# SPACE-BASED TELEMETRY AND RANGE-SAFETY STUDY TEST RESULTS AND FUTURE OPERATIONAL SYSTEM GOALS*†

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## ABSTRACT

The use of remote ground stations for telemetry data-relay in space launch applications is costly and limits the geographic locations for launches of future Reusable Launch Vehicle (RLV) systems. The National Aeronautics and Space Administration Space-based Telemetry and Range-Safety (STARS) Study is investigating the use of satellite data relay systems as a replacement or supplement for ground-based tracking and relay stations. Phase-1 of STARS includes flight testing that evaluates satellite data-relay feasibility, defines satellite system performance limitations, and generates requirements for the development of future satellite telemetry data relay systems. STARS Phase-1 ground-test results and goals for the Phase-2 system development and flight-testing are also presented.

## KEY WORDS

TDRSS (tracking and data relay satellite system), FTS (flight termination systems), Launch head, STARS (Space-based Telemetry and Range Safety)

## INTRODUCTION

The Space-based telemetry and range safety (STARS) study project is based on proposals submitted in response to a NASA Research Announcement (NRA) in August of 2000 for second generation reusable launch vehicle (RLV) operational requirements. Two proposals submitted by the National Aeronautics and Space Administration (NASA) Dryden Flight Research Center (DFRC) and one by Kennedy Space Center (KSC) with Goddard Space Flight Center (GSFC) were combined into a single study proposal and the resulting proposal was accepted and funded in January 2001.

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The STARS goal is to demonstrate the capability of a space-based platform to provide range user and range safety support and to evaluate a reduction in the operational cost of ground-based range assets by providing a reliable communications link for next generation launch technology (NGLT) vehicles utilizing current state-of-the-art satellite technologies. The high cost is a result of the operations and maintenance of these remote range systems that are manned to support launches. Figure 1 shows the differences between current and future range implementations. The space-based concept could support future expendable launch vehicle (ELV) and unmanned aerial vehicle (UAV) range requirements.

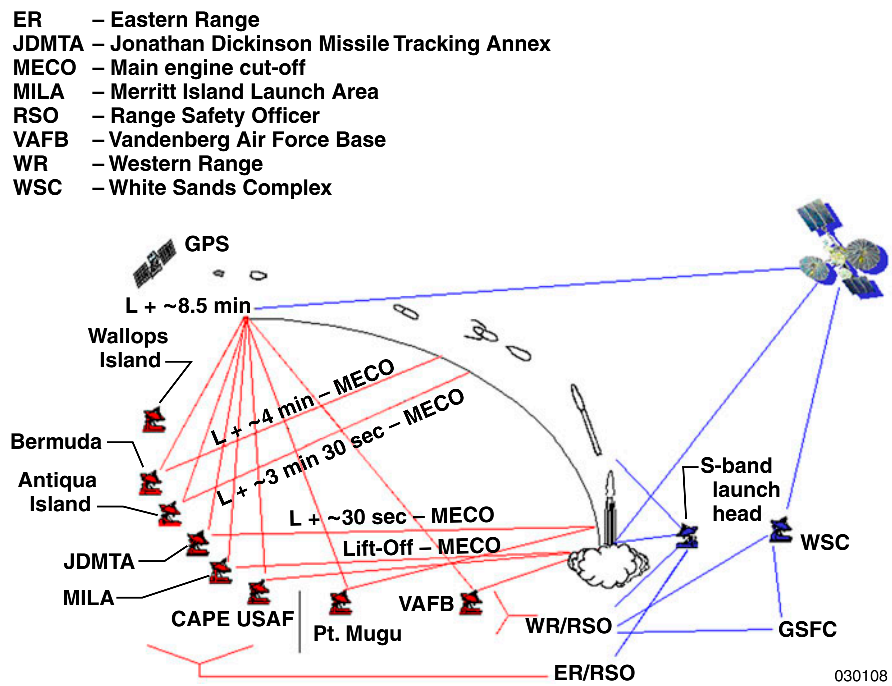

Figure 1. Space-based range and range safety—today and 2025.

## FLIGHT DEMONSTRATION OVERVIEW

The STARS flight demonstration incorporates two systems required for a future satellite-based range. The first is a range safety (RS) system which provides a platform for investigating the feasibility of replacing current range safety assets with an integrated on-board flight termination transmit and receive system that is capable of providing position, vehicle health, and flight termination functions. The second is a range user (RU) system providing a test bed for the study of telemetry links performance limitations over satellite links. The first flight demonstration (FD-1) will be conducted on a F-15B aircraft at DFRC using the NASA tracking and data relay satellite system (TDRSS).[1]

## HARDWARE CONFIGURATION: RANGE SAFETY SYSTEM

The STARS RS system consists of the following hardware; TDRSS low-power transceiver (LPT), command and data handler (C & DH), S-Band power amplifiers, transmit and receive bandpass filters (BPF), hybrid couplers, a power divider, global positioning system (GPS) receiver, GPS low-noise amplifier (LNA) as well as TDRSS receive (RCV), TDRSS transmit (XMT), and GPS antennas. The configuration of the RS system is shown in figure 2. The configuration on the aircraft includes upper and lower (dashed lines) GPS, and TDRSS antennas, which feed or are fed from the hybrid couplers and a power divider.

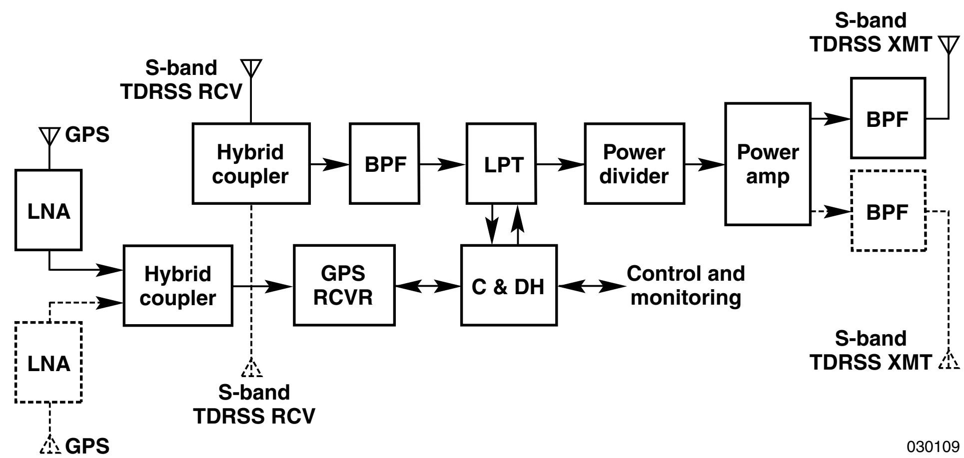


Figure 2. Range safety system for STARS.

The RS system includes both TDRSS and launch head (ground station) forward and return links. The forward link is a 400 bps link that allows the transmission of range safety commands directly to the F-15B research aircraft from the launch head transmit system at DFRC or to the satellite link through NASA Integrated Services Network (NISN), White Sands Complex (WSC) and the Tracking and Data Relay Satellite (TDRS). The return link is a 10 kbps data link that can be received at DFRC directly or through TDRS, WSC and NISN. Figure 3 illustrates the paths of data flow for the RS data links.

The RS 400 bps forward link data is comprised of frame synchronization, frame counter, and command word information. The commands transmitted to the range safety system include digital words, which represent standard analog flight termination systems (FTS) *Monitor*, *Arm*, and *Terminate* commands. The forward link data is generated using a custom programmable logic device (PLD) design and the data is transferred from the DFRC mission control center (MCC) to the launch head and TDRSS forward link transmitters.

The RS return link data format consists of status and data from the LPT (TDRSS receiver and transmitter), C & DH, and GPS receiver (RCVR). The data includes receiver estimates, the ratio of bit energy to noise power-spectral-density (Eb/No), average Doppler, hardware temperatures, FTS commands received, FTS status, frame synchronization, frame counter, GPS satellite and GPS receiver performance data. The C & DH controls the LPT and GPS receiver, collects forward-link data from the LPT and GPS receiver, and formats the data for return-link transmission.

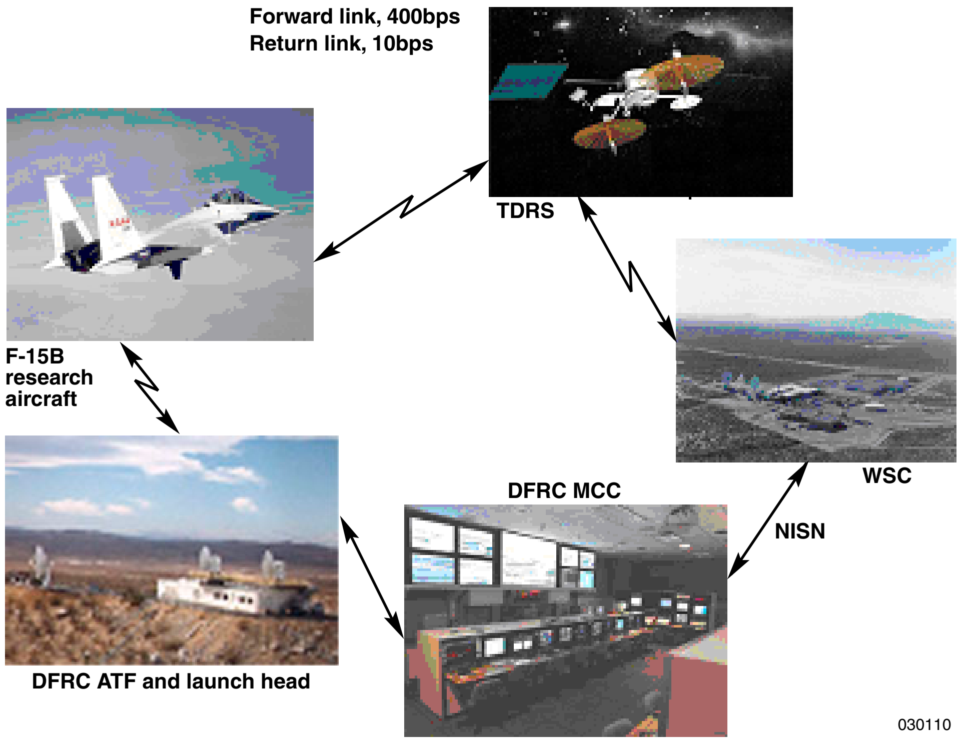


Figure 3. Range safety data flow.

The launch head and TDRSS forward link utilize different pseudorandom noise (PN) codes, which enables simultaneous transmission and reception of launch head and TDRSS forward links. The LPT includes four receivers; two that receive launch head PN encoded data and two that receive TDRSS PN encoded data. Hybrid couplers are utilized to allow the combined outputs of in-phase and out-of-phase upper and lower antennas to feed each receiver, (fig. 4).

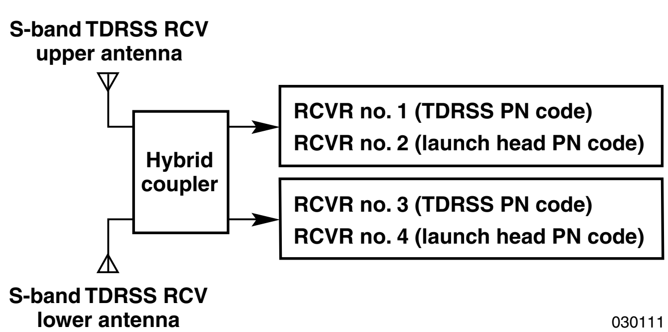


Figure 4. Range safety system receiver configuration.

The RS forward link is designed for 95 percent spherical coverage and a 12 dB link margin as stated in the RCC-319[2] requirements for analog flight termination system (FTS) requirements. The Range Commander's Council (RCC) Range Safety Group (RSG) is currently investigating digital FTS through the Enhanced Flight Termination System (EFTS) Program.[3] This investigation may indicate that the 12 dB link margin is not required for a digital system to yield performance and reliability equivalent to analog FTS. Phase-2 of STARS also plans to investigate system performance for cases when two satellites are used for range safety in order to determine link requirements for this alternate setup to allow a performance equivalent for current analog FTS and perhaps lower the link margin requirement.

## HARDWARE CONFIGURATION: RANGE USER SYSTEM

The STARS RU System consists of a data multiplexer, TDRSS transmitter (XMTR), power divider, RF power amplifiers, and TDRSS transmit antennas, (fig. 5). As with the RS system, the RU system includes a lower S-Band TDRSS power amplifier and an antenna fed by the power divider.

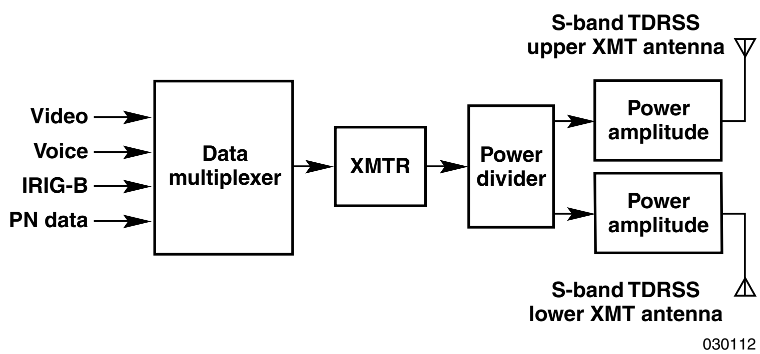


Figure 5. Range user system for STARS.

The RU system includes only a TDRSS return link, with no forward link implemented for FD-1. Range user data consists of International Telecommunication Union (ITU) H.261 Standard compressed digital video, digitized and compressed voice, digitized IRIG-B and an embedded ITU O.151 Standard 2047 ($2^{11}$-1) pseudorandom pattern, which is used for real-time pseudorandom bit error rate (BER) estimates. A custom PLD design is utilized to separate embedded BER data from the RU return-link data when received at DFRC.

The existing F-15B research aircraft instrumentation system has been modified to monitor temperature and status of some of the STARS hardware as well as the status of two analog flight termination receivers which have been installed for performance comparison with the RS FTS. This information is transmitted from the aircraft and received directly by DFRC for display in the DFRC MCC.

## FLIGHT TEST PLAN

The STARS flight demonstration No. 1 involves ground testing and approximately eight flights on a NASA F-15B research aircraft, (fig. 6). The tests in the STARS flight test matrix include a combined systems test (CST) on the aircraft to verify that no electromagnetic interference–electromagnetic compatibility (EMI–EMC) issues exist between the STARS hardware and the aircraft systems, which is a standard DFRC procedure prior to flight tests of any experiment.

| Profile | CST | Flight no. 1 | Flight no. 2 | Flight no. 3 | Flight no. 4 | Flight no. 5 | Flight no. 6 | Flight no. 7 | Flight no. 8 |
|---|---|---|---|---|---|---|---|---|---|
| Validate RF/EMC | X | | | | | | | | |
| Straight and level | | X | X | X | | | | | |
| High dynamics | | X | X | X | | | | | |
| Simulate launch vehicle | | | | | X | | X | | |
| Supersonic | | | | | | X | | X | |
| 0.85 M long distance | | | | | | | | | X |
| Low data rate | X | X | | | | | | | |
| Medium data rate | | | X | | X | X | | | X |
| High data rate | | | | X | | | X | X | |

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Figure 6. Flight test matrix for STARS.

The first three flights consist of level flight, pushup-pullover maneuvers, and dynamic maneuvers; including rolls, 360 deg turns, loops, and cloverleafs. The maneuvers for each of the first three flights are the same, however, the RU system will be set to a low (125 kbps), medium (250 kbps), or high (500 kbps) data rate to evaluate system performance. Two flights at medium and high data rates evaluate system performance in a simulated launch vehicle flight profile, both with and without an induced low-rate roll to simulate a shuttle-type liftoff roll. Two supersonic flights are used to evaluate Doppler performance and a long distance flight is also included, to demonstrate what happens on a hand-off between satellite and launch head. The aircraft heading and attitude is controlled as much as possible for all maneuvers in order to test the TDRSS link at various look angles and Doppler conditions.

The measurement of latency in satellite and ground links is not a goal of Phase-1 flight tests as the ground links have not been optimized. After the first flight demonstration has successfully demonstrated the capability to support RS and RU functions, hardware and data links will be optimized for Phase-2 testing and latency will be measured.

## TEST RESULTS

Compatibility testing of the flight hardware for both the RS and RU systems was completed at GSFC[4] in 2002. A calibrated GSFC antenna system was used for the test as opposed to actual flight antennas. The test included transmission of a 2047 pseudorandom pattern to characterize system performance. Figure 7 shows the BER curve for the 500 kbps RU system observed during the GSFC testing. The systems performance is within 1 dB of what an ideal TDRSS transmitter would be.

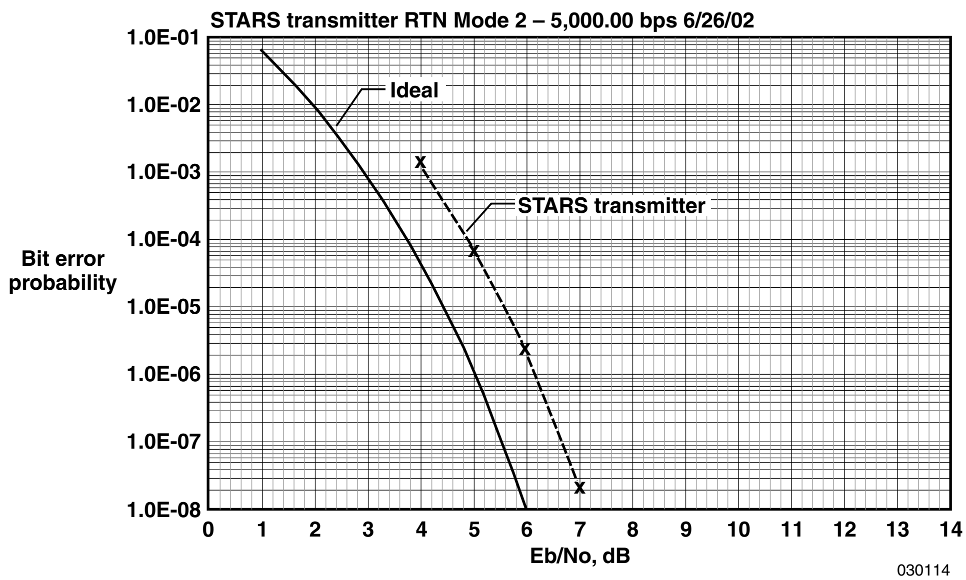


Figure 7. Goddard Space Flight Center 500 kbps TDRSS compatibility tests results.

End-to-end RU data flow ground tests (fig. 8) were performed at DFRC in early 2003 with the flight hardware installed on pallets for aircraft integration utilizing flight antennas. This test included transmission of actual flight data and yielded better than a 10E-6 BER at 250 kbps for the Eb/No values plotted in Figure 9.

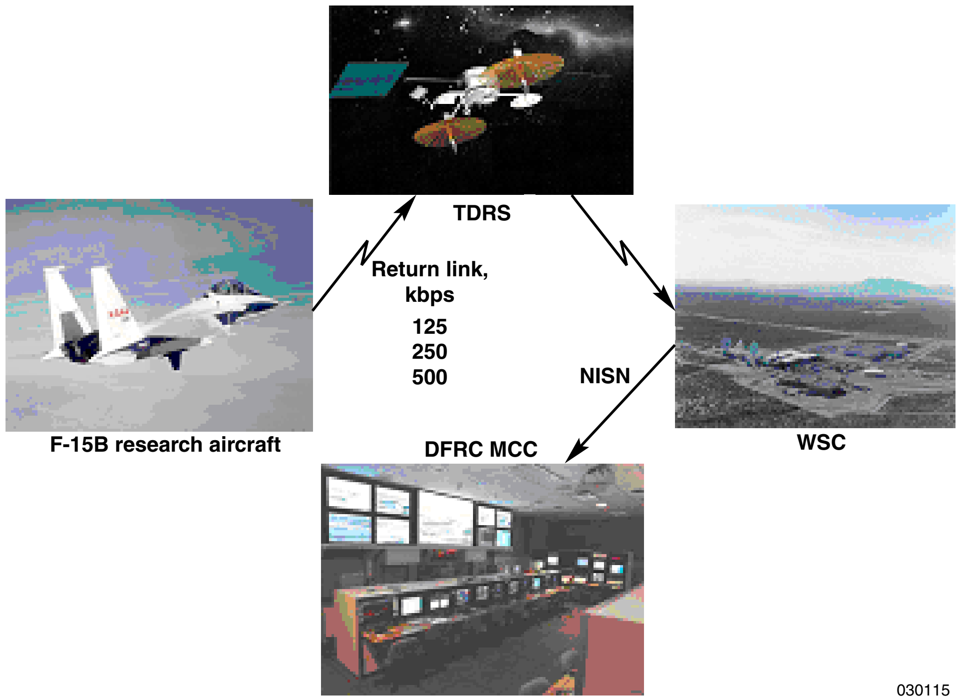


Figure 8. Range user data flow.

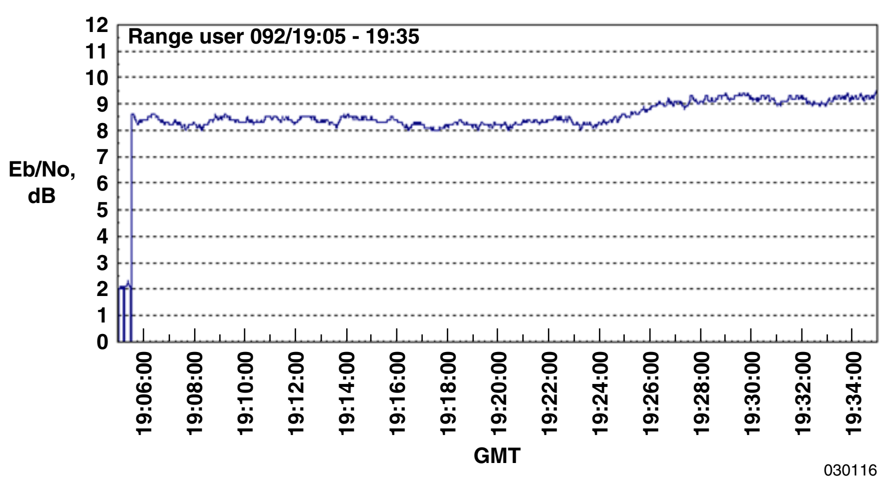


Figure 9. Dryden Flight Research Center 250 kbps end-to-end TDRSS test Eb/No.

Installation of the flight hardware on the test aircraft and combined systems tests are planned for completion at DFRC in May of 2003 and the hardware integration is expected to result in no detrimental affects to aircraft systems. Flight tests are scheduled in May and June of 2003 and the results of these tests will be presented during the October 2003 International Telemetry Conference.

## SECOND FLIGHT DEMONSTRATION GOALS

STARS second flight demonstration (FD-2) goals include enhancements to RS system hardware and the development of new RU system hardware. The RS system enhancements planned include modification of the RS hardware and ground links to optimize latency, link margin, test vehicle position measurement, and acquisition performance. The system modifications will support testing with multiple TDRSS satellites. Goals also include integration of the RS system LPT, C & DH and GPS hardware into a single standalone piece of flight hardware. The RU system for FD-2 will include the development of new hardware to support high data rates, 5 Mbps minimum, from the vehicle to TDRSS. The hardware under development includes a transceiver-transmitter, high-gain antenna system and Internet protocol (IP) data formatter.[5]

## SUMMARY

Successful demonstration of the STARS system should provide the technology to implement satellite-based range safety and telemetry systems on future RLV, ELV and UAV systems. The STARS systems would result in a significant savings in the ground support infrastructure required for these vehicles.

## REFERENCES


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