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On-Orbit Checkout Study
Final Report

Prepared by Advanced Mission Analysis Directorate
Advanced Orbital Systems Division

13 January 1977

Prepared for
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
Washington, D. C.

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Systems Engineering Operations
THE AEROSPACE CORPORATION

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ON-ORBIT CHECKOUT STUDY

FINAL REPORT

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FOREWORD

This report covers a study sponsored by NASA Headquarters and accomplished under the technical direction of the NASA Goddard Space Flight Center (GSFC). The initial NASA Headquarters Study Dir ector was William F. Moore of the Advanced Missions and Payloads Office (MK). When Mr. Moore's responsibilities changed, Dr. Robert Wilson became the Headquarters Study Director. Study Technical Director is Howard J. Pedolsky, GSFC.

The study technical effort was accomplished between 1 Octob 1975 and 30 June 1976. This study is the first in what is designed to be a series of small studies on the subject, the end product of which will be the requirements, general specifications, and plan for NASA to deve and implement on-orbit checkout of automated Shuttle payloads.

The technical work on this study was accomplished by:

Robert N. Constant	Computer and Data Bus
Richard M. Coulston	Timelines and Ground Support Equipment
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Erik Unt	Attitude Control and Guidance
Harry H. Yoshikawa	Thermal Control

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1. INTRODUCTION

The feasibility and need for on-orbit checkout of STS payloads is considered in this study. To be effective, checkout of Shuttle payloads on orbit would be accomplished while the payload is attached to the orbiter or while the payload is detached but still in the vicinity of the orbiter in space.

On-orbit checkout for STS payloads is potentially very desirable for all STS users. There are many considerations contributing to the need for on-orbit checkout. The payload project representative will have decisions to make after the powered flight of the Shuttle is completed. Major decision points are expected to occur when the payload is unberthed from the Shuttle (i.e., released by the payload support or cradle), when the payload is released by the Shuttle [usually from the remote manipulator system (RMS)], and when approval is given for the orbiter to leave the vicinity of the released payload. In order to make these decisions, the representative will need data on the condition of the payload. In addition, checkout would (1) be required for space resupply (space service) or assembly of a payload in space, (2) be required for checkout of zero-g devices, (3) prevent the loss of a nonreturnable STS payload suffering early degradation or failure, (4) prevent the return and refurbishment of payloads when adjustment or repair in space is possible, (5) prevent an extra flight for retrieving a payload which can be retrieved and returned for repair, and (6) decrease the elapsed time for satellite initiation.

All on-orbit checkout being considered in this study will be occurring in low altitude Shuttle orbits. There are several potential modes for carrying out on-orbit checkout; for instance, the checkout can be supported, controlled, and sequenced from the ground. The Operational Control Center accomplishing the on-orbit checkout tests can signal the payload and receive responses either through the orbiter communications system or by communicating directly with the payload. Another mode for on-orbit checkout operation makes use of on-board, in-flight, automated equipments for sequencing and controlling most of the checkout with the results being communicated to the ground.

The communication path becomes important to the checkout study. Communication through the TDRS (Tracking and Data Relay Satellite) either directly with the satellite or through the orbiter system is considered. The effects of accomplishing the checkout without the presence of the TDRS system using only the ground terminals and ground network are also considered. In the latter case, communication with the satellite can only be obtained when the satellite passes within sight of the ground station. Carrying automated checkout equipment in the orbiter bay would minimize the ground communications requirements by handling much of the detailed sequencing, tolerance checking, and data handling from elements of the checkout procedure. In this case, even without the TDRS, the elapsed time for checkout would be kept low since the checkout operation would generally be continuous. Thus the time would be minimized that the orbiter is tied up with the payload checkout. This is especially desirable for multiple satellite deployment flights or multiple satellite service flights.

It will be expedient to support payload checkout with the same equipment used at the factory as a part of the factory testing, and again using the same equipment as is used for prelaunch checkout and launch checkout. This keeps the same interface between the satellite and the checkout system, gives the operators a chance to practice and evaluate the on-orbit checkout on the ground prior to flight, and makes it easy to compare orbital checkout results with the ground-based checkout results.

An effective approach to implementing on-orbit checkout would be expected to provide support equipment and software, which could be applied to many STS users, thus sharing the cost of equipment development and procurement and software development and procurement over several payload projects.

1.1 OBJECTIVE

The objective is to investigate the feasibility and effectiveness of on-orbit checkout of advanced STS payloads. The feasibility of on-orbit checkout controlled and automatically accomplished by equipment which remains attached to the Space Shuttle is to be considered. On-orbit checkout which is controlled and sequenced by equipment at the payload operational control center is also to be considered.

1.2 QUESTIONS FOR STUDY

As the study was initiated, there were a number of questions about on-orbit checkout to which Aerospace hoped to provide answers or further insight. These questions were:

1. Is a thorough checkout of automated payloads in the orbiter bay feasible? Are the real-time process control equipment, time constraints and requirements within the state of the art? Can the satellite subsystems be sufficiently tested within the payload bay constraints? How much validation of checkout results is needed?

2. How much checkout automation is required to keep the elapsed time for checkout within orbiter payload time constraints and to satisfy the need to minimize human error in running checkout tests?

3. Where should automated process control equipment be located -- at the project operations control center or onboard the orbiter?

4. How much commonality is there between on-orbit checkout equipments required for different payload projects?

5. How beneficial is on-orbit checkout of automated payloads supported by the orbiter? What is the value of the benefits (i.e., savings due to correction of (1) launch and ascent induced failures, (2) satellite start-up failures, and (3) checkout after on-orbit repair)? What is the cost increment to implement and operate on-orbit checkout?

2. SUMMARY OF RESULTS

The three example satellites selected for this study were Stormsat, the Synchronous Meteorological Satellite (SMS/GOES), and the Technology Demonstration Satellite (TDS). The satellite projects and the rationale for their selection are described in Section 3.

2.1 SUMMARY OF TESTS

Figure 2-1 shows the top level on-orbit checkout test flow, assuming the tests all have positive results. During test period 1, the spaceborne testing equipment carried by the orbiter and the measuring equipment onboard the satellite (telemetry) is tested to verify that each is operating satisfactorily. The satellite command system is also checked Thermal stabilization with the satellite in the orbiter shadow is achieved in six to eight hours. During test period 2, satellite subsystem tests are run (see Section 4 for details) and thermal control by heaters is checked. Thermal stabilization with the satellite exposed to the sun (when the orbiter is in sunlight) is again achieved in an estimated six to eight hours. During test period 3, subsystem tests are again run in the "hot" condition, and heat rejection tests are made.

For test periods 1, 2, and 3, the options for testing the RF portion of the tracking, telemetry, and command (TT&C) subsystem in the satellite are either (1) through an RF link furnished as part of the checkout equipment, (2) through the orbiter/spacecraft (payload interrogator link), or (3) with the payload communicating directly with the ground For the third option, the digital bit stream runs through the orbiter to sate lite cable and umbilical.

In performing on-orbit checkout, several types of tests are carried out. Telemetry readout, status, and limit checking tests are performed on all the subsystems. Tests are made periodically and

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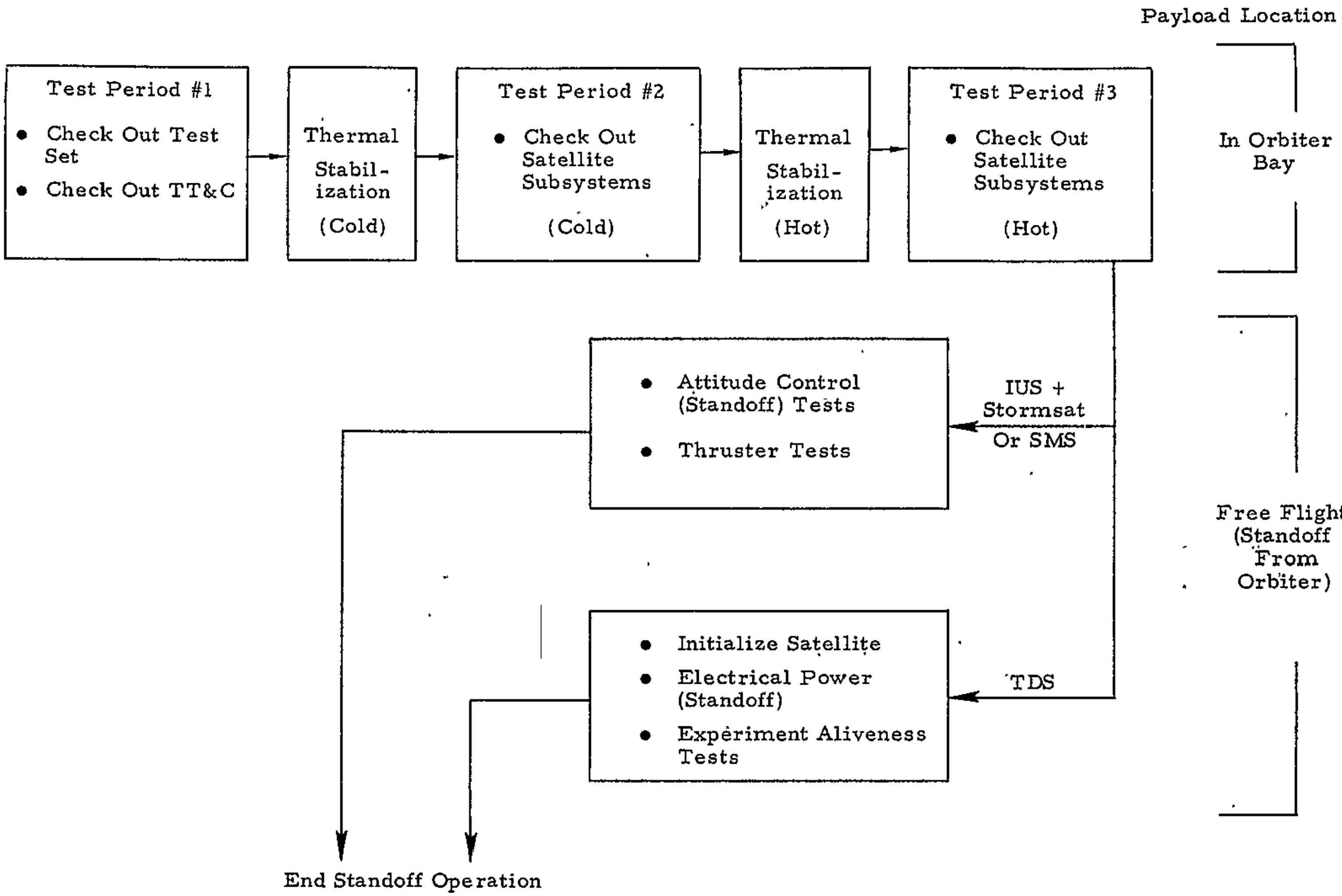

Figure 2-1. Generalized Top-Level Checkout Flow Assuming No Initial Failures

are like the tests often made during on-orbit operation and controlled from the payload operational control center (POCC). In addition to the status and limit checking, various stimuli are applied to the spacecraft attitude control system electronics and to the instrument electronics. Radio frequency (RF) tests are also made on the spacecraft command telemetry systems as well as any mission unique or instrument telemetry. Command response testing is also included for switching redundant components, making TT&C configuration changes, switching modes of operation for the electrical power subsystem, changing the configuration on the attitude control subsystem, and operating the reaction control system and propulsion valves. Tape recorders are tested. The thermostat functioning is checked and functional tests are run on subsystem heaters.

The satellite (and upper stage) are then deployed and parked in a standoff position relative to the orbiter and the remainder of the checkout tests completed.

Functional tests are made on the low altitude satellite mission equipment. Functional testing is also accomplished on the attitude control system sensors at low earth orbit altitude in the vicinity of the Shuttle. Solar arrays and antennas are extended and retracted while the satellite is in the vicinity of the orbiter. Thrusters are fired (in the standoff position). TT&C transponder frequency and power are also checked. The propulsion and reaction control subsystem requires sniff testing to help locate propellant leakage as well as propellant tank pressure decay checks.

2.2 ELAPSE TIME

Table 2-1 displays the estimated elapsed time for testing on orbit for each of the example satellites. It is estimated to take 24 hours to complete the testing. If anomalies are found, the test time may be extended.

Table 2-1. Successful Test Times[1], Hours

Subsystem	In-Bay Tests				Standby Tests			
	Required		May Be Needed		Required		May Be Needed	
	Stormsat	TDS	Stormsat	TDS	Stormsat	TDS	Stormsat	TDS
Communication and Data Handling								
TT&C	0.1	0.1	0.05	0.05	---	---	---	---
Data Handling	---	0.02	---	0.1	---	---	---	---
Electrical Power	0.1	0.1	0.1	0.1	0.2	0.2	---	---
Attitude Control	2.0	2.0	---	---	2.0	2.0	---	---
Propulsion & RCS	22.0	19.0	---	---	0.1	0.1	---	---
Experiments	1.0	---[5]	---	---	---	3.0	1.0[4]	---
Thermal	18.0	18.0	---	---	---	---	---	---
Satellite[2]	22.0	19.0	0.15[3]	0.25[3]	2.0	5.1	---	---

(1) Assuming nearly continuous coverage with (1) TDRSS and automatically controlled test equipment, or (2) on-orbit automatic checkout test equipment in the orbiter.

(2) Elapsed time estimated with parallel test operations.

(3) Does not add to elapsed time of "required" in bay tests.

(4) Not required if microwave sounder test accomplished in payload bay.

(5) Not required unless spacecraft operating mode excludes deploying solar arrays and maintaining satellite attitude in standoff mode.

2.3 SATELLITE CHECKOUT DATA FLOW AND EQUIPMENTS

The data flow for on-orbit checkout is shown for two of the major on-orbit checkout alternative modes. Figure 2-2 shows the data flow for ground-based checkout which is characterized by the location of the automatic sequencing equipment at the POCC. Figure 2-3 shows the data flow for the orbital-based checkout case which is characterized by having the checkout sequencing equipment in the orbiter bay with the checkout being monitored at the POCC. The study assumes that for either case the checkout crew will be located at the POCC during the period the satellite is being tested in on-orbit checkout. The location of the crew during ground rehearsal before launch was not studied. However, several alternative arrangements exist:

1. A checkout crew can be split between the payload location and the POCC. In this case, those at payload location (launch site) would return to the POCC location when the satellite was launched.

2. The checkout crew could be at the POCC prior to launch, during ground rehearsal, and during on-orbit checkout. Communication with the technicians and subsystem crews in the payload area will be maintained using teleconferencing techniques.

The ground-based checkout equipment referred to in Figure 2-2 is expected to be capable of automatically sequencing the on-orbit checkout tests by sending commands to the spacecraft and also commanding the on-orbit test equipment and monitoring the reaction noted by the POCC operations equipment. A manual mode of operation is also provided, primarily for use in diagnostic testing. The airborne checkout equipment, also noted in Figure 2-2, includes the checkout support

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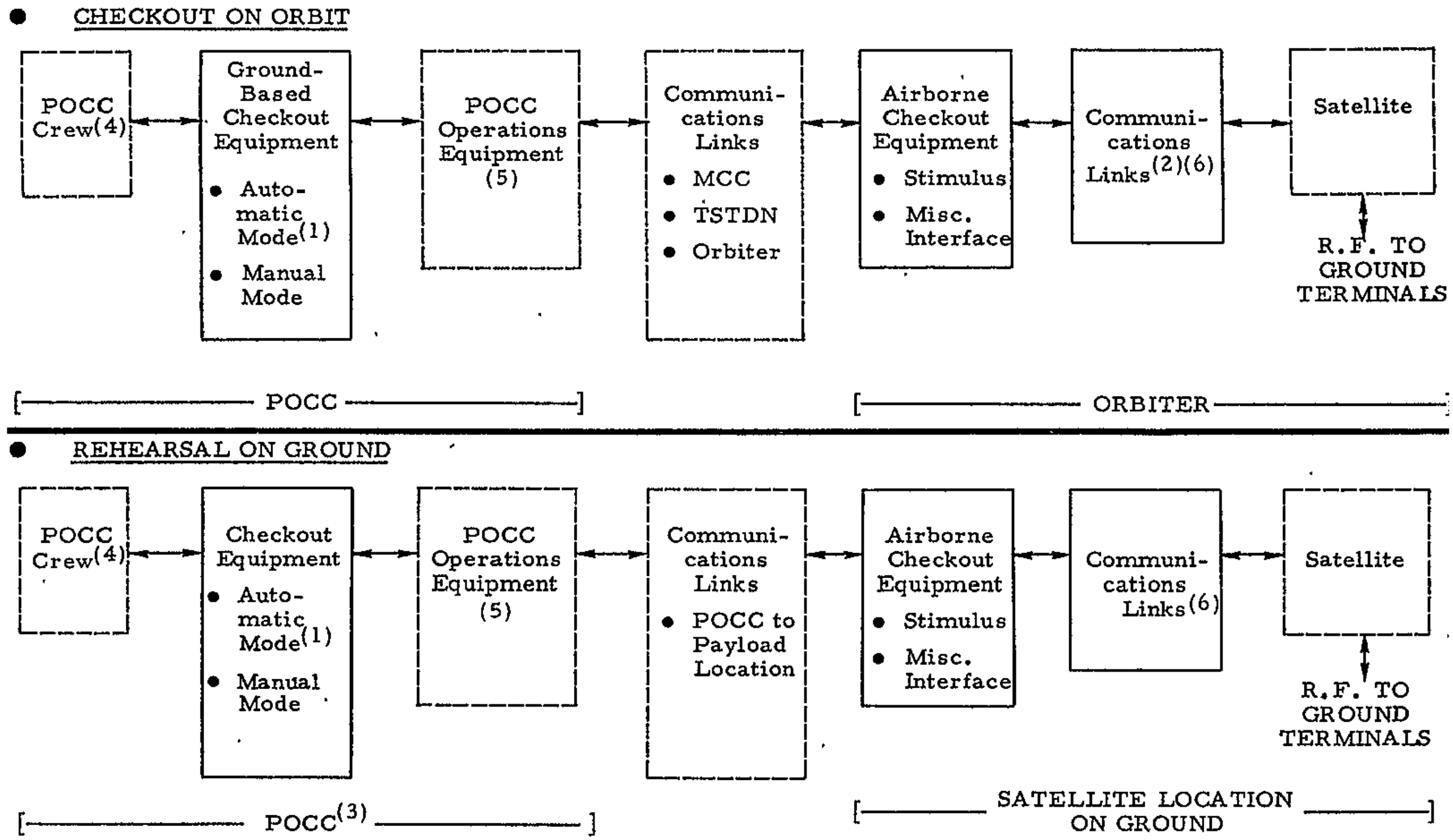
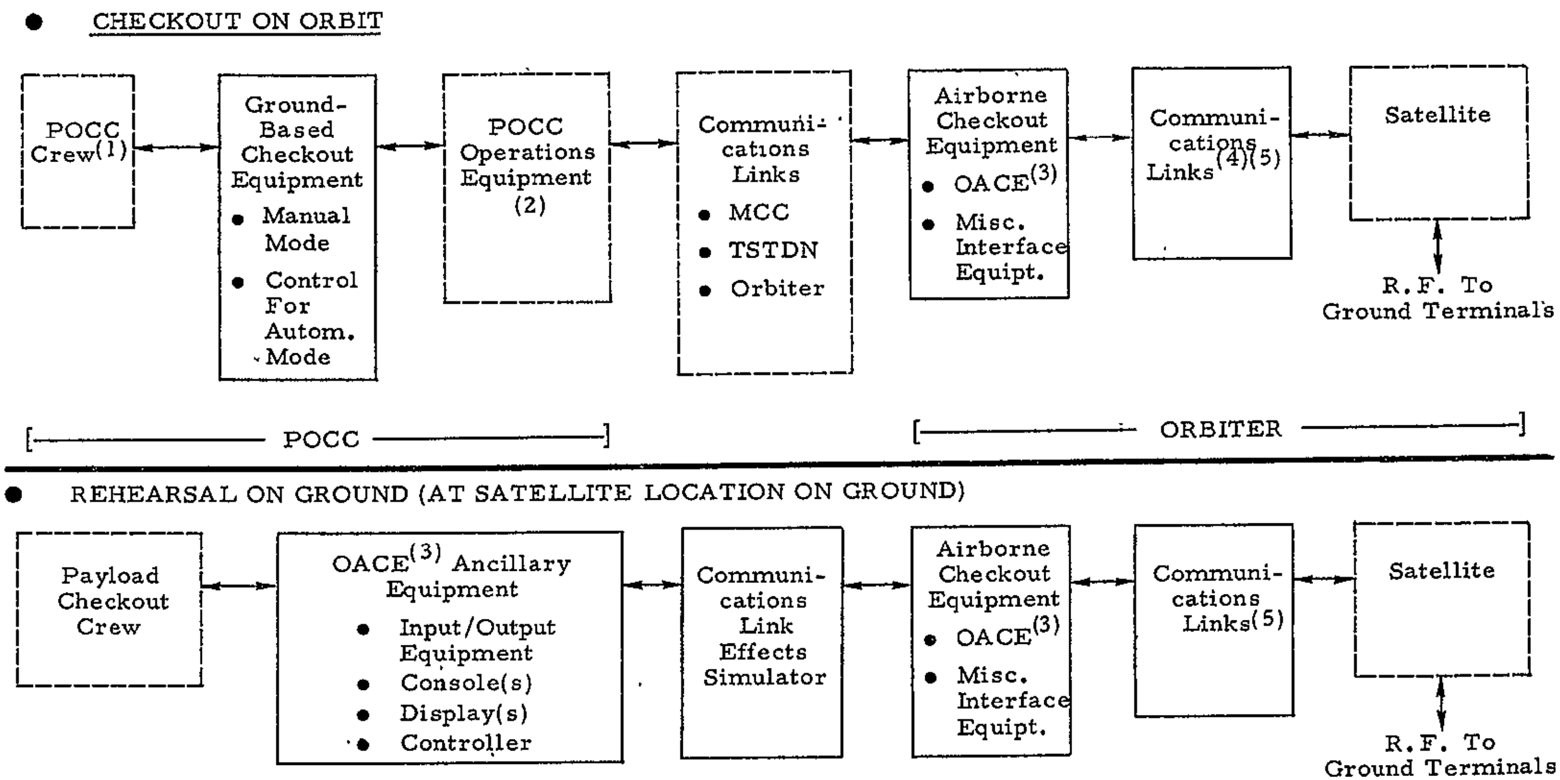


(1) Performed by ground-based automatic checkout equipment (GACE)
(2) RF link may be orbiter/payload link or checkout equipment
(3) Alternative is to move this equipment to satellite location for rehearsal
(4) Spacecraft subsystem and mission-peculiar equipment personnel for checkout
(5) Assumed to include telemetry decommutator and synchronizers, command encoder
(6) Links may not be needed under certain circumstances (see Note 2) and are eliminated

NOTE: Solid lines denote checkout equipment

Figure 2-2. Data Flow, Ground-Based (POCC) Checkout Case



(1) Spacecraft subsystem and mission-peculiar equipment personnel for checkout

(2) Assumed to include telemetry decommutator and synchronizer, command encoder

(3) OACE = On-Orbit Automatic Checkout Equipment

(4) R.F. link may be orbiter/payload link or checkout equipment; equipment includes transmitter(s), receiver(s), encoder(s), command decoder(s), and formatter(s)

(5) Links may not be needed under certain circumstances (see Note 2) and are eliminated

NOTE: Solid lines denote checkout equipment

Figure 2-3. Data Flow, Checkout Equipment in Orbiter Bay Case With Checkout Monitored at POCC

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equipment required to inject signals and stimuli into the satellite electronics systems (via hardline) and a command and telemetry system for remote control and monitoring of the support equipment.

The equipment noted on Figure 2-2 as communications links connecting the airborne checkout equipment to the satellite would function like a ground station to the satellite. It would be capable of transmitting commands to the satellite and receiving data from the spacecraft telemetry and from the instrument data system. These equipments are expensive and would only be included in rare cases when it was not feasible to check out the satellite RF links directly with ground terminals.

For the case shown in Figure 2-3, the ability to automatically sequence on-orbit checkout tests is included in the airborne checkout equipment. Specifically this means adding a computer and a computer interface unit to the on-orbit checkout system.

2.4 COMPARISON OF ON-ORBIT CHECKOUT MODES

Tables 2-2, 2-3, and 2-4 show a comparison of on-orbit checkout costs per launch for the development, procurement, and use of on-orbit checkout equipment and software. Six modes of operating the tests for on-orbit checkout are compared. Three ground-based test sequencing modes of operation and three space-based test sequencing modes of operation are shown. In each case, the RF tests made directly with the ground terminal are as low cost or lower cost than the other approaches. Ground-based test sequencing is lower cost than space-based test sequencing.

Table 2-2 depicts the cost comparison for the Technology Demonstration Satellite on-orbit checkout. For this satellite, the

Table 2-2. TDS On-Orbit Checkout Costs Per Launch, $M Equipment and Software(1)

Tests	Spaceborne Equipment		Ground Equipment	Software	Total(2)
	General Purpose	Special Purpose			
GROUND-BASED TEST SEQUENCING					
RF Tests(3) Thru Checkout Equipment/Spacecraft Link	0.157	0.129	0.021	0.125	0.432 (0.234)
RF Tests(3) Thru Orbiter/Spacecraft RF Link	0.157	-0-	0.021	0.125	0.303 (0.218)
RF Tests(3) Direct With Ground Terminal	0.157	-0-	0.021	0.125	0.303 (0.218)
SPACE-BASED TEST SEQUENCING					
RF Tests(3) Thru Checkout Equipment/Spacecraft Link	0.234	0.129	0.019	0.125	0.507 (0.309)
RF Tests(3) Thru Orbiter/Spacecraft RF Link	0.234	-0-	0.019	0.125	0.378 (0.293)
RF Tests(3) Direct With Ground Terminal	0.234	-0-	0.019	0.125	0.378 (0.293)

(1) Equipment and software can also be applied to launch site payload testing.
(2) Costs in parentheses assume 8 TDS satellites are launched; without parentheses assume 1 TDS satellite launched.
(3) Test of satellite TT&C RF equipment.

Table 2-3. Stormsat On-Orbit Checkout Costs Per Launch[1], $M Equipment and Software[2]

Alternative Testing Concepts For On-Orbit Checkout	Spaceborne Equipment		Ground Equipment	Software	Total
	General Purpose	Special Purpose			
GROUND-BASED TEST SEQUENCING					
RF Tests[3] Thru Checkout Equipment/Spacecraft Link	0.157	0.547	0.021	0.075	0.800
RF Tests[4] Thru Orbiter/Spacecraft RF Link	0.157	0.483	0.021	0.075	0.736
RF Tests[5] Direct With Ground Terminal	0.157	0.150	0.021	0.075	0.403
SPACE-BASED TEST SEQUENCING					
RF Tests[3] Thru Checkout Equipment/Spacecraft Link	0.234	0.547	0.019	0.075	0.875
RF Tests[4] Thru Orbiter/Spacecraft RF Link	0.234	0.483	0.019	0.075	0.811
RF Tests[5] Direct With Ground Terminal	0.234	0.150	0.019	0.075	0.478

(1) Two Stormsats assumed launched
(2) Equipment and software can also be applied to launch site payload testing
(3) Test of satellite TT&C RF equipment and wideband data system RF equipment
(4) Test of satellite TT&C RF equipment through orbiter link, wideband data system through checkout equipment link
(5) Test of satellite TT&C RF equipment through orbiter link or directly with the ground terminus. Wideband data system R.F. link is checked out directly with ground terminal.

Table 2-4. SMS/GOES On-Orbit Checkout Costs Per Launch[1], $M
Equipment and Software[2]

Tests	Spaceborne Equipment		Ground Equipment	Software	Total
	General Purpose	Special Purpose			
GROUND-BASED TEST SEQUENCING					
RF Tests Thru Checkout Equipment/Spacecraft Link	0.157	1.121	0.021	0.050	1.349
S-Band RF Tests Thru Orbiter/Spacecraft RF Link	0.157	0.887	0.021	0.050	1.110
RF Tests Direct With Ground Terminal[3]	0.157	0.663	0.021	0.050	0.891
SPACE-BASED TEST SEQUENCING					
RF Tests Thru Checkout Equipment/Spacecraft Link	0.234	1.121	0.019	0.050	1.424
S-Band RF Tests Thru Orbiter/Spacecraft RF Link	0.234	0.887	0.019	0.050	1.190
RF Tests Direct With Ground Terminal[3]	0.234	0.663	0.019	0.050	0.966

(1) Four SMS/GOES satellites assumed launched

(2) Equipment and software can also be applied to launch site payload testing

(3) Data collection system only, Wallops Island ground station outside of line-of-sight unless high inclination parking orbit is used.

wideband communication system is always tested out with the satellite in the standoff mode and the wideband system communicating directly with the ground terminal. The tradeoffs shown, therefore, are for the testing of the satellite TT&C RF equipment. When the RF tests are operated through the checkout equipment, a command transmitter and payload interrogator are supplied as part of the checkout equipment in the payload bay. The cost of these equipments is the difference between checkout costs for this option and the other two options. The cost of RF tests through the orbiter spacecraft RF link would be increased if special charges were made for the use of this link.

Table 2-3 shows the similar data for the Stormsat satellite case. In this case, the wideband data system RF link is expected to be tested with the satellite and interim upper stage (IUS) attached to the orbiter (see Section 4). The orbiter parking orbit passes over all the ground stations being considered for Stormsat on-orbit support. Figure 2-4 shows these on-orbit checkouts and costs for Stormsat as a function of the number of checkouts made. The mission model calls for two Stormsat satellites to be launched before 1985. The costs are very sensitive to the number of Stormsat satellites launched and checked out primarily because the non-recurring costs and special-purpose equipment costs are amortized over fewer launches.

Table 2-4 shows similar data for the SMS/GOES on-orbit checkout. The satellite has a large number of communication channels and hence the relatively high cost of special-purpose spaceborne checkout equipment. The low altitude parking orbit, during which on-orbit checkout would take place, does not pass within sight of the SMS/GOES ground terminal at Wallops Island. Thus, the main communication links cannot be checked out from the satellite directly to the ground terminals with RF tests.

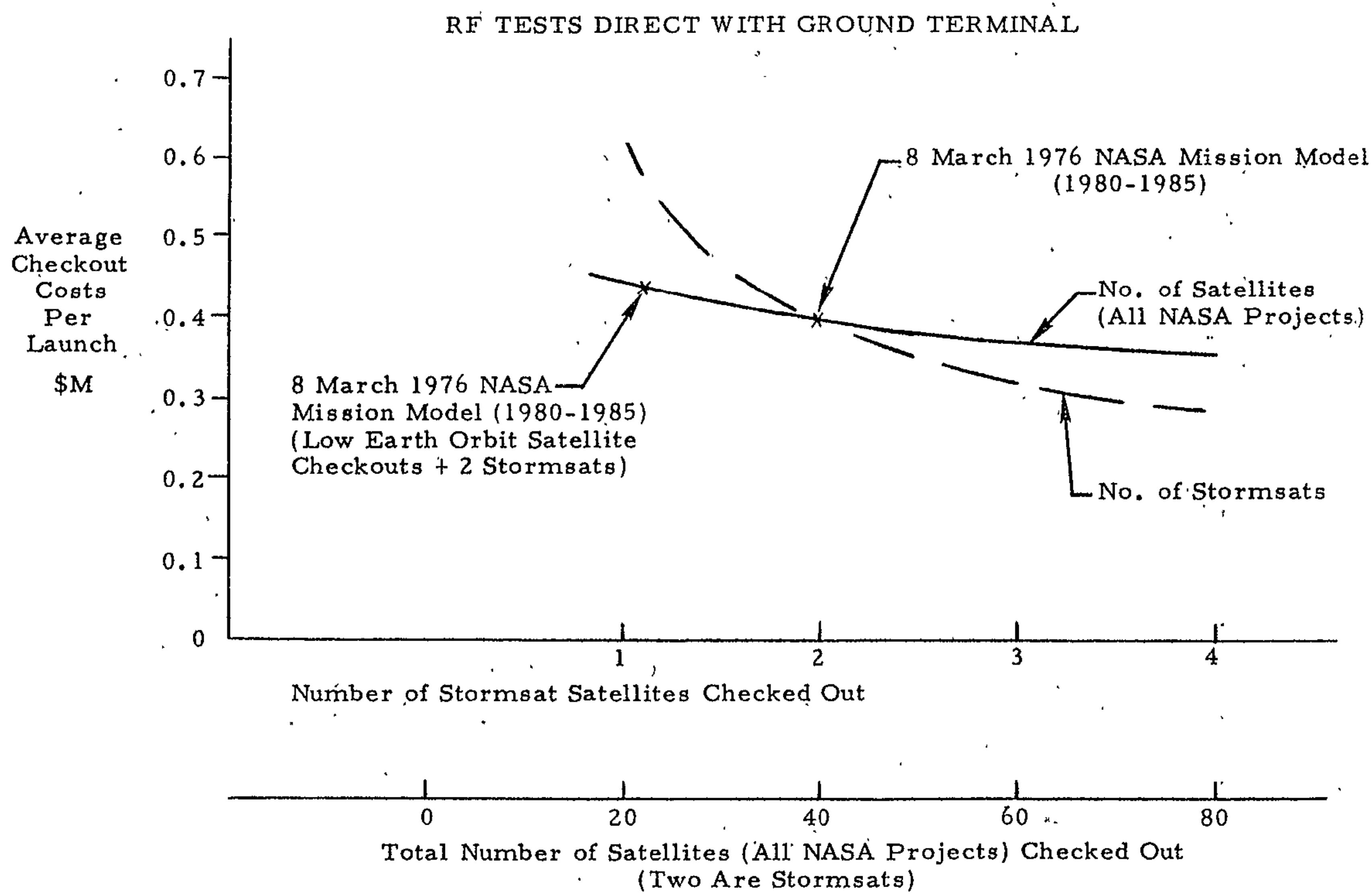

Figure 2-4. Stormsat, Sensitivity of On-Orbit Checkout Costs Per Launch Equipment and Software

2.5 THE POTENTIAL VALUE OF ON-ORBIT CHECKOUT

Table 2-5 shows the summary of on-orbit checkout cost benefit data. The potential savings resulting from returning satellites suffering early or infant mortality-type failures are shown. The cost of performing the checkout and maintaining the equipment which accomplishes the checkout is shown in adjacent columns. The column headed "Potential Loss" refers to the possible waste associated with returning a good satellite because of a false alarm (see Section 4.8), and the potential benefit, i.e., the potential savings minus the checkout costs and potential loss.

The data shows that on-orbit checkout of the low earth orbit satellite, Technology Demonstration Satellite (TDS), is justified on a cost benefit basis. Cost benefits are modest at two to three hundred thousand dollars per launch. It should be noted that these benefits can increase substantially if either (1) the orbiter or avionics could support on-orbit checkout with a lower charge, or (2) some of the checkout equipment replaced ground support equipment used for prelaunch satellite checkout. Either of these are quite possible but would require further definition of the systems and additional study effort to evaluate.

Additional potential benefits would result from on-orbit checkout but cannot be estimated in terms of cost. A satellite serviced on-orbit requires postmaintenance checkout. This can be accomplished by the on-orbit checkout testing described. Another potential benefit is the returning of failed satellites for diagnosis which is very beneficial for making design changes. The benefit comes in correcting the problem and only the problem causing the difficulty.

On-orbit checkout of Stormsat, a synchronous equatorial orbit satellite, does not appear to be justified on a cost basis benefit

Table 2-5. Summary of On-Orbit Checkout Cost/Benefit Data

Satellite Project	Upper Stage		Cost/Benefit Data Per Flight, $M				
	Identification	On-Orbit Checkout Of Stage	Potential Savings[1]	Checkout Cost		Potential Loss[4]	Potential Benefit[5]
				Equipment[2]	Maintenance[3]		
TDS							
Launch 1	---	---	0.7	0.3	0.1	0.1	0.2
Launch 8	---	---	0.7	0.2	0.1	0.1	0.3
STORMSAT	IUS	No	0.5/0.8[6]	0.4	0.1	0.1	-0.1
"	IUS	Yes	0.8/1.2[6]	0.4[7]	0.1	0.1	0.2
SMS/GOES	IUS	No	0.2/0.4[6]	0.9	0.1	0.1	-1.0
"	IUS	Yes	0.4/0.5[6]	0.9[7]	0.1	0.1	-0.7[8]
"	SSUS	Yes	0.3/0.4[6]	0.9[7]	0.1	0.1	-0.8

(1) From returning satellites suffering early failures (infant mortality).

(2) Assuming sequencing of checkout at POCC and RF checkout with ground terminal. This covers equipment plus software [DDT&E and procurement (non-recurring) costs].

(3) Maintenance of checkout equipment.

(4) Returning good satellites because of false alarm.

(5) Assumes infant mortality split before and after upper stage burn.

(6) Higher number assumes all satellite infant mortality occurs before upper stage burn; lower number assumes an even split before and after.

(7) Assumes satellite and upper stage are checked out using same general-purpose equipment.

(8) Negative benefit reduced (to approximately -0.2M$) if high inclination parking orbit is used.

unless the upper stage is also checked on orbit. In the latter case, the on-orbit checkout would prevent upper stage early failures from causing loss of the payload and the upper stage.

On-orbit checkout of the SMS/GOES satellite does not appear to be justified on a cost/benefit basis unless (1) the Shuttle parking orbit inclination is increased so that RF communications between SMS and Wallops Island is possible from the parking orbit, (2) the upper stage is checked out as well as the satellite, and (3) the SMS upper stage is sharing the payload bay with other satellites which are also tested on orbit using the multipurpose on-orbit checkout equipment. Even then, the economic benefits for SMS/GOES satellite checkout are marginal.

3. SATELLITES FOR STUDY

Considerable effort was spent at the beginning of the study (1) obtaining an initial understanding of on-orbit checkout and the options available for carrying out the testing, (2) establishing criteria for selecting satellites for study which were representative of a cross-section of payloads, and then (3) actually carrying out this selection. The utility of on-orbit checkout to the STS user falls into four categories: (1) it enables the user to obtain a "satellite condition" data base on which to make decisions for normal on-orbit actions, (2) it enables the user to obtain a "satellite condition" data base on which to base decisions on contingency actions, (3) it enables the user to verify payload safety status independent of the caution and warning system, and (4) it enables the user to perform satellite tests under orbital conditions for the purpose of qualifying new or modified payload hardware.

The first two items above were the most important considerations. Normal decisions which the user would need to make correctly in order to have a successful program included the decisions to (1) power-up the payload, (2) give approval to unberth the payload, (3) give approval for IUS flight or payload translation away from the orbiter, (4) give approval for performing the next step in an on-orbit service mode, and (5) give payload approval for return. Decisions the user would be making on contingency actions included (1) approval to retrieve a failing payload, (2) approval to reberth a failing payload, and (3) decision to perform a payload repair. Since this was to be a general study, whose results were expected to be applicable to many satellites, it was also important to select a cross-section of satellites for study which represented most of the different types on which on-orbit checkout would be applicable. Considerations in selecting the satellites thus came down to the following criteria:

1. Select at least one IUS payload
2. Select at least one orbiter payload
3. Select at least one payload which would share the orbiter
4. Select at least one payload transitioning from expendable launch vehicles
5. Select at least one payload which was a new payload for the STS
6. Select a large, complex payload
7. Select a small payload
8. Select a TDRS-compatible payload
9. Select at least one ground terminal-compatible payload
10. Select at least one payload employing a modular spacecraft
11. Select a payload which was non-modular
12. Select at least one payload which was serviceable on orbit
13. Select a spacecraft which includes a digital computer on board
14. Select a spacecraft with extendibles
15. Select at least one ETR and one WTR launched payload
16. Select a commercial satellite
17. Select satellites with information available on satellite tests and checkout pre-launch
18. Select satellites with repetitive launches

In addition, it was desirable to consider the potential difference between near-term (payloads transitioning from an expendable launch vehicle to the STS) and far-term (payloads designed for transportation by the STS) payloads. In the near-term it is expected that the uncertainties in the STS environment would effect the desirability of on-orbit checkout. In the far-term it is expected that orbiter payload services would be in wider use, having gone through a demonstration and de-bugging period earlier.

In order to carry out the payload selection for use in this study, data were obtained and tabulated for 18 candidate payloads. Table 3-1 is a summary of the information obtained on these candidate payloads. The three payloads selected for study (Stormsat, Synchronous Meteorological Satellite/GOES, and Technology Demonstration Satellite) are boxed on the table. The selection of these satellites satisfied all the criteria except for 6, 8, and 16, as listed above. The most difficult criteria to satisfy, yet one of the more important, was the requirement that data be available on prelaunch checkout and test for the satellite system selected and that documented satellite descriptions be available to support this study effort. The last column in Table 3-1 is included for convenience, but will be discussed elsewhere since it is a result of the study.

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Table 3-1. Summary, On-Orbit Checkout Study Candidate Payloads

	IUS Payload	Orbiter Payload	Multiple Payload	Payload Modified For STS	Payload Designed For STS	Large Complex Payload	Small Payload	TDRS Compatible	Ground Terminal Compatible(1)	Modular Spacecraft	On-Orbit Serviceable	Launch Site ETR	Launch Site WTR	Available Data Test And Checkout	Commercial Spacecraft	Spacecraft Digital Computer	Including Extendibles	Capture For On-Orbit Checkout
1. Stormsat	x				x				x	x		x		x(3)		x	x	Yes*
2. Synch. Eq. Obs. Sat.	x				x				x	x	(2)	x				x	x	Yes*
3. ATS-6	x								x			x		x(4)		x	x	Yes*
4. Domsat or Intelsat	x			x					x			x			x			No**
5. Defense Support Program	x			x					x			x		x(5)			x	No**
6. Fleetsatcom	x		x	x					x			x					x	No**
7. Global Positioning Sys.	x		x	x			x		x			x					x	No**
8. GOES (Adv. SMS)	x		x	x			x		x			x						No**
9. EOS-B (Landsat)		x	x		x			x		x	x		x	x(3)		x	x	Yes
10. EOS-D (Technology Demonstration Sat.		x			x				x	x	x		x	x(3)		x	x	Yes
11. Solar Max. Miss.		x	x		x				x	x	x	x		(3)		x	x	Yes
12. EOS-E (Ocean Dynamics)		x	x		x				x	x	x		x	(3)		x	x	Yes
13. EOS-E (Weather and Climate)		x	x		x				x	x	x		x	(3)		x	x	Yes
14. Lg. Space Tel.		x			x	x		x				x		(3)		x	x	No
15. DSCS (Modular)	x		x		x					x	(2)	x					x	Yes*
16. DSP (Modular)	x		x		x					x	(2)	x					x	Yes*
17. IUS		x	x		x											x		Yes*
18. STP 72-2		x					x		x				x	x(6)			x	Yes

(1) May require antenna relocation or additional wide-beam antenna when satellite is attached to STS.
(2) Service by Tug.
(3) See MMS document and GE EOS Report #6 for general information.
(4) On-orbit checkout reports and handbook available.
(5) Countdown and telemetry list available.
(6) TT&C measurements list and launch operations document are available.

* Capture if on-orbit checkout is applied to IUS and ground terminal is in view from orbiter parking orbit.

** May check out on orbit after techniques demonstrated by NASA etc. (second-generation STS payload).

3.1 TECHNOLOGY DEMONSTRATION SATELLITE (TDS)

The Technology Demonstration Satellite program is conceived as an on-going project. The first launch is planned as a part of the Shuttle orbital flight test program. The satellite configuration planned at the time of the initiation of this analysis was frozen in order to accomplish the On-Orbit Checkout Study. This time period was early March 1976. Since that time period, the satellite has been through many changes, particularly in the instrument complement. The satellite briefly described in this section is the version frozen in March for this study.

The satellite is to demonstrate technology for hydrology and for air quality measurement. The hydrology instrument is a large (10 ft x 40 ft) synthetic aperture L-band radar. The air quality measurement instruments go by the following labels:

(1) LACATE
(2) HALOE
(3) SER
(4) CIMATS
(5) MAPS
(6) THIR
(7) VTPR

CIMATS stands for Correlation Interferometer for Measurements of Atmospheric Trace Species. The CIMATS instrument is a correlation interferometer which selectively measures the change in the infrared radiation due to specific trace constituents in the atmosphere. The instrument operates in two modes: (1) Limb scanning (solar looking) for measurement of the lower atmosphere, and (2) downward looking for global mapping of the troposphere.

THIR stands for Temperature Humidity Infrared Radiometer. It measures infrared radiation from the earth in two spectral bands, and from these measurements provides pictures of cloud cover, three-dimensional mappings of cloud cover, and temperature mapping of clouds, land, and ocean surfaces.

HALOE stands for Hallogen Ocultation Experiment. It is a multi-spectral, gas-filter correlation radiometer with azimuth and elevation pointing capability to track the sun during occultation events. The experiment uses technology developed in the MAPS program. MAPS is a gas filter correlation radiometer under development for aircraft use.

VTPR stands for Vertical Temperature Profile Radiometer. LACATE is another occultation instrument.

The instruments for TDS are mounted on the Multimission Modular Spacecraft (MMS) satellite. This spacecraft is described in References 1 and 2. An exploded view of the on-orbit serviceable spacecraft is shown in Figure 3-1.

The TDS is a low-altitude satellite; no upper stage is required.

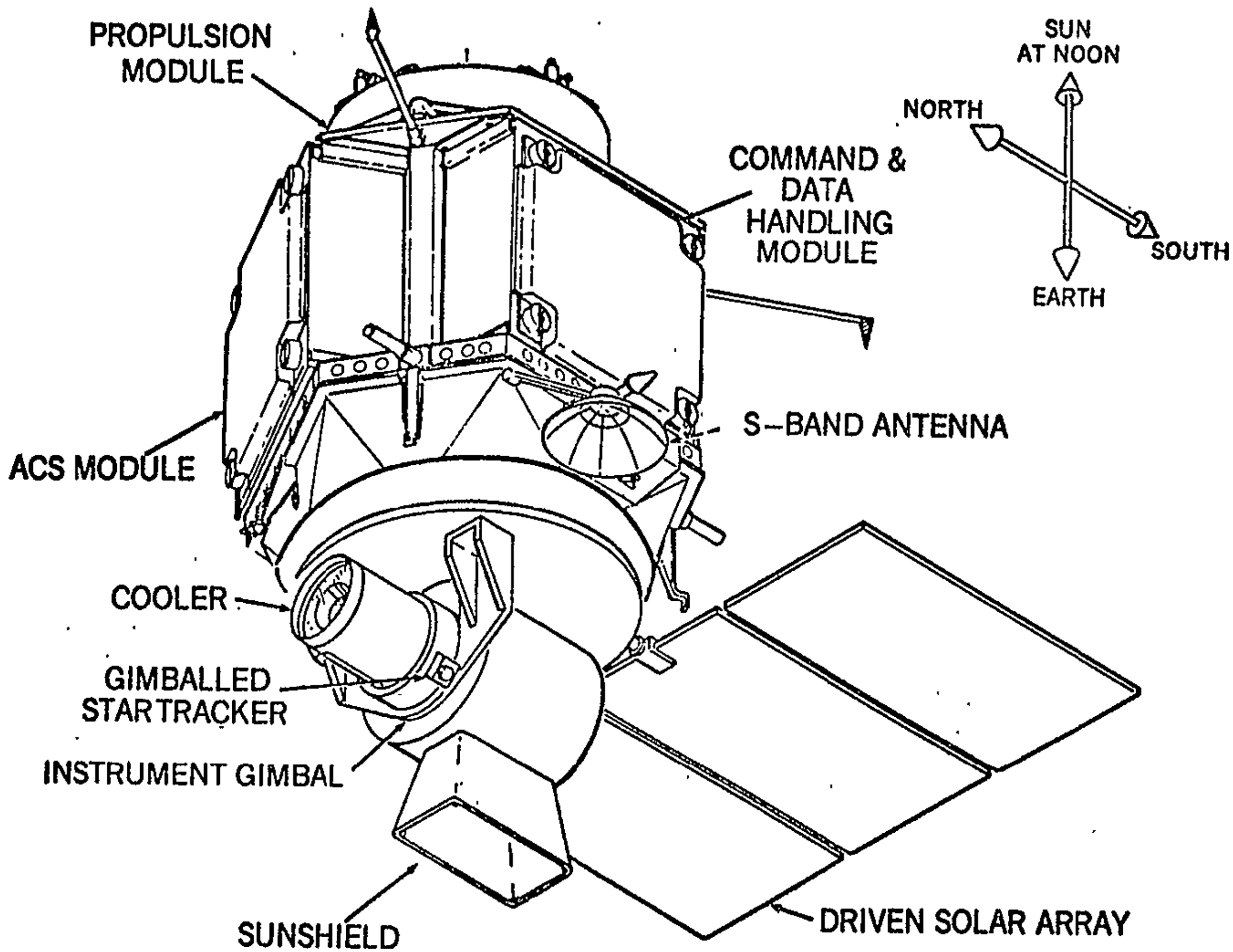

Figure 3-1. Stormsat Configuration

3.2 STORMSAT

3.2.1 Spacecraft Description

The Stormsat satellite will consist of a spacecraft (the MMS, described below) and an instrument module. Figure 3-1 shows the two main sections integrated to form the Stormsat. Figure 3-2 is an outline sketch showing the spacecraft, with the Interim Upper Stage (IUS) and microwave radiometer in the launch configuration.

3.2.1.1 Multi-Mission Modular Spacecraft (MMS)

The MMS is now being developed by NASA GSFC to be used as the service module for a wide variety of missions. The MMS contains all housekeeping subsystems that are required for the efficient running of the spacecraft. The MMS consists of:

- Mechanical support structure
- Thermal subsystem
- Power module
- Attitude control module
- Communications and data handling module
- Propulsion module
- Integration electrical subsystem.

The above systems, as shown in Figure 3-3, are combined to make the MMS which is integrated with the payload of the spacecraft, the instrument module. The MMS subsystems are described in detail in Reference 1.

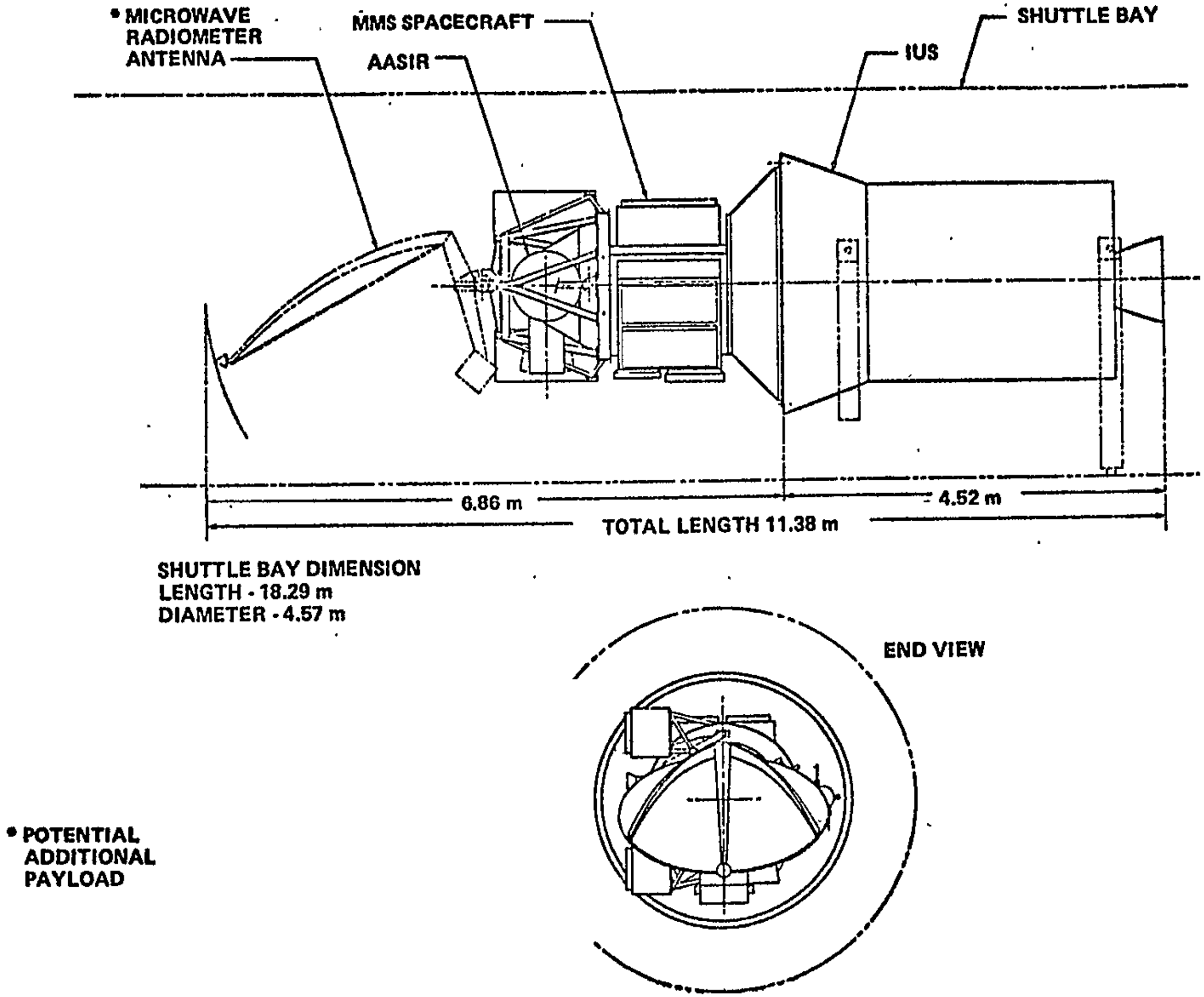

Figure 3-2. Stormsat In Launch Configuration

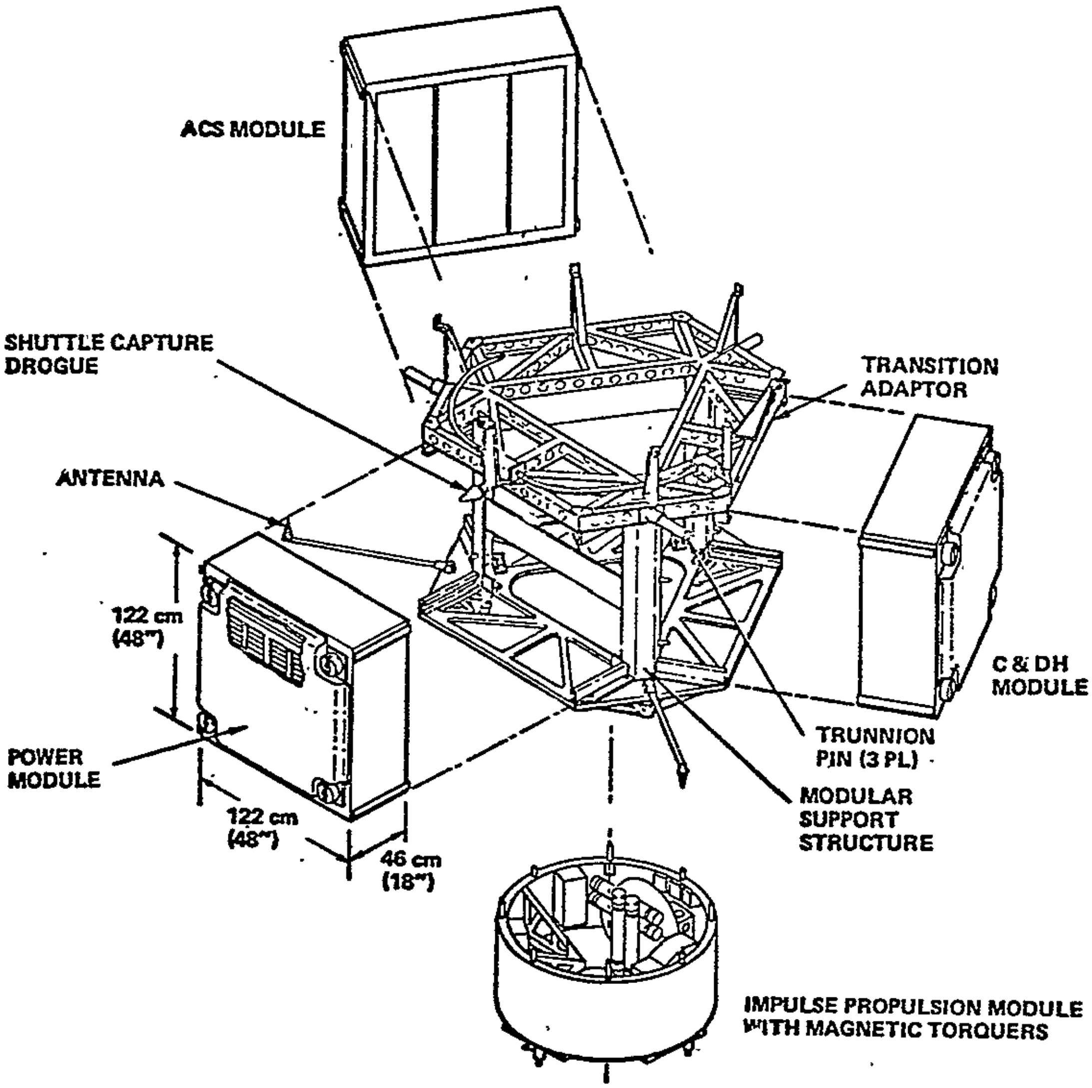

Figure 3-3. MMS Baseline Structure

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3.2.1.2 Instrument Module

The instrument module consists of the AASIR mounted on a gimbal, the wideband communications subsystem, and possibly a microwave sounder.

3.2.1.2.1 AASIR and Gimbal

The AASIR is an advanced development from the VISSR and VAR instruments. These instruments are the primary payloads for the SMS/GOES series of spacecraft. The AASIR will permit high resolution visible imaging, IR imaging, and sounding, all of which will be carried out simultaneously and in real time. These functions can be carried out over the entire earth disk, or the frame size can be decreased to study smaller regions of interest and to study rapidly changing phenomena.

The instrument contains a 40 cm (16 in.) telescope, a single-axis object plane scanning mirror, a set of aft optics, and approximate detectors. The major capabilities of the baseline AASIR are listed in Table 3-2.

A passive cooler is used with the IR detectors. The entire instrument is carried in a gimbal, connecting it to the spacecraft. The scan mirror provides one axis of scan, while an orthogonal axis is provided by the movement of the entire instrument within its gimbal.

3.2.1.2.2 Wideband Communications Subsystem

The wideband communications subsystem consists of a multiplexer, a wideband transmitter, and an S-band antenna.

Table 3-2. Baseline AASIR Characteristics

Characteristics	Units
Size	64 cm diameter, 170 cm long
Weight	114 kgm
Power	50 watts average
Optical Aperture	40 cm
Sounding Channels	13.5 km resolution 7 channels 15 μm, CO_2 absorption 5 channels 4 μm, CO_2 absorption 2 windows 3.7 μm, 11.1 μm 3 H_2O channels 6.71 μm, 7.25 μm, 12.67 μm
IR Imaging Channel	4.5 km resolution 11.1 μm
Visible Channel	750 m resolution
Average Data Rate	Full Earth 3.26 MBS (750 km) 0.195 MBS
Sounding and Imaging are done simultaneously	

3.2.1.2.3 Microwave Sounder

In the microwave spectrum of the earth's atmosphere below 200 GHz there are resonance lines of: (1) water vapor molecules near 22 GHz and 183 GHz, and (2) oxygen molecules near 60 GHz and 118 GHz. The 22 GHz and 60 GHz lines are being utilized for remotely measuring the tropospheric temperature profile and water vapor content in a number of satellite experiments and operational sensor systems such as Nimbus-5 NEMS, Nimbus-6 SCAMS, Nimbus-G SMMR, and Tiros-N MSU. The two remaining lines near 118 GHz and 183 GHz could provide similar temperature and water content information with the height extended up to the stratosphere region. The single molecular rotation line of oxygen at 118.75 GHz is relatively isolated, and its simple Zeeman split pattern makes it easier for temperature measurements at heights above 40 km.

3.3 SYNCHRONOUS METEOROLOGICAL SATELLITE (SMS/GOES)

The synchronous meteorological satellite is a spin-stabilized, synchronous satellite. The satellite obtains day and night information on the earth's weather by means of earth imaging, retransmission of image data, data collection, data relay, and space environment monitoring. The satellite weight is 625 kg (1,379 lb). This includes 338 kg (743 lb) for the apogee boost motor. The SMS spacecraft is displayed in Figure 3-4. Documents describing the SMS spacecraft and its subsystems are listed as References 2 through 20.

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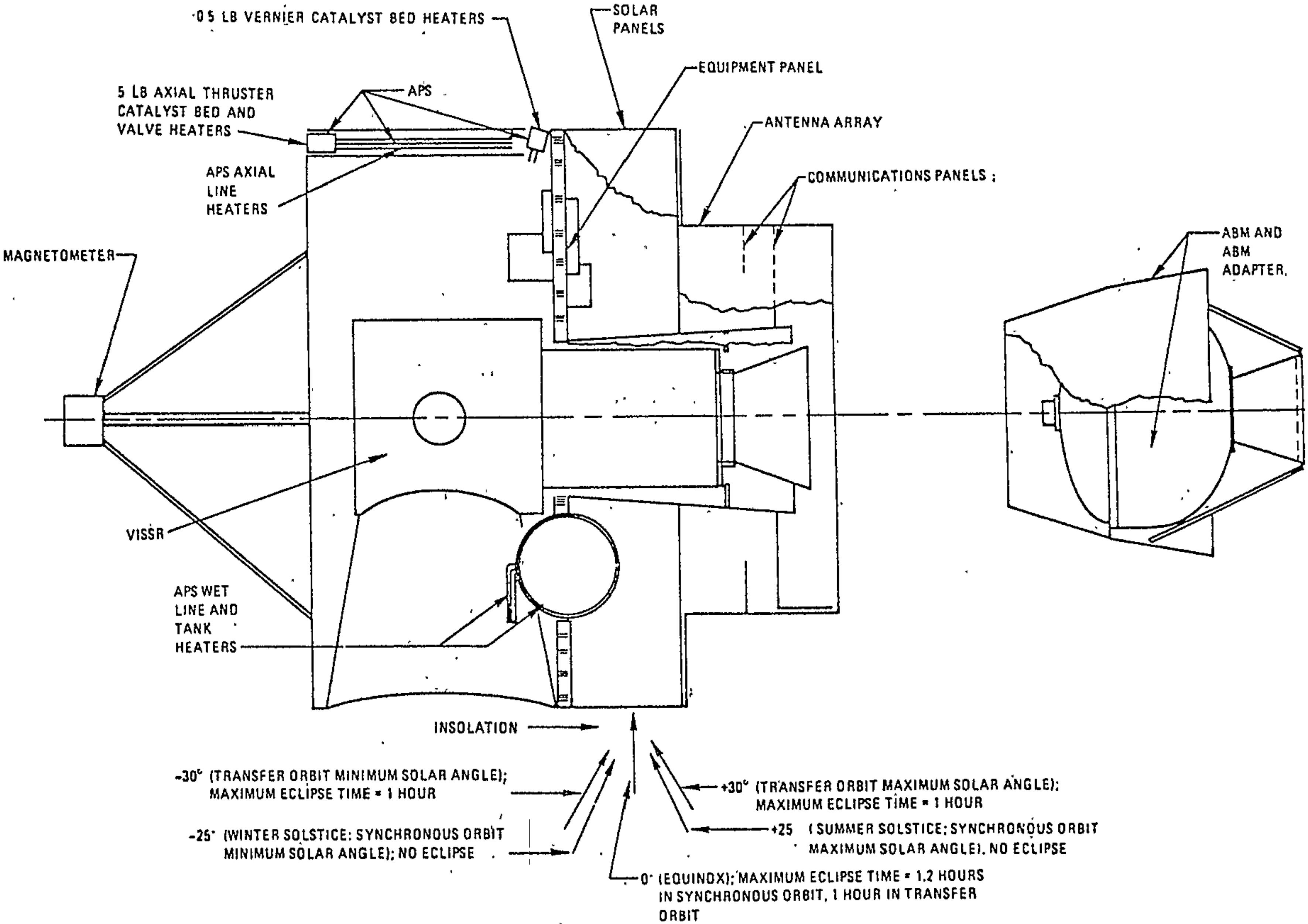

Figure 3-4. SMS Spacecraft Configuration

4. SUBSYSTEM TESTS AND SUPPORT EQUIPMENT

4.1 APPROACH TO TASKS

The subsystem tests and support equipment are identified for on-orbit checkout of each of the satellites studied by specialists in the appropriate subsystem areas. Each of the subsystem specialists worked against the following background given to them for use in their task of defining and describing on-orbit checkout tests. In addition to this background, the recommendations by the subsystem specialists are based on their experience and judgment on tests appropriate for on-orbit checkout.

1. Checkout Goal: The goal of the checkout is to reveal the presence of a large portion (80 to 90 percent) of anomalies resulting in a large degradation of satellite capability.

2. Shuttle-launched satellites and replacement modules are assumed to have been checked out prior to launch.

3. Tests are judged by <u>each</u> subsystem specialist to be sufficient to reach the checkout goal.

4. Backup tests or measurements are provided for "false alarm" protection (see Section 4.8 for discussion of false alarm considerations).

5. Testing in the payload bay is preferred over the standoff location since (1) satellite loss is avoided if TT&C or stabilization capability is lost, (2) orbiter power is available for running checkout, and (3) orbiter communications links are available with nearly continuous TT&C coverage through TDRS.

6. Tests are recommended in the standoff location when confidence in the validity of test results is significantly enhanced in a standoff mode as compared to the payload attached mode or when accomplishing the test in the attached mode might be hazardous.

7. The objectives of on-orbit checkout and testing are:

   a. Obtain a data base to decide on normal on-orbit actions (approval of next steps in the operating procedure). An example of these next steps on which decisions or approvals may be required are:

      (1) Power-up the payload

      (2) Unberth the payload

      (3) Deploy the payload

      (4) Start satellite initiation sequence

      (5) Initiate IUS flight for payload translation

      (6) Orbiter support to payload complete, no longer required for escort

      (7) Retrieve payload

      (8) Return payload to ground

      (9) Proceed to next step in on-orbit service.

   b. Obtain a data base for decisions on contingency actions

      (1) Jettison or abandon payload

      (2) Retrieve failing payload

      (3) Reberth failing payload

      (4) Initiate payload repair action

      (5) Switch to redundant payload component

      (6) Return payload to earth.

The on-orbit checkout support equipment identified in these efforts is integrated into a checkout system using several different approaches as discussed in Section 5. The tests and equipment are operated as described in Section 6.

4.2 COMMUNICATIONS AND DATA HANDLING

The communications and data handling subsystem tests for all three satellites are described in Tables 4-1 through 4-3. Table 4-1 covers the communications and data handling (C&DH) subsystem tests for the spacecraft elements of each of the satellites. Table 4-2 covers the SMS mission-peculiar communication subsystem tests, and Table 4-3 covers the Technology Demonstration Satellite mission-peculiar experiment communications, a wide-band data system. Table 4-4 presents the communications and data handling testing timeline information and estimated power consumption.

Test equipment required for all satellites is (1) RF absorption material in the payload bay, and (2) the wiring and cabling in the payload bay connecting the various elements involved in the operation of satellite checkout on orbit. Orbiter communication system compatibility equipment is also required. For the test options studied where RF testing is accomplished with checkout support equipment-supplied RF link between the support equipment itself and the satellite, additional communications test equipment is required. This additional communications test equipment includes probes, payload bay receivers, and payload bay transmitters.

4.2.1 Multimission Modular Spacecraft (MMS) Data Handling Checkout

The MMS, which is a spacecraft portion of Stormsat and TDS, has data handling equipment which is integral with the C&DH subsystem. This data handling equipment consists of Standard Telemetry and Command Components (STACC) elements, a spacecraft onboard computer, and computer interface unit. This section describes tests recommended for checkout of the data handling elements.

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Table 4-1. C&DH Subsystem Tests[1]

Subsystem Element	On-Orbit Tests			Payload and Test Location		Test Priority
	For:	Indications: Primary	Indications: Backup	In Bay	Standoff (2)(3)	
• Transmitter & RF Coupling to Antenna	• General Performance, Aliveness	• RF on Proper Channel • RF Power	• Redundant Transmitter (All)	SMS: VHF Stormsat: S-Band TDS: S-Band		1
• Telemetry Digital Multiplexing (& Premodulation Processor for MMS)	• General Performance, Aliveness	• Synchronize Decom	• Redundant Units (All)	All		1
• Telemetry (& Data Bus)	• Status Data Readout (Telemetry Aliveness)	• Compare to Normal Values	• Repeat Test & Compare to Normal • Diagnostic Tests As Required	All		1
• Real Time Telemetry Processor	• Function (Telemetry Aliveness)	• Compare to Normal Values	• Redundant Unit	SMS		1
• Command Receiver, PSK Demod (MMS Only), Bit Detector (SMS Only), Decoder, Distribution (& Data Bus)	• Sensitivity (Command Aliveness)	• Command/Response (Reduced Power)	• Alternate Command	SMS: VHF Stormsat: S-Band TDS: S-Band		1
• TT&C	• Satellite Subsystem & Mission Peculiar Checkout	• (See Table of Tests)		All		-
	• Redundant TT&C Components	• Comparison With Normal Values	• Diagnostic Tests As Required			2

(1) With link established and telemetry powered up
(2) Diagnostics for other subsystems
(3) Assumes comm. link via IUS as necessary

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Table 4-1. C&DH Subsystem Tests (Cont'd)

Subsystem Element	On-Orbit Tests: For:	Indications: Primary	Indications: Backup	Payload and Test Location: In Bay	Payload and Test Location: Standoff	Test Priority
• Transponder	• Range Signal Turnaround and Coherent Drive (Tracking Aliveness)	• Received Range Signal & RF Shift	• Redundant Unit	All		2
• Tape Recorder	• Function	• Comparison of Stored Data Stream With Playback	• Redundant Unit (If Available)	MMS		1
	• End of Tape	• Telemetry Signal	• Operate Tape Recorder			3
• TT&C	• Fault Isolation Between TT&C and Other Subsystems(1)	• Use Other Measurements As Indicator • Separate Indicators of Same Effect				2
• Alternate RF	• Function	• Part of Mission-Peculiar Tests		SMS		2
• On-Board Computer and Computer Interface Unit	• Functional Performance	• Execute Test Equipment Self-Diagnostic Command & Monitor Results Via Telemetry	• Redundant Unit			

(1) Performed only when necessary

Table 4-2. SMS Mission-Peculiar Communications Subsystem (Electronically Despun Antenna)

Subsystem Element	On-Orbit Tests			Payload and Test Location		Test Priority
	For:	Measurements		In Bay	Standoff	
		Primary	Backup(1)(2)			
• Transponder(3) (UHF & S-Band), RF Coupling, Antenna	• Function	• Interogate/ Response: Frequency Power (All Modes)		X		1
		• Compare to Normal Values		X		
		• Command/ Response (For TT&C Capability)		X		
• Mission-Peculiar Equipment	• Checkout	• Compare to Normal Values		X		1
• Payload Comm	• Redundancy Checks	• Compare to Normal Values		X		2
• Antenna (UHF & S-Band(4) (Includes Power Ampl.)	• Function	• Interogate/ Response • Command/ Response		X		1
• Antenna (UHF & S-Band)(5)	• Antenna Spin	• RF Signal vs Time		X		1

(1) Redundant unit, where available
(2) Diagnostics
(3) Antenna in direction A
(4) Antenna in direction B
(5) Antenna electronically spinning

Table 4-3. TDS - Experiment Communications

Subsystem Element	On-Orbit Tests			Payload and Test Location		Test Priority
		Measurements				
	For:	Primary	Backup[(1)(2)]	In Bay	Standoff	
• Transmitter, RF Coupling, Antenna	• General Performance	• RF On Proper Channel • RF Power Level		X	(3)	1
• Transmitter Input Circuitry and Signal	• Status Data Readout	• Compare to Normal Values		X	(3)	1
• Mission-Peculiar Equipment	• Checkout	• Compare to Normal Values		X	(3)	1
• Experiment Comm	• Redundancy Checks (As Appropriate)	• Compare to Normal Values		X	(3)	2

(1) Redundant unit, if available

(2) Diagnostics

(3) Test in standoff position if radiation from payload bay to ground is not feasible.

Table 4-4. C&DH Testing Information

Subsystem Element	Priority	Test Time (Min)	Real Time	Primary Power (Watts)	Rationale
Transmitter, RF Coupling, Antenna	1	2	Yes	40	Aliveness Check
Telemetry Digital Mux., Status (All), Real Time Telemetry Processor (SMS Only)	1	7(2)	Yes	40	Aliveness Check
Command Receiver, Demod. & Decoding	1	1	Yes	40	Aliveness Check
TT&C Redundant Components	2	2	Yes(1)	40	Aliveness Check
Transponder Ranging & Coherent Drive	2	1	Yes	40	Aliveness Check
Tape Recorder Function	1	1	Yes	50	Aliveness Check
End of Tape (MMS Only When Required)	3	2 x 3	No (Run) Yes (Check)	55	Performance Check

(1) Interleaved with satellite subsystem and mission-peculiar checkout
(2) Accomplishes a status check of all subsystems

The STACC is designed to verify that the interface circuits operate correctly and that the STACC response to commands is correct. Specific tests are described below.

1. <u>STACC-Command Detector Checkout</u>

   The purpose of this test is to verify proper STACC response to specific commands, either from the ground or the on-board computer.

2. <u>STACC Remote Interface Unit-External Device Checkout</u>

   The purpose of this test is to verify that the interfaces between the remote interface unit (RIU) and the external devices operate correctly. Commands either from the computer or the ground will instruct the STACC to exercise the RIU and the expected interface response will be verified again, either by the computer or by the ground.

3. <u>STACC/Computer Checkout</u>

   The purpose of this test is to verify proper response between the STACC and the onboard computer. Ground commands, computer commands, and built-in test stimuli will be required to conduct this test. Typical signals to be checked out include interrupt requests and data transfers.

4. <u>STACC-Premodulator Processor Checkout</u>

   The purpose of this test is to verify that the telemetry format generator, along with its interface to the premodulator processor, operates properly. Commands will instruct the formatter to provide specific telemetry data to be checked, again either by the onboard computer or on the ground. This test overlaps with tests recommended for telemetry and command.

5. Diagnostic Monitor Check

The purpose of this test is to check for proper operation of specific internal test points such as voltage levels, temperature monitors, and clock pulses. These signals will be sent to the RIU, forcing the conditioning and subsequent telemetering. This monitor check will be included in the telemetry data and limit checks.

6. Over-Under Voltage Tests

The purpose of these tests is to verify that the STACC operates properly when the primary input voltage is at pre-specified voltage levels. This is classified as a contingency or backup test. Tests similar to those described in 1 through 5 above will be performed while at the off-nominal voltage levels. It is expected that the C&DH subsystem would provide its own circuitry to enable these tests to be made.

For planning purposes, it is estimated that the tests above will require 3,000 words of storage to sequence and to verify responses. The test execution time is estimated to be five minutes. This set of recommended tests for on-orbit checkout is based on the information in References 1 and 21 through 25.

This paragraph describes on-orbit checkout requirements for the spacecraft computer. The spacecraft onboard computer is defined in Reference 1. The purpose of the checkout is to verify the proper operation of the computer while in the orbiter payload bay and in the vicinity of the orbiter. Specific checkout tests are:

Memory Verification

This test verifies that the memory contents have not degraded and that read-write circuits are operating properly. The tests performed include a bit check-sum test, and read-write verify tests. These tests are performed automatically on a periodic basis or on command. For an 8,000 word memory it is anticipated that the test would require half a second for execution and 150 words of storage.

2. CPU Verification

The purpose of this test is to verify that all the Central Processing Unit (CPU) hardware operates properly. This will be done by executing a subroutine that exercises all instructions along with various registers. This test will be performed automatically on a periodic basis and on command. It is anticipated that this test will require half a second and will require 350 words of storage.

3. Input /Output Verification

The purpose of this test is to verify that the input/output (I/O) circuits operate properly. The tests will be "wrap-around" type, i.e., the computer will issue outputs which will become the inputs for verification. These tests are either periodic or commanded and will require 100 words of storage.

4. Other Subsystem Tests

The purpose of these tests is to verify that the hardware and functional interface with external subsystems (such as sensors, attitude control system, etc.) operate properly. The specific interfaces to be exercised and the functions to be performed by the computer will be defined by the checkout requirements of the various external subsystems.

5. Command Execution Verification

The purpose of this test is to verify that the computer responds properly to external commands. This test will require up to half a second for execution along with 100 words of storage. The redundancy reconfiguration command will be included in this test.

6. Over/Under Voltage Tests

The purpose of this test is to verify that the computer operates properly when the primary input voltage is at prespecified voltage levels. Tests 1, 2, and 3 described above will be performed while at the off-nominal voltage levels. These tests are classified as contingency or back-up tests.

7. Monitor Tests

The purpose of this test is to check some specific internal test points. Typical signals to be monitored include power supply voltage levels, "keep alive" signal, clock-pulse signal, and temperature monitor. These signals will be sent to the Remote Interface Unit (RIU) for subsequent telemetering to the ground or to the computer for limit checks.

4.3 ELECTRICAL POWER

Elements of the electrical power system considered in this study are: (1) solar array, (2) batteries, (3) power conditioning and control, and (4) electrical harness and distribution. A simplified block diagram of the electrical power system for the Multimission Modular Spacecraft (MMS) is shown in Figure 4-1. Table 4-5 shows the SMS power subsystem instrumentation which is considered typical for this study.

The electrical power subsystem tests recommended are described in Table 4-6. In summary, it does not appear that there are any areas where extensive checkout of the system would be needed; however, further studies in the area should be conducted as designs are finalized.

4.3.1 Solar Array

Power output capability of the solar array cannot be determined until after the array has been deployed and positioned relative to its orbit. Therefore, there is little which can be accomplished by Shuttle-based checkout of the solar array which could not have been better accomplished prior to launch.

It is felt that the Shuttle-based checkout would involve a visual inspection of the array to assure that there has not been any damage as a result of the launch. In preparation for deployment there may be some requirements to remove snubbers or vibration restraints which will not be needed for the deployment sequences.

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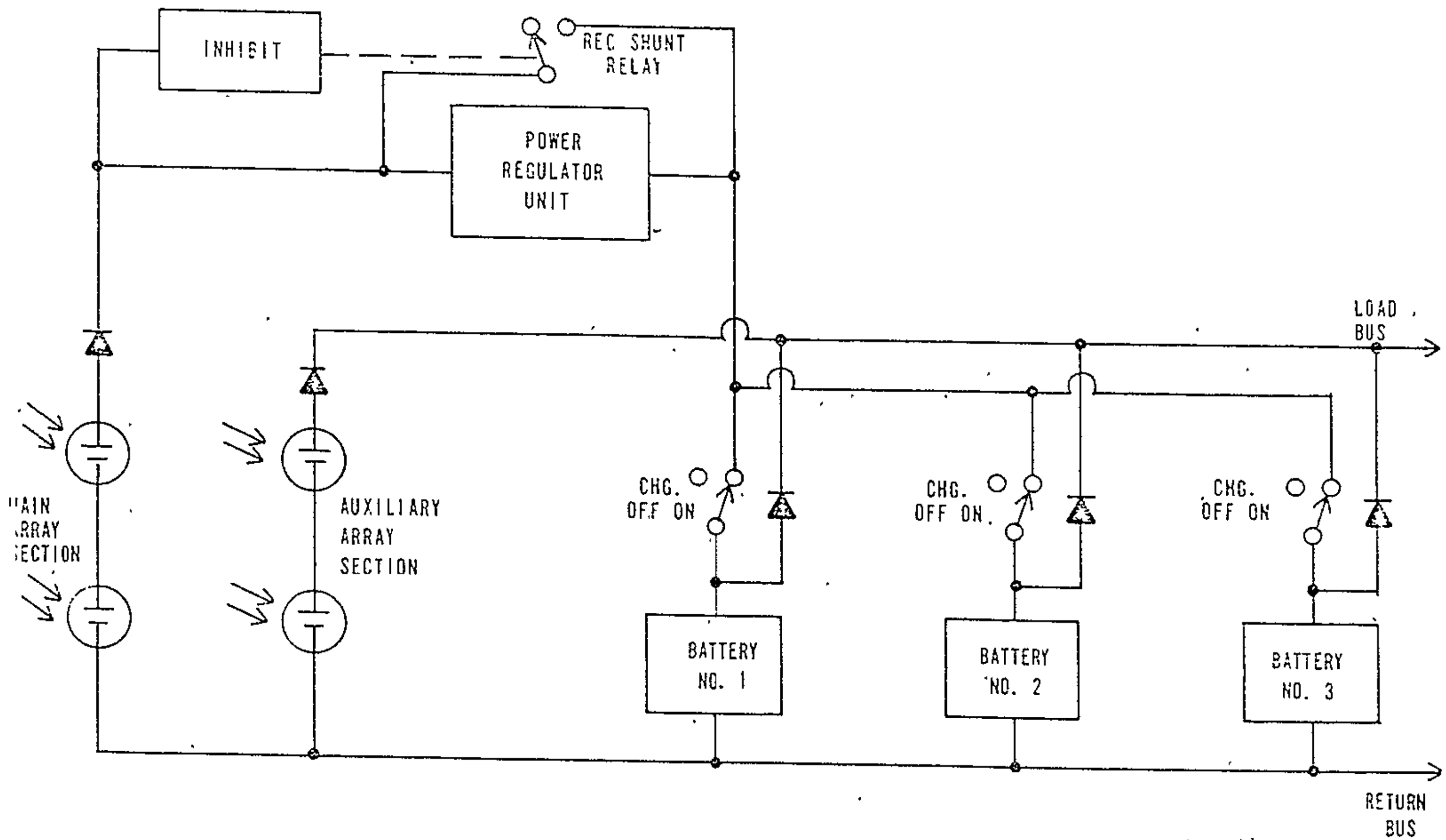

Figure 4-1. Simplified Block Diagram - Electrical Power

Table 4-5. SMS Power Subsystem Instrumentation

Title of Measurement	Type of Electrical Signal	Measurement Range	Measurement Accuracy
Main Bus Voltage	Analog	0 to 32 V	± 0.64V
Control Bus Current	Analog	0 to 8 A	± 0.24A
Main Bus Current	Analog	0 to 8 A	± 0.24A
Battery 1 Temperature	Analog	-10° to $+50^{\circ}$C	± 1.5°C
Battery 2 Temperature	Analog	-10° to $+50^{\circ}$C	± 1.5°C
Power Control Unit Temperature	Analog	-10° to $+50^{\circ}$C	± 2.5°C
Solar Array Temperature (Middle)	Analog	-150° to $+100^{\circ}$C	± 3.0°C
Solar Array Temperature (Forward)	Analog	-150° to $+100^{\circ}$C	± 3.0°C
Solar Array Temperature (Aft)	Analog	-150° to $+100^{\circ}$C	± 3.0°C
Battery 1 Voltage	Analog	0 to 32 V	± 0.64V
Battery 2 Voltage	Analog	0 to 32 V	± 0.64V
Control Bus Voltage	Analog	0 to 25 V	± 0.50V
Solar Array Current	Analog	0 to 8 A	± 0.24A
Battery 1 Charge Current	Analog	0 to 0.5 A	± 0.15A
Battery 2 Charge Current	Analog	0 to 0.5 A	± 0.15A
Battery 1 Discharge Current	Analog	0 to 15 A	± 0.30A
Battery 2 Discharge Current	Analog	0 to 15 A	± 0.30A
Battery 1 Relay Status On/Off	Bilevel		
Battery 2 Relay Status On/Off	Bilevel		
ABM Ignite Status	Bilevel		

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Table 4-6. Electrical Power Subsystem Tests

Subsystem Element	On-Orbit Tests			Payload And Test Location		
	For:	Measurements				
		Primary	Backup	In Bay(1)	Standoff	
• Solar Array	• Solar Panels	• Visual Examination	• Array Output & Temps.	All(2)	All	2
	• Deployment Mech.	• Visual Examination	• Array Output & Temps.	---	TDS	1
	• SADA or Slip Rings	• Continuity	• Bus Voltage & Current	All	All	2
• Batteries	• Cell Integrity	• Nom Voltages and Currents	• Voltages & Currents Over Charge/Discharge Range	All	All	1
	• Capacity(3)			All	All	2
	• Voltage			All	All	1
• Power Conditioning And Control	• Battery Charge Rates & Voltages	• Nom Voltages and Current Under One Mode	• Nom Voltages and Currents Under All Modes	All	---	1
	• Voltage Control	• Line Voltages	• Voltage at Diff Rates	All	---	1
	• Power Quality (Regulation)	• Line Voltages	• Voltage at Diff Rates	All	---	1
	• Relay Position And Operation	• Status Verification	• Functional Equip't Check	All	---	1
	• Redundancy	• Status Verification	• Functional Equip't Check	All	---	1
	• Fuses	• Functional Equip't Check	• Continuity Check (2)	All	---	2
• Harness & Distribution	• Integrity	• Functional Equip't Check	• Continuity Check (2)	All	---	2
	• Switches & Relays	• Status Verification	• Functional Equip't Check	All	---	1
	• Fuses	• Functional Equip't Check	• Continuity Check (2)	All	---	2

(1) Payload supported by cradle or platform
(2) Limited to visible portion
(3) In case of suspected problem

4.3.2 Batteries

Until deployment the satellites will derive their power needs from Shuttle-based systems so the batteries should be approximately in the same state as when launched. During this period the batteries should be maintained under trickle charge. It is unlikely that the batteries will have any problems prior to separation from the Shuttle, so the only checks necessary will be to assure that power transfer to internal power supply has been accomplished. For the retrieval mode it is likely that any on-orbit difficulties can be diagnosed by telemetry prior to retrieval.

4.3.3 Power Conditioning and Control

While it is unlikely that the power conditioning and transfer system will encounter any problems prior to deployment, some checks on voltage outputs and current levels for the battery charge controller should be conducted. It would also be desirable to check any redundant circuits.

For the retrieval mode it is probable that any malfunctions would be identified from telemetry prior to retrieval. It would be best to proceed with replacement of any suspected defective modules rather than proceed with any extensive diagnostics before the retrieval.

4.3.4 Electric Harness and Distribution

Verification of the harness and distribution system does not need to be specifically checked since the aliveness test of the various subsystems will provide assurance of its capabilities.

4.4 ATTITUDE CONTROL

4.4.1 Introduction

In a typical complex system such as a satellite, a failure causes the signals or the states of the system to change at more points than just the output of the failed component. A similar statement pertains to the nature of the stimulus which is applied to the component for a failure detection or isolation purposes. For that reason it is most desirable to exercise a complex system in its normal operating environment and mode so that some confidence in the realistic nature of the stimulus exists.

The basic premise given for this study is that the normal thorough preparation and testing is performed on the satellite before boost by the Shuttle and that the number of critical failures in the satellite immediately after boost and shortly after satellite power turn-on is relatively small. Based on past practice with telemetry, it is reasonable to presume that adequate information exists for pinpointing the failure. However, one can isolate failures with the redundancy testing scheme.

In addition, the benefits obtained from sequential (repeated) testing for decision making are well established in radar and communications work for detecting signals and noise, and also originally in production testing. Therefore the backup test approach includes repeating the primary tests and measurements made during on-orbit checkout.

4.4.2 Attitude Control Candidate Tests

The attitude control candidate tests recommended for on-orbit checkout are identified in Table 4-7. The equipment projected for accomplishing these tests includes stimulus generators and measurement equipment. The stimulus generators are a variable DC supply and a sinewave generator, both computer controlled and designed to be general-purpose spaceborne equipment. The measurement equipment is a sampling scope which is ground equipment located in the payload operational control center.

The time estimates for accomplishing the attitude control subsystem on-orbit checkout tests are shown in Table 4-8.

Table 4-7: Attitude Control Candidate Tests.

Subsystem Element	On-Orbit Tests			Payload and Test Location		Test Priority
	For:	Measurements: Primary	Measurements: Backup	In Bay	Standoff	
• All	• Status, Aliveness(1)(5)	• Telemetry	• Power Check	Stormsat, TDS	---	1*
	• Selected Command/ Resp. (1)(2)(5)	• Telemetry & Command	• Backup Channels	Stormsat, TDS, SMS	---	2
• Sun Sensor	• Aliveness & Convergence	• Outputs on Telemetry	• Backup Channels	---	Stormsat, SMS, TDS	3
	• Comparison Between Coarse & Fine Sensors	• Outputs on Telemetry	• Backup Channels	---	Stormsat, SMS, TDS	3
• Star Trackers	• Aliveness	• Outputs on Telemetry	• Backup Channels	---	Stormsat, TDS	3
• Earth Tracker	• Aliveness	• Outputs on Telemetry	• Backup Channel	---	SMS	2
• Magnetometer	• Aliveness	• Outputs on Telemetry	• Backup Channel	---	TDS	3
• Reaction Wheels	• Aliveness & Correlation with Satellite/ Orbiter Motion	• Outputs on Telemetry	• Backup Channel	Stormsat, TDS	---	2
• Inertial Reference Unit	• Compare Redundant Gyro Outputs with Primary Gyro Output(4)	• Outputs on Telemetry	• Backup Channel	Stormsat, TDS	---	2
• Integrated Attitude Control & RCS	• End-to-End Test (Stabilize Payload)	• Outputs on Telemetry	• Visual	---	Stormsat(3) TDS	2

(1) Thrusters disabled
(2) Including redundant electronic component check
(3) Assuming no interference between spacecraft and IUS/support and adequate time
(4) Motion provided by orbiter
(5) Includes thorough checks of the electronics

* Priorities based on potential value and ease of testing

Table 4-8. Attitude Control Subsystem Estimate of Elapsed Time for Tests (Hours)

	In-Bay	Standoff	Total
<u>Assuming Continuous Coverage</u>			
Stormsat, TDS	2	2	4
SMS	1	1	2
<u>Assuming Periodic (Ground Station) Coverage</u>	10 to 15 minutes of continuous coverage is adequate and does not change total time		

4.5 REACTION CONTROL SYSTEM AND PROPULSION

4.5.1 Introduction

The SMS and MMS propulsion subsystems were reviewed as typical of those requiring on-orbit checkout after an STS launch or after propellant/pressurant servicing. The ground rules and requirements were defined as follows:

1. Typical Subsystems:
   a. SMS and MMS
   b. Hydrazine, blowdown (no pressurization system)
2. Components Requiring Checkout:
   a. Thruster valves, function/leakage
   b. Isolation valves, function/leakage
   c. Heater circuit relays and thermostats
3. Systems Requiring Checkout:
   a. Plumbing/tank, leakage
   b. Heater circuit continuity
4. Checkout Modes:
   a. Post launch versus post servicing
   b. In orbiter bay versus orbiter standoff position.

4.5.2 Discussion

Table 4-9 lists the various checks to be accomplished, broken down by propellant system, thrusters, and heater system. A pressurization system section is also included, although not required for the

Table 4-9. On-Orbit Checkout - Propulsion Subsystem

Task	(Launch Checkout) (Launch Criterion)	Orbital Criteria		On-Orbit			
				Post Launch		Post Servicing	
		Primary	Backup	Bay	Standoff	Bay	Standoff
Propellant System							
Leakage Above Isolation Valves	Yes - Pressure Decay	Tank Pressure Decay(1)	Redundant Pressure and Temp. Measurements	Yes-P	Yes	Yes-P	Yes
Isolation Valve Leakage	Yes - Gas Flow	Tank Pressure Decay(1)		Yes	No	Yes	No
Isolation Valve Function	Yes - Position Switch/Gas Flow	Position Switch(2)	Tank Pressure Drop	Yes(1)	No	Yes	No
Leakage Below Isolation Valves	Yes - Pressure Decay	Tank Pressure Decay(1)	Redundant Pressure and Temp. Measurements	Yes-P	Yes	Yes-P	Yes
Thrusters							
Valve Leakage	Yes - Gas Flow	Catalyst Temperature	Pressure Decay	Yes-P	Yes	Yes-P	Yes
Valve Function	Yes - Gas Flow	Thruster Firing, Cat. Temp.(3)	Spacecraft Rates	No	Yes	No	Yes
Heater System							
Thruster Heaters	Yes - Resistance	Local Temp.	None(4)	Yes-P	Yes	Yes-P	Yes
Propellant System Heaters	Yes - Resistance	Local Temp.	None(4)	Yes-P	Yes	Yes-P	Yes

P = Primary Check

Table 4-9. On-Orbit Checkout - Propulsion Subsystem (Cont'd)

Task	(Launch Checkout) (Launch Criterion)	Orbital Criteria		On-Orbit			
				Post Launch		Post Servicing	
		Primary	Backup	Bay	Standoff	Bay	Standoff
Heater System (Cont)							
Circuit Relays	Yes - Temps.	Sys. Temp.	None(4)	Yes	No	Yes	No
Thermostats	Yes - Freon Cooling, Resistance	Local Temp. (5)	None(4)	Yes	No	Yes	No
Pressurization Syst. (If Required)							
Isolation Valve Function	Yes - Position Switch, Gas Flow	Position Switch	Propellant Sys. Pressure	Yes	No	Yes	No
Leakage Above Regulator	Yes - Tank Pressure Decay	Tank Pressure Decay(1)	Redundant Pressure and Temp. Measurements	Yes-P	Yes	Yes-P	Yes
Leakage Below Regulator	Yes - Tank Pressure Decay	Tank Pressure Decay(1)		Yes-P	Yes	Yes-P	Yes
Regulator Function	Yes - Propellant System Pressure	Prop. System Pressure(1)		Yes-P	Yes	Yes-P	Yes
Regulator Leakage	Yes - Propellant System Pressure	Prop. System Pressure(1)		Yes-P	Yes	Yes-P	Yes
Pneumatic Thruster	Yes - Gas Flow	Firing	Spacecraft Rates	Yes-P	Yes	Yes-P	Yes

(1) Standard instrumentation provides only gross detection; effect of temperature changes must be accounted for.
(2) Launched with isolation valves closed and thruster valves dry for STS.
(3) Requires opposite impulse nullification and consideration of plume impingement on payload or IUS.
(4) Requires study to define techniques for remote actuation.
(5) Redundant heater checkout thermocouples not recommended due to complexity.

two specific examples. For comparison, a column of standard pre-launch checkout tasks is also provided. All tasks may be accomplished in the orbiter bay, with the exception of warm gas thruster firings. The results of all in-bay tests should be continuously updated for at least 24 hours while the spacecraft is in standoff to ensure that marginal malfunctions are not inadvertently committed. In particular, pressure decay readings should be taken intermittently, starting as early as possible in the procedure, to provide a sufficient elapsed time for detectable changes.

The major difference between pre-launch and on-orbit testing is the lack of checkout AGE in the orbiter bay. The sensitive flow meters, pressure gages, and electrical resistance/current bridges (which are typically used as test equipment) are at least one order of magnitude more discerning than typical flight instrumentation. In fact, most such measurements are not included in the usual flight complement. Therefore, additional transducers of a new, high-resolution design will have to be added to each spacecraft.

An example of the resolution required may be based on the allowable leakage rate for thruster valves of five standard cubic centimeters of nitrogen per hour. This is equivalent to 3.5×10^{-3} psi per hour at 350 psi for tankage with a capacity equal to SMS, and 2.4×10^{-3} psi per hour for SPS-II. Assuming that the telemetry resolution is good to 2 psi, it would take at least eight hours for a gas leak to be detected (3 psi pressure decay) for SMS, and 50 days for SPS-II. The equivalent propellant leakage would not be detectable at all. Use of an added flight transducer with a full scale of approximately 10 psi at the loaded tank pressure appears to be necessary. Sensitive thermal instrumentation is also required to correct for pressure changes due to temperature variations. Each of the above should be redundant to prevent instrumentation failures from confusing the issue. Finally, the allowable leakage rate should be decreased, and duration of checkout must be increased to detect liquid leakage.

Some tradeoff instrumentation redundancy is required to limit the additional complexity to a reasonable amount. For example, if thermocouples are located with each system heater to establish circuit continuity, adding 50 to 70 redundant thermocouples appears to be unnecessary due to the multiplicity and redundant capability of the latest heater circuits to prevent hydrazine freezing with one heater out.

Functioning of thruster valves prior to priming the system below the isolation valves with propellant is possible; however, there would be no means of detection with systems as presently designed. Measurement of valve signature (current and voltage) would require resistors built into the flight harness and the associated complexity of additional signal wiring or transducers. Visual check of the outflow of gas on a flag or balloon-like nozzle closure would require system modifications for loading nitrogen below the isolation valves and a means for removing the gas flow indicators from the thrusters. Position switches may be necessary for future valve designs. At present, it has been concluded that the thrusters should be fired in the standoff position (unless cold gas is used) and system pressures and temperatures be monitored. Pairs would be fired simultaneously to minimize spacecraft motion.

Functioning of a heater circuit thermostat is normally checked at the factory by cooling with a cold gas stream, and usually not checked at the launch site. A means for such checks, both pre-launch and on orbit, is required and requires further study (for example, plumbing gas jets to each thermostat appears too complex).

4.5.3 Conclusions

1. On-orbit checkout should be equivalent to all pre-launch tests, but requires different techniques, instrumentation, success criteria, and a longer test duration.

2. Airborne instrumentation must be increased and made redundant in the primary areas. Pressure transducer sensitivity increase by an order of magnitude is required.

3. Methods for stimulating thermostats and detecting thruster valve functioning without firing should be studied.

4. The tests required are summarized in Table 4-10.

4.6 THERMAL CONTROL

The functioning of the thermal control of the satellite is tested during satellite on-orbit checkout. For the heater check the satellite is powered down and exposed to a cold environment, probably in the shadow of the orbiter. The temperatures of the satellite are monitored for verification of thermostatic control.

For the temperature control tests, the heaters would be manually commanded on and the satellite exposed to a warm environment as needed. The thermal tests would be actively run concurrently with the satellite subsystem tests. All subsystem temperatures would be monitored during these thermal tests.

Approximately eight hours on orbit will be required to reach a steady-state cold case and another eight hours to reach a steady-state hot case. The test time at each of these conditions is estimated to be two hours. This is in addition to the elapsed time to arrive at a steady-state condition.

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Table 4-10. Propulsion and Reaction Control Subsystem Candidate Tests

Subsystem Elements	On-Orbit Tests			Payloads And Test Location		
	For:	Measurements				
		Primary	Backup	In Bay	Standoff	
Propellant System	• Leakage Above Isolation Valves	• Tank Pressure Decay	• Duplicate Transducers And Thermocouples	All	All	1*
	• Isolation Valve Leakage	• Tank Pressure Decay	• Duplicate Transducers And Thermocouples	All	---	1
	• Isolation Valve Function	• Position Switch	• Tank Pressure Drop	All	---	1
	• Leakage Below Isolation Valves	• Tank Pressure Decay	• Duplicate Transducers And Thermocouples	All	All	1
Thrusters	• Valve Leakage	• Catalyst Temp.	• Pressure Decay	All	All	1
	• Valve Function	• Thruster Firing, Catalyst Temp.	• Spacecraft Rates	---	All(1)	1
Heater System	• Thruster Heaters	• Local Temp.	• None(3)	All	All	1
	• Propellant System Heaters	• Local Temp.	• None(3)	All	All	1
	• Heater Circuit Relays	• System (Local) Temperatures	• None(3)	All	---	1
	• Thermostats	• Local Temp.(2)	• None(3)	All	---	1

(1) Feasibility for IUS payloads may be limited by force allowable or plume impingement.

(2) Thermostat checkout techniques need study

(3) Backup not recommended, judged not with the added thermocouples, etc.

* All tests are first priority. The rationale is that each test is related to a potential single point failure.

Assuming a Multimission Modular Spacecraft configuration, it is estimated that during the subsystem check period the C&DH and attitude control subsystems will not require any heater power; however, thermal control for the power subsystem will require approximately 30 watts of heater power. This estimate also assumes that the Multimission Modular Spacecraft is erected out of the payload bay.

4.7 INSTRUMENT SUBSYSTEMS

Tables 4-11, 4-12, and 4-13 identify on-orbit tests for Stormsat, SMS, and TDS instrument checkout, respectively. Table 4-14 lists test information on test time, testing equipment projected, and the rationale for the testing approach and concepts.

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Table 4-11. Stormsat Instrument Subsystem Checkout Candidate Tests

Subsystem Element	On-Orbit Tests			Test Locations	
		Indications			
	For:	Primary	Backup	In-Bay	Standoff
• ASSIR IR(1)	• Sensor Electronics Aliveness(2)	• Response to Injected Signal	• Diagnostics Verifying Signal Injection	X	
Visible	• Visible Sensor, Sensor Electronics Aliveness(2)	• Visible Light Range Target Stimulated Signal Recognition	• Diagnostics Verifying Target Signal Aliveness	X	
• Atmospheric Microwave Sounder	• Sensor, Sensor Electronics, Gimbal, Scanning System Aliveness	• Space to Earth Viewing Signal Difference	-----	X(3)	X

(1) IR sensor check requires cryogenic cool-down (cooler to be supported in payload bay); may not be practical due to contamination.

(2) Gimbal and scanning system aliveness tests may not be practical since the mechanisms would have to be uncaged, tested, and recaged.

(3) Feasibility dependent on orientation of sounder in payload bay.

Table 4-12. SMS Instrument Subsystem Checkout Candidate Tests

Subsystem Element	On-Orbit Tests			Test Location	
		Indications			
	For:	Primary	Backup	In-Bay	Standby
• VISSR IR(1)	• Sensor Electronics Aliveness	• Response to Injected Signal	• Diagnostics Verifying Signal Injection	X	
Visible	• Sensor and Sensor Electronics Aliveness	• Visible Light Range Target Stimulated Signal Recognition	• Diagnostics Verifying Target Signal Aliveness	X	
• Environmental Monitoring Instruments(2)	• Sensor Electronics Aliveness	• Response to Injected Signal	• Diagnostics Verifying Signal Injection	X	

(1) IR Sensor Check Requires Cryogenic Cool-Down, Instrument Cooler Expected to be Inaccessible In Payload Bay

(2) Sensor Tests Require Low-Level Radioactive Source, Not Recommended.

Table 4-13. TDS Instrument Subsystem Checkout Candidate Tests

Subsystem Element	On-Orbit Tests			Test Location	
	For:	Indications			
		Primary	Backup	In-Bay	Standoff
• Air Quality Instrument VTPR[1] THIR[1] MAPS[2] CIMATS[2] SER(SAGE)[2] HALOE[2] LACATE[2]	• Sensor, Sensor Electronics, Scanning Systems, and Optical Alignment; Focus (End-to-End)	• Earth Radiance Stimulated Signals Coming Through	-----	X[3]	X[4]
• Hydrology Instrument L-Band Radar	• Array, Radar Electronics, and Array Pointing System	• Earth Reflected Signals Coming Through	-----	X[3]	X[5]

(1) Uncooled IR sensor

(2) Visible light sensor

(3) If TDS in vertical position on FSS platform, down pointing and limb pointing required

(4) Deployed solar arrays are used for power in standoff position. If the spacecraft operating mode excludes deploying solar arrays and maintaining satellite attitude, an alternate set of candidate tests would be recommended. Instrument targets would be set up in the payload bay as they normally are in thermo-vac tests.

(5) If needed (see 4 above), an alternate set of candidate tests is recommended using ground test equipment (e.g., echo box).

Table 4-14. Instrument Subsystem Test Information

ESTIMATE OF ELAPSED TIME FOR TESTS[1]

	In-Bay (Hours)	Standoff (# Orbits)	
	No Cool-Down	Stormsat	TDS
Assuming Continuous Coverage	<1	1	1-2
Assuming Periodic (Ground STDN) Coverage	1-16[2]	1-16[2]	1-4

RATIONALE FOR TEST APPROACH

End-To-End Tests of Instruments with Satellite Operating in Standoff Mode or on FSS Platform Checks Entire Instrument and Is Preferred When Feasible

In-Bay Tests Require New Equipments and Do Not Check All Elements of the Instrument

Cryogenic Cool-Down of Stormsat (AASIR) Instrument in Bay May Not Be Practical Due To Contamination. SMS/GOES (VISSR) Instrument Probably Not Accessible for Cooler

In-Bay Check of Optics Not Recommended, Optical Equipment May Be Too Costly and Bulky

EQUIPMENT LIST PROJECTED

Spaceborne

Visible Light Range Sensor Targets (e.g., modulated light emitting diode array) and Equipment to Verify Target Operation

IR Sensor Targets (black radiators with thermocouple) and Equipment to Defeat Space Reference Signal Requirement[3]

Simulated Detector Signal Generator, Leads and Signal Verification Equipment

(1) Configure satellite and carry out test.
(2) Real-time testing.
(3) Latter not required if instrument has internal chopper and/or reference.

5. CHECKOUT SYSTEM EQUIPMENT AND SOFTWARE CONCEPTS

5.1 GENERAL

The following general requirements for on-orbit checkout equipment have evolved.

1. The system reliability and bit error rates will be consistent with low false alarm rate characteristics (low false alarm rate requires that the user be protected against calling a good spacecraft bad and returning it for repair). In order to minimize false alarms, the equipment shall be self-checking and exhibit a man-machine interface which minimizes the possibilities of mistakes. The equipment also will permit realistic rehearsals of on-orbit checkout before flight to gain experience in avoiding mistakes.

2. Support equipment approaches for on-orbit checkout should be "general-purpose" wherever possible.

3. Ground initiated commands shall be authenticated before execution.

4. The checkout system shall keep the operator/test conductor informed about which test program is being run, the steps in process, keep a time log and estimated time to complete test. Any anomalies and discrepancies encountered during the test are reported to the operator.

5. Computer power, mass-memory size, and rapid access memory size will be consistent with checkout requirements.

6. The checkout computer will include interrupt and wait capability and be compatible with time-sharing and modular programming techniques.

7. Satellite test programs can be added or deleted while the on-orbit testing is being accomplished.

8. The checkout equipment shall be capable of operation in a manual mode with man controlling the checkout and its progress from the payload operational control center..

9. The checkout system shall be capable of automatically controlling test sequences and monitoring test results during payload on-orbit checkout without manual intervention.

5.2 ON-ORBIT CHECKOUT COMMUNICATIONS AND EQUIPMENT OPTIONS

The major options considered in this study for on-orbit checko communications and equipment are described in Figure 5-1. The applicability of these options to the payloads in this study are shown on the right-hand side. The most generally applicable approaches are Options 2, 3, and 4, which all make use of the TDRS system (which is, therefore, considered a part of the baseline communication path for this study). Option : goes through the orbiter data system, while Options 3 and 4 make use of the airborne checkout equipment as a part of the communication links. These approaches are, therefore, also baselined as part of this study. Further discussion of the alternative on-orbit checkout modes and the rationale for selection in the study are contained in Section 6.5.

For additional descriptions of the checkout equipment options, please refer to Figures 2-2 and 2-3. The actual equipments used are listed in Section 7. Of particular interest is the airborne or spaceborne checkout equipment. This is the equipment which is configured to operate as part of the orbiter payload and is located in the orbiter payload bay. It includes stimulus and signaling equipment plus the equipment required to command and measure the performance of the stimulus generation equipment. When the option is selected in which the payload checkout can be sequenced automatically using payload bay equipment, the spaceborne support equipment includes a computer.

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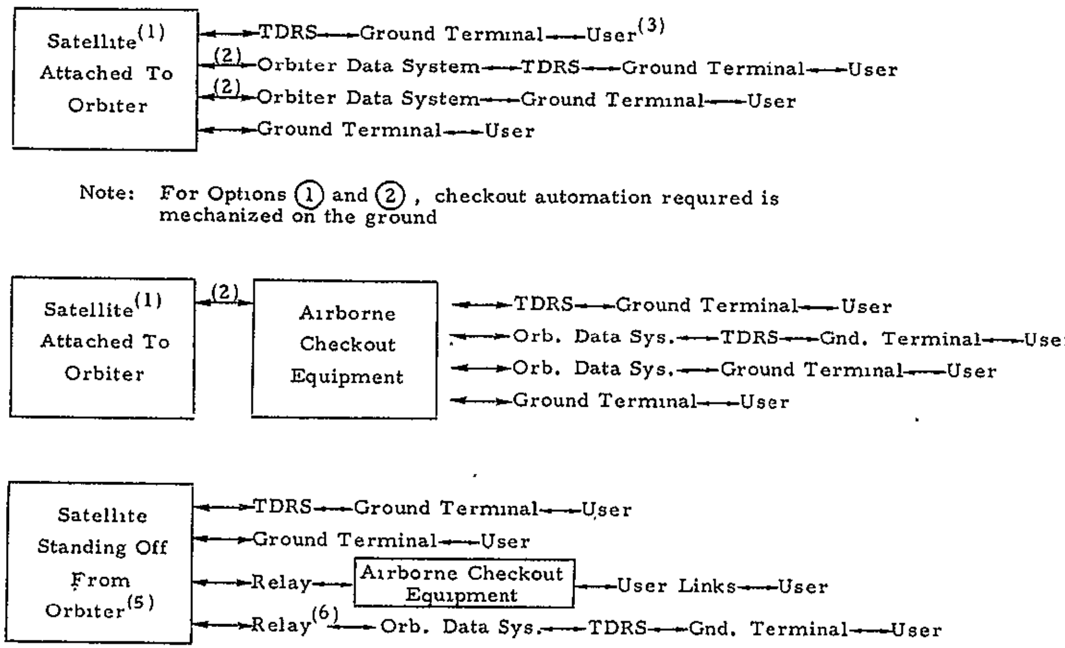

Option Number	Payload Applicability		
	IUS Payload	TDRS Yes	TDRS No
1		x	
2	x	x	
2a	x		x
1a	x(4)		x
4	x	x	
3	x	x	
3a	x		x
4a	x		x
1		x	
1a			x
3 4 3a 4a	x(7)	x	x
2	x(7)	x	x

(1) With or Without IUS
(2) Hardwire Satellite to Orbiter
(3) Operations Control and Satellite User
(4) If Antenna Pattern Permits
(5) Consider for satellite equipments not checked in payload bay
(6) Through Terminal Installed in Orbiter
(7) Capability is Satellite Design Dependent and Only Good Through Terminal Installed in Orbiter, Utility for In-Orbit Mission Equipment Checkout at Low Orbit is Questionable

Figure 5-1. Major Options for On-Orbit Checkout

Figure 5-2 displays a block diagram of the spaceborne checkout support system with and without automatic checkout equipment options. The concept displayed in Figure 5-2 makes use of standard satellite components expected to be available in this time period for applications to satellites and other spaceborne systems. Thus, the development cost of a new component or assembly is bypassed and only modification of already qualified components is required.

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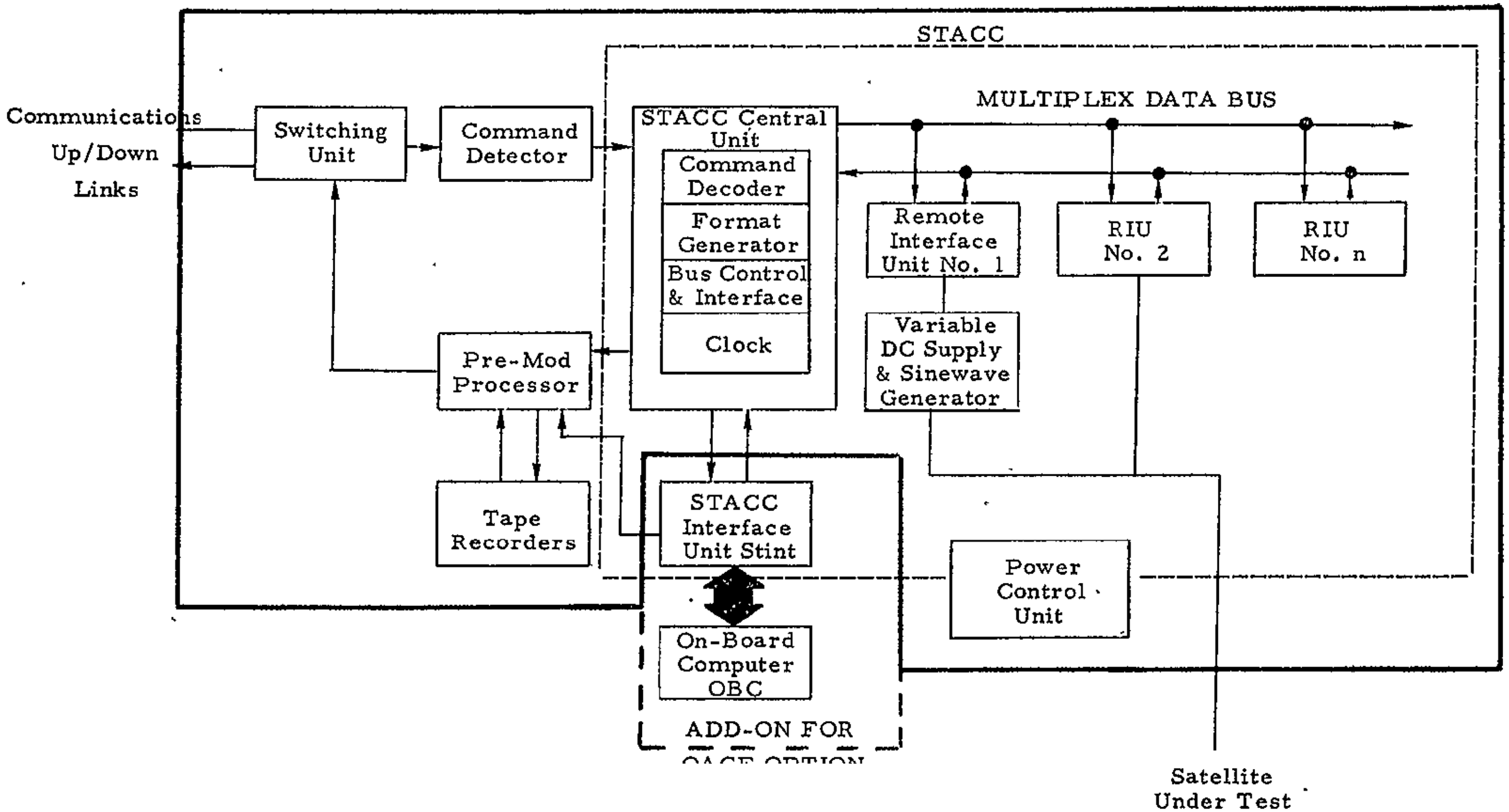

Figure 5-2. Spaceborne Checkout Support System and On-Orbit Automatic Checkout Equipment (OACE) Option Simplified Block Diagram of the Standard Telemetry and Command Component (STACC) Based System

6. CHECKOUT SYSTEM OPERATION

A generalized test for on-orbit checkout is described in Figure 2-1. This flow chart accommodates the on-orbit checkout tests recommended in Section 4. The time required to accommodate this testing, assuming successful tests, is brought to the satellites in Table 2-1. Many of the tests are real-time tests and, therefore, the times listed assume nearly continuous coverage of the on-orbit checkout testing program. This is accomplished either by using TDRS and automatically controlling the test from the ground, or using on-orbit checkout test equipment in the orbiter which is capable of automatically sequencing the test. As discussed in the previous section, the equipment proposed will be able to accommodate either one of these test schemes.

RF links between the satellite while attached to the orbiter and the orbiter checkout equipment were considered. These are desirable in order to accomplish as much of the checkout as possible while the payload is still attached to the orbiter. However, the RF equipment required to do this testing turned out to be more expensive than could be justified for this application. This is discussed in Section 7 of this report. The operational mode selected, therefore, was to accomplish the checkout of the RF portion of the telemetry and the RF portion of the command system for the satellite directly with the ground station while the satellite is still attached in the payload bay. Therefore, for Stormsat and TDS the TT&C subsystem checkout tests are run through the satellite-to-orbiter or satellite-to-checkout equipment umbilicals, except for the RF equipment tests. The RF equipment tests are run during the brief time that the ground station(s) are in sight. The SMS/GOES ground station at Wallops Island does not come into sight unless a special high inclination Shuttle parking orbit is used. This is not recommended since the Shuttle user charge would increase for this non-sharing orbit. These RF tests for mission-peculiar (usually wide-band) data systems can be checked out while the payload is attached or while it is in a standby mode and still be an acceptable approach. These mission-peculiar telemetry systems would also be checked out directly between the satellite and the ground station or between the satellite and the TDRS system in accordance with its normal operating state.

7. VALUE OF ON-ORBIT CHECKOUT (POTENTIAL COSTS AND BENEFITS)

7.1 COST ESTIMATES

Section 2, Summary of the Results of the Study, includes cost estimates for carrying out on-orbit checkout. It is the purpose of this section to discuss the basis for these cost estimates.

The cost estimates are based on the equipment and software concepts for checkout described in Section 5. The effect of the checkout equipment on STS transportation costs was estimated based on a JSC memorandum by Ed Dupnik. The transportation cost increment for checkout and checkout equipment is negligible and was assumed to be equal to zero for this study. An attempt was made to obtain the cost for operating the tracking and data relay satellite system (TDRSS) for on-orbit checkout. No information could be obtained that was useful in cost estimating in this study, and therefore TDRSS costs are neglected.

Cost estimates for both non-recurring and recurring costs for checkout equipment were made using the Aerospace component and equipment cost data base. The spaceborne equipment is either the same as or similar to satellite equipment and components in the data base. The cost estimates used in the study are displayed in Table 7-1. The costs of the equipments listed in Table 7-1 were included in the cost estimates for each of the satellites as they are required for the various on-orbit checkout tests for each of these satellites. In this analysis the equipments were treated as either general-purpose spaceborne equipments or special-purpose spaceborne equipments. The general-purpose

Table 7-1. Spaceborne Checkout Equipment Cost Estimates[1]
Thousands of 1975 Dollars

Equipment Descriptions	Non-Recurring		Recurring
	Adapt Existing Equipment	DDT&E for New Equipment	Unit Cost[2]
General Purpose Equipment			
1. Command Detector and Premodulation Processor[3]	180	---	324
2. STAAC Central Unit[3]	174	---	230
3. Standard Computer Interface[3]	68	---	36
4. Standard Computer[3]	420	---	356
5. Remote Interface Unit[3]	124	---	111
6. Power Control Unit[3]	69	---	62
7. Tape Recorder[3]	148	---	130
8. Variable DC Supply and Sinewave Generator	---	1200	291
9. Mass Memory Tape Unit	159	---	266
10. Switching Unit	44	---	74
Special Purpose Equipment			
1. Command Reformatter, Modulator[4]	98	---	266
2. Command Transmitter[4][5]	---	260	94
3. RF Coupling Hardware	14	---	58
4. Probe	26	---	46
5. Receiver[4][5]	---	450	72

(1) These equipment cost estimates are best available but subject to inaccuracies associated with estimating equipment concepts. The cost of integrating the equipments into a checkout system is included in the estimate.
(2) Average cost for first five units, except as noted.
(3) NASA STAAC equipment.
(4) Same unit for an MMS spacecraft.
(5) Tunable to assigned channel.

spaceborne equipments are equipment concepts usable in checking out all satellites studied in this analysis, and they are expected to be applicable to the additional satellites as indicated in Table 3-1 in the last column. This general-purpose equipment is also expected to be applicable to additional satellites in the NASA mission model. In this study it is assumed that checkout, and therefore checkout equipment, is not applicable to DoD satellites or commercial satellite projects. This is a conservative assumption for this study since it is known that the STP standard satellite project for DoD plans to accomplish on-orbit checkout. Plans for commercial satellites are unknown, their use of the STS has yet to be developed, but of course, they will probably use the on-orbit checkout equipment when it proves cost effective.

Special-purpose satellite checkout equipment is that which would normally apply to only one satellite project. These equipments would support checkout of mission-unique satellite subsystems, such as the experiments and instruments. An exception to this is the special-purpose equipment which supports the checkout for the multi-mission modular spacecraft (MMS). For the MMS checkout, special-purpose equipment costs which would be applied to all MMS spacecraft are treated as if the equipment is standardized and all projects using the MMS spacecraft make use of the same checkout support equipment. An example of the MMS special-purpose support equipment is the equipment complement supporting the spacecraft RF testing while the spacecraft is attached to the orbiter and communicating to checkout equipment also attached to the orbiter via the RF path.

Cost estimates for the general-purpose spaceborne equipment applicable to all satellites in this study are listed in Table 7-2. As described in Section 5, the equipment for the ground-based automated

Table 7-2. General-Purpose Spaceborne Equipment Cost Estimates Thousands of 1975 Dollars, All Satellites

	Non-Recurring Cost	Unit Cost
Ground-Based Automatic Case		
1 Command Detector 1 Premodulation Processor	180	324
1 STACC*	174	230
3 Remote Interface Units	124	333
1 Power Control Unit	69	62
1 Tape Recorder	148	130
1 Variable DC Supply 1 Sinewave Generator	1,200	291
1 Switching Unit	44	74
Subtotal	1,939	1,444
Orbiter-Based Automatic Case Additional Equipment(1)		
1 Standard Airborne Computer	420	356
1 Standard Computer Interface	68	36
1 Remote Interface Unit	124	111
1 Mass Memory Tape Unit	159	266
Subtotal	771	769
Ground-Based Case Subtotal	1,939	1,444
Total	2,710	2,213

No Equipment Charge Assumed For:

Telescope (MMSE)
Contamination Monitor (MMSE)
Orbiter RCS Propellant

Charged to Payload Independent of Checkout Requirements:

Payload Bay Cables and Disconnects for Electrical Power

* Standard Telemetry and Command Component

(1) Over that required for ground-based case.

checkout case is included in the orbiter-based automated checkout case. For the latter, an airborne computer and mass memory is included to accomplish the automated portion of the testing.

The cost estimates for the special-purpose spaceborne equipments are described in Tables 7-3 and 7-4 for two alternative approaches to RF testing. Table 7-3 lists the equipment and cost estimates for the cases with a RF test conducted between the spacecraft and the orbiter attached RF equipment for checkout. Table 7-4 describes the equipment and cost estimates for the case with the RF testing carried out between the spacecraft and the ground terminal(s). In this latter case, RF airborne checkout equipments are deleted.

In calculating the cost of checkout for specific satellite projects, the general-purpose equipment costs described in Table 7-2 were applied to each payload project assuming the equipment to be standardized and shared between projects. Thus the non-recurring costs could be spread over all projects to which the equipment is useful. Also, the number of units of equipment required to support the on-orbit checkout in the 1980s can be estimated, and the units themselves can be shared between projects, thus spreading the costs.

Using the information from the 8 March 1976 NASA mission model, the number of projects to which the on-orbit checkout equipment could be applied, and the number of units required to support these checkouts were estimated. The results of this are listed below as assumed usage:

1. It is assumed that 15 low earth orbit NASA and civil payload projects use general-purpose checkout equipment in the 1980-1985 time period for a total of 40 launches, with an average launch rate of 7 launches per year.

Table 7-3. Special-Purpose Spaceborne Equipment Cost Estimates
Thousands of 1975 Dollars

	Non-Recurring Cost	Unit Cost
Ground-Based Automatic Case or Spaceborne Automatic Case [Either Case with RF Tests Through Checkout Equipment/ Spacecraft Link]		
TDS and Stormsat(1)		
1 Command Transmitter(2)(3)	260	94
1 RF Coupling Hardware(3)	14	58
1 Receiver for TT&C(2)(3)	450	72
1 Probe(3)	26	46
Subtotal	750	270
Additional Equipment for Stormsat Mission Peculiars		
1 RF Coupling Hardware(4)	14	58
1 Receiver(2)(4)	450	72
1 Probe(4)	26	46
Sensor Signal Generator	150	50
Visible Light Range Target	50	50
Subtotal	690	276
SMS		
1 Command Reformatter, Modulator	98	266
1 Command Transmitter(2)	260	94
3 RF Coupling Hardware	14	174
1 Receiver(2)	450	72
5 Probes	26	230
1 Interrogator(2)	1,000	250
1 Transponder(2)	1,000	750
Sensor Signal Generator	150	50
Visible Light Range Target	50	50
Total	3,048	1,936

(1) And all satellites using MMS.
(2) Adapt ground test equipment concepts to become spaceborne equipments.
(3) Needed for TT&C checkout if conditions do not permit ground station checkout.
(4) Needed for wideband data checkout if conditions do not permit ground station contact.

Table 7-4. Special-Purpose Spaceborne Equipment Cost Estimates Thousands of 1975 Dollars

	Non-Recurring Cost	Unit Cost
Ground-Based Automatic Case or Spaceborne Automatic Case [Either Case with RF Tests Directly With the Ground Terminal]		
TDS		
No Special Purpose Equipment Required		
Stormsat		
1 Sensor Signal Generator	150	50
1 Visible Light Range Target	50	50
Total:	200	100
SMS[1]		
1 Command Reformatter, Modulator	98	266
1 Command Transmitter	260	94
2 RF Coupling Hardware	14	116
5 Probes	26	230
1 Interrogator	1,000	250
1 Sensor Signal Generator	150	50
1 Visible Light Range Target	50	50
Total:	1,598	1,056

(1) Assuming 28.5° inclined Shuttle parking orbit, no contact with Wallops Island.

2. It is assumed that 3 general-purpose spaceborne satellite checkout units will support the 7 launches per year, including prelaunch checkout and on-orbit checkout rehearsal as well as the on-orbit checkout activity itself.

3. For the special case of the MMS checkout support equipment, it is assumed that 10 projects use the MMS satellite in the 1980-1985 time period and accomplish on-orbit checkout for 25 launches, for an average rate of a little over 4 launches per year. During this period, two Stormsat satellites are assumed launched and checked out. During this period, one Technology Demonstration Satellite is assumed launched and checked out. In order to support the 25 launches in this time period, it is assumed that two special-purpose MMS checkout sets of equipment would be required to cover the activity.

The cost estimates per launch for spaceborne equipment for each of these projects studied are shown in Tables 2-2, 2-3, and 2-4 under the columns headed "spaceborne equipment."

The next column on these tables is headed "ground equipment." The cost per launch shown under ground equipment is based on the cost estimates described in the next paragraph. As discussed in the spaceborne general-purpose equipment, three units for the ground-based checkout equipment are expected to be able to support the NASA on-orbit checkouts from 1980 through 1985. For checkout cases studied where the automatic sequencing and control of the checkout is on orbit, the ground-based automated sequencing equipment is deleted; however, ancillary equipment is added for the airborne automatic checkout computer so that it may be used on the ground prior to launch to support prelaunch satellite checkouts and on-orbit satellite checkout rehersals.

The following cost estimates are for general-purpose programmable checkout equipment to be used for ground-based checkout of on-orbit satellites. Vendor's names and their part numbers are used for sizing only.

Ground-Based Automatic Sequencing and Control Checkout Equipment

1.	Process Computer with I/O Equipment and Controller DEC PDP-11/70, 64K Words	$60,000
	RSX-11 D Software for PDP-11/70 QJ580-AD Mag Tape (4/TR) Binaries	5,000
	QJ580-AE DEC Pack Binaries	5,000
2.	Mass Memory DEC RWP04-BA, 44 Million Word Disk Pack Drive and Two PDP-11/70 Control Units	47,000
3.	DEC TWV16-EA Magnetic Tape Transport and Control Unit 45 IPS, 800 BPI, 9 Track	15,500
4.	DEC LPL-VA Line Printer 132 Columns, 64 Character Printer and Control Unit, 300 LPM	10,500
5.	DEC CD11-A Card Reader 1000 Cards/Minute Reader and Control Unit 80 Column Punched Cards	5,100
		$148,100

Ground-Based Console for Test Operations

1.	Used for General Monitoring, Controlling, and Integration. (Includes: Cabling, Console Display, Switch Driver, Switching, Video Terminal)	$125,000

TT&C Measurement Equipment

1.	Bit Error Detection Device (Error detection could be accomplished on the orbiter. When the command is sent to the orbiter and the received command is transmitted back to the ground before release, command could be checked on the ground with a comparator.) Comparator Cost:	$10,000

7.2 COMPARISON OF ALTERNATIVE ON-ORBIT SATELLITE CHECKOUT MODES

Cost drivers for on-orbit checkout are the equipment and software costs. Insight into the relative costs of accomplishing on-orbit checkout can be obtained by comparing the equipment and software cost estimates.

Please refer to Table 7-5 for the Technology Demonstration Satellite. The space-based test sequencing, utilizing a computer as a part of the spaceborne checkout equipment, costs more than ground-based sequencing of the checkout tests. Both the ground-based test sequencing and the space-based test sequencing assume that the tracking and data relay satellite system (TDRSS) is relaying the data in real time. The increase in checkout costs due to operation of the spaceborne general-purpose computer is reflected in the difference in cost per flight under the column "spaceborne equipment general-purpose." The difference is about $77,000 per flight. When the RF tests are conducted through the spaceborne checkout equipment, the special-purpose spaceborne equipment reflects $129,000 for the RF equipment to accomplish the checkout.

For the Technology Demonstration Satellite, the ground equipment costs for the ground-based sequencing and the ground equipment costs for the space-based sequencing are approximately the same. In the space-based sequencing case, the computerization of checkout on the ground is not required, but the ancillary equipment required to exercise the space-based computer before launch brings the cost back up close to the ground equipment costs for ground-based test sequencing. The cost for coding the test programs on the computer is approximately the same whether the checkout is operated from the ground or from space.

Table 7-5. TDS On-Orbit Checkout Costs Per Launch, $M
Equipment and Software(1)

Tests	Spaceborne Equipment		Ground Equipment	Software	Total(2)
	General Purpose	Special Purpose			
GROUND-BASED TEST SEQUENCING					
RF Tests(3) Thru Checkout Equipment/Spacecraft Link	0.157	0.129	0.021	0.125	0.432 (0.234)
RF Tests(3) Thru Orbiter/ Spacecraft RF Link	0.157	-0-	0.021	0.125	0.303 (0.218)
RF Tests(3) Direct With Ground Terminal	0.157	-0-	0.021	0.125	0.303 (0.218)
SPACE-BASED TEST SEQUENCING					
RF Tests(3) Thru Checkout Equipment/Spacecraft Link	0.234	0.129	0.019	0.125	0.507 (0.309)
RF Tests(3) Thru Orbiter/ Spacecraft RF Link	0.234	-0-	0.019	0.125	0.378 (0.293)
RF Tests(3) Direct With Ground Terminal	0.234	-0-	0.019	0.125	0.378 (0.293)

(1) Equipment and software can also be applied to launch site payload testing.
(2) Costs in parentheses assume 8 TDS satellites are launched; without parentheses assumes 1 TDS satellite launched.
(3) Test of satellite TT&C RF equipment.

Stormsat on-orbit checkout costs per launch (Table 7-6) exhibit an increase in checkout costs in the special-purpose spaceborne equipment area relative to TDS. The increase reflects the cost of equipment required to accomplish low altitude on-orbit checkout for the Stormsat AASIR instrument. In the Stormsat on-orbit checkout cost per launch, a significant drop in the equipment software costs can be seen by making the RF tests directly between the satellite and the ground terminals. Digital data stream from Stormsat spacecraft telemetry is carried through the Stormsat to orbiter umbilical.

For Stormsat, carrying out the on-orbit checkout RF tests directly with the ground terminals is the recommended approach. For the Technology Demonstration Satellite it is recommended that the RF tests be carried out either through the orbiter/spacecraft RF (S-Band) link, which involves the orbiter-supplied payload interrogator unit, or carrying out the RF checkout tests directly with the ground terminal. For both satellites, the ground-based test sequencing is preferred on economic grounds, although this should be re-investigated when the TDRS user charges are available.

7.3 EFFECTS ON SPACE PROJECTS

It has been shown in other studies that satellites which have been checked out prior to launch will reveal extensive failures affecting the majority of the capability of the satellite to carry out the mission when the satellite initiation on-orbit is attempted. These studies, based on historical data, show that extensive early failures occur in six percent of the satellite launches. When an early payload failure occurs, but no checkout is performed, then the failed payload is deployed but cannot be retrieved. The satellite and any upper stage on the flight is lost. For the Technology Demonstration Satellite, it is estimated that the loss would be \$22M. For Stormsat with the initial upper stage, the estimated loss is \$27.5M. For SMS satellites with the IUS, the loss would be \$12.5M, and for the SMS plus solid spinning upper stage (SSUS), \$9M.

Table 7-6. Stormsat On-Orbit Checkout Costs Per Launch[1], $M Equipment and Software[2]

Alternative Testing Concepts For On-Orbit Checkout	Spaceborne Equipment		Ground Equipment	Software	Total
	General Purpose	Special Purpose			
GROUND-BASED TEST SEQUENCING					
RF Tests[3] Thru Checkout Equipment/Spacecraft Link	0.157	0.547	0.021	0.075	0.800
RF Tests[4] Thru Orbiter/ Spacecraft RF Link	0.157	0.483	0.021	0.075	0.736
RF Tests[5] Direct With Ground Terminal	0.157	0.150	0.021	0.075	0.403
SPACE-BASED TEST SEQUENCING					
RF Tests[3] Thru Checkout Equipment/Spacecraft Link	0.234	0.547	0.019	0.075	0.875
RF Tests[4] Thru Orbiter/ Spacecraft RF Link	0.234	0.483	0.019	0.075	0.811
RF Tests[5] Direct With Ground Terminal	0.234	0.150	0.019	0.075	0.478

(1) Two Stormsats assumed launched
(2) Equipment and software can also be applied to launch site payload testing
(3) Test of satellite TT&C RF equipment and wideband data system RF equipment
(4) Test of satellite TT&C RF equipment through orbiter link, wideband data system through checkout equipment link
(5) Test of satellite TT&C RF equipment through orbiter link or directly with the ground terminus. Wideband data system R.F. link is checked out directly with ground terminal.

For the on-orbit checkout scenario, the tests are configured to detect 80 to 90 percent of the early payload failures encountered. The failed satellite and upper stage are returned on the same flight and refurbished. Return transportation is at no additional cost. Refurbishment is estimated to cost \$8.6M for TDS, \$10.7M for Stormsat plus the IUS, \$5M for the SMS plus IUS, and \$3.5M for SMS plus SSUS. The potential savings for on-orbit checkout for these systems can thus be derived as:

1. TDS - \$13.4M (\$0.7M per flight statistically probable)[1]
2. Stormsat plus IUS - \$16.8M (\$0.8M per flight)
3. SMS plus IUS - \$7.5M (\$0.4M per flight)
4. SMS plus SSUS - \$5.5M (\$0.3M per flight).

These potential savings are summarized in Table 7-7. No statistical breakdown is available on upper stage boosted satellites, dividing the failures between low altitude boost and upper stage boost periods. A split is therefore assumed. The table also lists the checkout costs, including the equipment and software costs and the equipment maintenance cost estimated for each flight. An estimate is displayed for the potential loss which can occur when a good satellite is returned unnecessarily because of a false alarm encountered during satellite checkout In this study, special care has been taken to make testing and equipment provisions which minimize the potential loss.

Table 7-7 also displays the potential economic benefit for accomplishing on-orbit checkout for these satellite systems. Whether one or eight TDS satellites are launched, there is a potential economic benefit. For Stormsat, the economic benefit can be realized if the IUS

(1) Historical data shows that 6 percent of the payloads launched experience infant mortality (early failures) which makes the satellite unable to perform most of the functions (Reference 26, Section 3.3.3). Checkout testing is designed to reveal 80 to 90 percent of these failures.

Table 7-7. Summary of On-Orbit Checkout Cost/Benefit Data

	Upper Stage		Cost/Benefit Data Per Flight, $M				
				Checkout Cost			
Satellite Project	Identification	On-Orbit Checkout Of Stage	Potential Savings(1)	Equipment(2)	Maintenance(3)	Potential Loss(4)	Potential Benefit(5)
TDS							
Launch 1	---	---	0.7	0.3	0.1	0.1	0.2
Launch 8	---	---	0.7	0.2	0.1	0.1	0.3
STORMSAT	IUS	No	0.5/0.8(6)	0.4	0.1	0.1	-0.1
"	IUS	Yes	0.8/1.2(6)	0.4(7)	0.1	0.1	0.2
SMS/GOES	IUS	No	0.2/0.4(6)	0.9	0.1	0.1	-1.0
"	IUS	Yes	0.4/0.5(6)	0.9(7)	0.1	0.1	-0.7(8)
"	SSUS	Yes	0.3/0.4(6)	0.9(7)	0.1	0.1	-0.8

(1) From returning satellites suffering early failures (infant mortality).

(2) Assuming sequencing of checkout at POCC and RF checkout with ground terminal. This covers equipment plus software [DDT&E and procurement (non-recurring) costs].

(3) Maintenance of Checkout Equipment.

(4) Returning good satellites because of false alarm.

(5) Assumes infant mortality split before and after upper stage burn.

(6) Higher number assumes all satellite infant mortality occurs before upper stage burn; lower number assumes an even split before and after.

(7) Assumes satellite and upper stage are checked out using same general-purpose equipment.

(8) Negative benefit reduced (to approximately -0.2M$) if high inclination parking orbit is used.

is checked out. This activity counters the early IUS failures, thus enhancing the potential savings. The SMS/GOES satellite is too costly to check out in the normal 28.5° standard upper stage Shuttle parking orbit. The negative benefit is reduced if, for SMS/GOES, a high inclination parking orbit is used which overflies the Wallops Island station so that RF checkout may be accomplished directly with the ground.

8. RECOMMENDATIONS FOR ADDITIONAL EFFORT

Since the resources were not available to accomplish the entire On-Orbit Checkout Study originally conceived, a portion of this study was done under this contracted effort. It is recommended that the effort be continued in order to (1) define on-orbit checkout for specific low earth orbit altitude satellite designs, (2) study the upper stage and upper stage payload requirements for on-orbit checkout, and (3) recommend a plan for standard equipments and standard on-orbit checkout operations for NASA.

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