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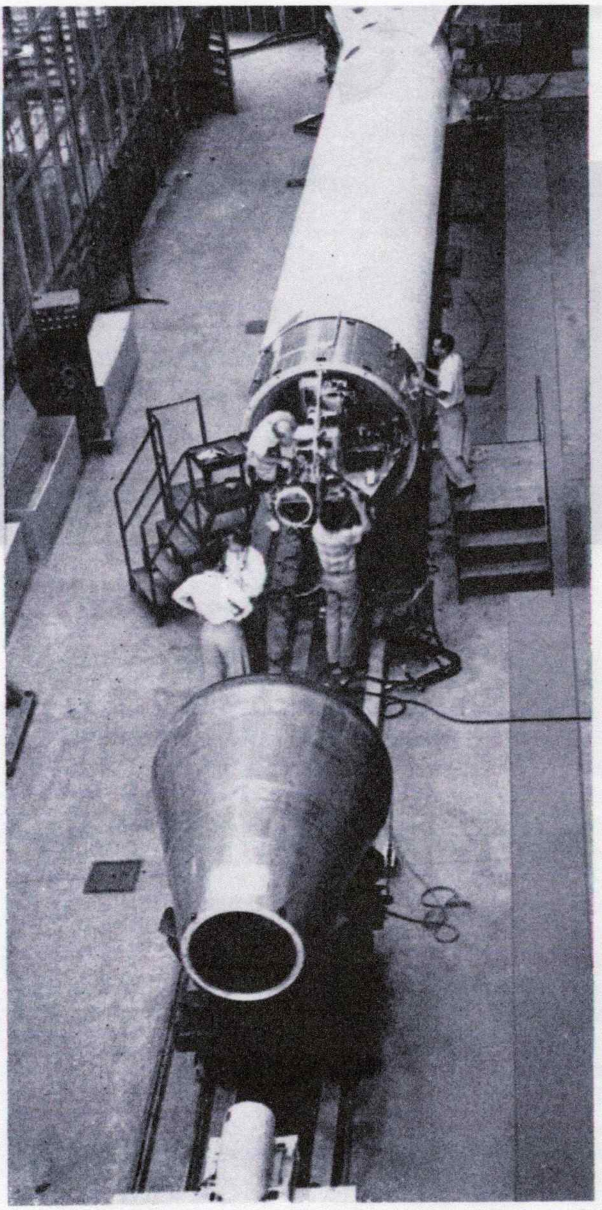

Fig. 1—A Jupiter-C missile on the track in position for final performance testing, with some testing in progress. The conical instrument-section cover has been pulled off to allow access to the instruments. To the left is a screen-wire r-f cage.

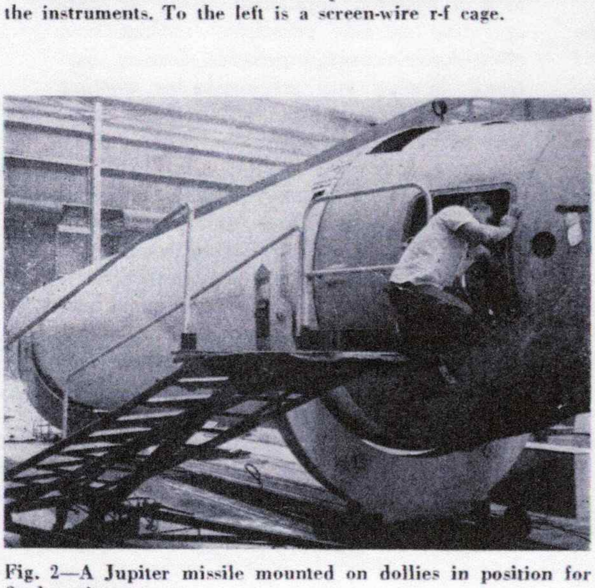

Fig. 2—A Jupiter missile mounted on dollies in position for final testing.

FINAL

Description of test equipment, facilities, and general procedures used in systems checkout and final simulated flight test for the Jupiter missile.

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THE JUPITER MISSILE, now in initial production stages, is the first long-range surface-to-surface guided missile successfully test flown in this country. It is an Army-developed missile for operational use by the Air Force. Developed by personnel of the Development Operations Division of the Army Ballistic Missile Agency, it contains both commercially available and specially fabricated components although, as might be expected, most of the major components are specially developed and fabricated. It has been possible to transpose many components from the system of the earlier Redstone missile directly to the Jupiter, thus reducing the development time necessary for the larger missile.

Both development and first production missiles are very carefully checked in every possible manner to insure reliable operation during firing. This article describes the final electrical and electromechanical testing of the missile before shipment to the firing site. Developmental final performance testing will eventually evolve into production final testing. In line with Army policy, the Army Ballistic Missile Agency accomplishes prototype production only; the production of the missile system, once it has reached the proper stage, is turned over to private industry. This frees the developing agency to take on new projects, and broadens the base of industrial support for the defense program.

General Approach

It should be noted that all components when received undergo a mechanical and electrical inspection and a

PERFORMANCE TESTING

of a Large Guided Missile

functional test as a component prior to assembly into a missile. In addition to this, the installation procedure during assembly is observed by inspectors at each stage of the process. For the sake of convenience and accuracy, for example, r-f antennas are tuned and matched before final assembly of the missile is completed, and accurate alignment of the major structural components is also assured at this time. While assembly is being completed on the top portion of the missile, the booster section, which includes the fuel and liquid oxygen tanks, the rocket engine and the tail, is given a performance test and is then sent to the test stand for static firing. It is next returned to the fabrication shop and assembly is completed. The entire missile is then put in a pressure cell and each of the individual pressure systems on the missile is checked for leaks and for satisfactory operation. When this testing is finished, the missile is moved into the proper area for final performance testing. (See Figs. 1 and 2.)

Test Details

The tests to be performed on the missile are laid out with regard to convenience, speed of operation and accuracy of results. In general, the tests will break down according to the special sub-systems of the missile. General practice has been to allow the group responsible for a particular sub-system to perform tests without any other group working on the missile at the same time. This permits the group doing the testing to have complete freedom with regard to having power on or off the missile, and with regard to control of missile conditions for the tests. The general sequence of tests is as follows:

1. *Continuity Test* — concerned chiefly with cable harness and connectors.

2. *Components Test* — concerned with operation of power plant and associated components.

3. *Overall Tests* — concerned with methods of cutoff of power plant, in-flight separation of the missile sections and other functions associated with the general missile network.

4. *Steering Tests* — checkout of the steering, attitude control, guidance, and certain special device systems.

5. *Measuring Calibration* — calibration and adjustment of the various missile measuring gages to coincide with laboratory curves.

6. *Telemeter Calibration* — testing of the telemeter system in conjunction with the measuring system to insure compatibility of results for telemetering accuracy.

7. *Special Tests* — as required.

8. *Simulated Flight Test* — simulation of complete takeoff and flight conditions in terms of missile operation, together with an r-f noise check.

Continuity Test. Although each cable is inspected after it is fabricated and prior to assembly into the missile, experience has shown that a check of this type after assembly of the missile is necessary to insure that no damage has occurred to cables and connectors during subsequent steps in assembly, and that cables are of proper length and connect properly to individual components. Before delivery of the missile for final testing, engineers go through the missile electrical network drawings and prepare check sheets for a complete connector-to-connector continuity test. The test is conducted according to this check sheet, and will generally reveal any wrong connections, damaged connectors, and high resistance connections in the network. This time is also used for inspection of the missile with a possibility of noting mechanical difficulties, improper "black box" installation, obvious damage, and other such items. It has also been demonstrated that performing a thorough check in this manner saves time in terms of trouble shooting during later missile testing. After continuity testing is completed, the various ground cables are connected to the missile and to the ground control consoles, and power is applied. At this time, indicating meters are carefully observed to detect any abnormal conditions.

Components Test. The components tested are chiefly those associated with the rocket engine. A section of the firing control panel in the ground console, Fig. 3, has been reserved for this test; the components test panel consists of a rotary selector switch and start and stop toggle switches whereby each solenoid valve associated with power plant operation may be energized individually. This panel section permits accomplishment of the major portion of the test by performing the

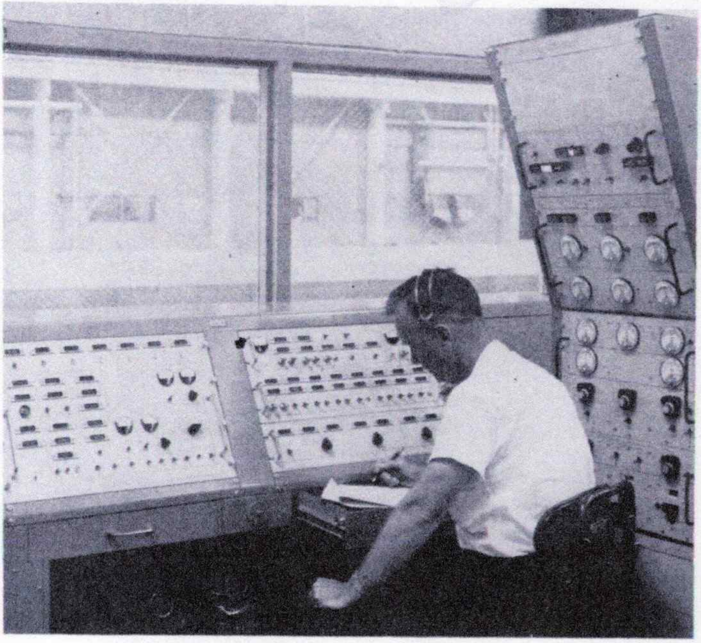


Fig. 3—Blockhouse panels, used later to fire the missile, are shown here in the control room being used for final testing. Indicator lights come on at proper times for lettered function indications.

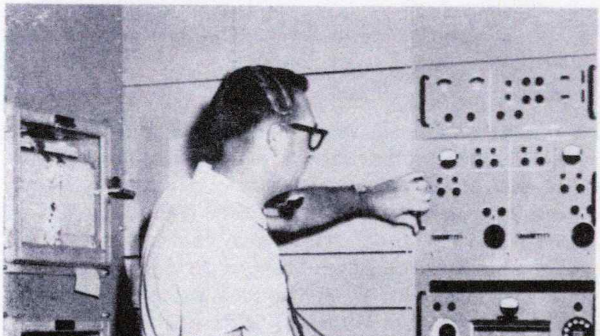


Fig. 4—The operator is shown observing a console panel set for quantitative testing of a portion of the steering system; this is a blockhouse fixture. At left the bank of sequence recorders is used for qualitative indication of missile functions.

switching operations as indicated. However, some other functions and items are also checked at this time as a matter of convenience—for example, the system for replenishing the supply of liquid oxygen in the tank before firing.

Since some valves are actuated by air pressure, which is in turn controlled by solenoid valves, the Components Test is first performed without pressure in order to obtain reasonable assurance that the electrical components are operating satisfactorily. It is then performed using pressure in order to check pneumatic operation of the valves. Several different types of indications of satisfactory operation are used, including audible indication of operation of the valves. In addition, 20-pen strip-chart recorders are connected with wiring provided in the missile and ground equipment networks for a qualitative indication of a signal to or operation of these components. Also, certain valves in the missile have a switch function which will indicate when the valve has been operated. These added together give a rather accurate indication of the results of the test.

Overall Tests. These tests are performed for the purpose of checking the sequence of operations involved in bringing the missile up to and through the point of simulated takeoff, and for checking the various methods of shutting off the power plant, separating the missile, supplying the tilt program to tilt the missile along the flight path, and other such functions as may be involved with the general network of the missile. The various methods of accomplishing each function are laid out and assigned to one of the three Overall Tests, one of which is not run until immediately prior to the Simulated Flight Test.

The first test, commonly referred to as the Cutoff Test, is not a true Overall Test in that the power plant sequence is not involved. It is possible to assign to the Simulated Flight Test and to each of the three Overall Tests, for example, one method of giving cutoff (shutoff of power plant burning). It then becomes necessary and convenient to check all of the other methods of cutoff on the Cutoff Test itself. The same general rule would apply to separation of the missile and to any of the other functions which might occur in this manner. The Cutoff Test makes an attempt to check every wire and circuit and every relay contact involved in the functions of cutoff, separation, and so forth, as previously mentioned. In general, the Overall Tests are planned to accomplish, as simply as possible, the proof of satisfactory simulation of take-off, of initiating cutoff in some particular manner, and of certain other functions of this nature.

Sequence recorders, the 20-pen qualitative recorders previously mentioned, are used rather extensively to monitor the Cutoff Test and the Overall Tests, especially where electrical signals are involved that are not readily perceived visually or aurally. This is particularly true with the time sequence of power plant functions, which occur rather rapidly. In order to establish that the sequence has been gone through correctly, it is necessary to have an indication that the functions have occurred in the proper sequence and with the proper time lags between the functions. These recorders are also quite useful when it becomes necessary to perform trouble shooting operations, especially where chains of relays or automatic sequences are involved. During the Overall Tests it becomes necessary to simulate certain functions such as pressurization of fuel and oxidizer tanks, burning of the power plant, and so on, since they are either impossible to perform in a hanger checkout or constitute a danger to operators. The simulation is generally accomplished by means of relays or switches.

A test procedure sheet is prepared according to the particular functions to be tested. This procedure sheet gives not only the sequence of operations, but also (in certain portions of the test) the time of the operations. A copy is given to each operator with his particular functions underlined in red. Each operator has a number, and a tape is prepared for a magnetic tape recorder which calls out only the operation numbers. The output of the tape recorder is transmitted over a telephone system to the test operators, who wear headsets and perform the function as called. The test engineer located at the console may stop or start the tape at will. A second tape recorder is used to monitor line traffic on the telephone system for later reference. In a series of operations, the commands are spaced about 5 sec apart. This system has been found to be quite satisfactory in the testing of this missile in that it gives a command which can be very well anticipated ahead of time; it is a command which can receive an acknowledgement, and further, it can be checked on later by means of the monitor tape.

Since takeoff is simulated during Overall Tests, it becomes necessary to transfer power for operation of the missile from the ground cables to what would normally be a missile internal source. For a flight missile this is a battery; however, in order that expensive batteries may not be used up in the test, cables are connected from ground generators to the corresponding missile cables prior to the time that the takeoff of the missile is simulated. In order that the missile may "know" that it has taken off, takeoff relays are activated in the missile. For the purpose of the Overall Tests, takeoff may be simulated either by switching a so-called "Simulated Takeoff" switch (and thus dropping out the takeoff relays on the missile) or by actually disconnecting the cables going to the missile from the ground console equipment. Generally, for the first Overall Test (not the Cutoff Test), it is desirable to simulate takeoff by disconnecting the cables to the missile. This is done in order to determine that the network has been designed in such a manner that "takeoff" can be achieved, power will continue to be available and operations will continue to be performed inside the missile even after these cables have been disconnected as they normally would be in a missile in actual flight.

Steering Tests. These tests, which are for the purpose of checking the steering, attitude control and guidance systems of the missile and certain special devices which will be described later, begin by testing the steering system, then add the other two systems individually. The Steering System Test is performed by using command voltages from potentiometers which are fed into the control computer (autopilot). Polarity and magnitude of control item deflections (for example, power plant swivel deflection), constitute the main body of the Steering System Test (see Fig. 4). This test is designed to check aerodynamic control constants built into the control computer. Feedback gains in the servo loops of course play a major part here. Careful checks must be made to insure that the aerodynamic constants change for various flight periods in the right magnitude, with the right polarity, and at the right time.

Fig. 5—Tilt table is used to simulate missile motion on the control gyros shown mounted on the table. The missile being checked is a Jupiter-C.

Attitude control of the missile about its center of gravity is maintained by means of gyroscopes, as is common with most large missiles. After the Steering System Test has insured that the proper signals will actuate the controls properly, signals from the gyros are fed into the control computer and the entire attitude control plus steering system is tested simultaneously (Fig. 5).

The guidance system is checked as an individual system, and its signals are observed to determine that they occur in the right sequence. When this has been accomplished, the signals from the guidance system are fed into the control computer for deflection checks with the steering system. Considerable effort has been expended to build testing consoles to check all three of these interrelated systems in order to assure a high degree of accuracy in hitting the target when the missile is fired. Generally, in the Steering System Tests, the special and accurate timing devices for the missile are checked at the same time.

At the end of the test of the steering, attitude control, and guidance systems, another Overall Test is performed. During the running of this test, all of the guidance and control system in the missile is active and the ground lines are disconnected in order to simulate takeoff. When this test is successfully completed it has been demonstrated that the missile will work properly with regard to the power plant sequence and general network system in conjunction with the guidance and control of the missile, including the basic missile timing system. During the running of the overall test the steering system is operated and the attitude control system is manipulated in a manner which will simulate missile motion. The output of the attitude control gyros then goes into the steering system and moves the control elements of the steering system in a manner which will represent a response to the attitude control system as it would occur during flight.

Measuring Calibration. In order to determine accurately the flight performance of a missile, it is necessary to make accurate measurements of many variables such as temperatures, vibrations, pressures, accelerations, control element deflections, and so on. In order to do this, measuring gages are installed on the missile and information from these gages is fed to the telemeter system. The gages may take various forms. For example, a deflection of some type might well be measured by the movement of a potentiometer. A pressure might well be measured by compression on a bellows and could be read from the movement of a potentiometer actuated by the bellows.

Since a telemeter system will normally have a particular voltage range in which information may be fed to the transmitter, it is necessary to modify the output of the various measuring gages, which may range from a very low voltage to a comparatively high voltage, so that these outputs may be acceptable to the telemeter system. This is generally done by means of an "adapter" box which may contain anything from a potentiometer up to a rather complicated amplifier. In calibration of the measuring system it is in most cases necessary only to adjust the gain of the adapter so that the output of the adapter from the measuring gage will match the output obtained in the laboratory. Thus a great many of the calibration activities fall into the category of simply verifying laboratory results after the measuring gage and, if necessary, the adapter are installed on the missile. In a number of cases, however, actual calibration curves on particular gages are run after the equipment is installed on the missile. This would be particularly necessary in cases of items which might not be completely assembled until the missile itself is completely assembled. Records of the measuring calibration are made on recorders (Fig. 6), and then submitted to a separate evaluation group which compares the records with the laboratory curves for the particular gages and measurements and determines whether the value for the output of the gage is acceptable, or whether the gage has to be readjusted, reworked, or replaced.

Telemeter Calibration. It is difficult to separate entirely the functions of Measuring Calibration and Telemeter Calibration tests since they are so intimately related to one another in getting missile flight information back to ground. Inaccurate or undependable results from measuring and telemetering could possibly cause development of the missile along false lines. As long as the missile is in a development stage, and even into production, it is very desirable, at times, to measure what occurs during flight. The major portion of the time given to final performance testing of developmental missiles is given to the important area of Measuring and Telemeter Calibration. After Measuring Calibration has been completed, a Telemeter Calibration Test is run in which measuring information from the gages is fed through cables to the recorders on which the measuring calibration has been performed. These values are printed on the recorders, the information values are switched to the telemeter transmitters, the information as transmitted is picked up on an antenna located near the roof of the

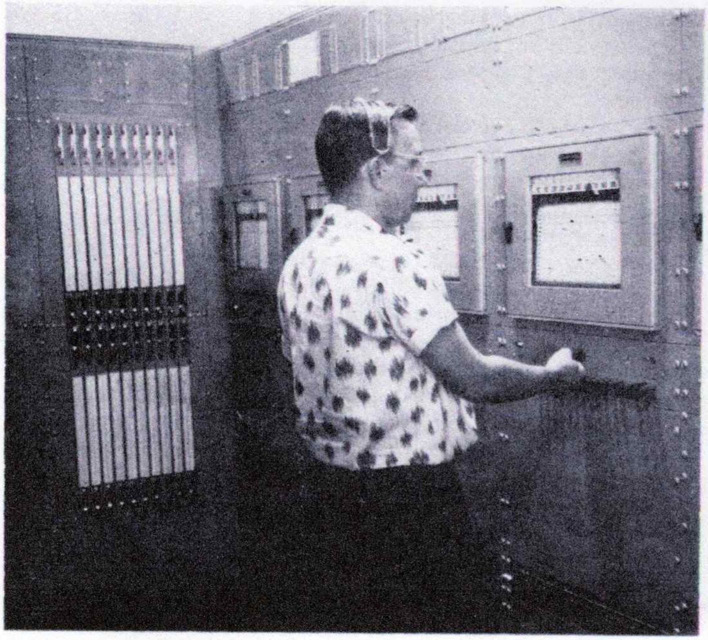


Fig. 6—The operator is here shown recording the output of a single measuring gage under calibration. Since the recorders in *measuring calibration are used as a load on the measuring* gages, substituting for the telemeter subcarrier oscillators, the value of the input impedance of the recorders has been changed to correspond to this. To the left is seen a "harp" bank. In each panel in the bank is a set of individually isolated horizontal and vertical wires which may be interconnected by means of a small clip. By using this bank, any wire on any incoming cable from the missile may be connected to any individual recorder point in the whole room. The bank shown has the possibility of 162,000 different connections, thus providing maximum flexibility in minimum space. Facilities for patching into the building communication system are provided below the recorders.

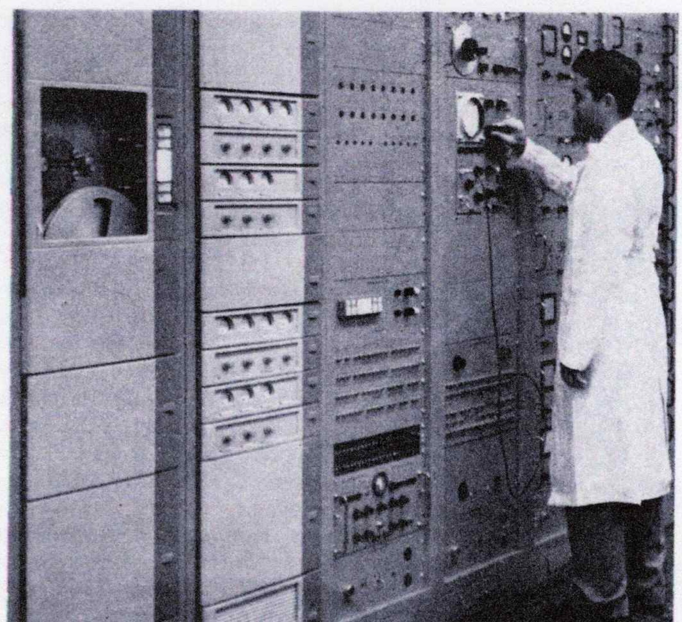


Fig. 7—A portion of the telemeter ground station. To the left are controls for the tape recorders which record the incoming signal. The operator on the left is adjusting an oscilloscope for monitoring the output of the telemeter receiver. To his

building, and is fed into the telemeter ground station where it is decoded and again recorded. The values from the telemeter records are then compared with the values as printed through cables on the recorders, and it is determined whether they compare within a certain fixed tolerance. In order to provide a reference source for precise measurement on the missile, a measuring voltage power supply is aboard which has an output voltage of 4.97 volts, accurate to ±0.03 volt. To run the Telemeter Calibration Test a fixed value is set into all the missile gages and the information is telemetered from all gages simultaneously. The output of the ground station receiver is recorded on oscillographic recorders (Fig. 7). In addition to this, a backup station records the values on a magnetic tape recorder in case of failure of the main ground station. If the value of the output of the measuring gages is held to within ±1 per cent of the laboratory value, and if the values of the telemetering recordings are held to within ±3 per cent of the recorded output of the gages, the total error of the system (including an allowance of approximately 1 per cent for reading error) will then come to approximately ±5 per cent. This is a rather rigid requirement for accuracy as to output; however, the successful development of both the Redstone and the Jupiter missiles has demonstrated that it pays off.

Special Tests. In order to answer problems that arise suddenly, to try new methods of various sorts, or to have opportunity to check special individual missile systems that ordinarily would not tie in with any of the other system tests, a time is set aside for making special tests. A missile which has been assembled and almost completely checked for shipment to the firing site will present the most desirable condition for making this type of test. In order to insure that the missile is still in excellent operating condition after these tests have been run, the tests are run prior to the major final test, which is the Simulated Flight Test. The special tests may take several forms, such as test of the rate of air flow from high pressure tanks, inverter operation and loading, special telemetering tests, special types of cooling tests, valve operations, and so on. Generally, however, the common denominator is the necessity for knowledge concerning the effects on a complete system or on the missile as a whole.

A third Overall Test, which is run just prior to the Simulated Flight Test, has, over a period of time, become gradually more elaborate. It is generally run by giving simulated takeoff by switch. This allows the ground cables to remain connected to the missile and thereby provides a means of obtaining missile function signals during the time that flight is being simulated. This is advantageous in that timing can be rather well established, certain functions can be determined as having been executed in proper sequence, and observations can be made which would not be possible with the ground cables disconnected from the missile. In addition to this, the steering and guidance and control systems are active for this time, and all of the r-f systems are active in order to observe whether or not there is any mutual interference between the r-f systems. The test itself approaches the elaborateness of a Simulated Flight Test, yet is somewhat abbreviated, less formal, and therefore easier to handle. A successful completion of this test indicates that the missile is in proper condition for performing a Simulated Flight Test in which all

Fig. 7-B

immediate right are the discriminator units for the various subcarrier oscillator channels. On the far right are oscillographic recorders for recording final output channel by channel.

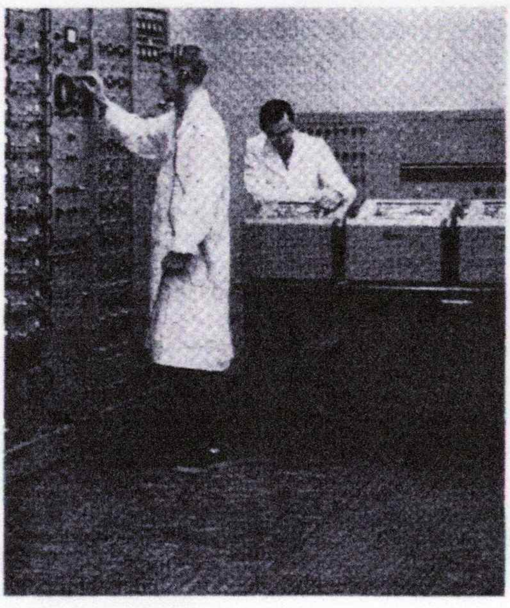
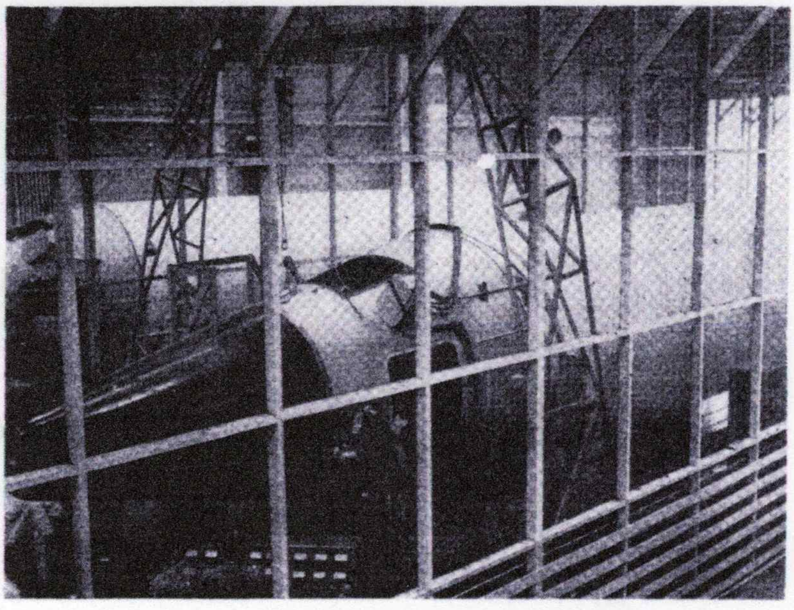


Fig. 8—Two Jupiters are shown here in position for final testing, viewed through the screen-wire r-f cage. The cage provides a reduction in ambient r-f noise level of about 300 to 1. It is completely bonded, with copper underneath the concrete floor, and the whole is grounded to the building ground, which is a large copper pipe sunk in a well drilled to the water level.



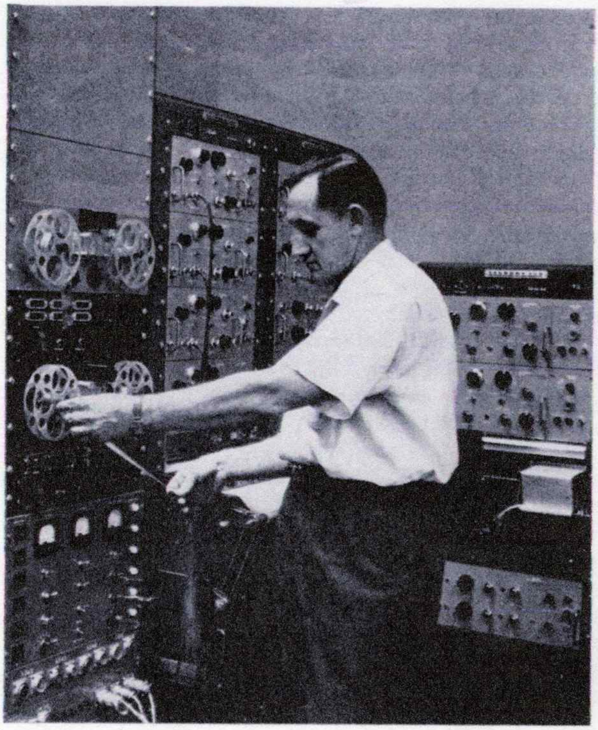


Fig. 9—Loading pre-punched paper tape into the reading device which will play the timing program for a particular test into the missile programming device. Recording equipment is used to check the program in the missile as it is read back.

systems are operating and a complete check on r-f noise and interference is made.

Simulated Flight Test. As the name indicates, the Simulated Flight Test attempts to simulate missile conditions during flight as far as simultaneous equipment operation is concerned. This is to be distinguished from the various Overall Tests in that, in most cases, certain individual systems are operated for the Overall Tests. The third Overall Test, as has been indicated, comes the nearest to being a complete Simulated Flight Test. During the Simulated Flight Test every attempt is made to check complete and simultaneous missile systems operation thoroughly. Even the countdown of time up to takeoff follows, as far as is feasible, the countdown before an actual firing.

The functions of the Simulated Flight Test are to check simultaneous operation of missile components and systems and to obtain a quantitative indication of r-f noise level emanating from the missile which might interfere with telemeter transmission, spuriously trigger r-f tracking devices, and so on. It would be impossible to make careful noise measurements in the vicinity of the assembly area with the high level of ambient noise coming from operation of machinery, electrical equipment or welding operations. For this reason all Simulated Flight Tests were for a long time held after normal working hours. However, tests were recently begun inside a large r-f screen made from a framework and window screen and arranged to completely cover one missile (see Fig. 8). It is possible to test inside this screen even with a rather high level of external ambient noise.

Since a check of r-f interference is an integral part of the Simulated Flight Test, components or systems are switched on one at a time. If any noise is noted, a check is made at that time to determine exactly how and why the noise exists. During the pre-takeoff warm-up period, most missile components and systems are switched on, given a brief operational test, and switched off again; the sequence recorders are also readied for power plant sequence operations and other electrical function indications. About 7 to 10 min before time for "takeoff," a recording is made through the calibration cables for the readings of all measuring gages; the cables are then connected to the telemeter transmitters for transmission during "flight" time. This gives, in addition to a qualitative and quantitative evaluation of occurrences during flight time, a possibility of checking any doubtful measurements left over from the Telemeter Test.

The timing of functions for testing operations is again given in the case of this test by a test program sheet in the possession of each operator. There is a total of about 20 operators involved. After warm-up and check, all systems and components are again switched on in the pre-takeoff sequence. When the time of takeoff arrives, the ground lines are disconnected from the missile simultaneously by a special disconnector, as in the case of the Overall Tests. Most of the operation from this point is automatically programmed by means of the on-board missile-programming device. This device has information fed into it from the punched-tape equipment shown in Fig. 9. However, several signals are put into the system manually for functional check during the flight time. For example, the gyros are tilted to check control displacements, pressures are varied to check pressure operations, and so on.

After the test is completed any obvious difficulties are discussed, sequence recorder records are evaluated, and telemeter records are gone over. Any discrepancies are gone into thoroughly and, if necessary, further checks are made. Further testing, however, is held to an absolute minimum, since this test is performed in order to demonstrate that the missile is functioning properly as a whole, and is ready for shipment to the firing site. After successful conclusion of this test, no further operations are permitted, other than preparation for shipment.

Summary

The final testing as presently conducted on the Jupiter missile is performed more as research and development final testing than as production final testing. In order that the firing group may have as much knowledge of the history of a particular missile as possible, a Final Performance Test Report is prepared in which a log of daily operations and individual system reports is included. This is shipped with the missile to the firing site. There is no doubt that the tests are not perfect as they are; however, improvement in methods and procedures occurs continually.

One fact that appears to stand out in missile testing is that missiles are unique and that methods that apply elsewhere are insufficient here. A missile test firing is a one-shot affair, and a rather expensive one. Rigid requirements for workmanship and component performance are therefore necessary. The record of success with the testing described here has been very good and is improving. ○ ○ ○