Space Based Communications

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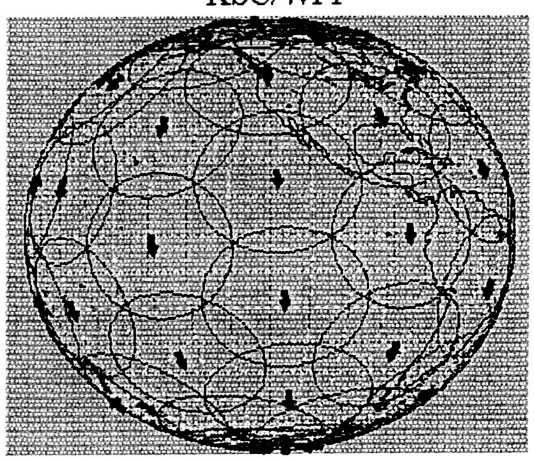
Flight Modem
KSC/WFF



Introduction

Current space lift launches on the Eastern and Western Range require extensive ground-based real-time tracking, communications and command/control systems. These 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 & Future

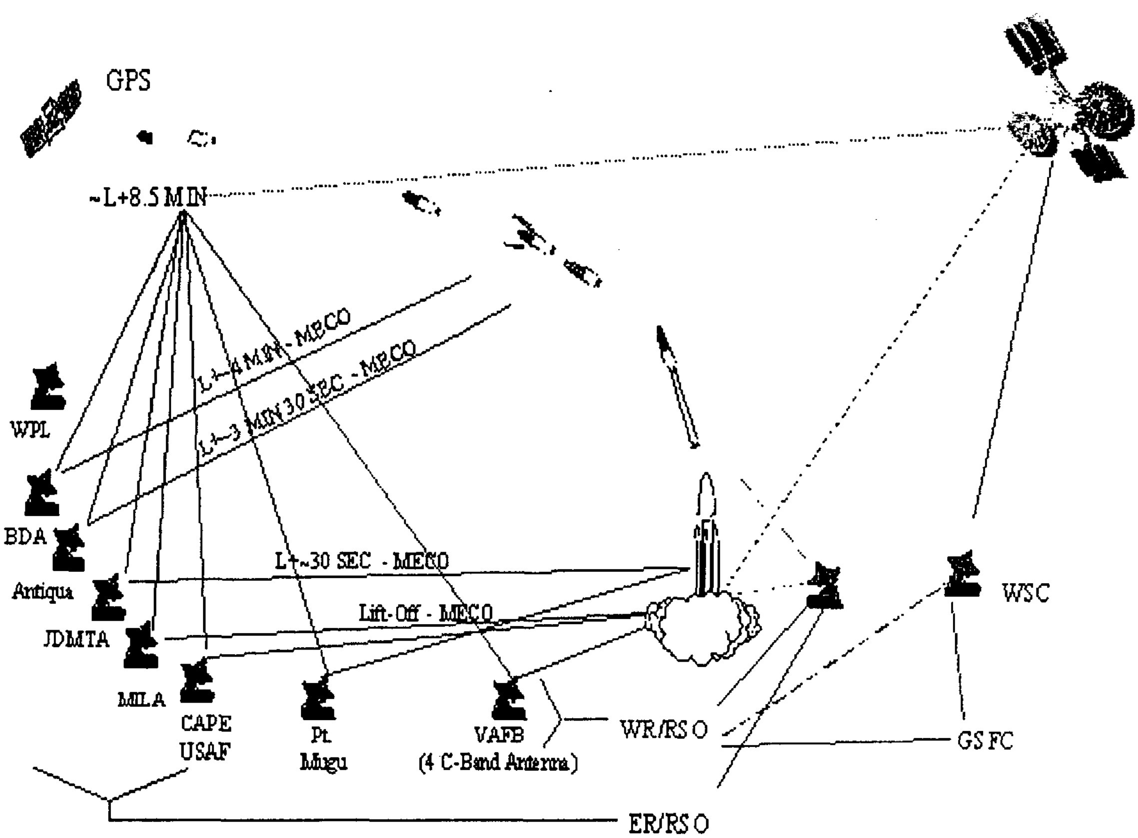


Figure 1. The existing range Eastern and Western Range assets are shown in red. A possible space-based configuration is shown in blue. Note that some launch head ground-based assets will still be needed for visibility and rapid response times shortly after liftoff.

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 a L1 carrier Coarse/Acquisition (C/A)-Code Global Positioning System (GPS) receiver, an on-board 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-15 at Dryden Flight Research Center 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 Wallops Flight Facility (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 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 system 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.

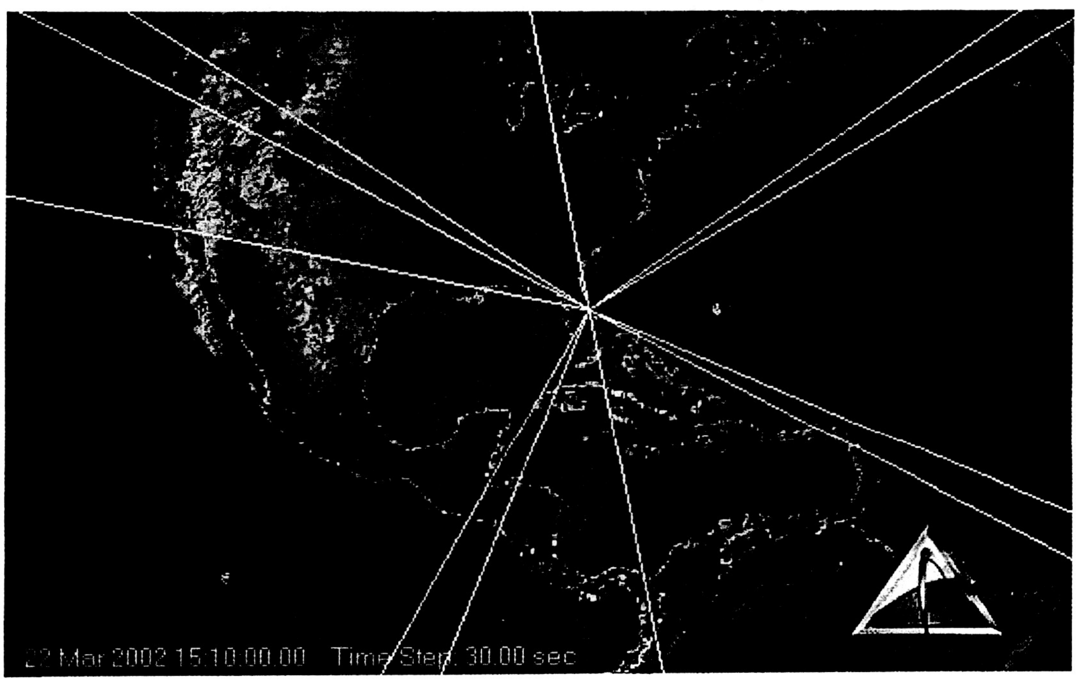


Figure 2. A typical snapshot of the GPS satellites (yellow) and Iridium satellites (red) in view during the first flight test.

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. (Note: the decreasing spot size with altitude decreases high altitude coverage). 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 2400 bps with a 12 dB link margin, although this can be increased to 3800 bps with a larger link margin. The primary gateway is in Tempe, AZ and there is a DOD gateway in Hawaii. The main satellite ground control station is in Leesburg, VA; a backup facility is being added in Chandler, AZ. 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: 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 IP is planned for the future.

Flight Test 1

On 22 March 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 1800 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 post-flight 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 post-flight analysis. A data flow diagram for the Flight Modem system is shown in Figure 3.

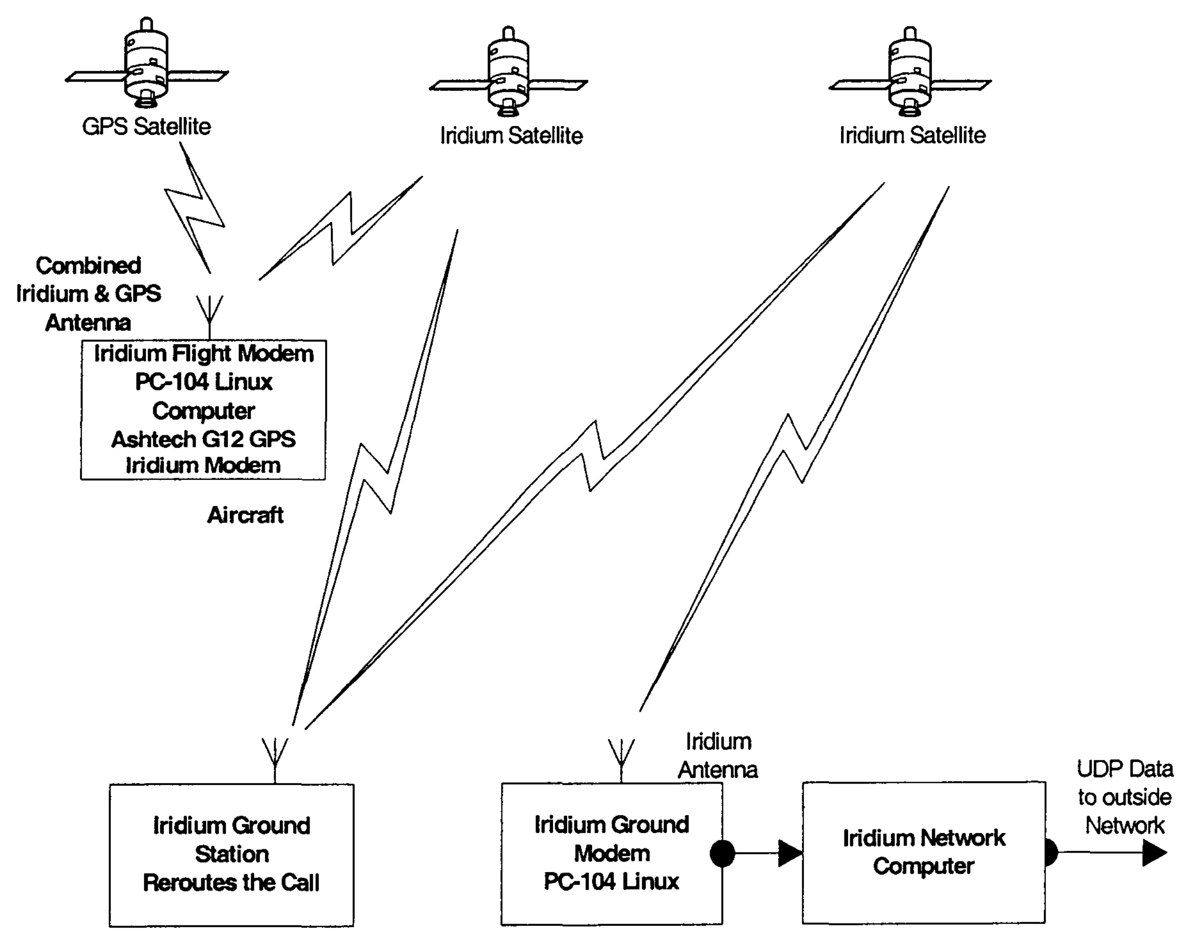


Figure 3. The configuration of Iridium Flight Modem during the first two test flights.

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 9000 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 were straightforward and easily fixed: a loose radio frequency cable and an intermittent power switch. The software problems were more involved. The most significant problem was re-establishing a link due to the set-up 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. The problems were addressed and another flight test performed.

Flight Test 2

On 31 May 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 re-establishing the link, although it did take about 30 seconds. The buffering problem did not reoccur. The 1800 bps position data was again displayed real-time at KSC and recorded for post-flight analysis. Data from an onboard GPS system was recorded and used for post-flight analysis. This was a very successful test and demonstrated Mobile-to-Mobile Iridium throughput at 1800 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 3400 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 post-flight analysis. The data was also sent to WFF using Universal Datagram Protocol (UDP) via a PSTN landline. GPS, velocity and attitude data from the on-board P3 navigation systems were made available for post-flight analysis.

Flight Test 3 was a 3-hour round-trip flight from WFF to Greensboro, NC on 19 June 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 30-120 s. Flight Test 4 was a 3 1/2 hour flight from WFF to Iowa on 24 June 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 P3 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 that 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 that 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 transmitting the data in binary format and maximizing the use of all bits in the data string; by transmitting differential values to effectively shorten the number of bytes required; by transmitting only essential fields in the GPS messages; and by 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 is planned within the next year.

STARS

Background

STARS is a multifaceted and multi-center 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 Dryden Flight Research Center (DFRC) and KSC/Goddard Space Flight Center (GSFC) to the Second Generation Reusable Launch Vehicle Project 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 comprised 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 multi-channel transceiver (LPT) by ITT and a state-of-the-art custom built flight processor (Command & Data Handler – C&DH). The Range Safety system also includes digitized FTS commands, a custom 10 kbps telemetry format, and digitized 400 bps FTS forward link. The Range User side 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.

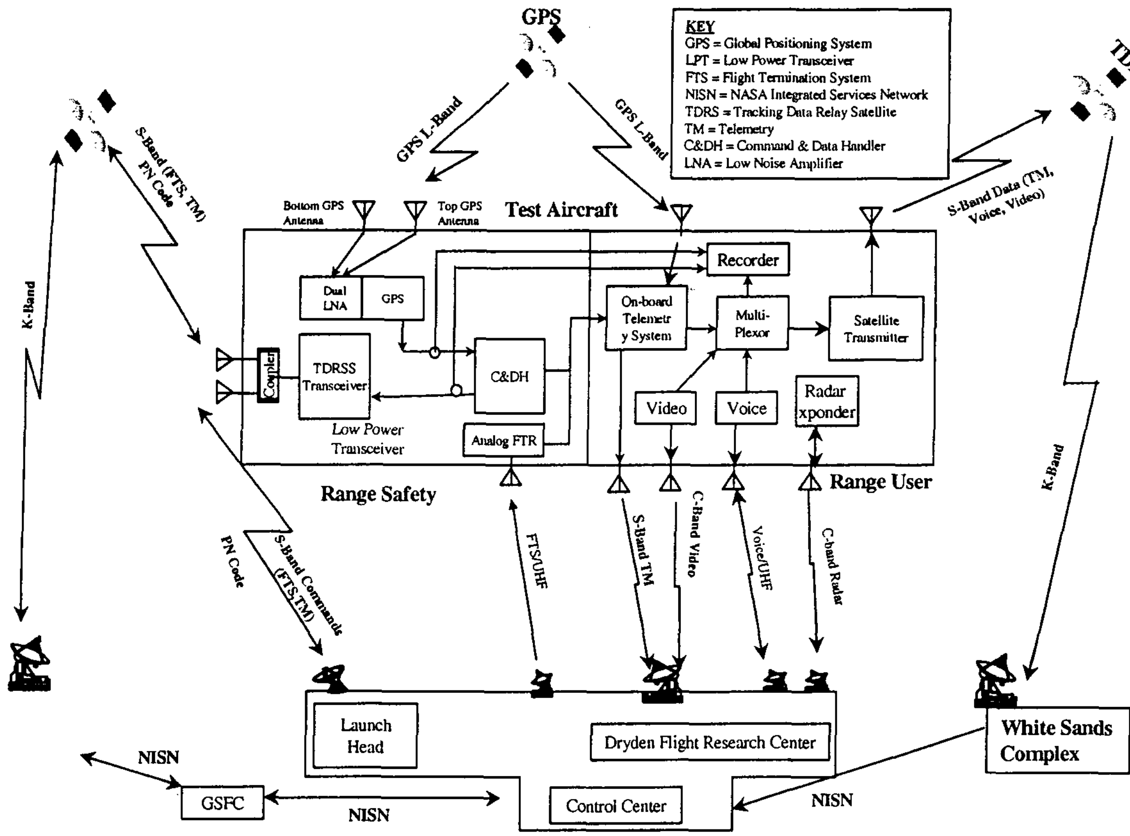


Figure 4. The basic system for STARS Flight Demonstration 1 scheduled to begin March 2003 at Dryden Flight Research Center.

Flight Demonstration #1

The first set of test flights are scheduled for March-April, 2003 on an F-15B at Dryden Flight Research Center. Eight flights are planned to test the system during a variety of maneuvers and speeds at altitudes up to 40k 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, cloverleaf's, pushover/pull-ups, 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 GSFC. KSC will be able to visualize the tracking using three-dimensional graphics and display many other parameters.

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 post-flight 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, LPT and FTS status) verified. The Range User side 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 be also be available for post-flight analysis and comparison.

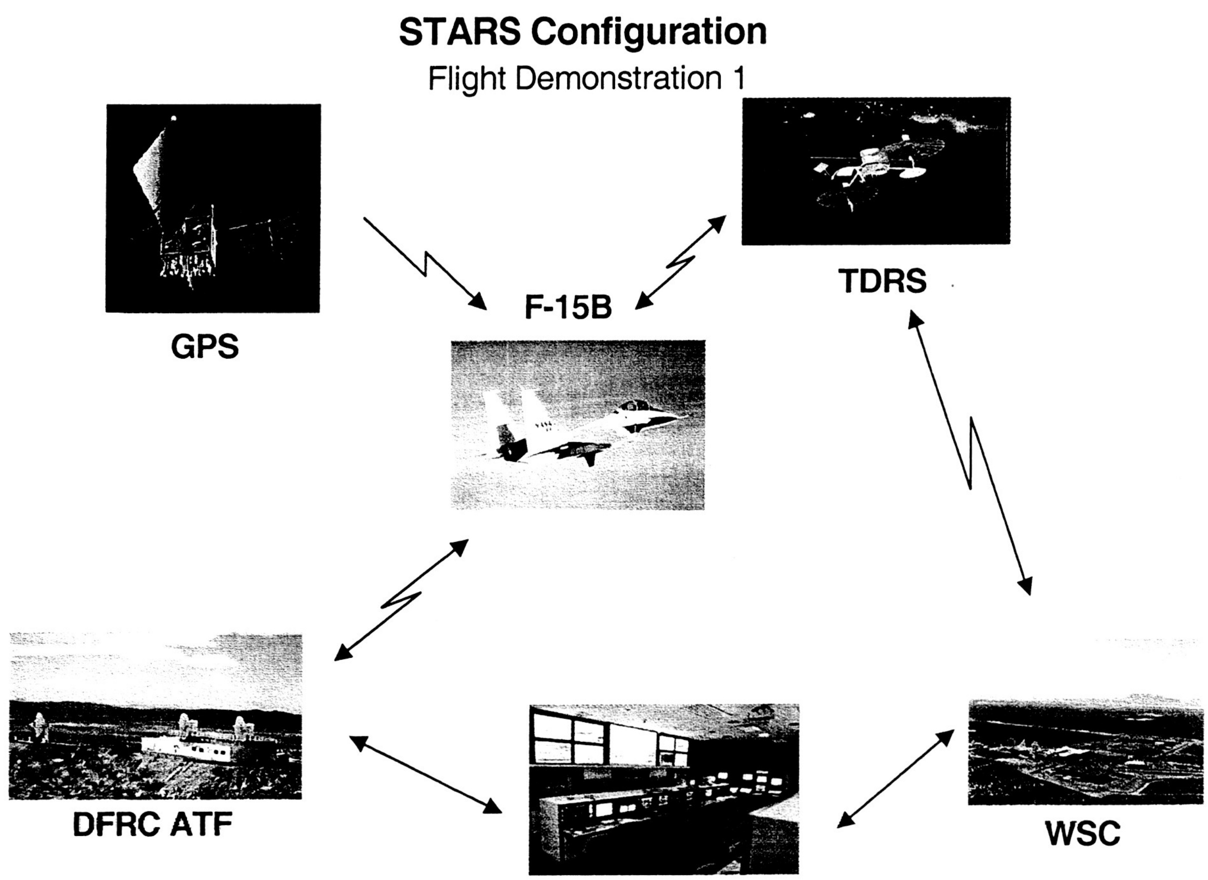


Figure 5. A simplified data flow diagram for STARS.

Flight Demonstration #2

The second set of test flights is currently scheduled to begin in September 2004 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 side. Specifically, the goals include: meet and verify the command and data latency, achieve and verify 95% spherical antenna coverage, implement Enhanced Flight Termination System (EFTS) forward link data protocol, provide encryption on the forward FTS commands, achieve 5-7 Mbps Range User return link data rates using an enhanced Range User transceiver and Ku-band phased array antenna, measure the carrier-to-noise ratio, handoff between 2 TDRS satellites in flight, and 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-33, X-34, and X-43 were potential vehicles at the time the proposal was written, but the SR-71, X-33, 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 between 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. These contributions include:

- Marshall Space Flight Center: Funding via Next Generation Launch Technology Program
- Kennedy Space Center: Program management, flight processor, post-flight analysis
- Goddard Space Flight Center: Flight hardware, TDRSS and communications support
- Wallops Flight Facility: Engineering support, environmental testing
- Dryden Flight Research Center: Flight hardware, flight test vehicle and range support
- Glenn Research Center: Preliminary research and analysis
- White Sands Complex: TDRSS and communications support
- Johnson Space Center: Micro-processor development
- Jet Propulsion Laboratory: FTS printed circuit board design
- Air Force 45th and 30th Space Wing Range Safety: Loaner equipment for the RU system for Demo 1, 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, 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 spaceports will be to use all available assets, ground and space-based, as intelligently as possible.