N81-14139

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COMPREHENSIVE TESTING OF A DEFENSE SYSTEMS COMMUNICATIONS SATELLITE

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ABSTRACT

This paper reviews the system level testing of the Defense Satellite Communications System III program concentrating on the results of the systems tests of the DSCS III Development Test Model (DTM). The DSCS III Development Test Model consisted of engineering components interconnected in an open bench layout. The DTM tests were performed to demonstrate satellite electrical performance characteristics, and to uncover design deficiencies and interface problems. The availability of the DTM test results prior to the fabrication of the flight model hardware permitted the incorporation of necessary design changes with a minimum impact on program costs and schedules.

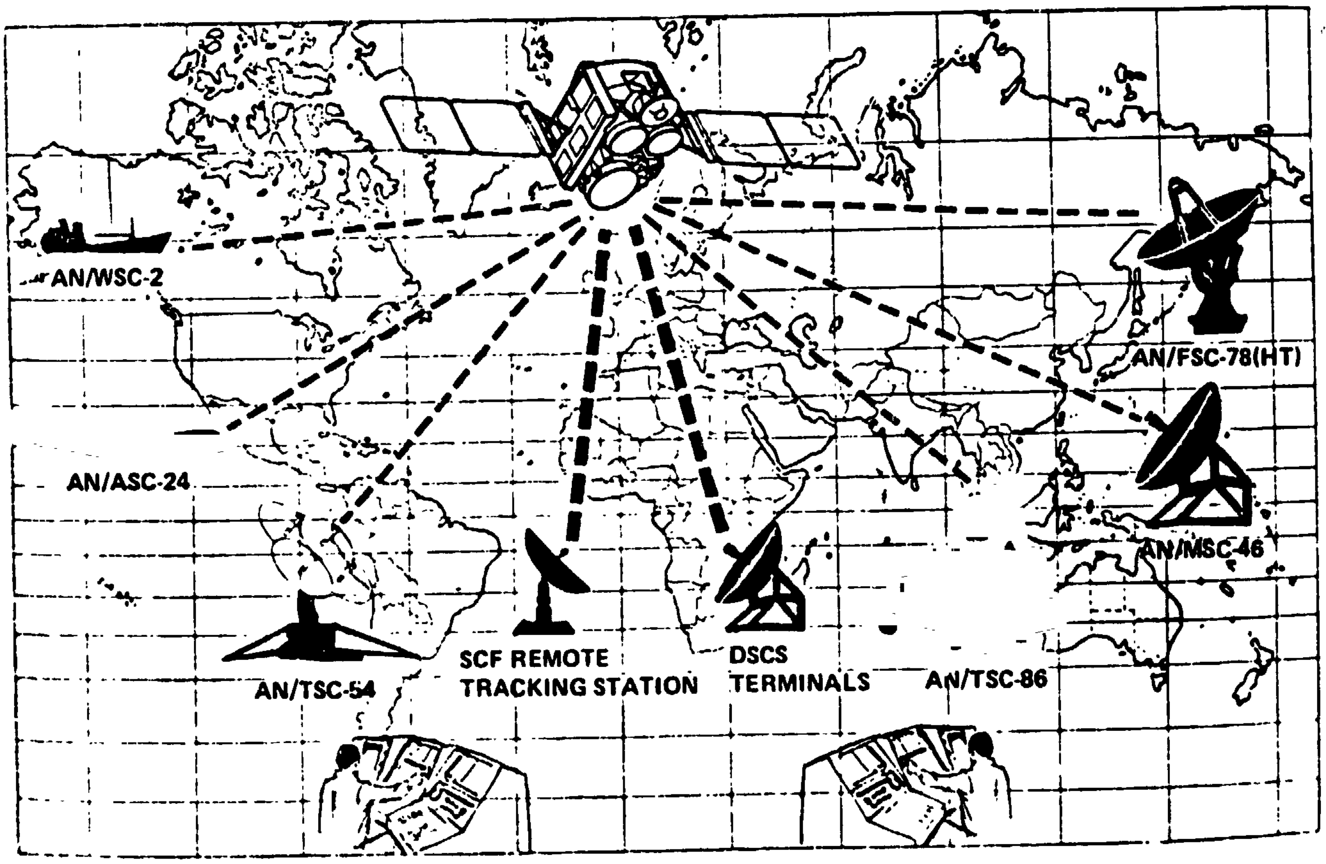
DSCS III SATELLITE

Mission Description

The goal of the DSCS III program is to provide a network of four operational communication satellites and two on-orbit spares in synchronous orbit. Each satellite is designed to have a life expectancy of ten years and the capability of being launched from a Titan booster or the Space Shuttle.

The six channel communications payload has anti-jam capability and nuclear survivability provisions. The primary system utilizes SHF (X-Band) frequencies to serve the Department of Defense World Wide Military Command and Control Communications System (WWMCCS), the ground mobile forces, the Defense Communications System (DSC), Navy Fleet Communications, the White House Communications Agency, and Allied Communications Network such as NATO. A secondary communications payload is an Air Force Satellite Communications Single Channel Transponder which provides service to Air Force elements. Figure 1 illustrates typical satellite system operation.

TYPICAL SYSTEM OPERATION



SPACE AND MISSILE SYSTEMS ORGANIZATION SATELLITE CONTROL FACILITY (SCF)

Ground control complex at Sunnyvale, Cal. monitors and controls the housekeeping of the DSCS III spacecraft via its Remote Tracking Station Network. The SCF also provides backup Communication Configuration Control functions.

DEFENSE COMMUNICATIONS AGENCY SATELLITE CONFIGURATION CONTROL ELEMENT (SCCE)

SCCE's provide in-band command and control of the payload configurations to meet worldwide user requirements. They also display selected payload and telemetry data.

Figure 1

The satellite weighs approximately 1870 pounds, with additional propellant load up to 600 lbs. The attitude control subsystem provides three axis stabilization and maintains pointing of the communications antennas towards the earth. Power to operate the satellite is collected by two unidirectional drive solar arrays. Command control and performance monitoring are accomplished by either S-Band or X-Band Telemetry Tracking and Command subsystems. Key satellite design and performance characteristics are listed in Figure 2.

EM	KEY FEATURES
craft ary	• 3-Axis Stabilized • Single Axis Sun Oriented • Large North/South Viewing Panels for Passive Heat Rejection • 10-Year Design Life • North/South Stationkeeping • Reliability Exceeds .7 at 7 Years • Low Life-Cycle Cost
: stem	• Command and Telemetry Interface with SCF, DCS Terminals, and Shuttle • Rapid MBA Reconfiguration • Incorporation of S Band and UHF COMSEC Equipment
nel ponder	• SHF and UHF Receive Frequency Capability • Compatible with initial AFSATCOM I System • High A/J performance with AFSATCOM II Modulation • Wide bandwidth, fast response synthesizer • Digital matched filter MFSK/FSK demodulator • Integral operational command via comm channel • High power UHF P.A. at 60% power efficiency
ude rol ystem	• Autonomous initial acquisition and operation • Time Shared Central Digital Processor for all Control Modes • Earth & Sun Sensors for Attitude Sensing • Four Skewed Reaction Wheels • .08°R, .08°P, 0.5°Y Control Accuracy
trical er ystem	• Regulated Bus — 28V ± 1% — 126 sq. ft. Solar Array — 1100 Watts Output (BOL) • 96 AHr NiCd Battery Capacity

ITEM	KEY FEATURES
Electrical Power Subsystem (cont.)	• Fully Redundant • Rapid Response to Load Changes • Load Fault Isolation • Transient Protection
Propulsion Subsystem	• Hydrazine Propulsion System with Redundant Thrusters and Tanks • 600 Lb. Capacity • FLTSATCOM Tanks • 1.0 Lb. Thrusters
Thermal Subsystem	• Passive • North/South Radiator Panels using Optical Solar Reflectors • Imposes no Satellite Operational Restrictions • Survive Failure Modes Including Attitude Loss and Total Battery Failure
Structure Subsystem	• Accessibility/Modularity • Parallel Subsystem Assembly and Test • North/South Array Through Drive Shaft • Independent Propulsion Module • Vibration Damped Equipment Panels • Lightweight/Stiff/Dimensionally Stable • Growth and Option Flexibility
Survivability	• Overall Hardening Approach is Based Upon JCS Guidelines
Launch Vehicle	• Titan IIIC • Shuttle • Titan 34D IUS

Figure 2

SUBSYSTEM DESCRIPTIONS

Electrical Power and Distribution

The Electrical Power and Distribution Subsystem (EPDS) provides for the conversion of solar energy to electric power, the regulation and distribution of power to the satellite subsystems (loads), and the storage of electrical energy in three nickel-cadmium batteries for use during eclipse periods.

The generation, regulation and storage of power is accomplished in the following components:

- Two Solar Arrays (2 solar panels per array)
- One Power Regulation Unit
- Two Shunt Dissipators
- Three Nickel Cadmium Batteries

Power distribution is accomplished by:

- South Power Controller
- North Power Controller
- Ordnance Controller
- Electrical Harness

Telemetry, Tracking and Command

The Telemetry, Tracking and Command Subsystem provides for the reception, decryption and decoding of commands; reception, filtering and transmission of the ranging signal; and formatting, encryption and transmission of satellite telemetry.

Attitude Control Subsystem

The Attitude Control Subsystem provides the function of attitude sensing, signal processing, drive signals for control actuation, control of Solar Array positioning, BFN reconfiguration and GDA positioning. The ACS also processes commands for mode switching and command data storage, and outputs telemetry to the CTU.

Communications Transponder Subsystem

The Communications Transponder Subsystem provides six SHF communications channels, each powered by its own TWT amplifier. Signals are received and transmitted through an interconnected set of antennas which includes:

- Two earth coverage receive horns
- Two earth coverage transmit horns
- One 61 beam receive antenna for selective coverage
- Two 19 beam transmit antennas for selective coverage
- One high-gain gimballed dish transmit antenna for adjustable coverage.

DSCS III TEST PROGRAM

Test Philosophy

The General Electric approach to the development of long life satellites is based on the concept that on-orbit failures which result in mission failure or degradation of performance can be eliminated from flight systems by three major techniques:

1. Failure prevention by thorough design
2. Failure removal by proper inspection and establishment of test screens
3. Failure protection by adequate redundancy and backup operational modes.

Strong emphasis is placed on comprehensive performance and environmental tests to provide effective screens to eliminate design deficiencies, inferior material and poor workmanship. These tests are progressive in nature, starting with the piece part level, followed by development tests of components, subsystems and development models, and continuing through the qualification and acceptance test at each level of assembly, and culminating with the final acceptance and certification of the flight satellite.

Maximum emphasis is placed on the comprehensive testing at the component and lower levels of assembly where defects are most easily detected and rework has a minimum impact on cost and schedule. Testing at the subsystem levcl of assembly is applied on certain subsystems which require unique performance characteristics to be verified that are impractical, or too costly, to verify at the satellite level of integration. Major emphasis is also applicable at the satellite level where the system is fully configured for flight verification of system compatibility and performance under environmental conditions representative of the mission.

DSCS III Test Program

1. Development Testing

Development tests were used to verify critical design areas prior to the design freeze and to prove the adequacy of the system design with respect to performance requirements. The development program included material and specimen evaluations, breadboard tests of circuits and subassemblies and integrated systems tests employing Structural, Thermal and Electrical Development Test Models.

2. Qualification Testing

Qualification testing provided verification of hardware design by subjecting parts, components, and critical subsystems to environmental levels and durations in excess of what they are expected to experience during flight. The assembled Qualification Satellite in turn undergoes a complete program of environmental tests.

3. Acceptance Testing

The components, subsystems and satellite which comprise the flight satellites follow the same test program as the qualification units, except that the environmental test stress levels are lower in magnitude and shorter in duration.

DEVELOPMENT TEST MODEL

The DSCS III Development Test (DTM) provided an electrical systems representation of the satellite by interconnecting engineering model components in an open bench layout. This configuration served as a systems level test screen for the early detection of system incompatibilities and design problems.

Test Objectives

The primary objectives of the DSCS III Development Test Model tests were:

- To validate electrical systems compatibility at the satellite systems level.
- To demonstrate ground software/satellite compatibility.

Some of the secondary objectives that were also accomplished during DTM testing are as follows:

- To develop electrical integration and performance procedures for the qualification and flight satellites.
- To demonstrate electrical auxiliary ground equipment/satellite compatibility.
- To train test personnel.
- To obtain engineering test data for preliminary design evaluation.

Test Configuration

The DTM system tests were performed in the open bench layout as depicted in Figure 3.

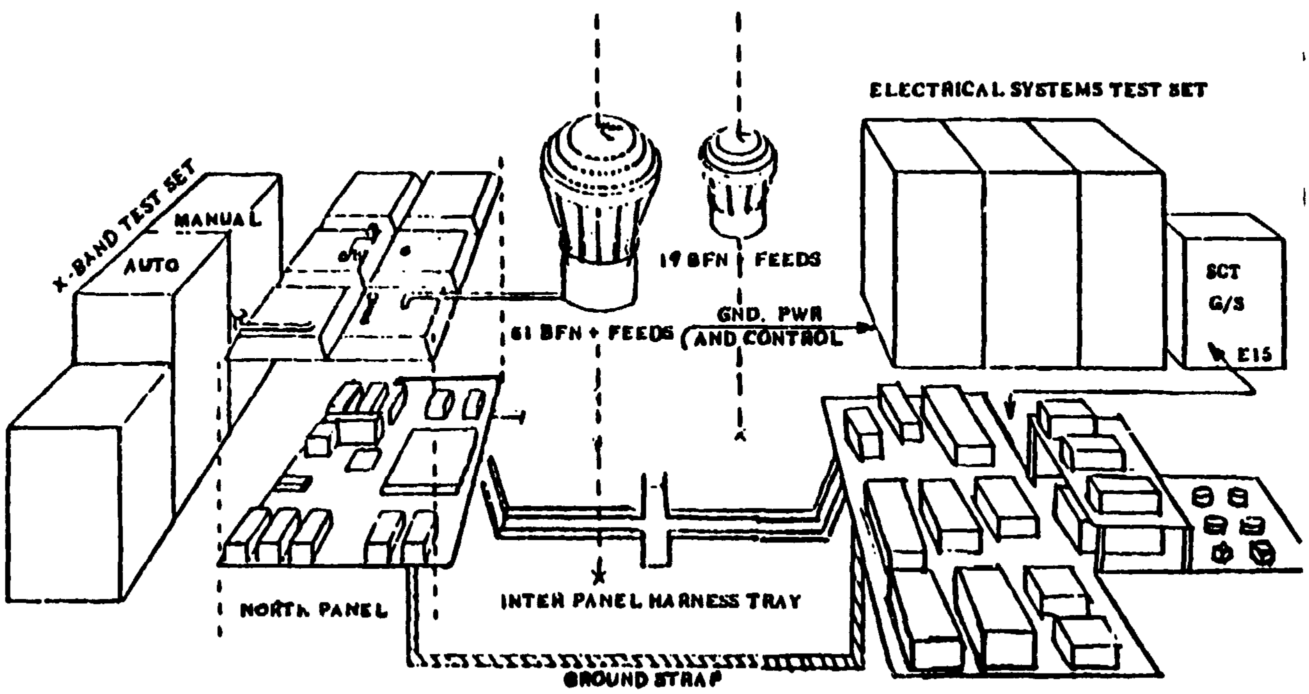


Figure 3. Development Test Model (DTM)

Test Sequence

The sequence of tests established for the DTM correspond to the integration and ambient functional tests that the qualification and flight satellites would undergo. The only additional environment to which the DTM was exposed was the EMC environment. Figure 4 illustrates the DTM test sequence and duration. During all powered testing the command and telemetry software were employed.

Test anomalies are documented by means of a problem report system. In this system all potential problems, or unexplained occurrences relating to test procedures, electrical AGE, software, hardware, drawings and test data are reported. The problem report is addressed to the responsible engineer, or analyst, to investigate. Once the cause of the problem is diagnosed, corrective action is defined. The problem report remains open until the corrective action is completed. Upon successful resolution of the problem, the Problem Report Review Board will concur in closing the problem report. For the DTM testing, the Problem Report Review Board consisted of representatives from Systems Test, Engineering and Product Assurance.

In the performance of the DSCS DTM tests, a total of 249 problem reports were written. The problem report breakdown per failure types, and subsystem occurrence are presented in Table I. Currently the Qualification satellite is in the integration phase of testing. To date, 249 problem reports have been written, and Table II presents the same breakdown for the Qualification satellite problem reports. It should be noted that the Qualification satellite includes more actual hardware than the DTM, as well as a complete set of operational software, much of which was not available for DTM.

Test Results

The DTM tests provided verification of 85% of the spacecraft system level electrical performance requirements as delineated in the prime item specification. These results were limited primarily by the test configuration and the available hardware.

Summary

The DTM test program served its purpose well, in that several hardware problems which required redesigns were uncovered. In addition, those portions of the Operations Software which were available at the time were exercised and necessary redesigns incorporated.

Hardware Redesigns

Hardware redesigns generated by the DTM test program are herein summarized by subsystem.

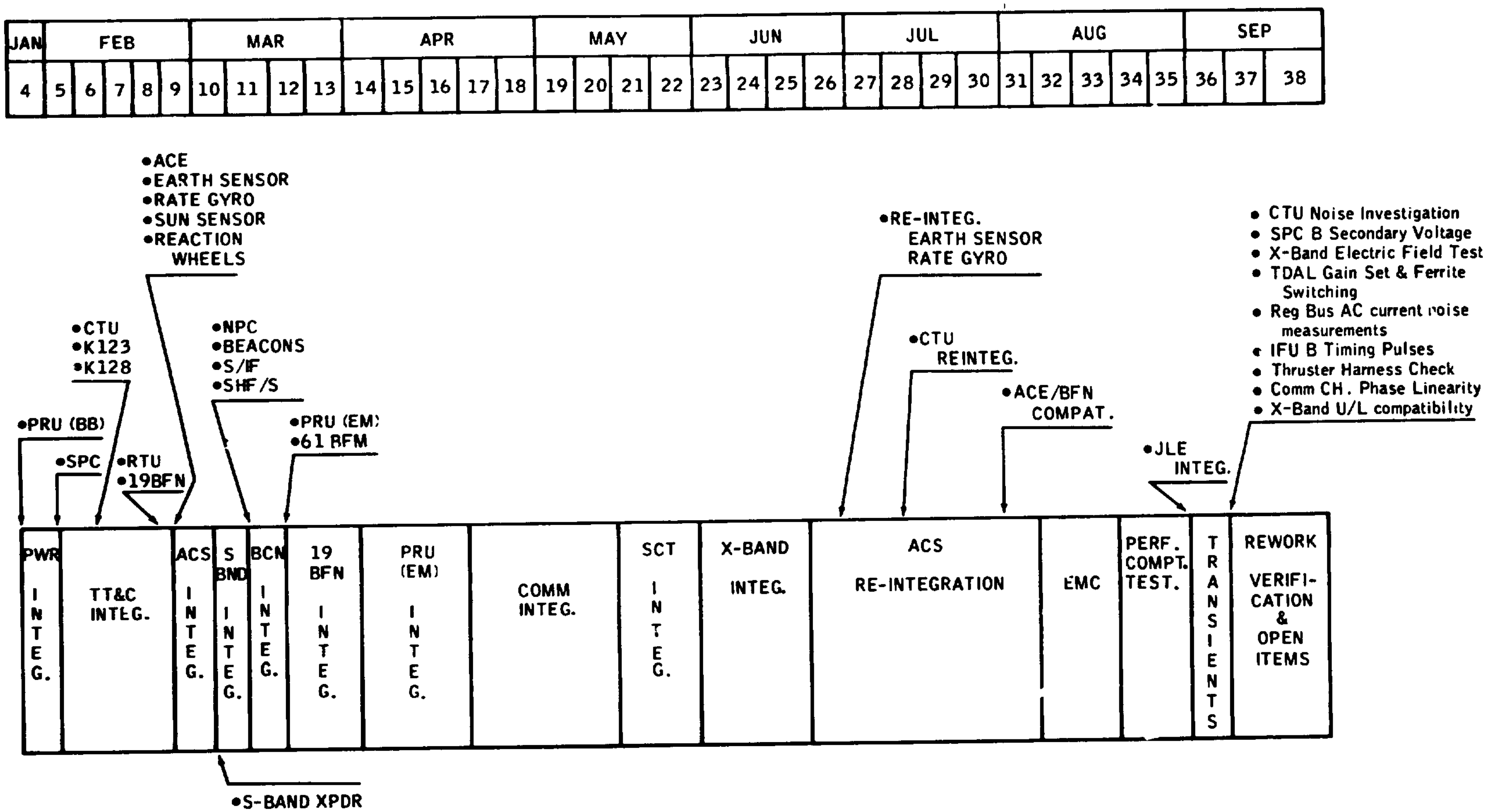


Figure 4.- DTM test schedule.

TABLE I

DTM PROBLEM REPORTS

Category	Nature of Problem	Quantity	% of Total
Satellite Hardware			
	Design	27	
	Failure	14	
	Workmanship	17	
		58	23.3
Ground Station			
	Design	3	
	Failure	15	
	Workmanship	6	
		24	9.6
Software			
	Design	27	10.8
Documentation			
	SW Data Base	9	
	Procedures	11	
	Drawings & Specs	23	
	Duplication of Problem Report	32	
		75	30.1
Test Related			
	Test Errors	31	
	Test Configuration Limitation	14	
		45	18.1
Unresolved		20	8.1

TABLE II

QUAL PROBLEM REPORTS

Category	Nature of Problem	Quantity	% of Total
Satellite Hardware			
	Design	3	
	Failure	3	
	Workmanship	11	
		17	6.8
Ground Station			
	Design	4	
	Failure	25	
	Fabrication	7	
	Documentation	7	
		43	17.3
Software			
	Design	25	
	Documentation	2	
	Operation	2	
		29	11.6
Documentation			
	SW Data Base	40	
	Procedures	52	
	Drawings & Specs	23	
	Duplication of P.R.	13	
		128	51.4
Test Related			
	Test Errors	14	
	Test Config/Limitations	6	
	Test Equip. Failures	2	
		22	8.8
Unresolved		10	4.1

Electrical Power and Distribution Subsystem

- Oscillations on the regulated voltage bus traced to marginal capacitance value in the power regulator feedback loop.

Attitude Control Subsystem

- Incorrect phasing of the reaction wheel tachometer signals.
- Incorrect phasing of the gimballed dish antenna motor drives.
- Several logic and timing signal problems associated with the imbedded software in the attitude control electronics.

S-Band Telemetry, Tracking and Command

- Logic circuitry in command, telemetry unit disabled telemetry unit when both X-band decryptor units were powered off.

- Command counter bit stream presented to telemetry processor in reverse order.

- Several logic and timing signal problems in association with other hardware units.

X-Band Telemetry, Tracking and Command

- Phasing of clock timing signal inverted.

- Interface problem in ground encryption equipment.

- Faulty cross-strapping design with two groups of redundant equipment.

SHF Communications Transponder

- Improper loading of ferrite switches in command interface unit.

- Improper phasing of digital timing signals in command interface unit.

Software Redesigns

During the development testing of the hardware the majority of software modules were in the development phase themselves. Sufficient software was available to provide S-band and X-band command generation and telemetry processing of the normal housekeeping functions and to provide a limited capability for antenna reconfigurations. Since the software is primarily designed for an orbit operation, some design modifications were required to accommodate in-house testing. However, the command and telemetry software modules were tested and several design modifications defined.

CONCLUSIONS

Satellite hardware problems have been reduced - by a factor of three - between the DTM and the qualification satellite integration tests and satellite design problems have been reduced by a factor of nine.

Testing and troubleshooting at the DTM level was less expensive since the number of people in a DTM test crew was fewer than the number of people in a Qual or Flight test crew.

The rework of qualification hardware to incorporate design changes impacts program costs in two ways, viz.:

(1) Cost for requalification tests of hardware
(2) Cost for down time and schedule slip at systems test level.

The 27 design problems in DTM effected nine different components which would have required (if not detected in DTM) requalification of each of these components at the qualification satellite test level.

The cost of down time and schedule slips at the system test level which would impact the launch date, etc. is unmeasurable.

The substantial complexity of the DSCS III satellite necessitates the use of systems level development tests such as the DTM tests in order to accomplish verification of electrical systems compatibility and system design with minimum impact on program costs and schedules.