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A Common Communications, Navigation & Surveillance Infrastructure for Accommodating Space Vehicles in the Next Generation Air Transportation System

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Suborbital space flight and space tourism are new potential markets that could significantly impact the National Airspace System (NAS). Numerous private companies are developing space flight capabilities to capture a piece of an emerging commercial space transportation market. These entrepreneurs share a common vision that sees commercial space flight as a profitable venture. Additionally, U.S. space exploration policy and national defense will impose significant additional demands on the NAS. Air traffic service providers must allow all users fair access to limited airspace, while ensuring that the highest levels of safety, security, and efficiency are maintained. The FAA's Next Generation Air Transportation System (NextGen) will need to accommodate spacecraft transitioning to and from space through the NAS. To accomplish this, space and air traffic operations will need to be seamlessly integrated under some common communications, navigation and surveillance (CNS) infrastructure. As part of NextGen, the FAA has been developing the Automatic Dependent Surveillance Broadcast (ADS-B) which utilizes the Global Positioning System (GPS) to track and separate aircraft. Another key component of NextGen, System-Wide Information Management/ Network Enabled Operations (SWIM/NEO), is an open architecture network that will provide NAS data to various customers, system tools and applications. NASA and DoD are currently developing a space-based range (SBR) concept that also utilizes GPS, communications satellites and other CNS assets. The future SBR will have very similar utility for space operations as ADS-B and SWIM has for air traffic. Perhaps the FAA, NASA, and DoD should consider developing a common space-based CNS infrastructure to support both aviation and space transportation operations. This paper suggests specific areas of research for developing a CNS infrastructure that can accommodate spacecraft and other new types of vehicles as an integrated part of NextGen.

I. Introduction

The demand for the nation's airspace is projected to rise sharply over the next 25 years, due, in part, to the emerging commercial space transportation industry. Growth in this industry, coupled with an expected doubling of air traffic operations over the next 10 years, will require expanding the current National Airspace System (NAS) services and capabilities to meet this demand. From an air traffic perspective, space and aviation operations must be seamlessly integrated. To achieve that goal, space-based communications, navigation, surveillance (CNS) technologies must be leveraged as part of the Next Generation Air Transportation System (NextGen).

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This paper describes how Automatic Dependent Surveillance – Broadcast (ADS-B), the System-Wide Information Management/Network-Enabled Operation (SWIM/NEO), and mobile/satellite communications, which are elements of NextGen, can help achieve the nation's goals in space transportation, as well as safely increasing NAS capacity and operational efficiency. This paper then suggests specific areas of research for developing a future CNS infrastructure that can accommodate spacecraft and other new types of vehicles as an integrated part of NextGen.

II. Background

Suborbital space flight and space tourism are new markets that are expected to significantly impact future NAS operations. In 2004, Paul Allen, co-founder of Microsoft, Burt Rutan, founder of Scaled Composites, and Richard Branson, Virgin Atlantic Airways founder, announced a partnership to operate the world's first commercial space tourism flights. These entrepreneurs share a common vision that sees commercial space flight as a profitable venture. Numerous other private companies are also developing space flight capabilities to capture a piece of an emerging commercial space transportation market. There are new incentives being offered to entice the industry. These include an annual X-Prize Cup, a new America's Space Prize for an orbital reusable launch vehicle (RLV), and Centennial Challenges that are being sponsored by NASA to foster the development of exploration technologies. In addition to NASA's initiatives, DoD will add even greater demands on our limited airspace to meet Responsive Space national defense needs. Air traffic service providers must allow all users fair access to limited airspace, while ensuring that the highest levels of safety, security, and efficiency are maintained.

It is envisioned that daily space launch and reentry flights will occur at "spaceports" throughout the United States and the world. As the number of spaceports (and spaceflights) increase, the existing air traffic infrastructure will be inadequate. Expanded CNS capabilities will be needed to provide air traffic services with situational awareness information to safely separate aircraft and space vehicles operating in a new future NAS domain, which is the Space and Air Traffic Management System (SATMS) concept. Advances in vehicle design, avionics, and air and space traffic management technologies will make frequent commercial space access a reality, and a Spaceflight Management Toolkit (SMT) under development by the FAA, will be needed to help air traffic service providers manage a diverse traffic mix of aircraft and space vehicles operating within extended NAS boundaries. These tools will require interfaces with space mission control centers, range, weather, spacecraft, launch and landing support vehicles, and possibly other data sources to provide strategic planning and real-time situational awareness information.

NextGen is the set of new technologies and operational capabilities being developed by the FAA, NASA, DoD, and other federal agencies to meet these future air transportation challenges. NextGen calls for the harmonization of aircraft equipage and global air transportation by employing uniform standards, procedures, and air and space transportation policies worldwide, to enhance safety and efficiency on a global scale. As part of NextGen, the FAA has been developing Automatic Dependent Surveillance Broadcast (ADS-B) which utilizes the Global Positioning System (GPS) to track and separate aircraft. Another key component of NextGen, SWIM, is an open architecture network that will provide NAS data to various customers and air traffic system tools and applications. Air traffic service providers will need to obtain real-time space vehicle data (i.e., position and state vectors) to support Collaborative Air Traffic Management (CATM), as defined in the FAA's Enterprise Architecture (EA).

NASA and DoD are currently developing a space-based range (SBR) concept that also utilizes GPS, communications satellites and other CNS assets. The future SBR will have very similar utility for space operations as ADS-B and SWIM have for air traffic. Perhaps the FAA, NASA, and DoD should consider developing a common space-based CNS infrastructure to support both aviation and space transportation operations.

As an element of the NAS, SATMS will be expected to accommodate space operations with minimal impact to air traffic operations. SATMS will need to handle several different flight profiles, depending on the space vehicle's flight regime and mission. These profiles could follow typical launch trajectories such as today's multi-stage Atlas and Delta expendable launch vehicles (ELVs), or could utilize an aircraft launch-assist profile like SpaceShipOne. SpaceShipOne was ferried by aircraft to an altitude of approximately 50,000 feet, released to fly a near vertical rocket-powered trajectory for almost 90 seconds, and returned to Earth as a glider.

The SATMS-defined passageway for space vehicles transitioning through controlled airspace is the space transition corridor (STC). The STC provides for dynamically reserved and released airspace that allows space vehicles to transition through the NAS. The size and duration of an STC is based on the performance of the vehicle, demands on surrounding airspace, and safety considerations.

III. Automated Dependent Surveillance-Broadcast

ADS-B can transmit GPS-derived data (time, position, type, speed, and aircraft identification) by means of a broadcast-mode data link to users that are equipped to receive and process the data. In general, ADS-B updates occur every 1-5 seconds, depending on the physical link (e.g., 1090 Mode S ES; Universal Access Transceiver; or VHF Data Link). In addition to providing local air traffic information to the flight deck, track data is transmitted to air traffic controllers on the ground. The FAA anticipates that ADS-B will provide many benefits, including extending the coverage of current ground-based secondary surveillance radar, especially in en route and terminal areas, to increasing air-to-air situational awareness, as well as on airport surfaces to reduce incursions.

There are currently 31 active satellites in the GPS constellation orbiting Earth at an altitude of 20,200 km (12,600 miles) with a 12-hour period. Each GPS satellite has an atomic clock and continually transmits a navigation message that contains the current time. The time-contained messages with other parameters are used to calculate the location of each satellite. GPS signals travel at the speed of light through outer space and slightly slower through the atmosphere. GPS receivers use the signal transmission time between the satellite and the receiver to compute the distance to each satellite. The receiver can then calculate its location.

ADS-B is being developed to meet future aviation requirements. However, space vehicles transitioning to and from space will also be operating in ADS-B serviced airspace. An enhanced version of ADS-B that also meets the navigation and surveillance needs for space vehicles operating within the NAS may be desired. Commercial aircraft typically fly traveling at cruising altitudes between 10,000 – 40,000 ft, and speeds of 200 to 500 mph, and for that case, ADS-B has a maximum accuracy of approximately 7.5 m (25 ft). However, space vehicles' flight profiles are much more extreme. For example, during its return from space, the Shuttle decelerates from roughly 17,000 mph to 215 mph, and descends over 175 miles in altitude as it traverses the 13,000 miles to its landing site. During a typical landing, the Shuttle passes through 60,000 ft altitude (FL600) at supersonic speeds, less than 15 miles and 5 minutes prior to touchdown. How would ADS-B perform under that scenario? NASA is currently conducting research to investigate those and other performance issues associated with tracking space vehicles using GPS and communications satellites. Figure 1 illustrates a possible ADS-B architecture with enhancements for space vehicles.
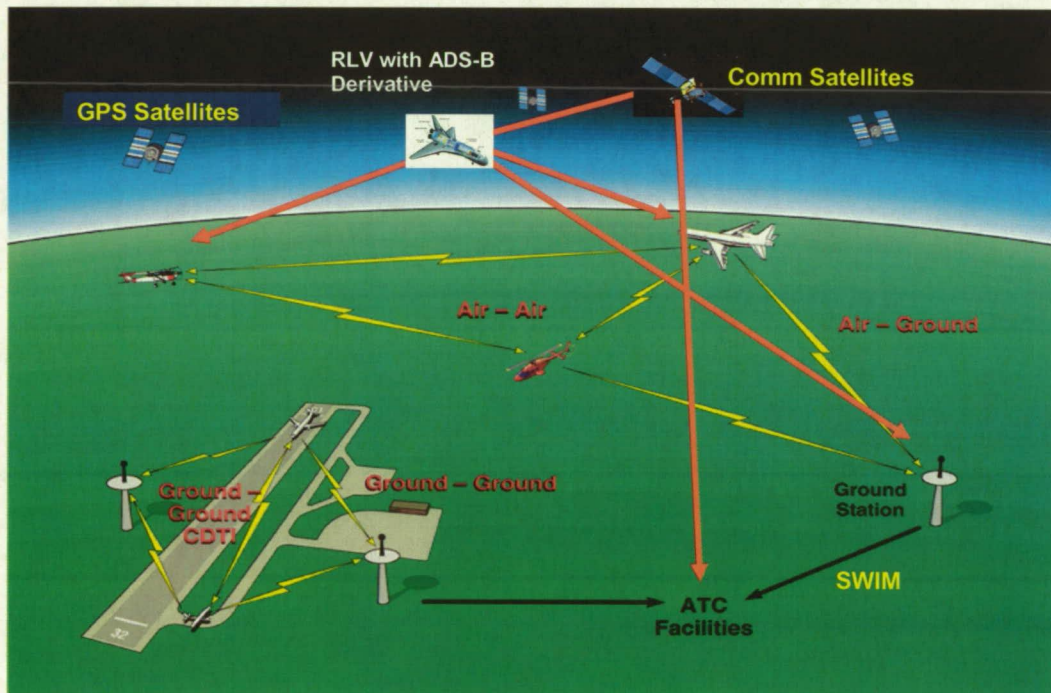

Figure 1: Enhanced ADS-B Concept

IV.   System-Wide Information Management Network & Airborne Communications/Data Link

Track data and other space vehicle state information could be provided to air traffic services via satellite data link and disseminated over the SWIM network. According to the Communications Enterprise Architecture (EA), the FAA is planning to conduct studies to identify needs, requirements, and designs for mobile air/ground communications. The EA roadmap shows digital aeronautical-mobile services being developed in the 2008-2018 timeframe and commercial satellite communications capabilities being developed in the 2016-2022 timeframe. Aeronautical Data Link (ADL), another key component of the EA, is scheduled to be developed in the 2008 to 2012 timeframe, with enhancements to provide expanded services being developed in the 2016 to 2022 timeframe. This migration to a space-based communications architecture offers an opportunity to include new customers, such as space vehicles, in a future communications infrastructure not as add-ons, but as integrated components of NextGen.

The FAA currently requires that operators have two independent methods of tracking their space vehicles during ascent and descent. ADS-B could satisfy one method of tracking, and an onboard Inertial Navigations System (INS) with ADL could serve as the independent backup method. Typically, telemetry data, which includes INS state vectors and other vehicle and payload data, is down-linked from the rocket to the Mission Control Center (MCC) and the range during flight. In the future, communications satellites could provide that link and an interface to SWIM. SWIM will be both an information sharing and an application integration platform which can provide authorized users and applications the ability to securely obtain information in the required format from source(s) at the appropriate time(s), independent of location. Furthermore, SWIM will be compatible with other agency information systems such as the Department of Defense's (DoD's) Global Information Grid (GIG) Enterprise Services and other data sources.

V.   The Future Range

Many U.S. space launch operations occur at the Eastern Range (ER), located at Cape Canaveral Air Force Station (CCAFS), and the Western Range (WR) at Vandenberg Air Force Base (VAFB). These and other ranges currently rely on expensive ground-based radar, telemetry receivers, and flight safety systems. The future range architecture will employ GPS and communications satellites that provide global coverage with greater flexibility and responsiveness. The Air Force and NASA have initiated a policy that by 2010, all launches on the ER and WR will require GPS Metric Tracking. Figure 2 presents a comparison of today's ground-based range with a space-based architecture.
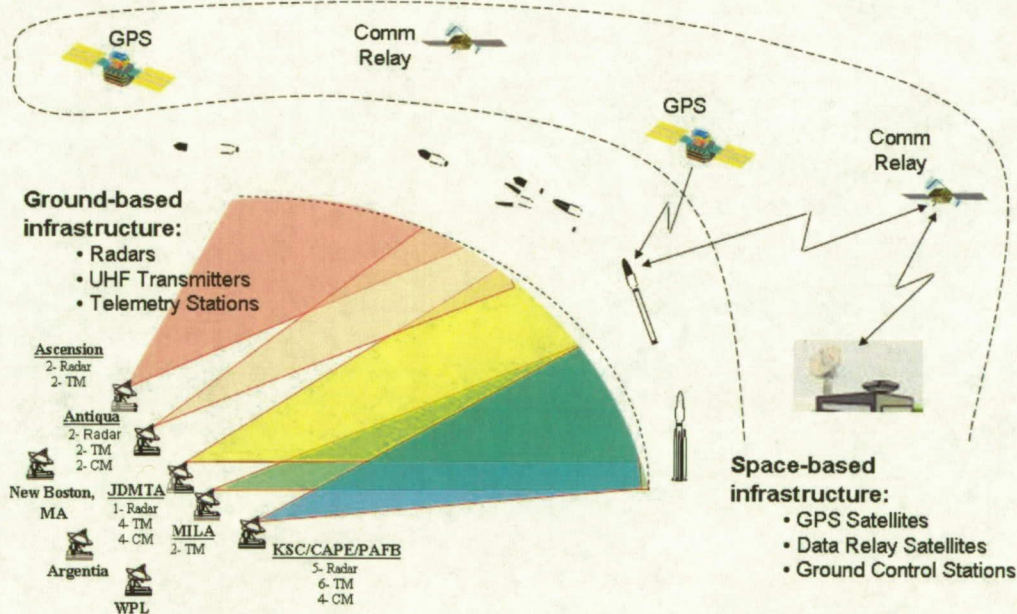

Figure 2: Ground-Based and Space-Based Range Architectures

The NASA Advanced Systems Division at Kennedy Space Center, Florida has been conducting flight experiments for the past seven years to demonstrate the feasibility of using GPS receivers on various aerospace vehicles and sending back the flight data via a satellite system. The satellite systems used were the Iridium Commercial System and the NASA Telemetry and Data Relay Satellite System (TDRSS). The aerospace test vehicles included a slow moving Piper Cub, a P3 Orion, Global flyer, NASA's F15-B test aircraft flying up to supersonic speeds (June-July 2003), and hypersonic sounding rockets (December 2005). The development system had many names over the past several years, but is currently called the Space Telemetry and Range Safety System (STARS). STARS is a proof of concept system to determine if operational costs can be reduced, and if operational flexibility can be increased by using a spaced-based communications architecture to relay telemetry from launch vehicles to the ground and flight termination signals from the ground to the vehicle. This system has to be very reliable and robust. Test flights have shown the STARS concept is viable.

The ability of STARS to maintain a satellite communication link with TDRSS satellites during dynamic aircraft flights was successfully demonstrated during the test flights using the F15 aircraft as well as the sounding rocket. STARS was able to acquire and maintain lock between the high-dynamic vehicles and a satellite-based system. The flight profile of the F15 included straight and level trajectories, rolls, loops, clover-leafs, pull-ups and pull-downs. STARS simultaneously received commands from the ground and transmitted GPS data (latitude, longitude, altitude, and speed) as well as system health back to the ground. The STARS transmission data rate is 10 kbps and uses a JAVAD JNS 100 GPS receiver. STARS maintained the communication links on two different F15 flights of over 10 hours and with speeds up to Mach 1.1 and altitudes in excess of 30,000 feet. STARS also maintained the communication link on a dedicated sounding rocket test flight, with speeds of over 4473 mph (greater than Mach 6.5 at altitudes over 30,000 feet), reaching an altitude of 490,000 feet, or 93 miles above the earth.
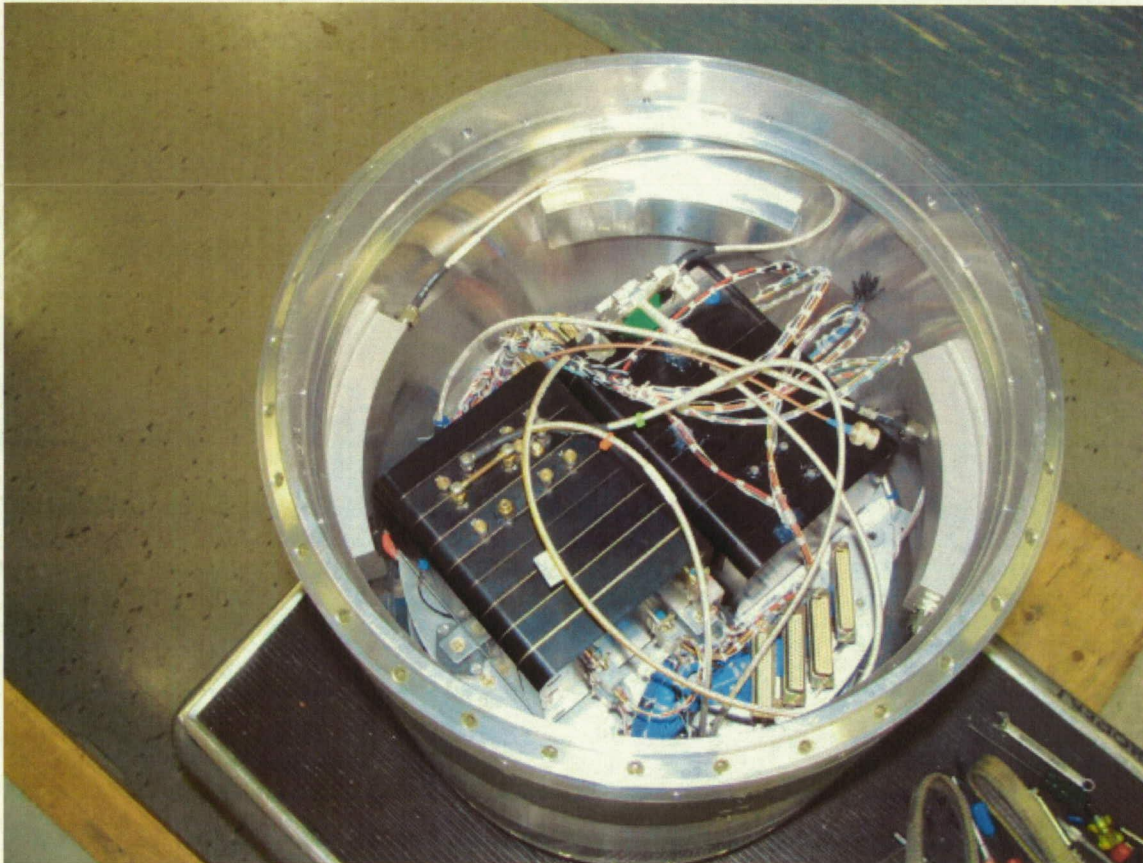

Figure 3: STARS Flight Hardware Enclosed in the Sounding Rocket

Other sounding rocket flight tests were conducted using GPS with different communications configurations and payloads. A configuration which used the commercial Iridium Satellite System was developed and tested. This configuration included a PC-104 computer with an Ashtech G12 GPS receiver and an Iridium Modem. This design could simultaneously receive commands from the ground and send GPS data consisting of latitude, longitude, altitude, speed as well as the health of the system back to the ground using the Iridium Satellite System. The Iridium service has a data rate of 3.3 Kbps and costs about 70 cents a minute. Iridium also has a short burst messaging service that is a lower data rate, 450 bps but is more reliable and cheaper. In comparison, TDRSS typically costs $100 per minute, and has data rates of 100-3000 Kbps, depending on the satellite and channel configuration. The sounding rocket's typical trajectory from Wallops Island, Virginia is shown in Figure 4.
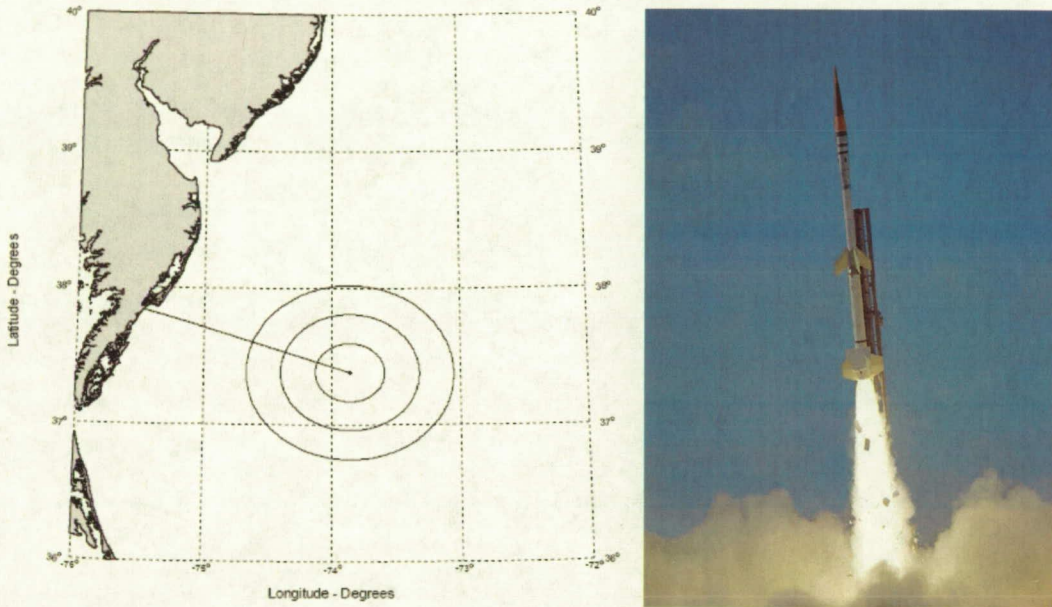
Figure 4: Launch Trajectory for Soundings Rocket (December 2005)

All of the flight experiments that used either the Iridium Satellite System or TDRSS had to meet a 12 dB link margin. Link margin is defined as the additional power over what it would take to close the link between a transmitter and receiver. The added power is needed in a mobile system because the radio frequency energy can fluctuate over time and the added power is need to overcome interference (e.g., atmospheric conditions, rain attenuation, antenna orientation, etc.).

STARS flight test results have shown that the link margin required for a critical system such as STARS can be achieved on high performance aircraft as well as other aerospace vehicles. STARS demonstrated this using TDRSS. However, the Iridium System also had a 12 dB Link Margin on their normal data service and if the short burst messaging service is used the link margin increases to 15 dB, making Iridium even more reliable. Recently, standards and recommended practices were approved by the International Civil Aviation Organization (ICAO) Council to allow use of the Iridium commercial satellite constellation for aircraft communications on transatlantic flights. This expanded use of Iridium for aeronautical services could further support the creation of a common space-based CNS infrastructure. Iridium's 66 low Earth orbiting (LEO) satellites provide complete global coverage, including poles, oceans and airways. Iridium's aeronautical satellite terminals are less costly to install and maintain than those needed for geostationary satellite systems, such as TDRSS.

Other sounding rocket test flights involved evaluating the Autonomous Flight Safety System (AFSS), which is being developed by NASA. The AFSS processors are pre-loaded with flight safety termination rules and vehicle parameters. The AFSS does not use a satellite communications system but it relies on GPS as well as an Inertial Navigation System to determine the position of the vehicle. A prototype AFSS has flown on a sounding rocket out of White Sands, New Mexico and on the SPACE X Falcon One Rocket. All of the AFSS flights were successful in that they tracked the rocket and notified a central computer when the rocket's flight rules were violated.

VI.   Benefits of a Common Space-Based CNS Infrastructure

The FAA, NASA, and DoD are developing space-based CNS capabilities for similar reasons – all three agencies believe that a space-based architecture provides global CNS services at a lower cost than ground-based systems. Below are some of the benefits of developing a common integrated space-based CNS infrastructure for both air traffic and space operations:

It should be cheaper to combine the resources of three agencies to develop space-based CNS services, than if each agency were to independently develop separate systems.

The NextGen plan, which represents the interests of seven federal agencies, calls for the harmonization of avionics and procedures worldwide. An integrated space-based CNS infrastructure is probably the only feasible architecture to accomplish this goal.

SATMS will require integrated CNS services and a situational awareness picture that can provide flight plan, vehicle state, and CATM information for both aircraft and space vehicles operating in the NAS.

A common space-based CNS infrastructure is probably the best method to satisfy an FAA licensing requirement for tracking space vehicles, while also providing data to make national traffic flow management decisions that are equitable for all NAS users, especially as more spaceports become operational in the future.

VII.   Proposed Research

The FAA's research and development program, in part, will address key operational, design, and human performance issues during the evolution of NextGen by identifying challenges, understanding barriers, and developing solutions. Considering the potential benefits listed previously, it could be worthwhile developing a common CNS infrastructure that could be shared by both air and space vehicle operators. The following areas of research would address some of the technical and implementation issues associated with developing a common infrastructure.

Common CNS Architectural Study. For certain flight regimes, there will be different GPS performance and tracking accuracies associated with ADS-B aircraft and space vehicles. There will also be differences in link margins, data message sizes, error rates, protocols, and other communications system characteristics. As a first step, a study that investigates potential CNS architectures and performance requirements should be conducted.

SWIM and Satellite Network Simulations. Based on communications system characteristics and performance parameters identified during ADS-B development, and SBR flight tests conducted by NASA, define test scenarios for air-to-ground communications and SWIM configurations to evaluate integrated air and space traffic operations in a simulated environment. A primary goal of this research would be to identify NextGen CNS requirements needed for supporting both space and air traffic operations, and to mitigate technical, acquisition, and implementation risks.

Human-in-the-loop Studies. Investigate human factors considerations, such as graphic user interface (GUI) design, situational awareness, data link message sets, CATM decision support tool functionality, flight deck vs. ground-based responsibilities, failure mode and recovery procedures, and conduct safety assessments in a simulated environment. Operational issues associated with transitioning to the SATMS concept for NextGen would be evaluated.

Flight Demonstrations. Demonstrate integrated CNS architectures with airline and space vehicle flight tests.

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Problem Statement

The Next Generation Air Transportation System (NextGen) will need to accommodate spacecraft transitioning to and from space through the National Airspace System (NAS).

To accomplish this, space and air traffic operations will need to be seamlessly integrated under a common communications, navigation and surveillance (CNS) infrastructure.

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NextGen

- NextGen is the set of new technologies and operational capabilities being developed by the FAA, NASA, DoD, and other agencies from the Joint Planning and Development Office (see http://www.jpdo.gov/).

- NextGen calls for the harmonization of aircraft equipage and global air transportation by employing uniform standards, procedures, and air and space transportation policies worldwide to enhance safety and efficiency on a global scale.

- Automatic Dependent Surveillance Broadcast (ADS-B) utilizes the Global Positioning System (GPS) to track and separate aircraft.

- The inter-faciltity System-Wide Information Management (SWIM) Network is an open architecture network that will provide air traffic data to various customers, system tools and applications.

- Space-based air/ground communications too be supported by Aeronautical Data Link (ADL).

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Space & Air Traffic Management System (SATMS)

The National Airspace System (NAS) and NextGen must accommodate future space operations with fair access to all users while maintaining the highest possible levels of safety, security, and efficiency.

- SATMS will not be a system separate from the NAS, but rather an expansion of NAS capabilities to support commercial space operations.

- SATMS is expected to facilitate emerging space transportation markets and a variety of vehicles with minimal impact to air traffic operations.

- Future space operations will require enhanced traffic management tools and expanded CNS services which will be part of SATMS.

- The space transition corridor (STC) will be a SATMS-defined passageway that will allows space vehicles to safely transition through the NAS.

- STC status, space and air traffic scheduling, and temporary flight restrictions will be managed with the help of decision support tools.

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SATMS

The SATMS Concept of Operations (CONOPS):

- Represents a framework for <u>seamlessly integrating</u> space vehicles on their way to and from space with more traditional air traffic operations

- Calls for <u>assured separation</u> between space and air traffic

- Will require <u>new space and air traffic management tools</u> and enhanced communications, navigation, and surveillance services

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US Spaceports

Numerous coastal and inland launch facilities will support commercial launches and recoveries in the future

Kodiak Launch Complex

Spaceport Washington

Montana Spaceport

Wisconsin Spaceport

South Dakota Spaceport
(location TBD)

Nevada Test Site

Utah Spaceport

California Spaceport

Mojave Civilian Test Flight Center

Virginia Space Flight Center
Wallops Flight Facility

Vandenberg AFB

Edwards AFB

Oklahoma Spaceport

White Sands Missile Range

Southwest Regional Spaceport

Spaceport Alabama

LEGEND
Federal Spaceport
Non-Federal Spaceport
Proposed Non-Federal Spaceport

Texas Spaceport
(3 proposed sites)

• Cape Canaveral Spaceport
• Kennedy Space Center
• Cape Canaveral AFS
• Florida Space Authority Spaceport

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Vehicle Types

Shuttle

Hypersonic

Recreational/ Commercial

Expendables

Future RLVs

Sea Launch
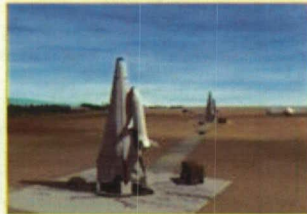
Sub-orbital

Small Rockets

Heavy-Lift

Future Expendables

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Possible Future Space-Airspace Domains

Regions of Jurisdiction and Authority

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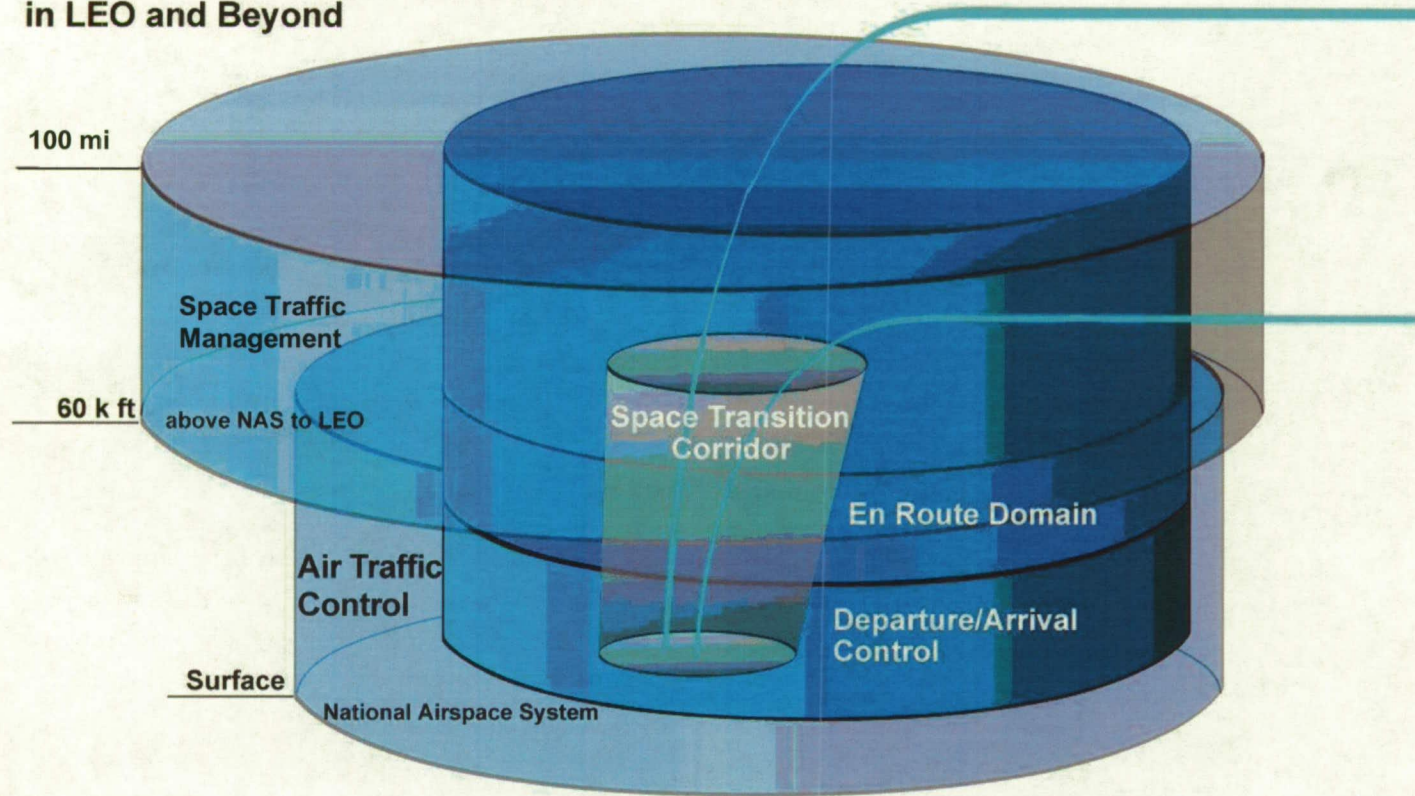
Today's Range vs. Space-Based Range
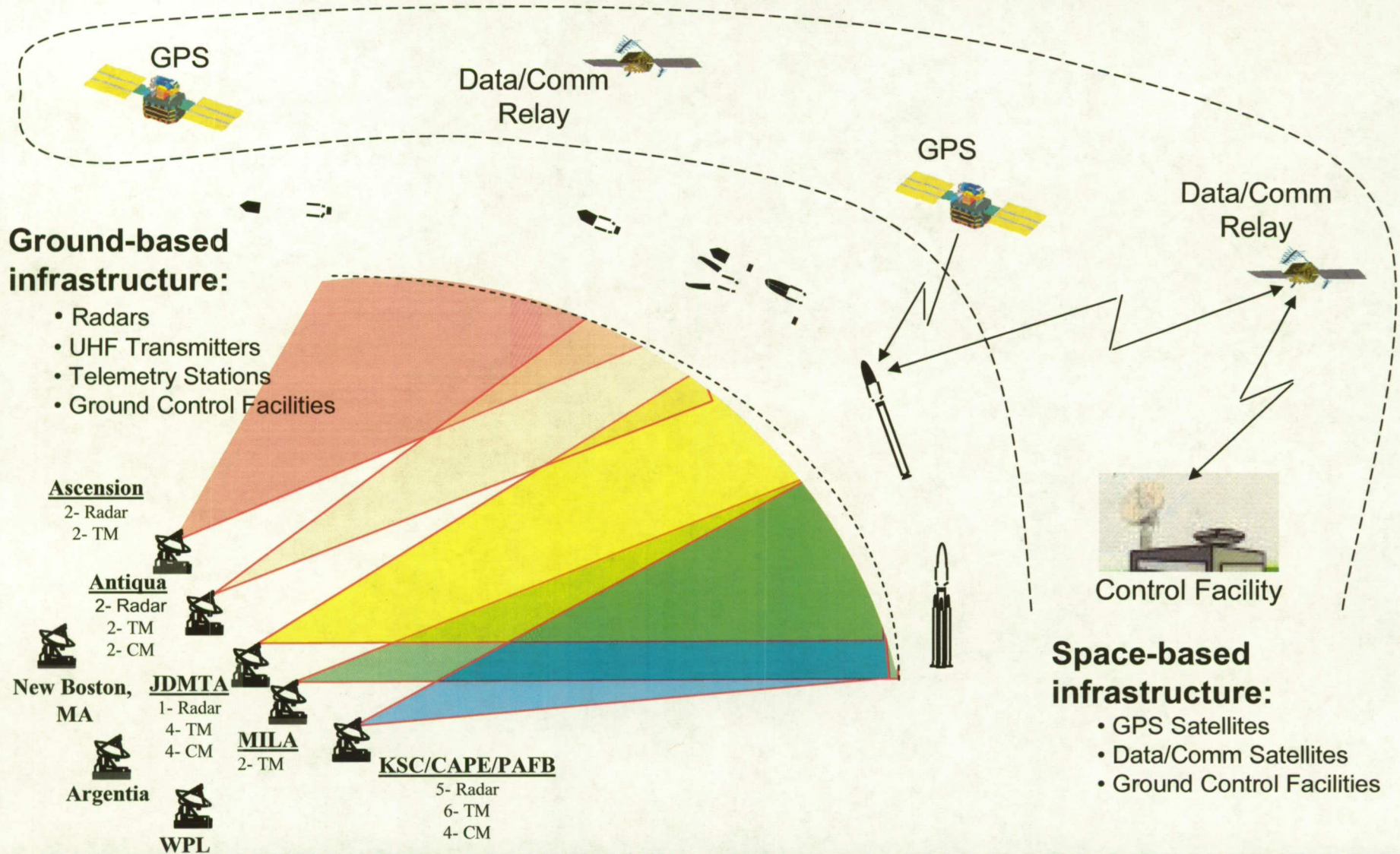
GPS

Data/Comm Relay

GPS

Data/Comm Relay

Ground-based infrastructure:

- Radars
- UHF Transmitters
- Telemetry Stations
- Ground Control Facilities

Ascension
2- Radar
2- TM

Antiqua
2- Radar
2- TM
2- CM

New Boston, MA

JDMTA
1- Radar
4- TM
4- CM

MILA
2- TM

Argentia

WPL

KSC/CAPE/PAFB
5- Radar
6- TM
4- CM

Control Facility

Space-based infrastructure:

- GPS Satellites
- Data/Comm Satellites
- Ground Control Facilities

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Space-Based Range (SBR) Benefits

- Reduce Range O&M costs by eliminating some of the ground-based downrange infrastructure required to support flight termination, vehicle tracking and vehicle telemetry

- Increase Range responsiveness (reduce launch turnaround times; reduce launch delays and scrubs due to range instrumentation)

- Increase vehicle telemetry data rates

- Increase Range capacity (support multiple vehicles simultaneously; increased launch trajectories; launch from a spaceport anywhere in the US)

- Global Coverage

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Current DoD/NASA Policy Direction

- Jan 2005 U.S. Space Transportation Policy
  - "The Secretary of Defense and the Administrator of NASA shall operate the Federal launch bases and ranges in a manner so as to accommodate users from all sectors; and shall **transfer these capabilities to a predominantly space-based range architecture** to accommodate, among others, operationally responsive space launch systems and new users."

- Policy Memo from Michael O'Brian, NASA Associate Administrator for External Relations, to Ronald Sega, Under Secretary of the Air Force, September 8, 2006
  - "…for vehicles that launch after 2010, …the Air Force will make GPS metric tracking a standard a standard part of the range infrastructure…"

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NASA's Space-Based Telemetry & Range Safety (STARS) Test Flights and Demonstrations

… to demonstrate the performance, flexibility, and possible cost savings of using space-based communications assets during vehicle launches and landings.

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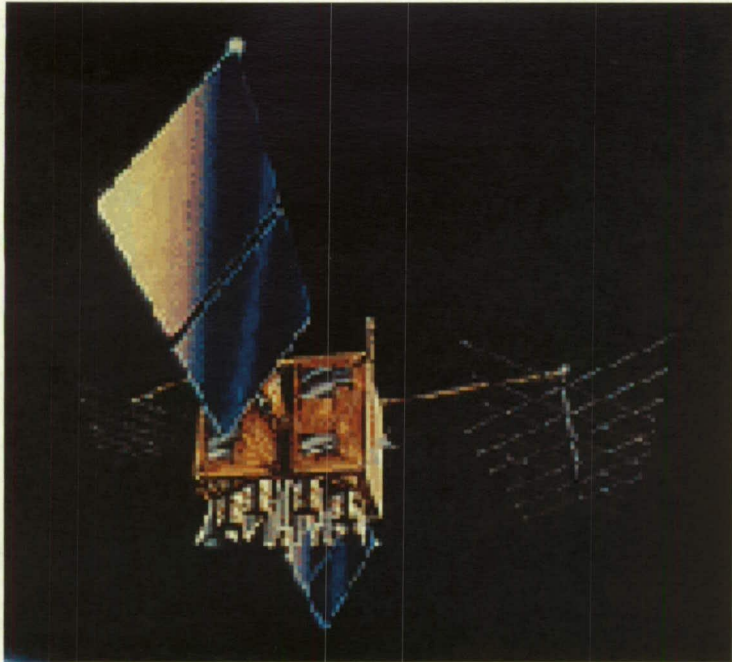# STARS Test Flight/Demonstration Objectives

Test/Demonstrate space-based communication technologies during supersonic and hypersonic flight for Range Safety and Range User Systems.

- **Range Safety System** (Flight Termination, Vehicle Tracking)
    - Objective: To meet intent of range safety requirements
        - Bidirectional
        - Low rate, high link margin
        - Simultaneous Forward Link – range safety commands with performance comparable to existing flight termination systems (840 bps)
        - Return Link – vehicle health, status and tracking data (10 kbps)

- **Range User System** (Video, Voice, Vehicle Data)
    - Objective: To maximize high data rate capabilities
        - Unidirectional or Bidirectional
        - Forward Link – vehicle command and control, voice and data communications (secondary objective)
        - Return Link – vehicle telemetry, voice and video links (up to 15 Mbps)

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STARS F-15 Test Flight Configuration

Global Position
System (GPS)
Satellite

F-15B

Tracking & Data Relay
Satellite System (TDRSS)

Dryden Flight
Research Center (DFRC)
Aeronautical Tracking
Facility (ATF)

DFRC Mission Control
Center (MCC)

White Sands
Complex (WSC)

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STARS Test Flights

STARS F-15 Test Flight #1 (June & July 2003)

- Proof of Concept for supersonic flight (up to Mach 1.1)
- TDRSS was used for the space-based communications.
- Many dynamic maneuvers were performed and various configurations were tested.
- Each of the seven test flights lasted about an hour.
- Utilized COTS Ashtec Z-12 GPS receiver.
- Utilized Omni patch antennas (combined S-band/L-band receive antennas on top and bottom of the F-15B and S-band transmit antennas located on the top and bottom of the F-15B)

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STARS Test Flights

STARS F-15 Test Flight #2 (November 2006 – February 2007)

- Similar to F-15 Test Flight #1 with enhanced flight hardware.

- Proof of Concept for supersonic flight (up to Mach 1.1)

- Tested the Range Safety system with TDRSS satellites, perform a "fly-away" maneuver to transition from launch head to satellite, and gather additional data latency measurements.

- The Range User system tested a phased-array Ku-band antenna with data rates of 5—10 Mb/s.

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F-15 Test Flight Results

Range Safety (RS)

- Verified link margin, acquisition/reacquisition, lock, Bit Error Rate (BER), and simultaneous forward links (satellite and launch head).
- Received and processed Flight Termination System commands (100% of all FTS commands were successfully initiated: over 300 Arm and Terminate commands were sent during the flight tests)
- Receive and process GPS metric tracking data.
- Transmit tracking, telemetry, and status data from a high dynamic vehicle to DFRC via WSC (Data was also transmitted to KSC, GSFC, and WFF in near real-time for monitoring).
- Processes and display the RS return link data.
- Required 12 dB link margin was verified.
- Test objectives were satisfied.

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F-15 Test Flight Results

Range User (RU)

- Verify link margin, acquisition/reacquisition, and lock
- Transmit RU data (video, voice, and telemetry) from a high dynamic vehicle to DFRC via WSC.
- Processes and display the RU return link data.
- The required 12 dB link margin was verified.
- Test objectives were satisfied.

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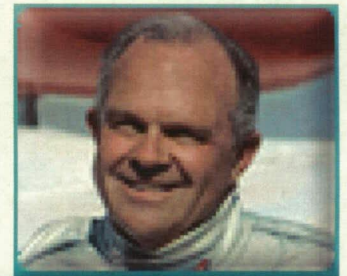
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STARS Flight Demonstration

GlobalFlyer (March 2005)

- Provided low-rate video during the 67-hour global flight.
- Video and voice transmitted via Iridium Satellites during pilot interviews throughout the mission.
- Presented an opportunity to compare predicted and actual link margins for many hours during mostly straight and level global flight using a simple one-antenna configuration on a nonconductive airframe.

In memory of Steve Fossett

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STARS Test Flight

Sounding Rocket (December 2005)

Terrier MK70 Improved-Orion, two-stage suborbital sounding rocket used in STARS test flight at Wallops Island Flight Facility (WFF).

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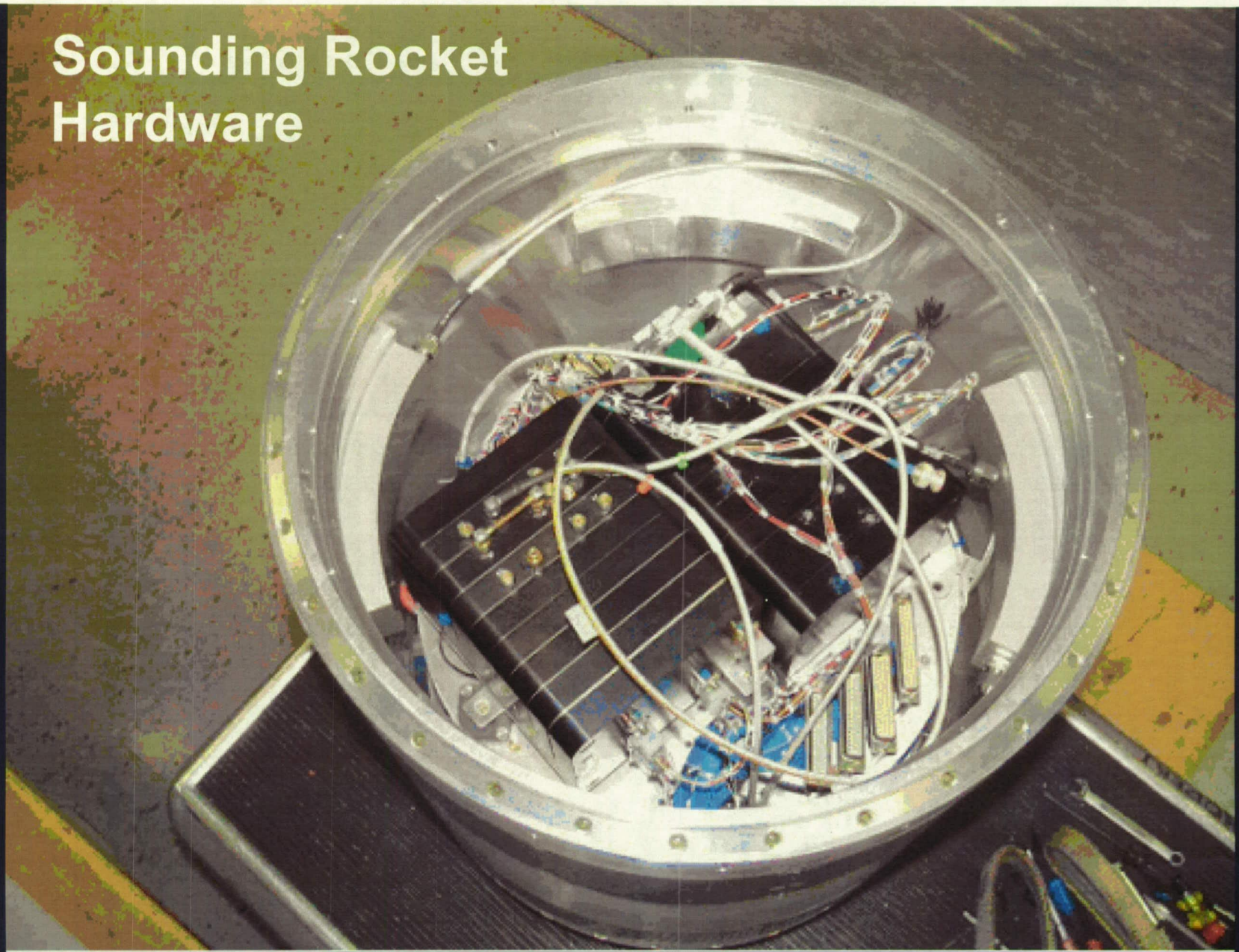# Sounding Rocket Flight Hardware

Antennas
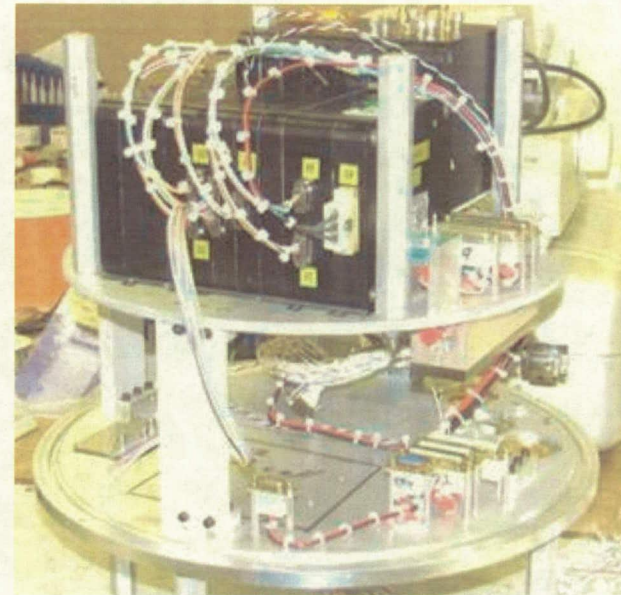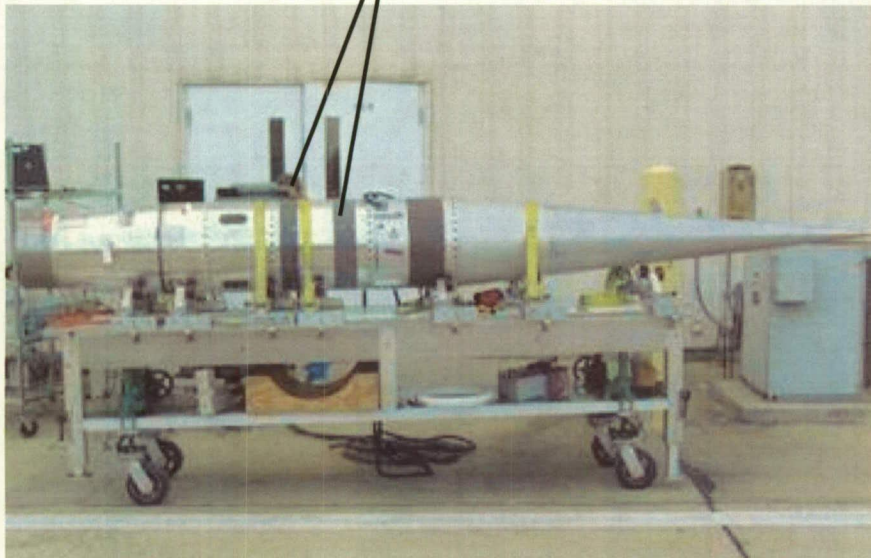
Interior View of Flight Hardware

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Sounding Rocket Hardware

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Sounding Rocket Test Results

- Sounding rocket flight tests conducted using GPS with Iridium satellite communications configurations.

- Test configuration included a PC-104 computer with an Ashtech G12 GPS receiver and an Iridium Modem.

- This design simultaneously received commands from the ground and sent GPS data consisting of latitude, longitude, altitude, speed as well as the health of the system back to the ground.

- The Iridium service has a data rate of 3.3 Kbps, and also has a short-burst messaging service at 450 bps.

- All test messages were successfully transmitted, received and processed during a hypersonic flight (> Mach 6).

- The 12 dB link margin requirement was verified.

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NextGen Considerations for Supporting Space Operations

- **Communications, Navigation and Surveillance (CNS) Services**

  - **Enhanced Automated Dependent Surveillance Broadcast (ADS-B)**

  - **System-Wide Information Management (SWIM) Network**

- **Decision Support Tools (DSTs)**

  - **Traffic Flow Management**

  - **Terminal/En Route/Oceanic Air Traffic Domains**
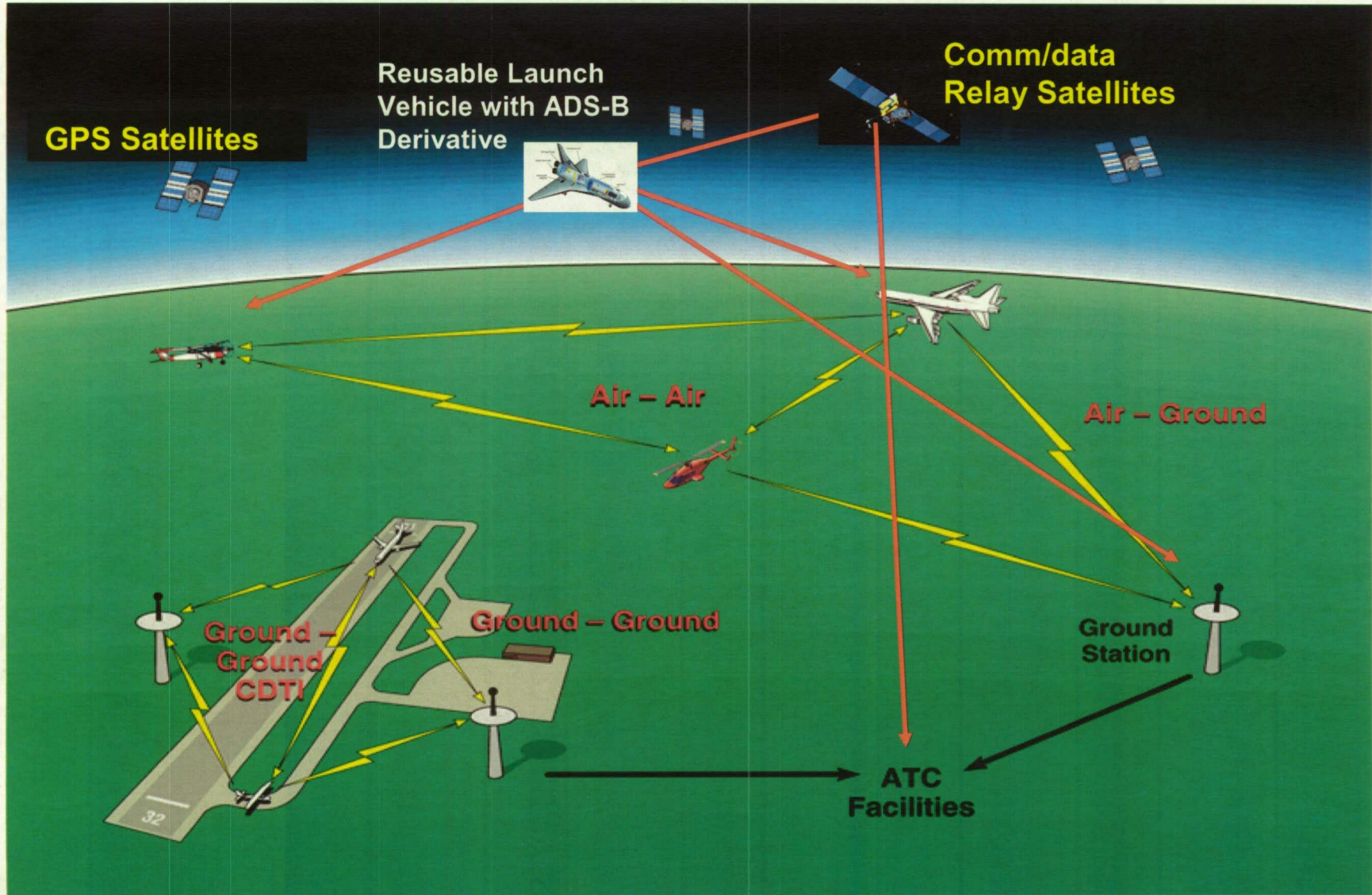
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Enhanced ADS-B Concept

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Possible SATMS Architecture in NextGen

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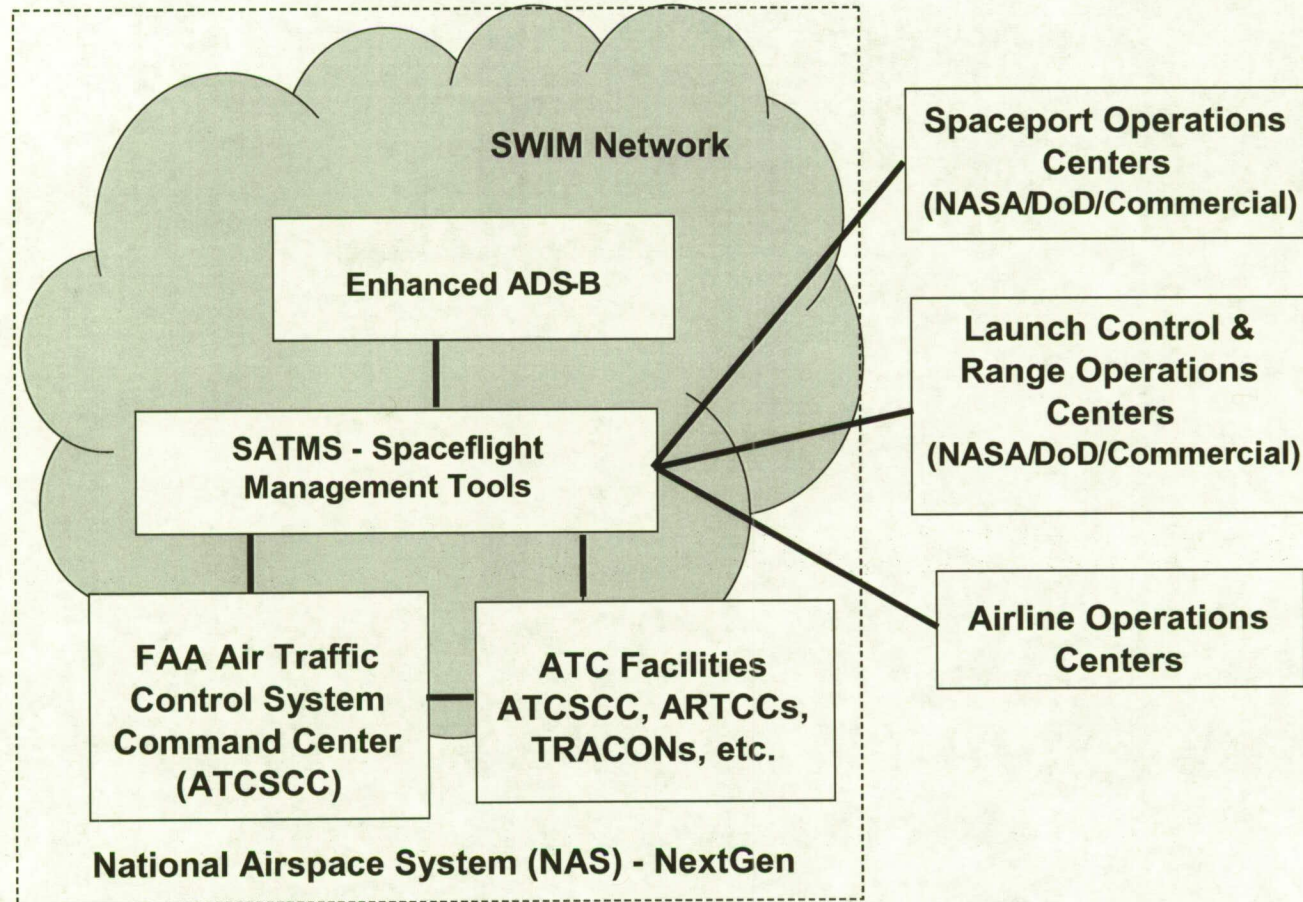
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Benefits of a
Common CNS Infrastructure

- It should be Cheaper to combine the resources of three agencies to develop space-based CNS services, than to develop separate systems.

- An integrated space-based CNS infrastructure is the only feasible architecture that can harmonize air and space transportation, and safely and efficiently integrate air traffic and space operations.

- SATMS will require integrated CNS services to ensure safe separation of aircraft and space vehicles operating shared airspace.

- A common space-based CNS infrastructure is probably the best method to satisfy an FAA licensing requirement for tracking space vehicles, while providing data for national traffic flow management decisions that are equitable for all NAS/NextGen users, especially as more spaceports become operational in the future.

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Proposed Research

1. <u>Common CNS Architectural Study</u>. For certain flight regimes, there will be different GPS performance and tracking accuracies associated with ADS-B aircraft and space vehicles. There will also be differences in link margins, data message sizes, error rates, protocols, and other communications system characteristics. As a first step, a study that investigates potential CNS architectures and performance requirements should be conducted.

2. <u>SWIM and Satellite Network Simulations</u>. Based on communications system characteristics and performance parameters identified during ADS-B development, and SBR flight tests conducted by NASA, define test scenarios for air-to-ground communications and SWIM configurations to evaluate integrated air and space traffic operations in a simulated environment. A primary goal of this research would be to identify NextGen CNS requirements needed for supporting both space and air traffic operations, and to mitigate technical, acquisition, and implementation risks.
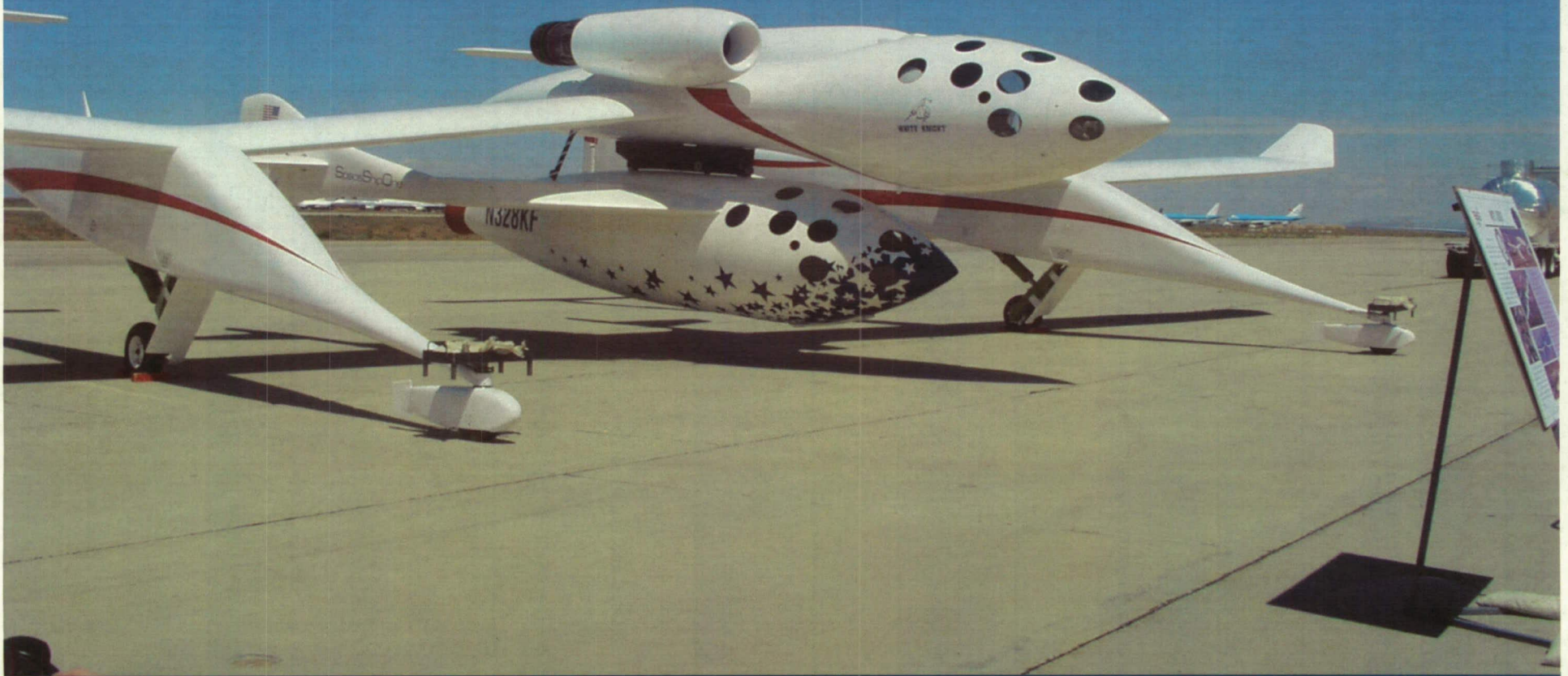
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Proposed Research

3. <u>Human-in-the-loop Studies</u>. Investigate human factors considerations, such as graphic user interface (GUI) design, situational awareness, data link message sets, CATM decision support tool functionality, flight deck vs. ground-based responsibilities, failure mode and recovery procedures, and conduct safety assessments in a simulated environment. Operational issues associated with transitioning to the SATMS concept for NextGen would be evaluated.

4. <u>Flight Demonstrations</u>. Demonstrate integrated CNS architectures with airline and space vehicle flight tests.

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Questions

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