SYSTEM TESTING OF COMMUNICATIONS AND TRACKING LINKS FOR FIRST ORBITAL FLIGHT OF THE SPACE TRANSPORTATION SYSTEM (STS)

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ABSTRACT

Verification testing of the communications and tracking (C&T) links prior to the first STS flight has been a prime concern. The C&T system for the Space Shuttle orbiter (SSO) provides for the transmission and reception of voice, command data, tracking data, telemetry, television, main engine data, external tank (ET) data, and payload data between the flight vehicle and the ground (communication between detached payloads and ground is achieved via the SSO as bent-pipe data or as part of the standard pulse code modulation telemetry data), and for the transmission and reception of voice and/or data between the flight vehicle and extravehicular activity (EVA). The C&T links will be operated during preflight, in-flight, and postflight phases of the orbital flight test (OFT) program.

The verification testing program for C&T links makes use of the results obtained from element-level component and subsystem tests and analyses, and adds this information to the data from a series of combined-element analyses and system-level tests to ensure that performance requirements are met.

A verification network outlines major paths leading toward integrated verification of the C&T links for OFT. A matrix illustrates the STS C&T system verification requirements versus the testing facilities and identifies STS RF links test at various facilities. Another matrix shows the verification requirements, methods and criteria, and hardware and software requirements of all facilities for each RF link. The role of each facility in the verification process is described. Special tests that have supported overall readiness are listed.

INTRODUCTION

A number of papers have been written describing the Space Shuttle orbiter (SSO) communications and tracking (C&T) system,[1] but the verification of these subsystems as an integrated system has not been discussed. Although the initial verification testing aim is to ensure readiness for the first STS flight, the same verification methods will ultimately be used for the operational STS and full-up C&T system.

C&T SYSTEM

The C&T system for the SSO involves all elements of the flight vehicle and its interfaces, including the launch and landing (L&L) facilities, the Mission Control Center (MCC), the Goddard Space Flight Center (GSFC), the Space Flight Tracking and Data Network (STDN), the Air Force Satellite Control Facility (AFSCF), Space-Ground Link Subsystem (SGLS), military tactical air navigation (TACAN), civilian TACAN, and military/civilian UHF voice systems. The C&T information is processed and displayed to flight and ground personnel in real time or near real time. An overall block diagram of the activated links is shown in Figure 1.

VERIFICATION PROGRAM

The integrated verification program[2] for C&T makes use of the results obtained from the element-level component and subsystem tests and analyses, and adds this information to the data from a series of combined-element analyses and system-level tests to ensure that the performance requirements are satisfied.

Figure 2, which depicts the verification network, outlines major paths leading toward integrated verification of the system for flight (OFT and operations). Table 1, which illustrates the Space Shuttle C&T system verification requirements versus facilities, provides quick identification of Shuttle vehicle RF links tested at various facilities. The verification requirements, methods and criteria, and hardware and software requirements of all facilities for a typical RF link are described in Table 2.

Special tests and analyses that complement the results of the link tests described are shown in Table 3. All the special tests are important to the requirements, and those performed at KSC prior to launch determine the readiness of the C&T links. The analyses, including special studies to determine link margins, will be the basis for verifying some criteria.[3]

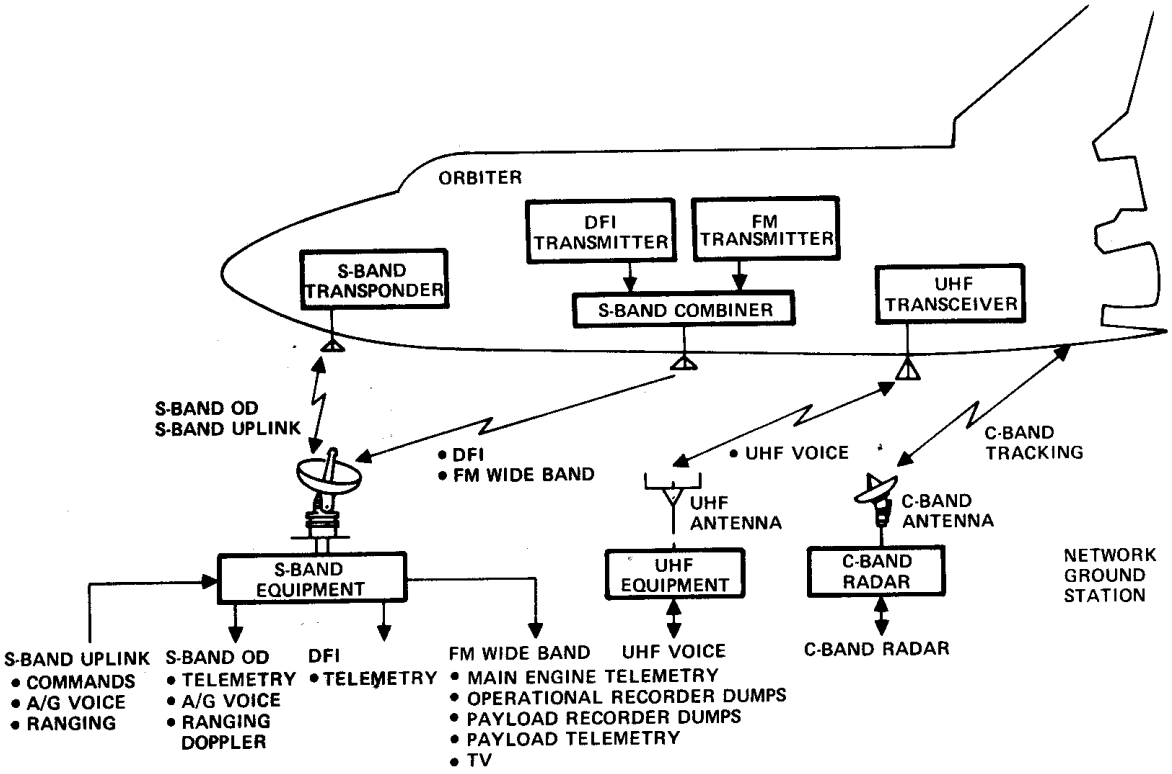

Figure 1. Orbiter- to- Ground Data Links

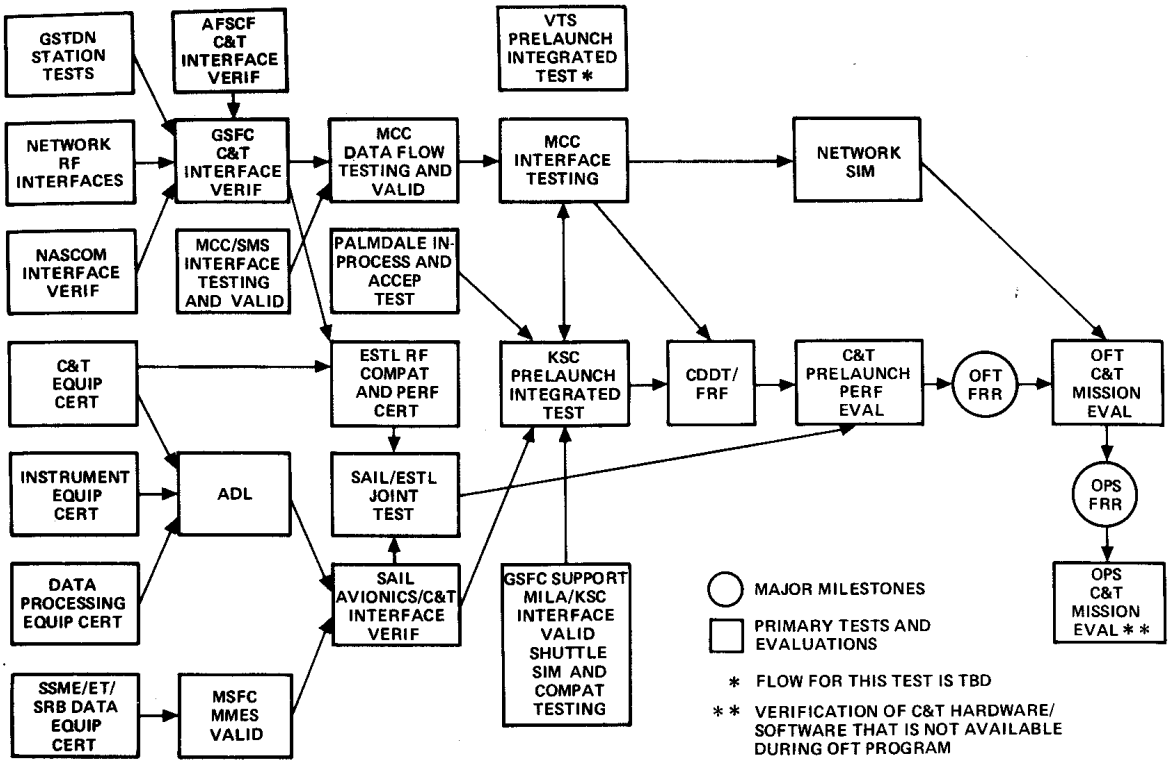

Figure 2 Communications and Tracking System Verification Network

Table 1. Space Shuttle Orbiter Communications and Tracking System Matrix of Verification Requirements Versus Facilities

C&T System Verification Requirement	Facilities*							
	ADL	ESTL	Pmdl	SAIL	ESTL/ SAIL	MCC INT	KSC L&LF	Flight Test Requirements
SSO/GSTDN S-band PM direct up/downlinks	X	X	X	X	X	X	X	X
SSO/GSTDN S-band FM direct downlinks	X	X	X	X	X	X	X	X
SSO/GSTDN S-band DFI FM direct downlink	-	X	-	-	-	X	X	-
SSO/AFSCF S-band PM direct up/downlinks	X	X	X	X	X	X	X	X
SSO/AFSCF S-band FM direct downlink	X	X	X	X	X	X	X	X
SSO/AFSCF UHF voice up/downlink	X	X	X	X	X	X	X	X
SSO/GSTDN UHF voice up/downlinks	-	X	-	-	X	X	X	X
SSO/EVA UHF forward/return links	-	X	-	-	-	-	X	X
CCTV performance	-	-	-	-	-	-	-	X
SSO/GSTDN S-band two-way Doppler	X	X	X	-	X	X	X	X
SSO/GSTDN S-band metric data	X	X	X	-	X	X	X	X
SSO/GSTDN S-band ranging	X	X	X	-	X	X	X	X
SSO/AFSCF S-band metric data	X	X	X	-	X	X	X	X
C-band skin tracking	-	-	-	-	-	X	-	-
L- band TACAN	X	-	X	X	-	-	X	X
Radar altimeter	X	-	X	X	-	-	-	-
Microwave scanning-beam landing system	X	-	X	X	-	-	X	-

*ADL = Avionics Development Laboratory
ESTL = Electronic Systems Test Laboratory
Pmdl = Palmdale Facility
SAIL = Shuttle Avionics Integration Laboratory
KSC L&LF = Kennedy Space Center Launch and Landing Facility

Table2. SSO/GSTDNS-Band PM Direct Uplink and Downlink Verification (Channel/Data: uplink command, uplink voice, downlink telemetry, downlink voice mode; Requirement: Space Shuttle orbiter low and high power, low and high data rate, with and without ranging)

Facility	Verification Requirement	Verification Method/Criteria	Hardware/Software Requirements
ADL	Line replaceable unit (LRU) compatibility	Perform functional checkout.	Prototype hardware
	Interface with MDM, MTU, PCMNU, ACCU, and EIU	Perform functional checkout.	ADL-developed software
	GCIL verification	Perform functional checkout.	
	Up/downlink voice	Perform subjective voice quality evaluation.	
	Uplink command	Monitor command rejection rate.	
	Downlink telemetry	Monitor telemetry BER.	
	Quad antenna selection	Perform functional checkout in manual and auto modes.	
	RF compatibility	Perform functional checkout in conjunction with GSFC VAN.	
ESTL	Up/downlink acquisition	Verify procedure per ICD.	Prototype and flight-qualifiable hardware (share with SAIL)
	Up/downlink TDM	Verify BER is 10^{-4} or less for ICD-specified P_{rec}/N_o values.	ESTL-developed software
	Uplink command	Verify command rejection rate is less than 1.26×10^{-2} for 10^{-4} command decoder input BER.	

Facility	Verification Requirement	Verification Method/Criteria	Hardware/Software Requirements
	Up/downlink voice	Verify word intelligibility is 90 percent or better for ICD-specified P_{rec}/N_o values.	
	Downlink telemetry	Verify BER is 10^{-4} or less for ICD-specified P_{rec}/N_o values.	
	RF compatibility	Perform functional and operational checkout.	
Palmdale	Interface with other avionic subsystems (instrumentation, EPDC, DPS, GN&C, and D&C)	Perform functional and operational checkout.	Flight hardware Flight software
	Transmission of voice and telemetry; reception of voice and command	Perform functional and operational checkout.	
SAIL	Interface with other avionic subsys tems (instrumentation, EPDC, DPS, GN&C, and D&C)	Perform functional and operational checkout.	Flight qualifiable hardware (share with ESTL)
	Interface with LPS	Perform functional and operational checkout.	Flight software
	Quad antenna selection	Perform functional checkout in manual and auto modes.	
ESTL/SAIL	Data flow	With SAIL simulating Shuttle vehicle and ESTL simulating GSTDN ground station, perform functional checkout.	Flight-qualifiable hardware Flight software
	Uplink command	Perform command functional checkout.	
	Up/downlink voice	Perform subjective voice quality evaluation.	
	Downlink telemetry	Verify data flow.	

Facility	Verification Requirement	Verification Method/Criteria	Hardware/Software Requirements
MCC Integration	MCC/GSFC/GSTDN data flow MCC/GSFC/AFSCF (I OS only) data flow MCC/MILA data flow	Verify functional and operational hardware/software interface compatibility for full network simulations and perform prelaunch checkout for voice, command, and telemetry channels.	Flight hardware Flight software
KSC L&LS Integration	Shuttle interface	Perform functional checkout.	Flight hardware Flight software
	Orbiter/OPF integration (hardline and RF) COMSEC test in OPF	Perform functional and operational checkout; verify voice,command, and telemetry channel performance.	
	Orbiter/OPF/MILA/MCC interface	Perform functional, operational, and interface checkout.	
Flight Test Requirement	Verification Requirement	Verification Method/Criteria	Hardware/Software Requirements
	Up/downlink voice	Evaluate postflight performance.	Flight hardware
	Uplink command		Flight software
	Downlink telemetry		
	Quad antenna patterns	Analyze postflight performance.	

Table 3. Special Tests and Analysis

Special Tests	Test Location
S-band and UHF direct lines SRB plume effects	To be performed at Thiokol Corp. in Brigham, Utah, during SRB DMA (development motor) and DM-2 static firing tests.
S-band TDRSS relay link RFI	On-orbit test, ESTL
Rendezvous radar	To be performed at White Sands, New Mexico
TDRS-A on-orbit communications (IUS/SSO/TDRS/ESTL)	To be performed at ESTL
TACAN end-to-end	To be performed at SAIL
Scott AFB TACAN flight	To be performed at Scott AFB
OV-101 EMI	To be performed at Palmdale
OV-102 on-pad RFI	To be performed at KSC
GSFC VAN S-band PM/FM compatibility	To be performed at KSC
GSFC VAN S-band PM/FM compatibility	To be performed at Ponce de Leon
Spacelab high-rate multiplexer/SSO Ku-band system interface	To be performed at ESTL
Orbiter integrated test (OIT)	To be performed at KSC
MCC-H interface test OPF/pad	Performed at KSC (OMI S0002)
Tempest test in OPF	Performed at KSC
Shuttle interface test (LPS) - VAB	Performed at KSC (OMI S0008)
Plugs-out overall test and reconfiguration (LPS) - pad	Perf ormed at KSC (OMI S0010)
Wet CDD/flight readiness firing (LPS) - pad	Performed at KSC (OMI S0014)
Launch readiness verification (LPS) - pad	Performed at KSC (OMI S0015)
Analysis	
RF coverage analysis - dynamic circuit margin plot, mission coverage time, etc.	
Circuit margin document - baseline circuit margin for nominal flight cases for all links.	

LABORATORY INTEGRATED VERIFICATION

Three laboratory facilities are used individually and in combination to verify the requirements for Shuttle communications and tracking: Shuttle Avionics Integration Laboratory (SAIL) and Electronic Systems Test Laboratory (ESTL) at Johnson Space Center (JSC), and the Avionics Development Laboratory (ADL) at Downey, California. Orbiter C&T hardware is tested to verify the interface compatibility of line replaceable units (LRU's), and the C&T system is tested to verify the interface requirements with other avionic subsystems in the ADL through the use of ADL-developed software and prototype hardware. The flight-qualifiable hardware and flight software are tested to verify interface requirements with other element avionic subsystems in the SAIL. RF compatibility tests, certification, and verification of performance between the C&T and the ground network equipment take place in the ESTL. A SAIL/ESTL joint test is conducted to verify that RF-related interfaces can generate, process, and distribute compatible data formats. All verification information from the SAIL and ESTL tests is made available for analysis at the C&T prelaunch performance evaluation. Additionally, the results of the tests are applied to the C&T system prelaunch integrated test and the countdown demonstration test/flight readiness firing (CDDT/FRF).

PALMDALE C&T SYSTEM INTEGRATED VERIFICATION

The Palmdale final assembly facility performs primarily in-process and acceptance tests. The flight-qualified C&T LRU's are installed on the flight vehicle after functional checkout. The C&T system is tested and verified as a part of the overall avionic system. The flight hardware is tested to verify the interfaces of the LRU's, and the C&T system is tested by flight software to verify the interface with other subsystems in the avionic system.

Calibration data—such as transmission powers, receiver automatic gain control (AGC), transmission and reception cable losses, frequency deviations, etc—are recorded and documented to support postflight analyses. The performance of the C&T system is verified against the procurement specifications. The various operational modes for each RF link are verified through display and control (D&C) panel selection and ground commands (via ground command interface logic). All verification information from Palmdale is made available for reference during prelaunch integrated test and for analysis at the C&T prelaunch performance evaluation. However, some tests that cannot be conducted due to either retrofit of LRU's or lack of testing equipment are to be performed during prelaunch integrated testing at Kennedy Space Center (KSC) or Vandenberg Air Force Base.

STDN INTERFACE VERIFICATION

The STDN for OFT is composed of tracking and data stations located at various geographic sites around the world. The station capabilities include communications, tracking, and data acquisition and handling. Central control is through the NASA communication (NASCOM) at GSFC for operational interface with MCC and the L&L facility. Shuttle requirements for integrated C&T are verified by means of data from STDN station tests, network RF interface verification, and NASCOM interface verification.

Equipment interfaces are validated during MCC data flow tests, MCC interface testing, and the full-up network simulations. The interface requirements between selected ground station equipment and the orbiter C&T hardware are verified during ESTL testing. Special verification of interface requirements is obtained from Merritt Island (Florida) launch area (MILA)/KSC validation. The ground/STDN (GSTDN) collective interface requirements are verified during MCC/MILA/KSC functional operation during CDDT/FRF. The results of all the interface operations are evaluated for compliance with requirements prior to the first manned orbital flight (FMOF) in the areas of compatibility with range safety, C-bank skin track, National Aeronautics and Space Administration (NASA) and Department of Defense (DOD) prelaunch validation, and end-to-end data flow.

A comprehensive program of Shuttle simulation and compatibility test support is carried out by GSFC for C&T integration and verification. A portable simulator system is programmed to represent the OFT vehicle. This simulator is located at the GSTDN sites to conduct telemetry data flows with the Network Operations Control Center (NOCC) at GSFC. Network commands are generated from the NOCC, and the data are displayed and recorded for analysis. The portable simulation system permits C&T compatibility tests between the GSTDN remote site and NOCC. Thus, problems and contingencies are worked out before the MCC interface tests.

AIR FORCE SATELLITE CONTROL FACILITY INTERFACE VERIFICATION

Ihe AFSCF is the DOD agency responsible for the management, design, operation, and maintenance of a worldwide network. The AFSCF space-ground link system (SGLS) comprises six remote tracking stations (RTS’s) at six geographically dispersed locations and a Satellite Test Center (STC) in Sunnyvale, California. Three RTS locations have single stations, and three locations have dual stations that can support two flight vehicles simultaneously. The details of support for orbiter C&T verification and compatibility testing are being planned. Shuttle requirements for integrated C&T are verified by means of data from SGLS station tests and network RF interface verification. The capability exists for full-up simulation with RTS. The Air Force Indian Ocean station (IOS) is planned to support NASA missions during the OFT program.

MCC INTEGRATED VERIFICATION

The Mission Control Center is an integrated flight control facility designed to interface with the STDN and AFSCF, providing voice, telemetry, command, television, and tracking support that links the Shuttle vehicle with the ground. The verification program for MCC/C&T integration includes a series of data flow tests and validation activities. Initially, the data flow tests are conducted with test data base software; gradually, a transition is made in the prelaunch time frame to all-up equipment and software interface tests of the Shuttle vehicle, networks, and MCC. Data flow testing between MCC and GSFC/AFSCF is conducted to verify the capability of the systems to meet interface requirements. Data flow verification with the MILA station is established after the flight configuration is completed, preparing MCC to support CDDT/FRF demonstrations.

MCC interface testing includes software validation of the MCC/GSFC/STDN and MCC/GSFC/AFSCF interfaces, full network simulations for functional checkout, and Shuttle vehicle prelaunch verification support of the KSC and Vandenberg Air Force Base integrated checkout program. The MCC interface tests demonstrate the various C&T functions initiated by MCC uplink commands—such as S-band components and system control and switching—transmission of Shuttle abort request, orbiter on-board recorder controls, and orbiter computer pulse, code modulation master unit (PCMMU) and mass memory control initiated by various software control and modification commands. The tests also demonstrate the capability for voice communications via orbiter S-band, Ku-band, and UHF links with MCC.

KSC LAUNCH AND LANDING SYSTEM C&T VERIFICATION

C&T system development and functional integration with the L&L system is carried out as part of the overall verification activity established for the Shuttle vehicle by KSC. L&L-developed operations and maintenance instructions (OMI’s) include C&T test and checkout operations of the vehicle with the GSTDN station at MILA and the MCC, and C&T test and checkout operations of the vehicle with the Tracking and Data Relay Satellite System (TDRSS) with MILA as the ground station, the MCC, and the orbiter processing facility (OPF). As a prelude to these operations, C&T interfaces between the KSC launch processing system (LPS) and the Shuttle vehicle are tested in the SAIL to verify functional data flow requirements. The results of these tests are analyzed and integrated with the information from the ESTL RF compatibility and performance certification for use in the KSC prelaunch integrated tests, including C&T tests supported by the MCC as part of the OMI’s involved (e.g., the first MCC interface test with the vehicle in the OPF, the orbiter integrated tests in the OPF, the Shuttle interface test in the vertical assembly building, the wet CDDT/FRF during launch readiness verification at the pad, the interface checks with range safety, a second MCC interface test at the pad, the

dry CDDT, and the countdown before launch). During each of these OMI activities, the MCC communication and data lines with MILA are used while the L&L C&T system is linked via RF and/or hardline with MILA to verify the functional hookups.

IN-FLIGHT VERIFICATION OF C&T SYSTEM

The final phase of the verification process for the C&T system is an analysis of system performance under operational environments in which the ground facility's compatibility with the Shuttle vehicle subsystems is tested by operational procedures. More specifically, the C&T end-to-end performance is evaluated in accordance with flight test requirements (FTR's) with regard to S-band PM and FM direct links (GSTDN and AFSCF), solid rocket booster (SRB)/main propulsion system (MPS) plume effects on S-band links, high-altitude TACAN, UHF voice link, EVA voice/data link, closed-circuit television, S-band payload links (NASA and DOD), and S-band PM and FM antenna pattern tests.

ORBITER DATA REDUCTION COMPLEX

The Orbiter Data Reduction Complex is a Space Shuttle facility involved in processing engineering data generated during the SAIL tests and the OFT program (including post-OFT FTR data). Data tapes from SAIL tests and from OFT telemetry are processed to permit postflight evaluation of the Shuttle vehicle performance and analysis of problems, to support SAIL avionics certification, to provide quick-look data, and to provide near-real-time monitoring of selected thermal parameters for evaluation of in-flight thermal conditions. The C&T system is one of the primary disciplines making use of the complex for the overall verification process.

SUMMARY

The verification testing program is planned to ensure that the C&T links are ready to support the first orbital flight. Not only will the equipment be tested but, through simulation and special tests, the support personnel also will be trained for the mission.

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