CHAPTER 20

ROCKET TESTING

20.1. TYPES OF TESTS

Before rocket propulsion systems are put into operational use, they are subjected to several different types of tests, some of which are outlined below in the sequence in which they are normally performed.

1. Manufacturing inspection and fabrication tests on individual parts (dimensional inspection, pressure tests, x-rays, leak checks, electric continuity, electromechanical checks, etc.).
2. Component tests (functional and operational tests on igniters, valves, thrusters, controls, injectors, structures, etc.).
3. Static rocket system tests (with complete propulsion system on test stand): (*a*) partial or simulated rocket operation (for proper function, calibration, ignition, operation—often without establishing full thrust or operating for the full duration); (*b*) complete propulsion system tests (under rated conditions, off-design conditions, with intentional variations in environment or calibration). For a reusable or restartable rocket propulsion system this can include many starts, long-duration endurance tests, and postoperational inspections and reconditioning.
4. Static vehicle tests (when rocket propulsion system is installed in a restrained, nonflying vehicle or stage).
5. Flight tests: (*a*) with a specially instrumented propulsion system in a developmental flight test vehicle; (*b*) with a production vehicle.

Each of these five types of tests can be performed on at least three basic types of programs:

1. Research on and development or improvement of a new (or modified) rocket engine or motor or their propellants or components.
2. Evaluation of the suitability of a new (or modified) rocket engine or motor for a specified application or for flight readiness.
3. Production and quality assurance of a rocket propulsion system.

The first two types of programs are concerned with a novel or modified device and often involve the testing and measurement of new concepts or phenomena using experimental rockets. The testing of a new solid propellant grain, the development of a novel control valve assembly, and the measurement of the thermal expansion of a nozzle exhaust cone during firing operation are examples.

Production tests concern themselves with the measurement of a few basic parameters on production propulsion systems to assure that the performance, reliability, and operation are within specified tolerance limits. If the number of units is large, the test equipment and instrumentation used for these tests are usually partly or fully automated and designed to permit the testing, measurement, recording, and evaluation in a minimum amount of time.

During the early development phases of a program, many special and unusual tests are performed on components and complete rockets to prove specific design features and performance characteristics. Special facilities and instrumentation or modification of existing test equipment are used. During the second type of program, some special tests are usually conducted to determine the statistical performance and reliability of a rocket device by operating a number of units of the same design. During this phase tests are also made to demonstrate the ability of the rocket to withstand extreme limits of the operating conditions, such as high and low ambient temperature, variations in fuel composition, changes in the vibration environment, or exposure to moisture, rain, vacuum, or rough handling during storage. To demonstrate safety, sometimes, intentional malfunctions, spurious signals, or manufacturing flaws are introduced into the propulsion system, to determine the capability of the control system or the safety devices to handle and prevent a potential failure.

Before an experimental rocket can be flown in a vehicle it usually has to pass a set of *preliminary flight rating tests* aimed at demonstrating the rocket's safety, reliability, and performance. It is not a single test, but a series of tests under various specified conditions operating limits, and performance tolerances, simulated environments, and intentional malfunctions. Thereafter the rocket may be used in experimental flights. However, before it can be put into production, it usually has to pass another specified series of tests under a variety of rigorous specified conditions, known as the *qualification test* or *preproduction test*. Once a particular propulsion system has been *qualified*, or passed a qualification test, it is usually forbidden to make any changes in design, fabrication processes, or materials without going through a careful review, extensive documentation, and often also a requalification test.

The amount and expense of testing of components and complete propulsion systems has decreased greatly in the last few decades. The reasons are more experience with prior similar systems and more confidence in predicting a number of failure modes and their locations. Validated computer programs have removed many uncertainties and obviated needs for tests. In some applications the number of firing tests has decreased by a factor of 10 or more.

20.2. TEST FACILITIES AND SAFEGUARDS

For chemical rocket propulsion systems, each test facility usually has the following major systems or components:

1. A test cell or test bay where the article to be tested is mounted, usually in a special test fixture. If the test is hazardous, the test facility must have provisions to protect operating personnel and to limit damage in case of an accident.
2. An instrumentation system with associated computers for sensing, maintaining, measuring, analyzing, correcting, and recording various physical and chemical parameters. It usually includes calibration systems and timers to accurately synchronize the measurements.
3. A control system for starting, stopping, and changing the operating conditions.
4. Systems for handling heavy or awkward assemblies, supplying liquid propellant, and providing maintenance, security, and safety.
5. For highly toxic propellants and toxic plume gases it has been required to capture the hazardous gas or vapor (firing inside a closed duct system), remove almost all of the hazardous ingredients (e.g., by wet scrubbing and/or chemical treatment), allow the release of the nontoxic portion of the cleaned gases, and safely dispose of any toxic solid or liquid residues from the chemical treatment. With an exhaust gas containing fluorine, for example, the removal of much of this toxic gas can be achieved by scrubbing it with water that contains dissolved calcium; it will then form calcium fluoride, which can be precipitated and removed.
6. In some tests specialized test equipment and unique facilities are needed to conduct static testing under different environmental conditions or under simulated emergency conditions. For example, high and low ambient temperature tests of large motors may require a temperature-controlled enclosure around the motor; a rugged explosion-resistant facility is needed for bullet impact tests of propellant-loaded missile systems and also for cook-off tests, where gasoline or rocket fuel is burned with air below a stored missile. Similarly, special equipment is needed for

vibration testing, measuring thrust vector forces and moments in three dimensions, or determining total impulse for very short pulse durations at low thrust.

Most rocket propulsion testing is now accomplished in sophisticated facilities under closely controlled conditions. Modern rocket test facilities are frequently located several miles from the nearest community to prevent or minimize effects of excessive noise, vibrations, explosions, and toxic exhaust clouds. Figure 20–1 shows one type of an open-air test stand for vertically down-firing large liquid propellant thrust chambers (100,000 to 2 million pounds thrust). It is best to fire the propulsion system in a direction (vertical

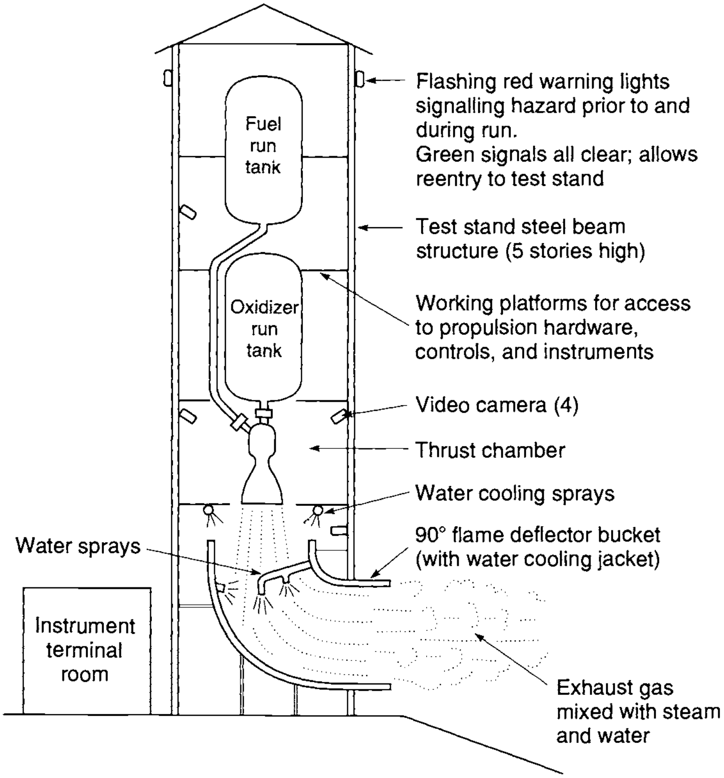

FIGURE 20–1. Simplified sketch of a typical static test stand for a large liquid propellant thrust chamber firing vertically downward. Only a small part of the exhaust plume (between the nozzle exit and flame bucket entrance) is visible. The flame bucket turns the exhaust gas plume by 90° (horizontal) and prevents the flame from digging a hole in the ground. Not shown here are cranes, equipment for installing or removing a thrust chamber, safety railings, high pressure gas tank, the propellant tank pressurization system, separate storage tanks for fuel, oxidizer, or cooling water with their feed systems, or a small workshop.

or horizontal) similar to the actual flight condition. Figure 20–2 shows a simulated altitude test facility for rockets of about 10.5 metric tons thrust force (46,000 lbf). It requires a vacuum chamber in which to mount the engine, a set of steam ejectors to create a vacuum, water to reduce the gas temperature, and a cooled diffuser. With the flow of chemical rocket propellant combustion gases it is impossible to maintain a high vacuum in these kinds of facilities; typically, between 15 to 4 torr (20 to 35 km altitude) can be maintained. This type of test facility allows the operation of rocket propulsion systems with high-nozzle-area ratios that would normally experience flow separation at sea-level ambient pressures.

Prior to performing any test, it is common practice to train the test crew and go through repeated dry runs, to familiarize each person with his or her responsibilities and procedures, including the emergency procedures.

Typical personnel and plant security or safety provisions in a modern test facility include the following:

1. Concrete-walled blockhouse or control stations for the protection of personnel and instruments (see Fig. 20–3) remote from the actual rocket propulsion location.

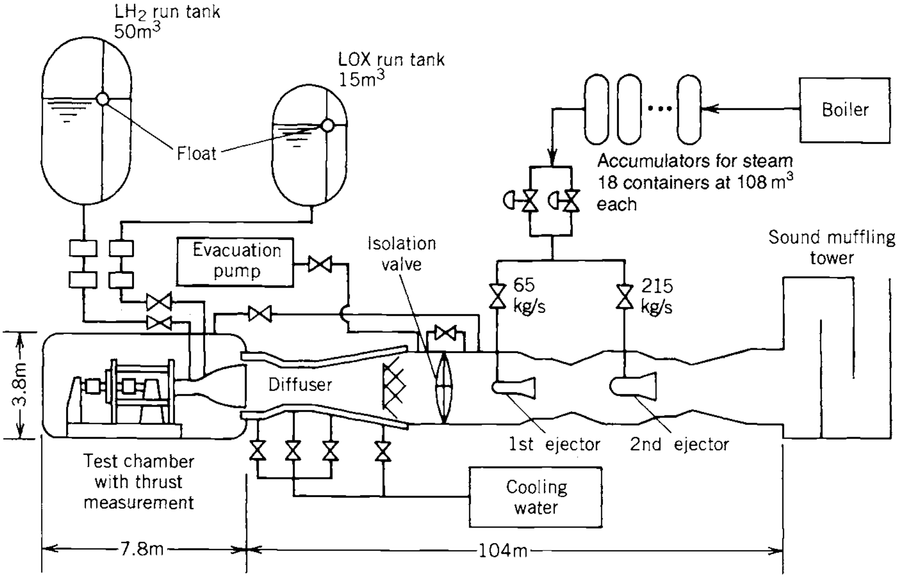

FIGURE 20–2. Simplified diagram of a simulated altitude, horizontal firing test facility for the LE-5 Japanese-designed thrust chamber (liquid oxygen–liquid hydrogen propellants) showing the method of creating a vacuum (6 torr during operation and 13 torr prior to start). The operating duration is limited to about 10 min by the capacity of the steam storage. (Reproduced from Ref. 20–1 with permission of the AIAA.)

FIGURE 20–3. Control room (inside a reinforced concrete blockhouse) for test operators, instrument recorders, and controls. Note the control console, closed-circuit television, radio and telephone, direct read-out meters, strip charts, high-speed tape recorders, oscilloscope, air-quality alarm, and emergency lights. (Courtesy of U.S. Air Force Phillips Laboratory.)

2. Remote control, indication, and recording of all hazardous operations and measurements; isolation of propellants from the instrumentation and control room.
3. Automatic or manual water deluge and fire-extinguishing systems.
4. Closed circuit television systems for remotely viewing the test.
5. Warning signals (siren, bells, horns, lights, speakers) to notify personnel to clear the test area prior to a test, and an all-clear signal when the conditions are no longer hazardous.
6. Quantity and distance restrictions on liquid propellant tankage and solid propellant storage to minimize damage in the event of explosions; separation of liquid fuels and oxidizers.
7. Barricades around hazardous test articles to reduce shrapnel damage in the event of a blast.
8. Explosion-proof electrical systems, spark-proof shoes, and nonspark hand tools to prvent ignition of flammable materials.
9. For certain propellants also safety clothing (see Fig. 20–4), including propellant- and fire-resistant suits, face masks and shields, gloves, special shoes, and hard hats.

FIGURE 20–4. Plastic safety suit, gloves, boots, and hood used by test personnel in handling hazardous or corrosive liquid propellants. Safety shower, which starts automatically when a person steps onto the platform, washes away splashed or spilled propellant. (Official U.S. Air Force photograph.)

10. Rigid enforcement of rules governing area access, smoking, safety inspections, and so forth.
11. Limitations on the number of personnel that may be in a hazardous area at any time.

Monitoring and Control of Toxic Materials

Open-air testing of chemical rockets frequently requires measurement and control of exhaust cloud concentrations and gas movement in the surrounding areas for safeguarding personnel, animals, and plants. A toxic cloud of gas and particles can result from the exhaust gas of normal rocket operation, vapors or reaction gases from unintentional propellant spills, and gases from fires, explosions, or from the intentional destruction of vehicles in flight or rockets on the launch stand. Environmental regulations usually limit the maximum local concentration or the total quantity of toxic gas or particulates released to the atmosphere. The toxic nature of some of these liquids, vapors, and gases has been mentioned in Chapters 7 and 12. One method of control is for tests with discharges of moderately toxic gases or products to be postponed until favorable weather conditions are present.

In ground tests, the toxic cloud source is treated as a *point source*, and in flight tests it is a *ribbon source*. The rate of exhaust cloud diffusion is influenced by many propulsion variables, including propellant, rocket size, exhaust temperature, and thrust duration; by many atmospheric variables, including wind velocity, direction, turbulence, humidity, and vertical stability or lapse rate, and by the surrounding terrain. Extensive analytical studies and measurements of the environmental exposure from explosions, industrial smoke, and gases, and exhausts from missile and space vehicle launchings give background useful for predicting the atmospheric diffusion and downwind concentrations of rocket exhaust clouds. Reference 20–2 describes hazards and toxic gas cloud dispersals and concentrations. Reference 20–3 evaluates the environmental impact of rocket exhausts from large units on the ozone in the stratosphere and on the ground weather near the test site; it concludes that the impacts are generally small and temporary. Reference 20–4 describes a test-area atmospheric measuring network.

A widely used relationship for predicting atmospheric diffusion of gas clouds has been formulated by O. G. Sutton (Ref. 20–5). Many of the most modern equations and models relating to downwind concentrations of toxic clouds are extensions of Sutton's theory. Given below are the Sutton equations of primary interest to rocket and missile operators.

For instantaneous ground-level point source nonisotropic conditions,

$$\chi_{(x,y,z,t)} = \frac{Q}{\pi^{3/2} C_x C_y C_z (\bar{u}t)^{3(2-n)/2}} \exp\left[(\bar{u}t)^{n-2}\left(\frac{x^2}{C_x^2} + \frac{y^2}{C_y^2} + \frac{z^2}{C_z^2}\right)\right] \qquad (20\text{–}1)$$

For continuous ground-level point source nonisotropic conditions,

$$\chi = \frac{2Q}{\pi C_y C_z \bar{u} x^{2-n}} \exp\left[-x^{n-2}\left(\frac{y^2}{C_y^2} + \frac{z^2}{C_z^2}\right)\right] \qquad (20\text{–}2)$$

where χ is the concentration in grams per cubic meter, Q is the source strength (grams for intantaneous, grams per second for continuous); $C_{x,y,z}$ are diffusion coefficients in the x, y, z planes, respectively; $\bar{u}$ is the average wind velocity in meters per second, t is the time in seconds, and the coordinates x, y, z are in meters measured from the center of the moving cloud in the instantaneous case and from a ground point beneath the plume axis in the continuous case. The exponent n is a stability or turbulence coefficient, ranging from almost zero for highly turbulent conditions to 1 as a limit for extremely stable conditions, and usually falling between 0.10 and 0.50.

A few definitions basic to the study of atmospheric diffusion of exhaust clouds are as follows:

1. *Micrometeorology*. Study and forecasting of atmospheric phenomena restricted to a region approximately 300 m above the earth's surface and a horizontal distance of approximately 5 miles.
2. *Lapse Rate*. The rate of decrease in temperature with increasing height above the earth's surface. The United States Standard Atmosphere has a lapse rate of about 6.4°C per 1000 m. Lapse rate is also affected by altitude, wind, and humidity.
3. *Inversion, or Inversion Layer*. Condition of negative lapse rate (temperature increases with increasing height). Usually formed near the ground at night.

The following are a few general rules and observations derived from experience with the atmospheric diffusion of rocket exhaust clouds:

1. Inversion presents a very stable layer and greatly reduces the vertical dispersion (the higher the lapse rate, the greater the vertical dispersion).
2. A highly stable atmospheric condition tends to keep the exhaust plume or cloud intact and away from the earth's surface except when the exhaust products are much heavier than the surrounding air.
3. High wind increases the rate of diffusion and reduces the thermal effects.
4. For short firings (< 500 sec) the approximate dosages downwind are about the same as from an instantaneous point source.
5. When the plume reaches about one-fourth the distance to a given point before emission is stopped, peak concentration will be about three-fourths of that from a continuous source of equal strength.
6. The presence of an inversion layer significantly restricts the mixing or diffusion capacity of the atmosphere in that the effective air mass is that mass existing between the earth's surface and the inversion layer.
7. Penetration of the inversion layer due to the buoyance force of the hot exhaust cloud seldom occurs.
8. Earth surface dosage drops rapidly when missiles or space launch vehicles are destroyed in flight above a height of 1500 m as compared to lower altitudes of 600 to 1000 m.

Interpretation of the hazard that exists once the concentration of the toxic agent is known also requires knowledge of its effects on the human body, plants, and animals. Tolerance limits for humans are given in Chapter 7 and in Ref. 8–5. There are usually three limits of interest: one for the short-time exposure of the general public, one for an 8-hr exposure limit, and an evacuation concentration. Depending on the toxic chemical, the 8-hr limit may vary from 5000 ppm for a gas such as carbon dioxide, to less than 1 ppm for an extremely toxic substance such as fluorine. Poisoning of the human body by exhaust products usually occurs from inhalation of the gases and fine solid particles, but the solid residuals that sometimes remain around a test facility for weeks or months following a test firing can enter the body through cuts and other avenues. Also, certain liquid propellants cause burns and skin rash or are poisonous when ingested, as explained in Chapter 7.

20.3. INSTRUMENTATION AND DATA MANAGEMENT

This section gives only a very brief discussion of this subject. For further study the reader is referred to standard textbooks on instruments and computers used in testing, such as Ref. 20–6. Some of the physical quantities measured in rocket testing are as follows:

1. Forces (thrust, thrust vector control side forces, short thrust pulses).
2. Flows (hot and cold gases, liquid fuel, liquid oxidizer, leakage).
3. Pressures (chamber, propellant, pump, tank, etc.).
4. Temperatures (chamber walls, propellant, structure, nozzle).
5. Timing and command sequencing of valves, switches, igniters, etc.
6. Stresses, strains, and vibrations (combustion chamber, structures, propellant lines, accelerations of vibrating parts) (Ref. 20–7).
7. Time sequence of events (ignition, attainments of full pressure).
8. Movement and position of parts (valve stems, gimbal position, deflection of parts under load or heat).
9. Voltages, frequencies, and currents in electrical or control subsystems.
10. Visual observations (flame configuration, test article failures, explosions) using high-speed cameras or video cameras.
11. Special quantities such as turbopump shaft speed, liquid levels in propellant tanks, burning rates, flame luminosity, or exhaust gas composition.

Reference 20–8 gives a description of specialized diagnostic techniques used in propulsion systems, such as using nonintrusive optical methods, microwaves, and ultrasound for measurements of temperatures, velocities, particle sizes, or burn rates in solid propellant grains. Many of these sensors incorporate specialized technologies and, often, unique software. Each of the measured parameters can be obtained by different types of instruments, sensors, and analyzers, as indicated in Ref. 20–9.

Measurement System Terminology

Each measurement or each measuring system usually requires one or more *sensing elements* (often called transducers or pickups), a device for *recording, displaying,* and/or *indicating* the sensed information, and often also another device for *conditioning, amplifying, correcting,* or *transforming* the sensed signal into the form suitable for *recording, indicating, display,* or *analysis.* Recording of rocket test data has been performed in several ways, such as on *chart recorders* or in digital form on *memory* devices, such as on magnetic tapes or disks. Definitions of several significant terms are given below and in Ref. 20–6.

Range refers to the region extending from the minimum to the maximum rated value over which the measurement system will give a true and linear response. Usually an additional margin is provided to permit temporary overloads without damage to the instrument or need for recalibration.

Errors in measurements are usually of two types: (1) *human errors* of improperly reading the instrument, chart, or record and of improperly interpreting or correcting these data, and (2) *instrument or system errors*, which usually fall into four classifications: static errors, dynamic response errors, drift errors, and hysteresis errors (see Ref. 20–10). *Static errors* are usually fixed errors due to fabrication and installation variations; these errors can usually be detected by careful calibration, and an appropriate correction can then be applied to the reading. *Drift error* is the change in output over a period of time, usually caused by random wander and environmental conditions. To avoid drift error the measuring system has to be calibrated at frequent intervals at standard environmental conditions against known standard reference values over its whole range. *Dynamic response errors* occur when the measuring system fails to register the true value of the measured quantity while this quantity is changing, particularly when it is changing rapidly. For example, the thrust force has a dynamic component due to vibrations, combustion oscillations, interactions with the support structure, etc. These dynamic changes can distort or amplify the thrust reading unless the test strand structure, the rocket mounting structure, and the thrust measuring and recording system are properly designed to avoid harmonic excitation or excessive energy damping. To obtain a good dynamic response requires a careful analysis and design of the total system.

A *maximum frequency response* refers to the maximum frequency (usually in cycles per second) at which the instrument system will measure true values. The natural frequency of the measuring system is usually above the limiting response frequency. Generally, a high-frequency response requires more complex and expensive instrumentation. All of the instrument system (sensing elements, modulators, and recorders) must be capable of a fast response. Most of the measurements in rocket testing are made with one of two types of instruments: those made under nearly steady static conditions, where only relatively gradual changes in the quantities occur, and those made with fast transient conditions, such as rocket starting, stopping, or vibrations (see Ref. 20–11). This latter type of instrument has frequency responses above 200 Hz, sometimes as high as 20,000 Hz. These fast measurements are necessary to evaluate the physical phenomena of rapid transients.

Linearity of the instrument refers to the ratio of the input (usually pressure, temperature, force, etc.) to the output (usually voltage, output display change, etc.) over the range of the instrument. Very often the static calibration error indicates a deviation from a truly linear response. A nonlinear response can cause appreciable errors in dynamic measurements. *Resolution* refers to the minimum change in the measured quantity that can be detected with a given instrument. *Dead zone* or *hysteresis* errors are often caused by energy absorption within the instrument system or play in the instrument mechanism; in part, they limit the resolution of the instrument.

Sensitivity refers to the change in response or reading caused by special influences. For example, the *temperature sensitivity* and the *acceleration sensitivity* refer to the change in measured value caused by temperature and acceleration. These are usually expressed in percent change of measured value per unit of temperature or acceleration. This information can serve to correct readings to reference or standard conditions.

Errors in measurement can arise from many sources. Reference 20–12 gives a standardized method, including mathematical models, for estimating the error, component by component, as well as the cumulative effect in the instrumentation and recording systems. Graphic recordings (error ranges ±0.2 to ±0.5% of strip chart span) and oscillographs (error ranges ±2.0 to ±3.0% of full scale), two of the analog-type recording devices, are used for giving quick-look data and to record high-frequency data or transient conditions; these transients are beyond the capability of digital recorders, which are usually limited to 100 Hz or lower as compared to 5000 Hz or higher for oscillographs.

Electrical interference or "noise" within an instrumentation system, including the power supply, transmission lines, amplifiers, and recorders, can affect the accuracy of the recorded data, especially when low-output transducers are in use. Methods for measuring and eliminating objectionable electrical noise are given in Ref. 20–13.

Use of Computers

Computers have become commonplace in the testing and handling of data in rocket propulsion. They are usually coupled with *sensors* (e.g., pressure transducers, actuator position indicators, temperature sensors, liquid level gauges, etc.), which provide the data inputs, with *controllers* (valve actuators, thrust vector controllers, thrust termination devices), which receive commands resulting from the computer outputs causing a change in the sensed quantity, and with *auxiliaries* such as terminals, data storage devices, or printers. Computers are used in one or more of the following ways:

1. The *analysis of test data* becomes a time-consuming difficult job without computers, simply because of the huge volume of data that is generated in many typical rocket propulsion system tests. All the pertinent data need to be reviewed and evaluated. The computer will permit *automated data reduction*, including *data correction* (e.g., for known instrument error, calibration, or changes in atmospheric pressure), *conversion* of analog data into digital form, and *filtering* of data to eliminate signals

outside the range of interest. It can also include *data manipulation* to put the test information into graphic displays or summary hard-copy readouts of selected, specific performance parameters.

On the basis of a careful evaluation of the test data the responsible engineers have to decide whether the test objectives were met and what changes to make or what objectives to set for the next test or the remainder of the current test. Reference 20–14 describes a software system that allows *automated test analysis* and *decision support* in evaluating the 50 million bytes of test data that are generated in a typical SSME test; it is based in part on the use of an expert knowledge system.

2. Modern testing systems use digital data bases for *recording and documenting* test records. Often only a portion of the recorded data is actually analyzed and reviewed during or after the test. In complex rocket propulsion system tests, sometimes between 100 or 400 different instrument measurements are made and recorded. Some data need to be sampled frequently (e.g., some transients may be sampled at rates higher than 1000 times per second), whereas other data need to be taken at lower frequencies (e.g., temperature of mounting structure may be needed only every 1 to 10 sec). Multiplexing of data is commonly practiced to simplify data transmission. Most rocket test computer systems contain a configuration file to indicate data characteristics for each channel, such as range, gain, the references, the type of averaging, the parameter characteristics, or the data correction algorithms. Most of the data are not analyzed or printed out as hard copy; a detailed analysis occurs only if there is reason for understanding particular test events in more detail. This analysis may occur months after the actual tests and may not even be done on the same computer.
3. *Sensing and evaluating failures* or *overlimit conditions* (excessive local temperature, vibration, or limiting local pressure) is aimed at detecting an impending malfunction and at deciding whether it is a serious problem. If serious, it can cause either an automatic correction or an automatic and safe shutdown of operation. Sensing of undesirable operating conditions can be accomplished much more rapidly on a computer than would be possible if a human operator were in the control loop. In some engine designs a critical failure is sensed by several sensors and the computer rapidly evaluates the signals from these sensors and causes a correction (or shutdown) only if the majority of sensors indicate an unsafe or undesirable condition, thus eliminating the occasional failure of an individual sensor as a cause for shutdown.
4. *Simulation* of tests can be accomplished by devising algorithms that allow a computer to respond in a manner similar to a rocket propulsion unit. The computer receives inputs from various sensors (valve position, thrust vector control position, unsafe temperatures, etc.), processes the data in a simulation algorithm, and then provides output of control signals (e.g.,

thrust change, shutdown) and also of simulated rocket performance (e.g., chamber pressure, specific impulse, side force, etc.). This computer simulation can be very economical compared to running additional tests. This can be a full off-line simulation (in a separate computer with simulated inputs) or a partial on-line simulation where the computer is coupled to an actual rocket engine or its components; this second type can be used to check out an engine just prior to, or in the first second of, a test run or test flight.

5. *Control of test operation* by computer allows the attainment of the desired test conditions in a minimum amount of time. This could entail a preprogrammed set of pulses for an attitude control thruster, a desired set of different mixture ratios to be achieved for a short time (say, 1 sec each) in a single test, or a planned variation of thrust vector control conditions. It can provide a closed loop control to attain desired operating conditions, including the paths along which these conditions should be achieved. It also makes it possible to control several variables at the same time (e.g., thrust, mixture ratio, and several turbine inlet temperatures). For some component tests programmable logic controllers are used to control the test operation instead of a computer, which usually requires some software development.

   In a multiple-static-test facility there can be a group of network-connected computers and databases to achieve some or all of the functions above. Some of the computer hardware would be part of the test article, some part of the test facility, and some can be located remotely and linked by a communications network. Reference 20–15 describes the engine control and computer system for the Space Shuttle main engine.

20.4. FLIGHT TESTING

Flight testing of rocket propulsion systems is always conducted in conjunction with tests of vehicles and other systems such as guidance, vehicle controls, or ground support. These flights usually occur along missile and space launch ranges, sometimes over the ocean. If a flight test vehicle deviates from its intended path and appears to be headed for a populated area, a range safety official (or a computer) will have to either cause a destruction of the vehicle, abort the flight, or cause it to correct its course. Many propulsion systems therefore include devices that will either terminate the operation (shut off the rocket engine or open thrust termination openings into rocket motor cases as described in Chapter 13) or trigger explosive devices that will cause the vehicle (and therefore also the propulsion system) to disintegrate in flight.

Flight testing requires special launch support equipment, means for observing, monitoring, and recording data (cameras, radar, telemetering, etc.), equipment for assuring range safety and for reducing data and evaluating flight test performance, and specially trained personnel. Different launch equipment is needed for different kinds of vehicles. This includes launch tubes for shoulder-held infantry support missile launchers, movable turret-type mounted multiple launchers installed on an army truck or a navy ship, a transporter for larger missiles, and a track-propelled launch platform or fixed complex launch pads for spacecraft launch vehicles. The launch equipment has to have provisions for loading or placing the vehicle into a launch position, for allowing access of various equipment and connections to launch support equipment (checkout, monitoring, fueling, etc.), for aligning or aiming the vehicle, or for withstanding the exposure to the hot rocket plume at launch.

During experimental flights extensive measurements are often made on the behavior of the various vehicle subsystems; for example, rocket propulsion parameters, such as chamber pressure, feed pressures, temperatures, and so on, are measured and the data are telemetered and transmitted to a ground receiving station for recording and monitoring. Some flight tests rely on salvaging and examining the test vehicle.

20.5. POSTACCIDENT PROCEDURES

In the testing of any rocket propulsion system there will invariably be failures, particularly when some of the operating parameters are close to their limit. With each failure comes an opportunity to learn more about the design, the materials, the propulsion performance, the fabrication methods, or the test procedures. A careful and thorough investigation of each failure is needed to learn the likely causes and identify the remedies or fixes to prevent a similar failure in the future. The lessons to be learned from these failures are perhaps the most important benefits of testing. A formalized postaccident approach is often used, particularly if the failure had a major impact, such as high cost, major damage, or personnel injury. A major failure (e.g., the loss of a space launch vehicle or severe damage to a test facility) often causes the program to be stopped and further testing or flights put on hold until the cause of the failure is determined and remedial action has been taken to prevent a recurrence.

Of utmost concern immediately after a major failure are the steps that need to be taken to respond to the emergency. This includes giving first aid to injured personnel, bringing the propulsion system and/or the test facilities to a safe, stable condition, limiting further damage from chemical hazards to the facility or the environment, working with local fire departments, medical or emergency maintenance staff or ambulance personnel, and debris clearing crews, and quickly providing factual statements to the management, the employees, the news media, and the public. It also includes controlling access to the facility where the failure has occurred and preserving evidence for the subsequent investigation. All test personnel, particularly the supervisory people, need to be trained not only in preventing accidents and minimizing the impact of a potential failure, but also how to best respond to the emergency. Reference 20–16 suggests postaccident procedures involving rocket propellants.

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