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Paper Session I-B - Space-Based Communications

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Space-Based Communications

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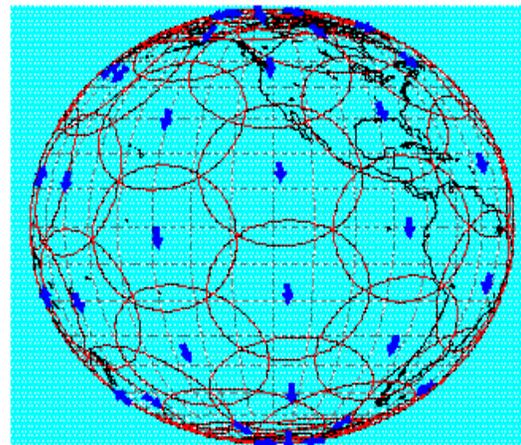
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Flight Modem
KSC/WFF



Introduction

Current space lift launches on the Eastern and Western Range require extensive ground-based, real-time tracking, communications, and command/control systems. These systems are expensive to maintain and operate and cover only limited geographical areas. Future spaceports will require new technologies to provide greater launch and landing opportunities, support simultaneous missions, and offer enhanced decision support models and simulation capabilities. These ranges must also have lower costs and reduced complexity, while continuing to provide unsurpassed safety to the public, flight crew, personnel, vehicles, and facilities. Commercial and government space-based assets for tracking and communications offer many attractive possibilities to help achieve these goals. Figure 1 demonstrates the primary existing Eastern and Western Range instrumentation sites and a possible future space-based configuration.

Space-Based Range and Range Safety Today and Future

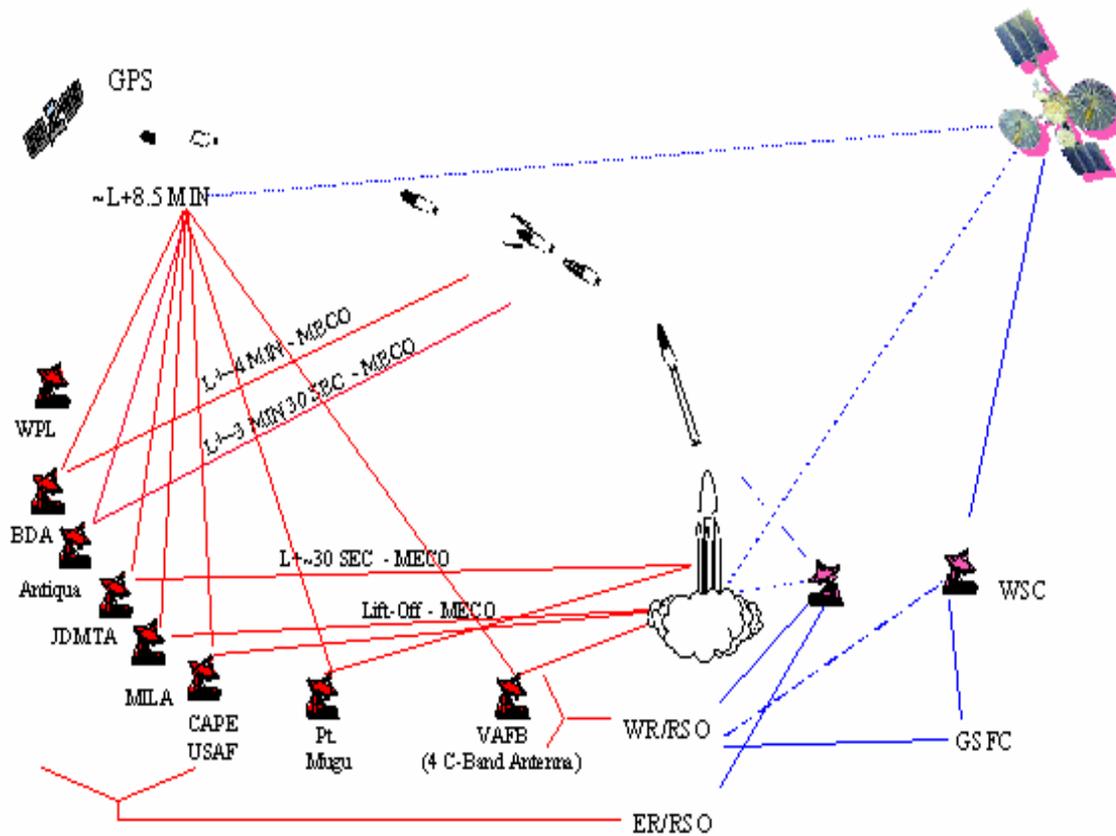


Figure 1. The existing Eastern and Western Range assets are shown in red. A possible space-based configuration is shown in blue. Note that some launch head ground-based assets will still be needed for visibility and rapid response times shortly after liftoff.

This paper describes two NASA proof-of-concept projects that seek to exploit the advantages of a space-based range: Iridium Flight Modem and Space-Based Telemetry and Range Safety (STARS). Iridium Flight Modem uses the commercial satellite system, Iridium, for extremely low-cost, low-rate, two-way communications and has been successfully tested on four aircraft flights. A sister project at Goddard Space Flight Center's (GSFC) Wallops Flight Facility (WFF) using the Globalstar system has been tested on one rocket. The basic Iridium Flight Modem system consists of an L1 carrier Coarse/Acquisition

(C/A)-Code Global Positioning System (GPS) receiver, an onboard computer, and a standard commercial satellite modem and antennas. STARS uses the much-higher-data-rate, NASA-owned Tracking and Data Relay Satellite System (TDRSS); a C/A-Code GPS receiver; an experimental low-power transceiver; custom-built command and data handler processor; and digitized flight termination system (FTS) commands. STARS is scheduled to fly on an F-15B at Dryden Flight Research Center (DFRC) in the spring of 2003, with follow-on tests over the next several years.

Iridium Flight Modem

Background

Iridium Flight Modem is a joint project at Kennedy Space Center (KSC) and WFF to investigate the feasibility of using the Iridium satellite system for low-rate, full-duplex, two-way communications (GPS tracking data and commands). Flight Modem uses commercial off-the-shelf (COTS) communications equipment (Motorola 9500 series modems), a high-dynamics Ashtech G-12 C/A-Code GPS receiver, and a PC-104 computer. The target applications for this project are tracking and telemetry for weather balloons (tracking weather balloons is the most frequently used application for the Ranges' radars), manned and unmanned aircraft tracking and commanding, and possibly two-way backup communications systems for rockets. KSC has tested Iridium Flight Modem during four aircraft flights by sending GPS data to ground modems via Iridium Flight Modems, recording and comparing this data with other tracking data, and making a first attempt at measuring the total data latency. These tests are described in more detail in the following sections.

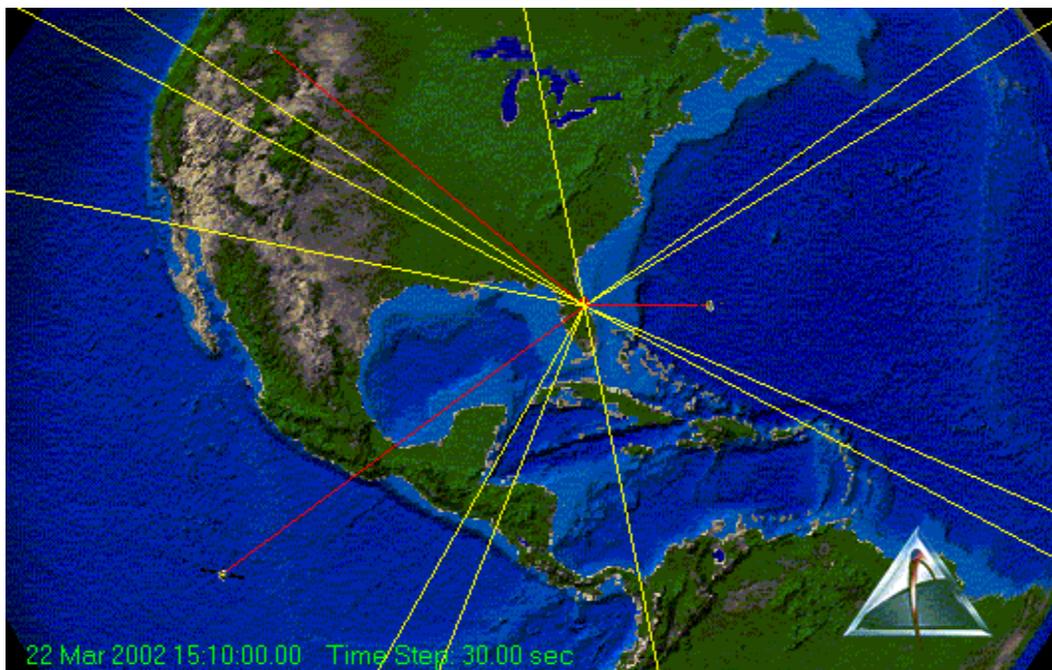


Figure 2. A typical snapshot of the GPS satellites (yellow) and Iridium satellites (red) in view during the first flight test.

Iridium is a commercial, global cell phone system with worldwide coverage provided by 66 Low Earth Orbit (LEO) satellites equally spaced in 6 orbital planes at an altitude of 780 km. There are 48 spot beams per satellite, each with a diameter of about 48 km (30 miles) on the Earth's surface. L-band frequencies are used for the uplink/downlink segments, and the signaling is frequency division multiple access/time division multiple access (FDMA/TDMA). The guaranteed data rate is 2,400 bps with a 12-dB

link margin, although this can be increased to 3,800 bps with a smaller link margin. The primary gateway is in Tempe, Arizona, and there is a Department of Defense (DOD) gateway in Hawaii. The main satellite ground control station is in Leesburg, Virginia; a backup facility is being added in Chandler, Arizona. The current cost of modems is ~\$1,200. The price is estimated to drop to \$200. Airtime is currently ~\$0.80 per minute and may also decrease in the future.

Various types of connections are available, including mobile-to-Public Switched Telephone Network (PSTN), PSTN-to-mobile, mobile-to-mobile, and direct Internet, where Iridium is the internet service provider. Short-burst messaging capability is in beta testing and mobile-to-direct Internet Protocol (IP) is planned for the future.

Flight Test 1

On March 22, 2002, a prototype Iridium Flight Modem using a DOS-based operating system was tested on a privately owned Piper Cherokee flying in and around KSC airspace. This was a flight of opportunity that was also testing a COTS 900-MHz, wireless, spread-spectrum, frequency-hopping, line-of-sight system for certification of the Microwave Scanning Beam Landing System (MSBLS) and Tactical Air Navigation System (TACAN) installations at the Shuttle landing sites.

Iridium Flight Modem sent GPS position data at 1,800 bps via the Iridium satellite and ground network (figure 2) to a modem in the KSC industrial area where it was displayed in real time and recorded for postflight analysis. The 900-MHz wireless system sent data to a ground station at the south end of the Shuttle Landing Facility (SLF) where it was recorded and used as truth for the postflight analysis. A data flow diagram for the Flight Modem system is shown in figure 3.

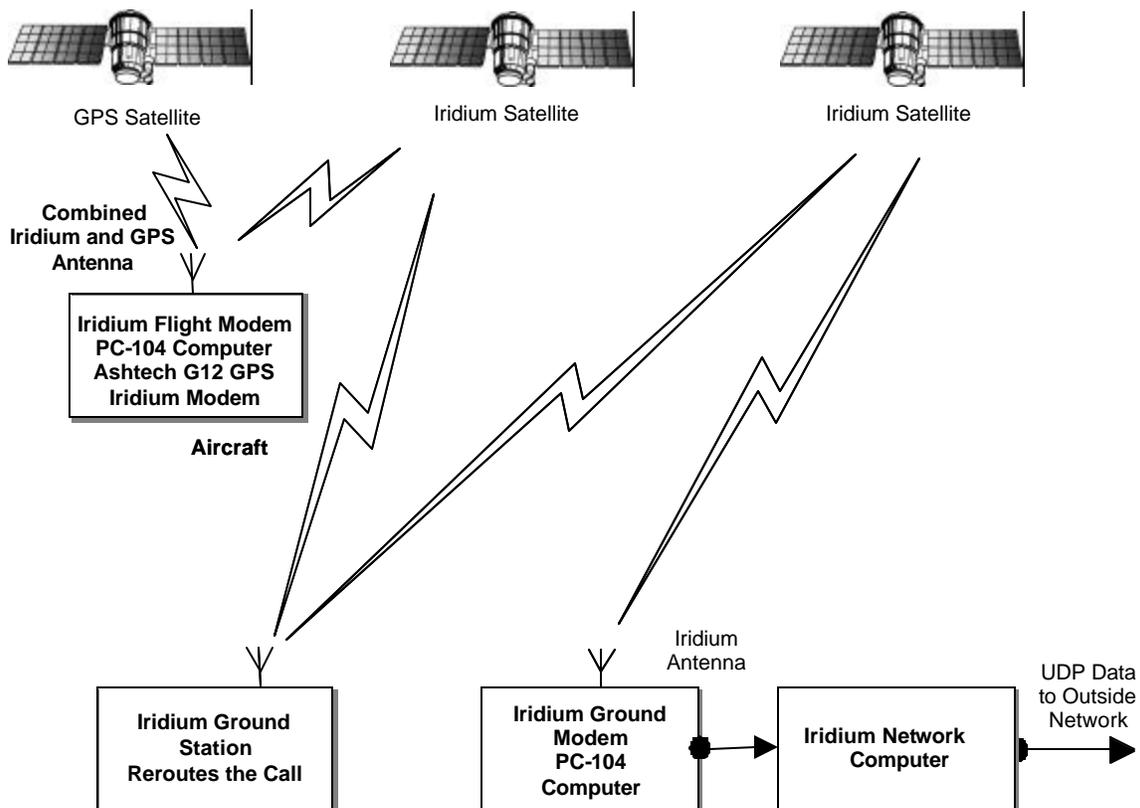


Figure 3. The configuration of Iridium Flight Modem during the first two test flights.

The 2.4-hour flight from Merritt Island Airport (MIA) followed a path typical of the flight inspection routes flown by the Shuttle landing aids certifications program for MSBLS and TACAN. Because this was a shakedown flight, the flight maneuvers were very benign with speeds around 100 knots, altitudes below 9,000 ft, and slow turns. The Iridium Flight Modem did not maintain a continuous communications link throughout the flight due to hardware and software problems, recording only 20 minutes of data. The hardware problems – a loose radio frequency and an intermittent power switch – were straightforward and easily fixed. The software problems were more involved. The most significant problem was reestablishing a link due to the setup of the AT command set. There were also problems with the buffering, resulting in much of the data being retransmitted. Nevertheless, both the Iridium Flight Modem and the 900-MHz wireless system worked under benign flight conditions and the test was deemed a success. The results were reported in document KSC-YA-5896 dated May 24, 2002. The problems were addressed and another flight test performed.

Flight Test 2

On May 31, 2002, after changing to a Linux operating system and correcting the retransmission problem, a second flight test of the Iridium Flight Modem was flown on the same private plane out of MIA. The flight lasted about 45 minutes and flew a series of banked turns and spirals over the Atlantic Ocean off the coast of KSC. Only one dropout was recorded when the plane was making a 60° banked turn. There were no problems reestablishing the link, although it did take about 30 seconds. The buffering problem did not recur. The 1,800-bps position data was again displayed real-time at KSC and recorded for postflight analysis. Data from an onboard GPS system was recorded and used for postflight analysis. This was a very successful test and demonstrated mobile-to-mobile Iridium throughput at 1,800 bps for GPS data.

Flight Tests 3 and 4

Flight Tests 3 and 4 were flights of opportunity on a P-3 Orion flying out of WFF. Another message containing velocity information was added, and the transmission rate was increased to 2 Hz for both the position and velocity messages (about 3,400 bps total). Plans were made to measure the data latency using one of the atomic clocks at KSC and the time in the GPS data messages. As before, the Flight Modem data was sent to KSC via the Iridium satellite and ground network, displayed real-time and recorded for postflight analysis. The data was also sent to WFF using Universal Datagram Protocol (UDP) via a PSTN landline. GPS, velocity, and attitude data from the onboard P-3 navigation systems were made available for postflight analysis.

Flight Test 3 was a 3-hour, round-trip flight from WFF to Greensboro, North Carolina, on June 19, 2002. There was one long dropout in the beginning for about 30 minutes. Once the link was reestablished, the data was more reliable, with other dropouts lasting from 30 to 120 s. Flight Test 4 was a 3-1/2-hour flight from WFF to Iowa on June 24, 2002, for a geophysical mapping operation. There were fewer data dropouts than on any of the other tests, none longer than 120 s.

The data latency averaged 0.72 s from “data sent” to “data received.” Comparisons between the P-3 navigation data and the Iridium Flight Modem data indicated that the largest position differences were about 0.0025° latitude and about 0.003° longitude, with the averages about a factor of three smaller, corresponding to typical horizontal differences of about 150 m. Unfortunately, it was not possible to compare altitude differences because the aircraft was using a radar altimeter and the GPS receiver in the Iridium Flight Modem measured height above the reference ellipsoid. Differences in ground track and ground speed were less than about 3° and 1 m/s, respectively.

Ongoing Research

Since these tests, the modems have been upgraded to Motorola 9505 modems with better shielding and an extended AT command set; the system redial time is down to 10 s; and the operating system has been upgraded to VxWorks.

Research is underway to increase the data rate and reliability by using two modems simultaneously. One idea is to have two modems multiplexed together, so if one fails, the other modem will continue sending data at half the data rate when both are functioning. Another possibility is to have one of the modems acting as a hot standby so one modem is always sending data. If the first should fail, the second modem will start sending data immediately, resulting (theoretically) in no delay. A third idea is to have one modem always sending data down while the second receives commands from the ground. If the first fails, the second modem sends the data down to the ground as the primary information.

The latency issue is being evaluated with the goal of reducing it to 0.1 s. KSC is investigating the limits of the applicability (e.g., maximum altitude and speed) of the Iridium Flight Modem for various aerospace vehicles using simulations (in particular, Satellite Tool Kit). Work is also underway on compressing the data to increase the effective data rate by (1) transmitting the data in binary format and maximizing the use of all bits in the data string, (2) transmitting differential values to effectively shorten the number of bytes required, (3) transmitting only essential fields in the GPS messages, and (4) lowering the ratio of absolute to incremental fields.

Future Flight Tests

Additional aircraft and balloon tests will be done as opportunities become available. A sounding rocket test combining both Iridium and Globalstar Flight Modem at either WFF or White Sands Complex (WSC) is planned within the next year.

STARS

Background

STARS is a multifaceted and multicenter NASA project to determine the feasibility of using TDRSS and GPS to provide reliable communication, telemetry, and tracking for a variety of launch vehicles. STARS is based on two proposals submitted by DFRC and KSC/Goddard Space Flight Center (GSFC) to the Second-Generation Reusable Launch Vehicle Program to reduce launch costs and increase capability. These two proposals were combined into a single study proposal that was accepted and funded in January 2001. STARS has recently been funded for continuation under the new Next-Generation Launch Technology (NGLT) Program.

STARS is composed of the Range Safety and Range User systems. The hardware in the Range Safety system includes an Ashtech Z-12 L1,L2 C/A-Code GPS receiver for metric tracking; a new, versatile, low-power, multichannel transceiver (LPT) by ITT Industries; and a state-of-the-art, custom-built flight processor (Command and Data Handler [C&DH]). The Range Safety system also includes a digitized 400-bps FTS command link and a custom 10-kbps telemetry format containing tracking data and health and status indicators for the LPT and C&DH. The Range User system uses broad-bandwidth communications (~400 kbps) for voice, video, and vehicle/payload data. Figure 4 shows the basic system for the first flight demonstration described in more detail below.

Flight Demonstration #1

The first set of test flights are scheduled for March to April 2003 on an F-15B at DFRC. Eight flights are planned to test the system during a variety of maneuvers and speeds at altitudes up to 40,000 feet. These include straight and level flight, 45° climb/70° descent, rolls at rates up to 200°/s, turns at up to 4 g's, cloverleaves, pushover/pullups, long-distance over-the-horizon (from the "launch head"), and supersonic flight. A simplified data flow diagram is shown in figure 5. The 10-kbps Range Safety data will be sent in near real time to KSC and WFF. KSC will be able to visualize the tracking using three-dimensional graphics and display many other parameters. DFRC will also have the ability to display real-time data during the flights at its Aeronautical Test Facility (ATF).

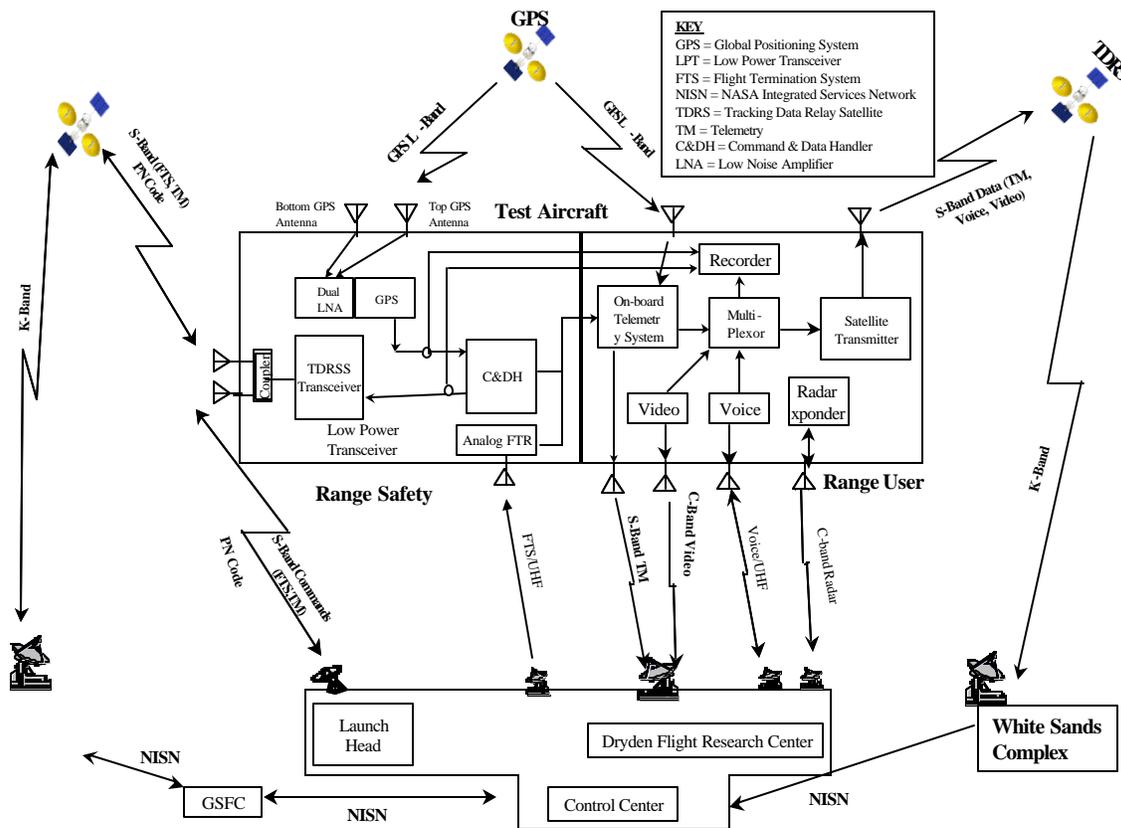


Figure 4. The basic system for STARS Flight Demonstration 1 scheduled to begin March 2003 at Dryden Flight Research Center.

The primary goals of the first demonstration include verification of the ability to acquire the satellites and tests of the LPT and C&DH under flight conditions. Of particular interest are the performance of the digitized FTS commands, the telemetry processing, and the coverage of the antennas. As figure 4 shows, there will be antennas on the top and bottom of the aircraft for the GPS, Range Safety, and Range User TDRS links. All data sent from and received on the ground will be recorded for postflight analysis. Acquisition, reacquisition, and signal lock will be correlated with attitude rates recorded by the onboard aircraft instrumentation system. The link margins will be characterized and the 10-kbps return link Range Safety telemetry data (GPS data and LPT and FTS status) verified. The Range User system will test only the return link using COTS hardware, providing approximately 400-kbps data rate (voice, video, data). The recorded 400-bps FTS commands will be used to characterize the forward bit error rate. The vehicle will be tracked by ground-based radar and this data will also be available for postflight analysis and comparison.

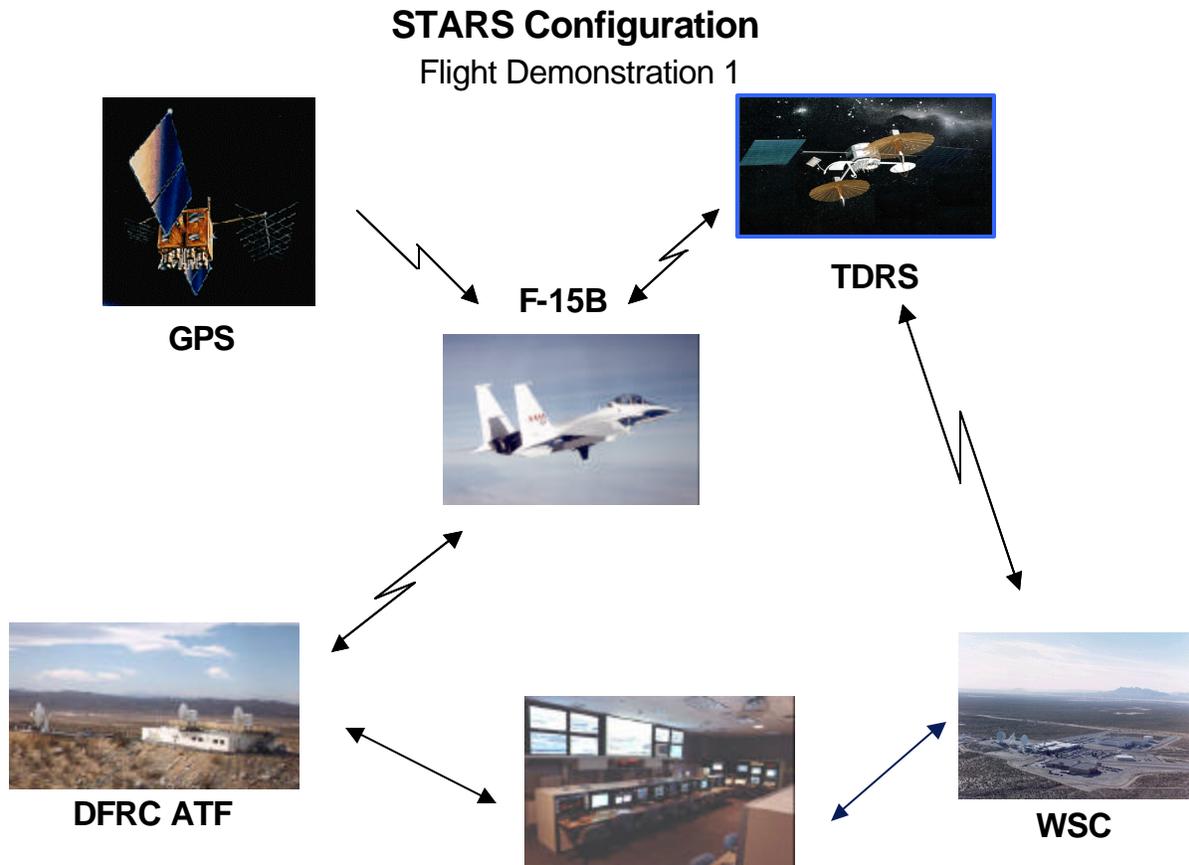


Figure 5. A simplified data flow diagram for STARS.

Flight Demonstration #2

The second set of test flights is currently scheduled to begin in FY04 on the NASA F-15B at DFRC. The basic goals are to meet the Range Safety requirements and increase the data rate on the Range User system. The specific goals of the Range Safety system are to meet and verify the command and data latency, to achieve and verify 95-percent spherical antenna coverage by handing off between two TDRS satellites in flight, to implement Enhanced Flight Termination System (EFTS) forward-link data protocol, and to provide encryption on the forward FTS commands. The specific goals of the Range User system are to achieve 5-to-7-Mbps Range User return link data rates using a Ku-band phased-array antenna, to measure the carrier-to-noise ratio, and to verify the vehicle's attitude with an onboard inertial measurement unit.

Flight Demonstration #3

The schedule is for a hypersonic flight in January 2006. SR-71, X-34, and X-43 were potential vehicles at the time the proposal was written, but the SR-71 and X-34 are no longer available, and the X-43 is too small to fly the STARS hardware. STARS is looking for flight opportunities on other recoverable vehicles, or maybe an expendable launch vehicle if the equipment can be recovered. The X-37, X-43C, and Kissler K-1 are possible options.

Interagency and Intercenter Cooperation

Flight Modem and STARS are excellent examples of collaboration and partnerships among many of the NASA Centers, their support contractors, and the United States Air Force. Nine NASA facilities, as well as the Eastern and Western Ranges, are involved in STARS. Their contributions include:

- Marshall Space Flight Center: Funding via Next-Generation Launch Technology Program
- Kennedy Space Center: Program management, flight processor, postflight analysis
- Dryden Flight Research Center: Flight hardware, flight test vehicle, and range support
- Goddard Space Flight Center: Flight hardware, TDRSS, and communications support
- Wallops Flight Facility: Engineering support, environmental testing
- White Sands Complex: TDRSS and communications support
- Glenn Research Center: Preliminary research and analysis
- Johnson Space Center: Microprocessor development
- Jet Propulsion Laboratory: FTS printed circuit board design
- Air Force 45th and 30th Space Wing Range Safety: Loaner equipment for the Range User system for flight demonstration #1 and design-review support representing the Range Safety requirements and interest

Flight Modem is a smaller project than STARS, involving mainly KSC and WFF, but the cooperation has been just as superb as with STARS. A number of the participants are active in both of these and other Advanced Range Technologies projects.

The Air Force Range Safety community has been very responsive and helpful, always willing to answer questions and attend reviews and demonstrations.

Cost Benefits

The driving factors for STARS and Flight Modem are increased capabilities at reduced costs. According to the Report of the Defense Science Board Task Force on Air Force Space Launch Facilities, June 2000, the estimated cost of operating both the Eastern and Western Ranges was \$573M in FY00. The estimated savings of using a predominately space-based range instead of the existing predominately ground-based range – after development of the telemetry system and elimination of unnecessary range support equipment – is approximately \$30M to \$40M per year. Using GPS for metric tracking would eliminate the need for a number of the radars, saving an estimated \$20M to \$30M per year. After initial development and installation, there could be an additional savings over the years from what would be required to continue to upgrade and operate the radar infrastructure. The space relay of GPS data, vehicle telemetry, and FTS commands could save an additional \$11M per year.

Conclusion

Space-based communications projects like Flight Modem and STARS should help lead to a space-based range and its many advantages, namely the increased capability for more launches from more locations, decreased turnaround times, and reduced ground-based infrastructure. This should be accomplished while paying only for the services needed from satellite providers, instead of ultimately paying the direct costs to support an entire range that is often idle.

However, while a space-based range has many advantages, it is important to keep in mind that space-based assets cannot replace all ground-based systems. The requirements for quick response times shortly after liftoff and external visualization of the vehicle for troubleshooting and debris tracking, among others, will continue to demand some ground-based assets. The key to successful future space-ports will be to use all available assets, ground- and space-based, as intelligently as possible.