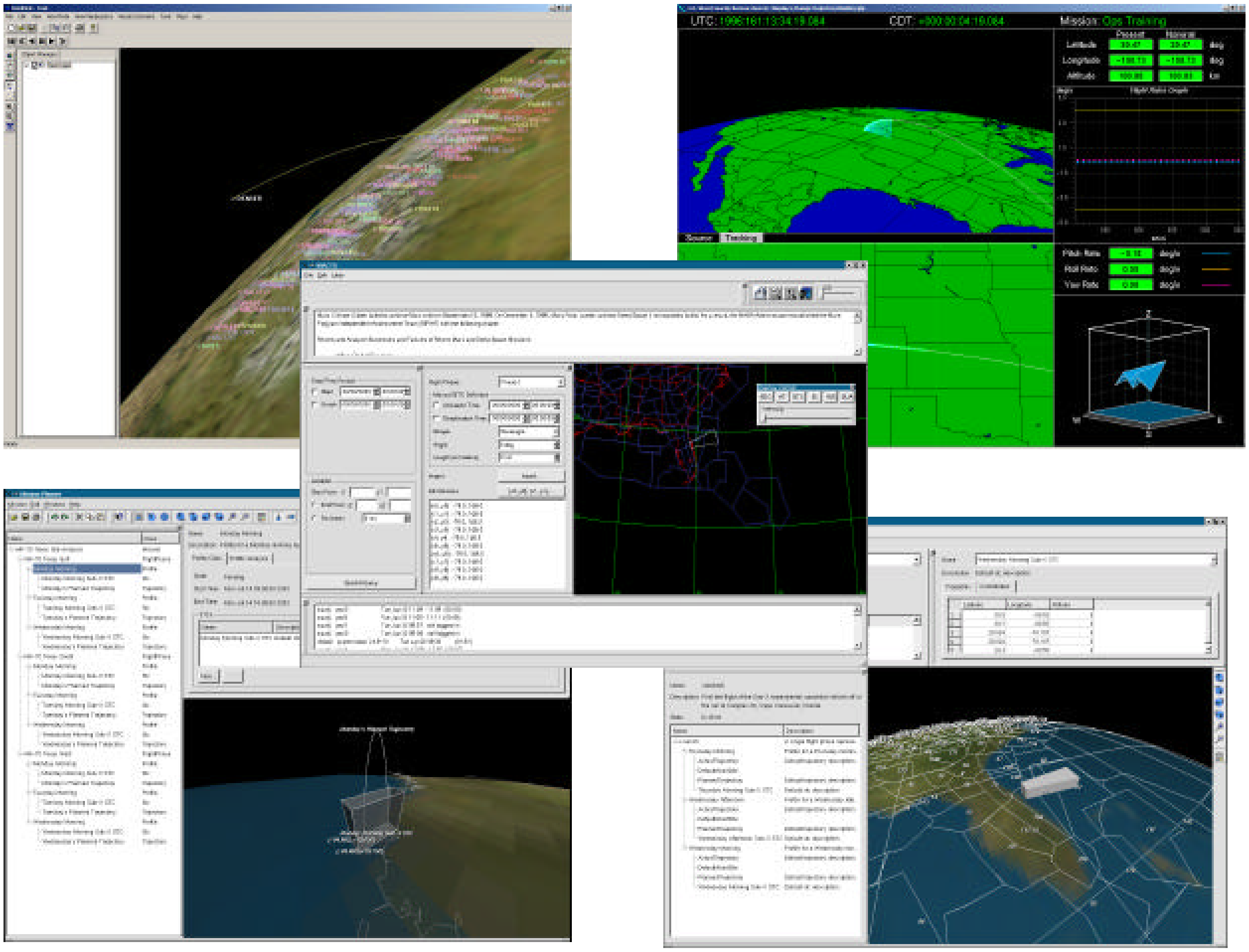

Figure 8. Mission Execution Decision Support Display Examples

CONCLUSIONS

Investigation in to approaches to creating an Integrated National Aerospace Control Toolset have shown it is possible to reduce the impact of space flight on the National Airspace through the use of traffic impact analysis and flight planning tools that fairly consider the needs and constraints of airspace users when planning space flight missions. Just as important, INACTS research has shown the potential for integrating many aspects of space operations across a common operating picture environment where situational awareness is shared and available to operators where needed. Collaboration infrastructure makes it possible for distributed personnel to share a common view of the mission plan and live operation.

Also, during INACTS research it has become increasingly clear that there are many advantages to breaking down operational barriers between mission planning and mission execution in order to reduce mission turnaround time. In fact, it seems increasingly feasible that mission-planning activities can be performed in near real-time, allowing mission plans to be generated and or modified on the fly. However, some challenges remain in the areas of real-time risk analysis. Tradition E_c calculations may be overly cumbersome for real-time operations. Additional research is needed in to new high-level risk assessment approaches that enable rapid, first-order analysis.

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[4] Integration of Traffic Flow Management Decisions, Sridhar, Chatterji, Grabbe, Sheth, AIAA, 2002

BIOGRAPHY

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Mr. Davis has over 15 years of system engineering and software development experience in the space industry. As Chief Technology Officer at Command and Control Technologies Corporation, he is widely recognized as a technology innovator in the field of launch and payload processing software. He has designed and managed the development of dozens of revolutionary space software systems that helped streamline Space Shuttle, International Space Station, and experimental launch vehicle operations.

His background includes space system operations, project management, systems engineering, and software development management for dozens of automated control and data systems. Mr. Davis led development of the real time data system for the Delta Clipper rocket, the first domestic reusable launch vehicle flown since the Space Shuttle. He was the key system architect for the payload processing system currently used for most Space Shuttle missions and was called upon to redesign the primary launch preparation system for NASA's International Space Station when the original design contractor could not meet requirements within budget. Mr. Davis possesses an M.S. degree in Computer Science from the Florida Institute of Technology.