CONTRACTOR POINT OF VIEW
FOR
SYSTEM DEVELOPMENT & TEST PROGRAM

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ABSTRACT

This paper will present industry's practice of testing space qualified hardware. An overview of the GPS Test Program will be discussed from the component level to the sub-system compatibility tests with the space vehicle and finally to the launch site tests at Vandenberg AFB, California, all related to the Rubidium clock.

INTRODUCTION

Rockwell International has been involved in the development and production of space qualified Rubidium Frequency Standards for the GPS Program since the initial inception of the program in 1974. To date, we have produced a total of 29 Rubidium clocks consisting or prototypes, engineering models, and production units.

The first series of six satellites are in orbit and have been declared operational, with each carrying three redundant Rubidium clocks. Initial test results demonstrated navigation accuracies of a few meters in three dimensions. Rockwell is currently in the process of developing Rubidium clocks on the Phase II/III Program for the GPS Satellites 9 through 12.

The Rubidium clock test cycle covers two major phases, the pre-production and the acceptance level testing. The pre-production covers the board, system assembly, and assembly tests. The acceptance level testing includes the environmental and certification tests. All Rubidium clock tests are performed in different test facilities of Rockwell's Defense Electronics Operations in Anaheim, California.

The space vehicle undergoes integrated acceptance testing through test conditions simulating and exceeding the environments which it will encounter from launch through on-orbit operation. The acceptance test of the space vehicle is performed at Rockwell's Space Operations and Satellite Systems Division at Seal Beach/Downey, California, and the North American Aircraft Division located in Los Angeles, California.

SPACE QUALIFIED TEST PROGRAM

Rubidium Clock Automated Test Station

Rockwell's Rubidium clock has been developed from a commercial Efratom Rubidium Frequency Standard. Extensive modification and repackaging have been performed to meet spacecraft requirements and to improve reliability and stability. Acceptance testing of production clocks are required to assure compliance with the design goals and conformity to the procurement specification.

Computer automation of the Rubidium clock testing is utilized because of the large amount of data to be gathered over an extended time period and the need to extensively process this data.

A central or a time share computer concept was selected to allow for greater versatility of utilization and to allow implementation of additional test stations. The computer system utilizes a sophisticated version of BASIC as the programming language available to users and can be extended to service up to 16 terminals. The time share computer is a pdp-11/35 microcomputer which includes 256K, 16 bit word fixed head disc, 1.2 mega bit word movable head disc, dual dectape storage and 28K words of core memory. It is essentially a minimum system requirement to support the data storage and processing requirements.

In the existing configuration, four terminals or test stations are supported by the pdp-11/35 minicomputer. Three of the four test stations are equipped with micro-computer systems that provide redundant data collection and storage capabilities if the time shared computer should fail. At the end of the test, these data would then be transferred to the pdp-11/35 for analysis. System redundance prevents the loss of test time without interruption. A functional block diagram of the Rubidium clock test station and a photo of three of the four test stations are shown in Figures 1 and 2 respectively.

A valuable feature of the RSTS time share concept utilized is the ability to access data being stored on disc from one program using one I/O port by executing an independent program from a second port. This feature allows data analysis without interrupting data collection program while using a number of different programs.

Failsafe features are incorporated into all test stations to protect against loss of data in the micro-computer due to transient in the power line voltage, clock supply over-voltage and current, over and under base-plate temperatures, and water flow rate restriction in the vacuum pumps.

Rubidium Clock Test

The testing of Rockwell's Rubidium clock is controlled by two specifications, one an assembly and alignment procedure and the second an Acceptance Test Procedure (ATP). These test procedures have been witnessed and certified by Quality Engineering. There are approximately 76 inspection points where a Quality Assurance Inspector must approve and stamp off the work before additional testing can proceed. All these steps are planned and recorded in a FAIR book system. FAIR is an acronym for Fabrication-Assembly-Inspection-Record.

This system also keeps track of all parts installed into the Rubidium clock. If a failure occurs during assembly, the retest must start over per the retest matrix listed in the assembly procedure. If a failure occurs during the ATP, the failure must be documented by Reliability Engineering, who also notifies the prime contractor, and generates a failure analysis report.

At the completion of a successful ATP the test data is assembled into a data package by Quality Engineering and a formal data review is conducted with the prime contractor, Air Force (SAMSO) and the technical consultants for the Air Force.

After the data review, the Rubidium clock is packaged and shipped to the prime contractor. The data is impounded in the Data Submittal department where it is available for review at a later date. This data includes all acceptance test record cards, "FAIR" books, computer printouts and strip charts.

Figure 3 shows the Product Acceptance test flow for the Rubidium clock from the Module Assembly level to the point of shipment, the space vehicle factory test. A typical calendar time for product acceptance test is approximately three months.

Space Vehicle Factory and Launch Site Tests

As prime contractor for the GPS Space Vehicle, installation of sub-systems and integration tests are initiated at Rockwell's

Seal Beach Operation Factory Test Clean Room Facility. Figure 4 shows the test flow and the type of tests performed at these levels on the space vehicle. The Rubidium clock is primarily tested for interface compatibility with the different sub-systems. The performance of the individual sub-system is tested at each phase of buildup to assure reliable operation during the five year mission life. The test criteria are structured to verify that each sub-system performance is within specified limits, and the performance is monitored for stability and continuity from test phase-to-test phase. Departures from expected performance, even well within specification limits, are evaluated in detail and corrective actions are implemented.

Two mobile vans equipped with test systems to perform factory tests follows the space vehicle to Rockwell's acoustics and thermal vacuum chamber environmental test facilities located in the Los Angeles area.

At Rockwell's Los Angeles Operation Acoustic Chamber, the space vehicle is subjected to a broad spectrum of acoustic frequencies to simulate the lift-off, boost, and separation environment. The thermal vacuum chamber at Rockwell's Downey, California, operation siumlates the heat, cold, and vacuum of space to verify assembly, workmanship of space vehicle components.

Figure 5 shows the qualification space vehicle in a thermal vacuum chamber. Each individual sub-system component is mounted on the Space Vehicle thermal control plates and driven to temperatures exceeding on-orbit temperatures by 21°C for qualification testing and 11°C for acceptance testing. The thermal design of the entire spacecraft is thus validated by thermal-vacuum testing in a large vacuum chamber with a typical test time of about 3 months. Each Rubidium clock is turned on in a programmed sequence to test stability at the temperature extremes with the four different sub-systems during the thermal vacuum tests. These four sub-systems include navigation; electrical power (Ni-Cd batteries); attitude and velocity control; and the telemetry, tracking, and command (Figure 6).

After the completion of the Thermal Vacuum Test, the space vehicle is shipped to Rockwell's Seal Beach Clean Room Facility for a series of final tests. These tests include the mission profile, space vehicle's static and dynamic balance and functional tests. One of the key tests is the spin balance which is designed to make precision determinations of the Space Vehicle Mass Properties.

At Vandenberg AFB, the space vehicle is prepared for launch by performing satellite and master control L&S band RF link comatibility tests and a simulated flight and mission dress rehearsal (Figure 7). Normally, one of three redundant Rubidium clocks is turned-on as a master clock for the L-Band RF link compatibility tests. The S-Band links with the Satellite Control Facility located in Sunnyvale, California, and is used as a downlink to receive the telemetry and other information from the satellite.

SUMMARY

It has been shown that the role of automation is essential in the development of a Space Qualified Test Program. Use of automation has been a key factor in the success of the test program to date. Because of the accelerated schedules and heavy demand on test systems, it is highly unlikely that the present state of development could have been achieved without automation techniques. Expertise in the field of precision frequency and time measurements as well as the capability to interface special test equipment with computer technology are essential in meeting test requirements for the space-qualified clocks. Automatic test systems have essentially provided unattended operation 24 hours a day, thus reducing cost and increasing productivity.

The test program plays a major role in producing Rockwell International products for Government contracts. By employing a regimented type test program, it has been shown that tests uncover latent faults which otherwise may have gone undetected. The program has also demonstrated interface compatibility among sub-systems. The use of well documented test procedures has provided uniform testing from location-to-location; test personnel-to-test personnel; and inspector-to-inspector.

In conclusion, when involved in a major program such as GPS, a considerable amount of effort is expended in tests and as such is a key element in the success of the program.

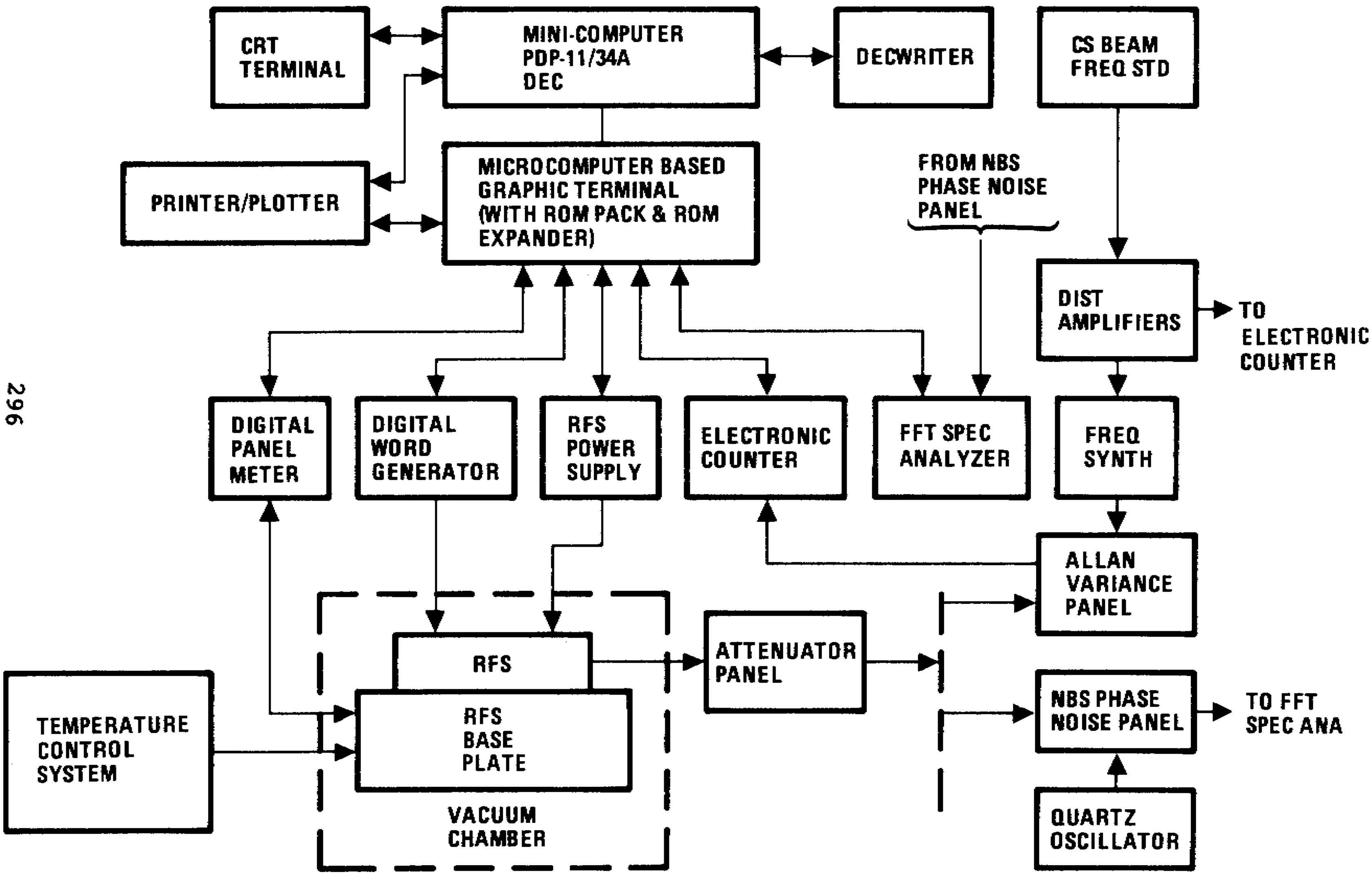

Figure 1. Functional Block Diagram of Automated Rubidium Clock Test Station

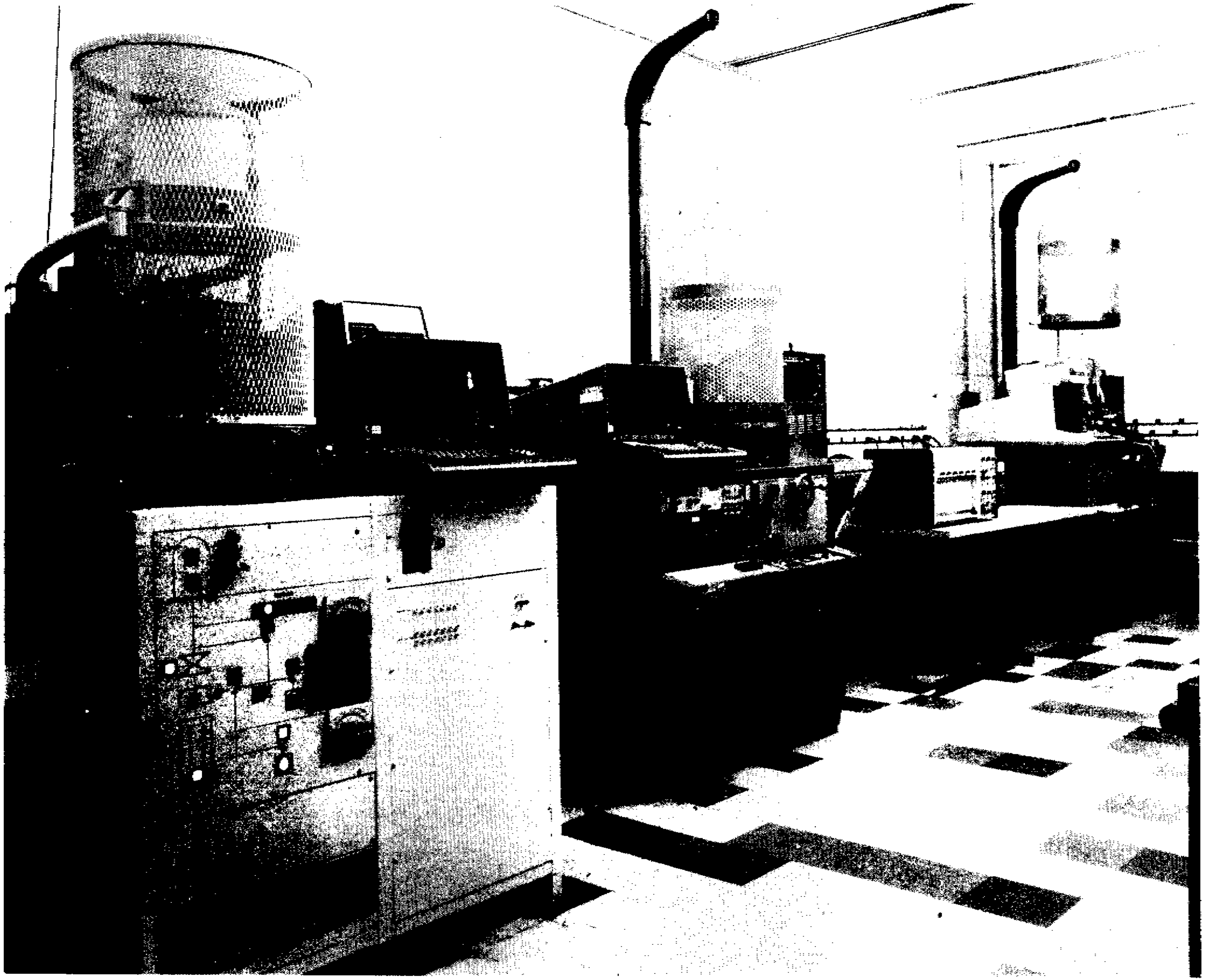

Figure 2. Automated Rubidium Clock Test Stations

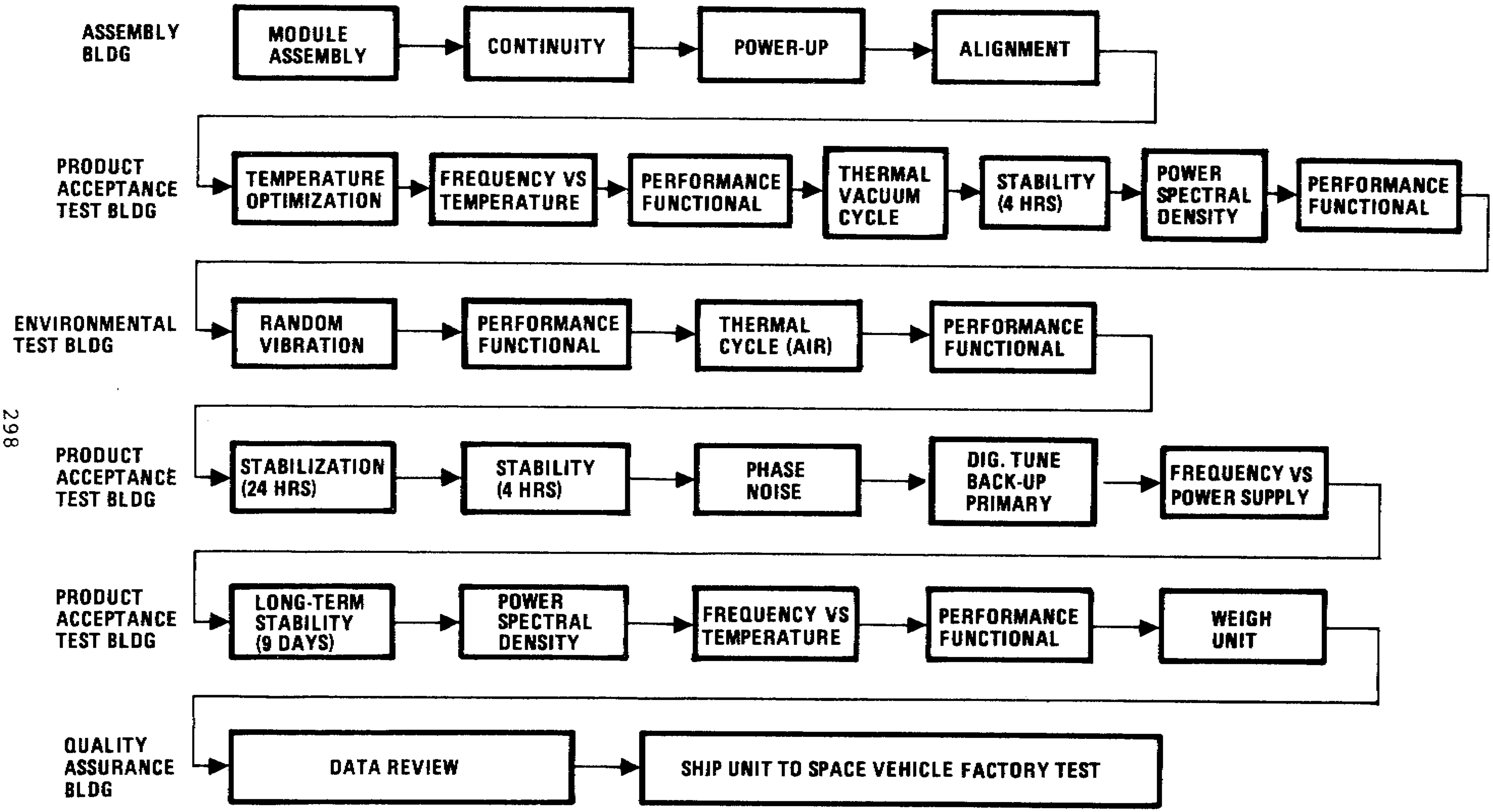

Figure 3. Rubidium Clock Test Flow

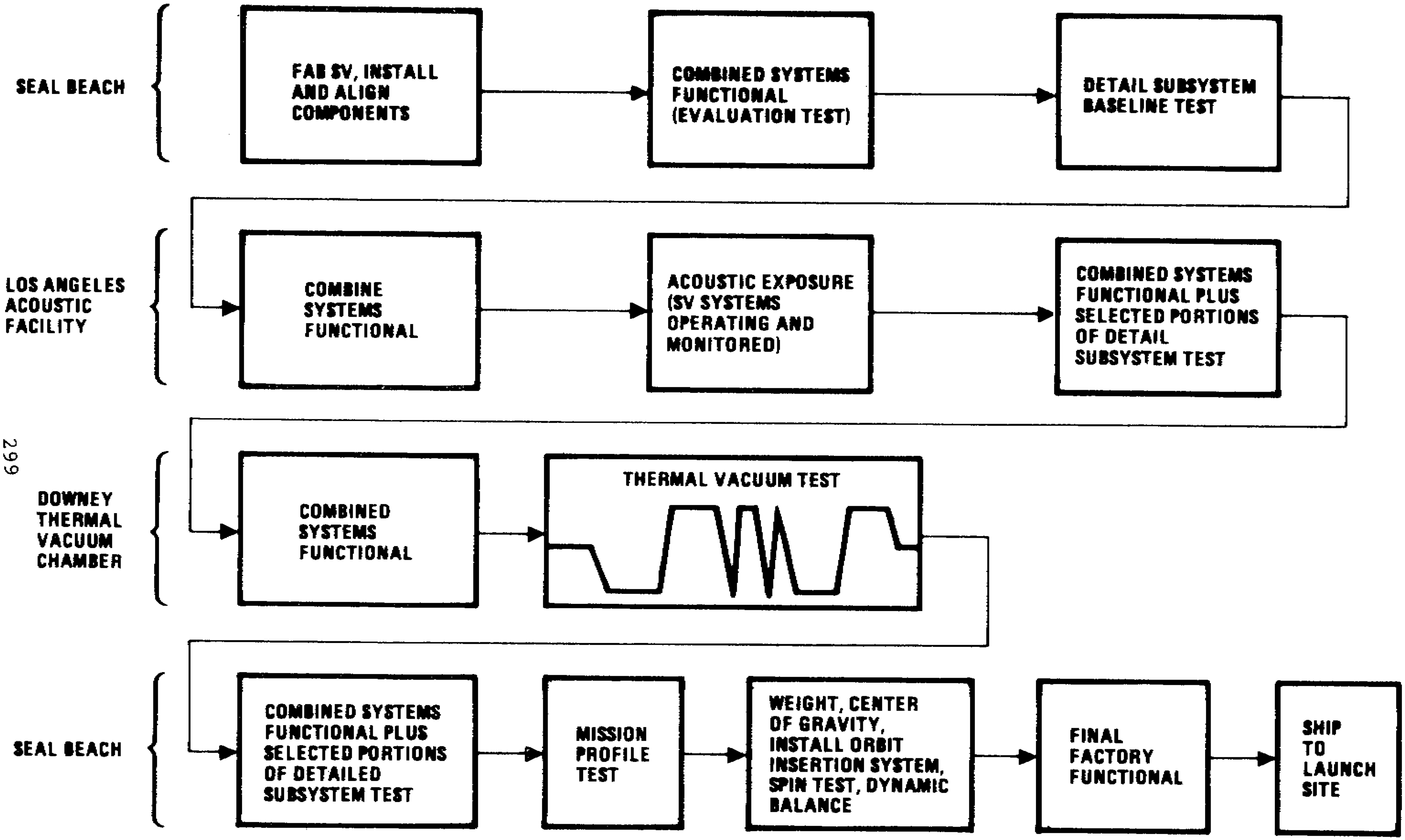

Figure 4. Space Vehicle Factory Test Flow

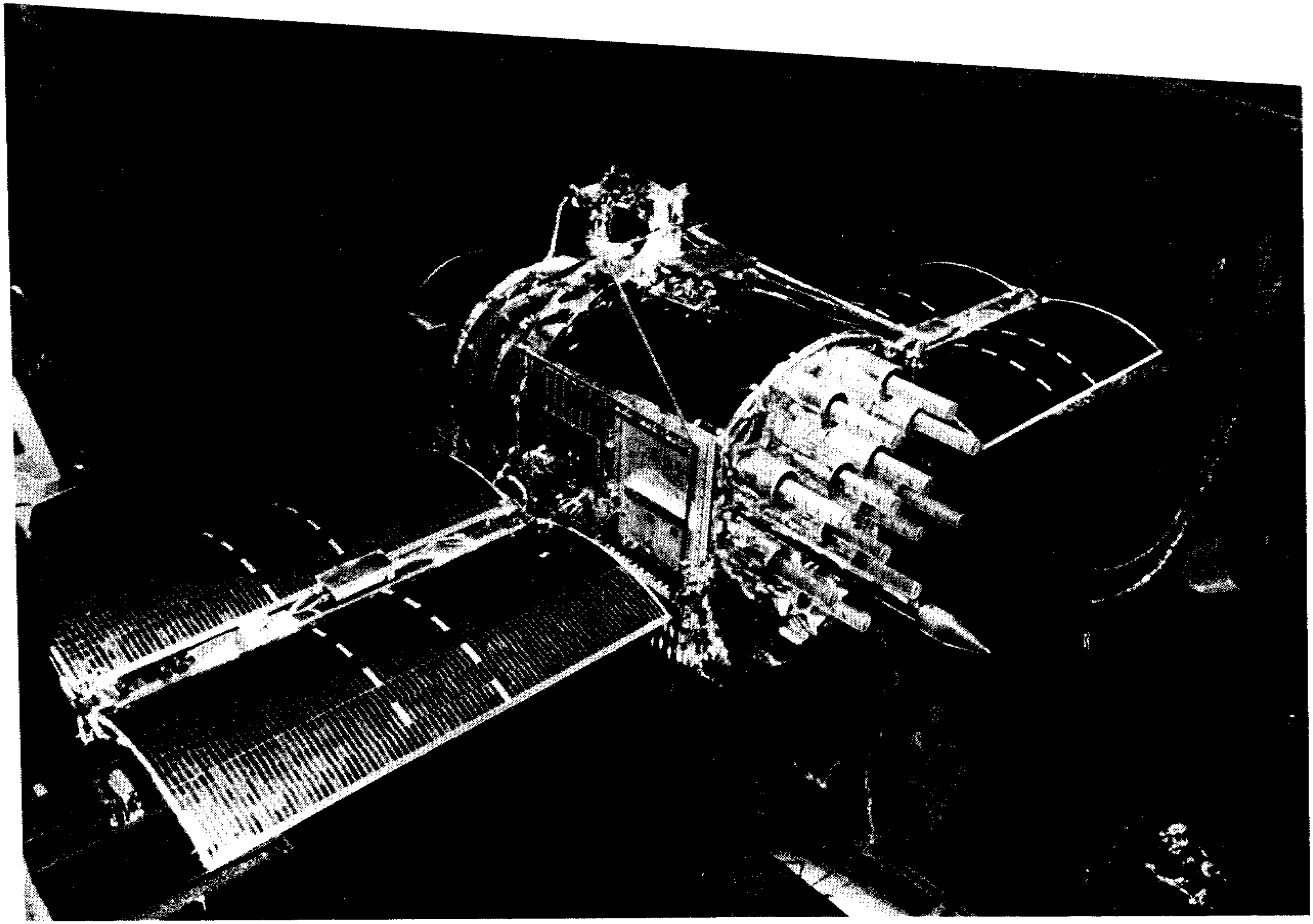

Figure 5. Thermal Vacuum Testing of Space Vehicle

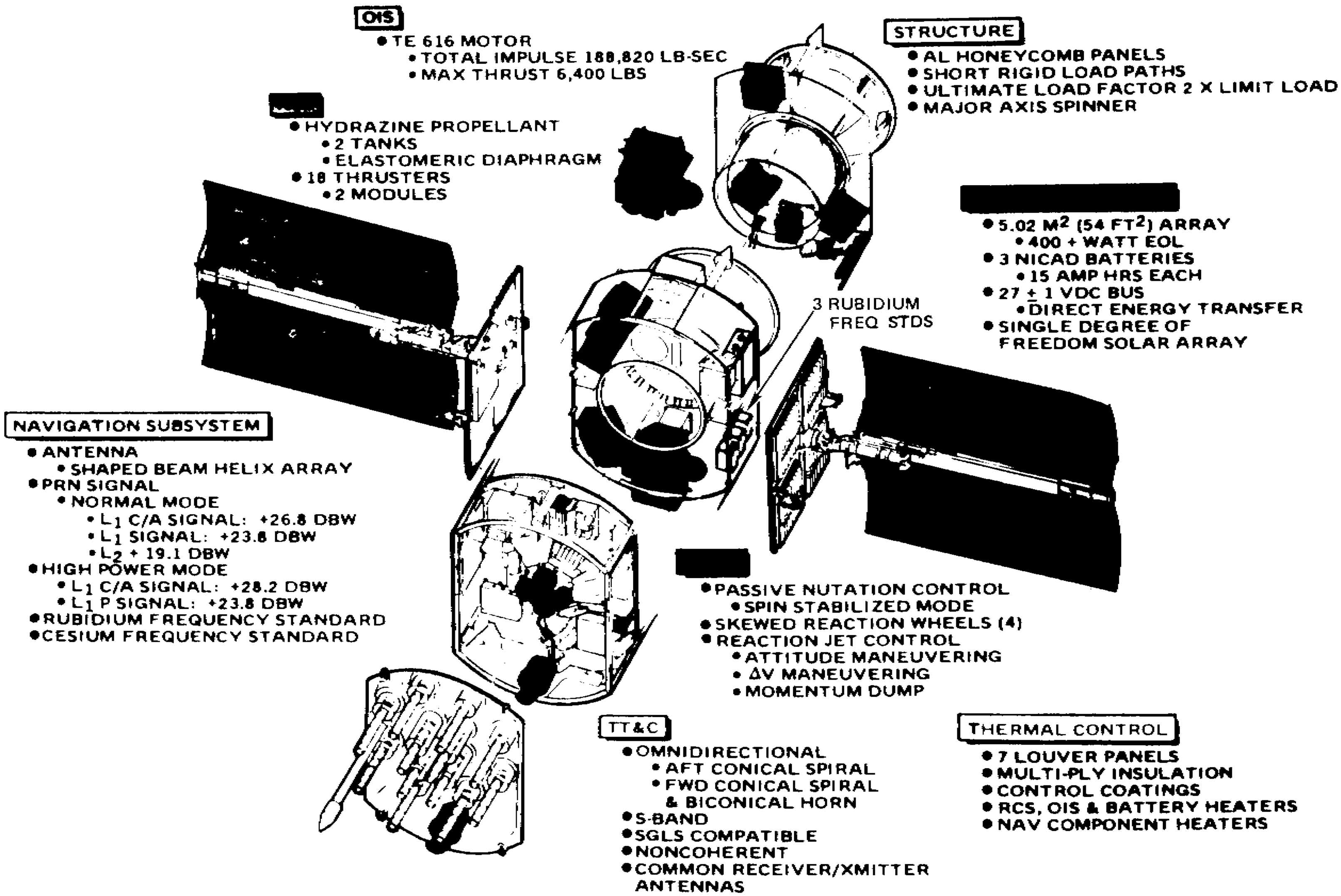

Figure 6. Satellite Subsystems

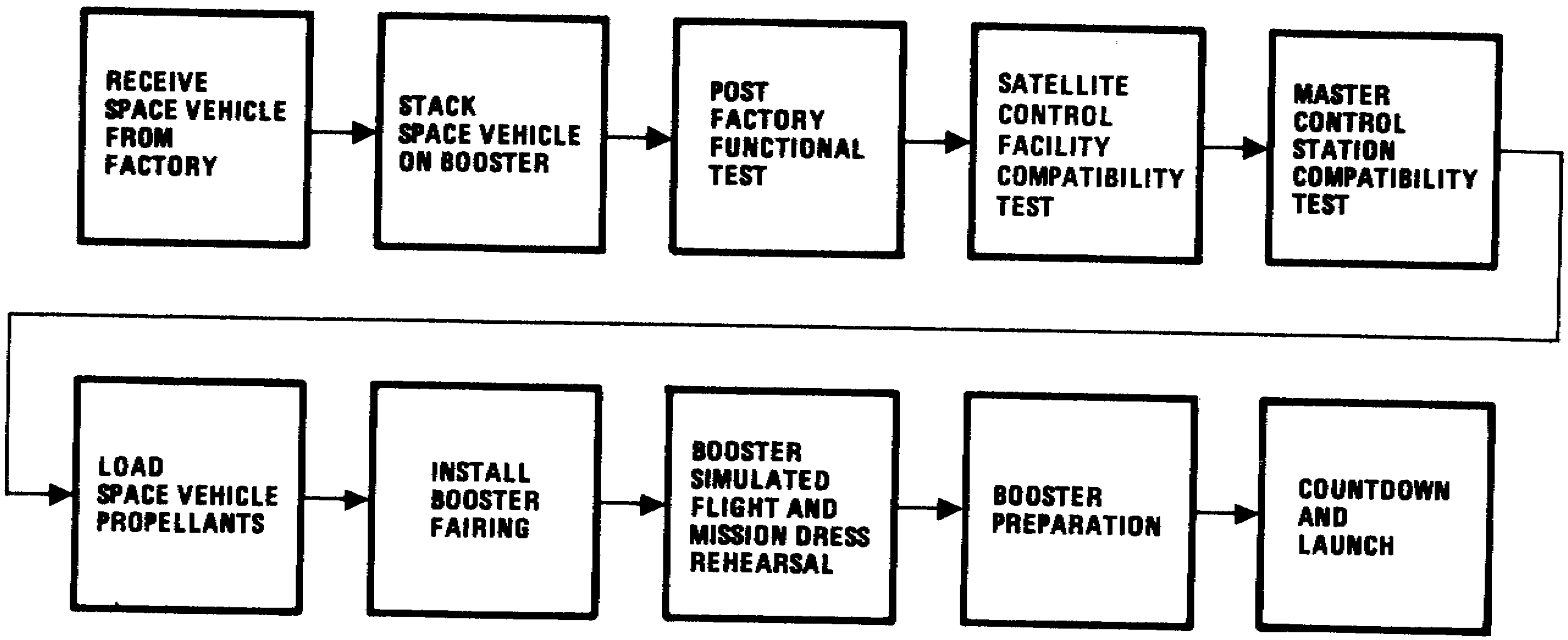

Figure 7. Launch Site Test Flow (Vandenberg AFB, California)

QUESTIONS AND ANSWERS

DR. VESSOT:

If you could explain a little more about what I consider to be the most important test -- and that is the on-going operation of the clock and the monitoring of its operation for very, very long periods of time. Even though these are extreme stages of testing, in my opinion, you do not observe the clock operating for as long as you possibly can while it is in your possession before it goes into space.

A lot of those long-term tests I feel are very minor.

MR. KOIDE:

The long-term tests uses trade-off schedules -- production schedule trade-offs. So, we felt that the long-term type testing will be the Allan variance test which will get out to 100,000 seconds. We get our data points up to about seven data points to give us some assurance of confidence that it has maintained this particular level of task.

DR. VESSOT:

This is not the kind of test I had in mind -- which is the test wherein you prove that this device is going to work for a period of several months while you still have it on the ground. At no time while it is in your possession, I feel, should you fail to take data from the clock in the operating condition.

This is the clean shake, shock, vibration, thermal vac, and all the rest of it -- keep it running and monitor it.

MR. KOIDE:

Yes, we do have the acceptance level testing for the rubidium frequency standard. Once the rubidium frequency standard gets over to the factory test level and integrated into the space vehicle, you are primarily concerned with the interface compatibility between systems.

So, you do monitor all the time -- you do the test while you are testing or monitoring the telemetry lines. You do a lot of other types of tests, but is mainly for the interface compatibility of other systems.

DR. VESSOT:

But does that interfere with the frequency or the stability testing?

MR. KOIDE:

No, that is not the prime function when we get into the vehicle testing.

DR. VESSOT:

I suggest that is a mistake; that you can't avoid that issue of keeping an eye on the piece while you still have it as long as you possibly can.

MR. KOIDE:

Well, we try to do that. We are trying to set up a long-term test, a life test for the RFS and that is another issue.

SESSION III

TIME TRANSFER

James A. Buisson, Chairman
Naval Research Laboratory