TECP 700-700
Materiel Test Procedure 5-2-500
19 January 1967 White Sands Missile Range

U. S. ARMY TEST AND EVALUATION COMMAND
COMMON ENGINEERING TEST PROCEDURE

TESTS OF SOLID PROPELLANT SYSTEMS

1. OBJECTIVE

Tests of solid propellant systems are conducted to determine the performance of solid propellant motors after being subjected to various environmental treatments and to ascertain tactical hazards, and methods of safety destruct.

2. BACKGROUND

Solid propellant static firing tests may have multiple purposes depending upon the design of the motor. A motor is usually fired to determine: the effectiveness of the case insulation, the extent of nozzle throat erosion, the thrust-versus-time history during a particular time interval such as during ignition or tail-off, pressure-versus-time history, the effect of a prior environmental treatment on the internal ballistics, and the operation of a thrust vector control mechanism or thrust cutoff device.

Tests of solid propellants are begun during research and development and continue throughout the engineering test phase to shelf and service life testing. Tests of research propellants are regularly conducted by manufacturers, utilizing standardized motor configurations, to determine the propellant's operating characteristics prior to delivery to the military test facility

3. REQUIRED EQUIPMENT

a. Manufacturers Instructions and/or Specifications
b. Static Firing Test Facility and Equipment as described in Appendix A
c. Hazard and Destruct Test Facility and Equipment as described in Appendix A
d. Propulsion System Component Test Facility, including:

1) Pneumatic Test Facility as described in Appendix A
2) Hydraulic Test Facility as described in Appendix A
3) Electrical Test Facility as described in Appendix A

e. Firing and/or Control Console for The Missile System Under Test
f. Applicable Missile Handling Dollies
g. Applicable Motor Mounts and Adapters as described in Appendix B
h. Motor Inspection Equipment as described in Appendix C
i. Required Instrumentation as described in Appendix D
j. Applicable Igniter (See Appendix E)
k. Fuel (gasoline, kerosene, etc.) and Flammable Scrap wood or

l. Fuel Oil and a sizable flat container used as a burner fed by remote control

m. Cal. 30 Rifles and Machine Guns/Cal. 50 Machine Guns/Cannon 40MM or smaller with appropriate ammunition

n. Insulated Chamber

o. Heating Equipment and Controls

p. Applicable Destruct Device (explosive charge, thermal grenade, shaped charge, etc.)

q. Transducers, Carrier Systems, and Recorders, as required

r. Thermocouples and Strip-Chart Recorders as required

s. Applicable Data Reduction and Conversion Equipment

t. Vibration Equipment as described in MTP 5-2-507

u. Temperature Chambers (-85°F to 125°F)

v. Applicable Shock Equipment as described in MTP 5-2-506

w. Drop-test tower with reinforced concrete or steel impact surface and suitable remote operated quick-release device.

Note: Drop tests may be conducted with irregular shapes or sharp edged structural members arranged to simulate impact on launchers, handling equipment, etc.

x. Motion Picture Cameras

1) 128 Frames per second
2) 1000 Frames per second
3) 6000 Frames per second

y. Sound Level Meters

z. Shock Curve Blast Indicators

aa. Continuity Tester

4. REFERENCES

A. MIL-STD-292A, Ballistic Nomenclature Rocket Static Tests, February 1958

B. American Standard Letter Symbols for Rocket Propulsion, American Society of Mechanical Engineers, ASA Volume 10, 1959

C. Glossary of Rocket Propulsion Terminology and Abbreviations, Aerojet General Corp., Product Training

D. JATO Manual SPIA M-1, Solid Propellant Information Agency, APL Johns Hopkins University, Silver Spring, Maryland

E. CPIA Publications Number 3, Static Test Safety Manual, Chemical Propulsion Information Agency, December 1962

F. MIL-E-5272, Environmental Testing of Aeronautical and Associated Equipment, April 1959

G. MIL-STD-210A, Climatic Extremes for Military Equipment, August 1957

H. AR 705-15, Research and Development of Material: Operation of Material Under Extreme Conditions of Environment, with Change 1, 14 October 1963

I. DA TB700-2, Explosives Hazard Classification Procedures

J. WSMR Technical Memorandum 268, Hazards Test of Double Base Propellant Grains and JATO's, October 1955

K. AMCR 385-224, Ordnance Safety Manual

L. Ignatowski, A. J. and Kart, M. W., Physical Property Evaluation and Design Concepts for a Practical Approach to Solid Propellant Development, Bulletin of 17th meeting of JANAF-ARPA-NASA Solid Propellant Group, Volume 1, May 1961

M. ORDP 20-282, Ordnance Engineering Design Handbook, Ballistic Missile Series, Propulsion and Propellants, May 1960

N. ORDP 20-296, Ordnance Engineering Design Handbook, Surface-to-Air Missile Series, Part 6, Structures and Power Sources, June 1962

O. Sutton, G. P., Rocket Propulsion Elements, Third Edition, John Wiley and Sons, Inc., New York, New York, and Chapman & Hall Ltd., London, England 1956

P. Wimpress, R., Internal Ballistics of Solid-Fuel Rockets, First-Edition, McGraw-Hill Book Company, New York, New York, 1950

Q. MTP 5-2-506, Shock Test Procedures

R. MTP 5-2-507, Vibration Test Procedures

S. MTP 5-2-583, Low Temperature Tests

T. MTP 5-2-594, High Temperature Tests

U. MTP 5-2-602, Equipment Safety Requirements

5. SCOPE

5.1 SUMMARY

Since a solid propellant firing test is unique for each type of motor, firing facility and specific purpose of performing the test, considerations and procedures are intentionally made general to provide tests that are applicable to a variety of solid propellant motors. Specific details that apply to the static firing of a particular solid propellant motor are contained in the applicable specification, along with the physical characteristics and performance requirements of the motor. A general coverage of testing techniques, instrumentation and facilities, hazards, safety practices, and interpretation of data, are included in this MTP. The following tests are described:

a. Motor Inspection - Inspection procedures to be performed prior to mounting the motor for a static firing test. These procedures describe a visual inspection of the motor and inspections using a borescope, X-ray machine, gammagraph, ultrasonic equipment, or profilometer.

b. Static Firing Operations - A description of the general procedure for conducting a solid propellant static firing.

c. Tactical Hazards Safety and Destruct Tests - The following tests may be conducted on complete production motors to determine tactical hazards and methods of safety destruct which include the following:

1) Open Flame Fire Test
2) Nozzle Exhaust Impingement Test
3) Sympathetic Detonation Test
4) Gunfire Test
5) Slow Heat Test
6) Safety Destruct Test
7) High Level Drop Test
8) Thrust Neutralizer Test

d. Igniter Tests - Procedures for conducting tests on production igniters to determine their reliability, the affects of age, storage conditions, and separate environmental conditions.

5.2 LIMITATIONS

None

6. PROCEDURE

6.1 PREPARATION FOR TEST

6.1.1 General

a. Personnel shall review all available pertinent manufacturer's instructions and/or specifications for the system to be tested, determine the test facilities required, and select the required test equipment.

b. The operator of the test equipment shall be familiar with the equipment, and shall comply with the pertinent operating instructions.

c. Assure that a log folder is prepared for each solid propellant system to retain a history of the system under test.

d. Assure that the test facility complies with the safety requirements of MTP 5-2-602.

e. Reports of previous solid propellant static firings should be reviewed if available.

f. Weigh and balance the motor and record its weight and center-of-gravity.

g. Measure and record the nozzle throat diameter at a minimum of three locations 120° apart.

6.1.2 Instrumentation

Data shall be recorded on magnetic tape, oscillograph, and strip-chart records depending upon the frequency response and accuracy specifications of required data.

Selection of the required transducers, carrier systems, recorders, conversion and reduction equipment shall be determined by the individual specifications and test requirements.

Appendix D describes the method used to obtain the various information.

6.2 TEST CONDUCT

6.2.1 Motor Inspections

a. Ground and restrain the motor as a precaution against accidental ignition.

b. Inspect the motor, using one or more combinations of the listed methods and record the following:

1) Propellant defects:

a) Cracks or voids

b) Abnormal surface conditions
c) Separations between the propellant and liner or inhibitor
d) Exudate or crystal formation on the propellant and metal parts
e) Blowholes
f) Presence of foreign matter
g) Lack of perfect bonding at interfaces if applicable - (two or more propellant compositions in single motor)
h) Shrinkage cavities

2) Motor defects

a) Dents or defects in the case
b) Defect in nozzle
c) Defects in igniter or nozzle insert
d) Defects in resonance suppressors
e) Defects in ignition harness

c. Inspection Methods (see Appendix C for descriptions)

1) Visual
2) Borescope
3) X-ray
4) Gammagraph
5) Ultrasonic
6) Profilometer

NOTE: Each of these methods has advantages and disadvantages but as yet no one method or technique has been found which always uncovers all of the flaws that are capable of causing malperformance and catastropic failures. See reference 4L for further information concerning the inspection of solid propellant motors.

6.2.2 Motor Static Firings

6.2.2.1 Preparation for Firing

a. Mount the motor on the applicable firing stand as described in Appendix B.
b. Prepare instrumentation as described in Appendix D.
c. Connect electrical system as required.

NOTE: Exercise extreme caution when connecting the test facility to the motor, ensuring that all lines are flexible so that thrust movement is unhampered.

d. Accomplish a complete check on all mechanical and electrical systems between the engine and the instrument and control room (automatic control console)
e. Clear all personnel not required for checking and installing the igniter. (See paragraphs 6.3.6.1 and 6.3.6.2 and Appendix E).
f. Prepare motion picture cameras to obtain complete camera coverage during firing operations.

g. Insure the correct, short, countdown program is programmed into the automatic control console.

h. Insure adequate manual control in the event of a malfunction.

i. Clear the firing area for all personnel.

NOTE: A live firing is hazardous and safety shall always be stressed.

6.2.2.2 Firing Operation

6.2.2.2.1 Ambient Firing Tests - Firing tests shall be conducted under ambient temperature conditions as follows:

a. Commence countdown
b. Commence camera coverage
c. Record the following during the firing operation:

1) Ambient Air temperature
2) Propellant temperature at the time of firing
3) Thrust versus time and pressure versus time
4) Igniter current
5) Igniter circuit zero time
6) Temperature at:

a) Motor case
b) Insulation
c) Nozzle
d) Jet deflectors

7) Strains at discrete points on the motor case
8) Components of thrust, for motors with thrust vectoring devices:

a) Gimballed nozzles
b) Jet vanes
c) Gas or liquid secondary injection
d) Canted nozzles

9) Vibration at various points on the motor and motor mount as required by the test engineer and/or test specifications.

6.2.2.2.2 Environmental Conditions - The test item shall undergo tests as described in the applicable portions of the following Materiel Test Procedures:

a. Low Temperature Tests as described in the applicable portions of MTP 5-2-583 with firing data as required in paragraph 6.2.2.2.1.

b. High Temperature Tests as described in the applicable portions of MTP 5-2-594 with firing data as required in paragraph 6.2.2.2.1.

c. Vibration Testing as described in MTP 5-2-507 with firing data as required in paragraph 6.2.2.2.1.

6.2.2.3 Post-Firing Operations

Remove the test motor from the firing stand and perform the following:

a. Weigh and balance the motor and record its weight and center of gravity.

b. Measure and record the nozzle throat diameter at a minimum of three locations 120° apart (see paragraph 6.1.1.g).

6.2.3 Motor Tactical Hazards Safety and Destruct Tests

a. Before conducting any complete hazard test program, consult reference 4I of this MTP for specific hazard test details.

b. Both high speed (1,000 frames per second) and normal speed (64 to 128 frames per second) camera coverage shall be provided, if possible, during the conduct of any of the tactical hazards safety and destruct tests.

c. All tests shall be conducted in accordance with the safety provisions and quantity distance tables outlined in reference 4K of this MTP.

d. Test motors shall be instrumented to record the specific data required for each type test.

e. Set-Up instrumentation to obtain blast data as follows:

1) Sound pressure level by means of pressure gauges to measure blast pressure (psig) or sound level meters capable of measuring decibels referenced to 0.0002 dynes/cm^2
2) Shock wave propagation by using ultra high speed (6,000 frames per second) cameras for blast wave time-of-arrival measurements

NOTE: Sound pressure level and shock wave propagation measurements shall be taken in a radial array (increments no larger than 45°) at distances specified in the test items test plan.

6.2.3.1 Open Flame Fire Test

a. One or more motors shall be subjected to open flame fire to simulate fires that may occur during shipment or storage.

b. Whether the motor shall be restrained to prevent movement or allowed complete freedom depends upon the following:

1) Location of the test site.
2) Degree of personnel protection available
3) The requirements of the test.

c. In any test, when allowing free movement, the distance to the nearest road or building shall be greater than the maximum ballistic range of the motor.

d. This test may be performed with the motor either in or out of its shipping container.

e. Prepare the test engine for burning by either of the following methods:

1) Using wood scrap

a) Lumber, and scrap materiel shall be placed under and around the test motor.

b) Ensure good combustion by spreading fuel oil or kerosene on the lumber and using a remotely operated ignition device.

2) Without wood scrap

a) Diesel or any other suitable fuel oil in a shallow pan shall be located to produce flame over the entire length of the motor.
b) This pan shall be fed continuously by remote control and ignited by a remotely operated ignition device.

f. Sufficient fuel shall be used to ensure that the entire test motor will be enveloped by flame for approximately 30 minutes.

NOTE: In most cases motor ignition will be followed by case rupture and the scattering of flaming propellant. Detonation shall be considered possible but seldom occurs.

g. Motion picture camera coverage of this test shall be required.
h. Record the following:

1) Time from fire ignition to motor ignition
2) Duration of propellant fires
3) Blast data

i. A fragment map of the area shall be made.

6.2.3.2 Nozzle Exhaust Impingement Tests

In the event of fires occuring during storage or shipment, the possibility always exists that the exhaust of a motor will impinge upon an adjacent motor. The nozzle impingement test shall be performed to determine the reaction of the target motor, deflagration and/or detonation, and the extent of hazards that result.

a. Two motors shall be restrained to prevent movement.
b. Place them so that the exhaust of the donor motor will impinge directly upon the case of the target motor.
c. Ignite the donor motor.
d. Note all results.
e. Motion picture coverage shall be required of this test.
f. Record the following:

1) Time from ignition of donor motor to ignition of target motor.
2) Blast data

g. A fragment map of the area shall be made.
h. At the discretion of the test director, record the following for the receiver motor.

1) Motor chamber pressure versus time
2) Motor thrust versus time.

6.2.3.3 Sympathetic Detonation Test

Sympathetic detonation tests shall be performed to determine the reaction of the target motor, full or partial detonation or deflagration, the action of the missile warhead, high explosive charges, shaped charges, and primacord in the event of accidental ignition of the warhead or enemy action involving the use of high explosives. The procedures, data requirements, and instrumentation of sympathetic detonation tests pertaining to laboratory and field tests of warheads and fuses are discussed in references 4I and 4J of this MTP.

The following general procedure shall be performed:

a. Determine reasonable proximity by simulating the situation, such as accidental ignition of the warhead while attached to the missile.
b. Place the target motor in reasonable proximity to the high explosive device or shaped charge.

NOTE: This test may be performed with the motor either in or out of its shipping container.

c. The high explosive device shall be initiated.
d. Motion picture camera coverage shall be required.
e. The following data shall be taken:

1) Time from initiation of the high explosive device to action from the target motor.
2) Blast data to determine the contribution of the target motor to blast over pressure.
3) All other data as specified in references 4I and 4J.

f. A fragment map of the area shall be made.

6.2.3.4 Gunfire Test

Gunfire tests simulate possible enemy actions as well as provide guidance to field commanders regarding the use of conventional weapons for destruct purposes to prevent enemy capture.

a. The gunfire test may be conducted on motors either in or out of shipping containers, depending on test objectives.
b. Restrain the motor and mount the chosen weapon at a selected range.
c. Gunfire tests shall be conducted at various ranges up to 500 yards using one of the following:

1) Cal. 30 rifle firing ball, armor-piercing, tracer ammunition.
2) A cal. 50 machine gun in single or automatic fire.
3) A 40MM cannon or smaller.

d. The attacking weapon shall be equipped for remote control firing and shall be boresighted.
e. The weapon shall be fixed in position.
f. Motors shall be subjected to gunfire from the various weapons

which simulate those expected to be used against a missile in its tactical employment.

g. Motion picture camera coverage shall be required of the test.

h. The following data shall be recorded:

1) Time from firing the attacking weapon to initial action of the motor.
2) Blast data.

i. A fragment map of the area shall be made.

j. Record the following at the discretion of the test director:

1) Motor chamber pressure versus time
2) Motor thrust versus time.

6.2.3.5 Slow Heat Test

a. The slow heat test shall be conducted to determine the autoignition temperature of the complete motor and the extent of hazards resulting from conditions which will expose motors to slowly increasing temperature.

b. These conditions will result from the following:

1) Smoldering fires
2) Storage in ship holds
3) Storage near heating equipment or steam lines
4) Temporary open storage of motors in desert areas.

c. Place the motor in an insulated chamber.

d. Restrain it to prevent movement.

e. Heating equipment shall be used to circulate heated air through the insulated chamber and around the motor.

NOTE: A tactical shipping container shall be used as the heating chamber if available.

f. Provide controls to accomplish the prescribed rate of temperature increase using the propellant temperature as the temperature indication.

g. Increase the temperature gradually until motor ignites.

h. Motion picture camera coverage shall be required.

NOTE: Motion picture camera coverage is difficult to achieve since the motor reaction may occur without much warning. Partial success has been achieved by triggering the cameras when the propellant temperature and chamber pressure show a rapid rise.

i. Event data may be assured by continuous coverage of the test with closed circuit television recorded on video tape. Systems for this purpose must have rapid rewind capability so that coverage may be provided essentially on a continuous basis.

j. Make a fragment map of the area.

k. Record the following:

1) Chamber temperature versus time.
2) Propellant temperature versus time.

3) Heating air temperature versus time.
4) Time from beginning of the test to motor ignition.
5) Motor chamber pressure versus time.
6) Blast data.

6.2.3.6 Safety Destruct Tests

Safety destruct tests shall be performed to determine the optimum method, such as explosive charge, thermal grenade, shaped charge, and gunfire, which can be employed to destroy materiel to prevent enemy capture.

a. Position and restrain the motor.
b. Ready the destruct device and apply it to the motor in the manner prescribed by the applicable procedures pertaining to the use of the destruct device.
c. Motion picture camera coverage shall be accomplished.
d. Safety destruct tests may be performed on a motor either in or out of the shipping container.

NOTE: So that the motor case will not become propulsive a destruct at or near the head end of the motor case is considered good practice.

e. A fragment map of the area shall be made.
f. The following data shall be recorded:

1) Detailed description of the destruct device.
2) Position of the destruct device.
3) Blast data to determine damage potential at various distances from the test.

6.2.3.7 High Level Drop Test

High level drop tests shall be conducted on live motors to assess the hazards involved in drops of missiles from launchers, handling devices, or transportation accidents using the applicable equipment described in MTP 5-2-506.

a. This test shall be conducted on motors both in and out of shipping containers and may be accomplished simultaneously with tests having objectives related to the shipping container.
b. Instrument the test motor with accelerometers to record the shock level.
c. Employ explosive safety destruct devices during this test to prevent accidents resulting from ignition of the motor.
d. Drop the motor from a prescribed elevation onto one of the following:

1) Reinforced concrete surface.
2) Steel surface
3) A surface employing sharp-edged structural members to simulate features of launchers and other obstacles that may be encountered.

e. Motion pictures shall be taken of the test.
f. The following data shall be recorded:

1) Shock registered on the motor and the container.
2) Blast data (if applicable).

g. A fragment map of the area shall be made (if applicable).
h. Still photographs shall be taken of resulting damage.

6.2.3.8 Thrust Neutralizer Test

Thrust neutralizers are deflector plates attached to the nozzle exit to deflect all exhaust gases radially and normal to the motor axis. Since thrust neutralizers allow only a small positive or negative thrust of solid propellant motors they are often used as safety devices during the shipping and handling of these motors. The effectiveness of thrust neutralizers is determined by one of the following methods:

a. Normal Static Tests

1) Prepare the system under test as described in paragraph 6.2.2.1 with the following exception:

a) The thrust indicator shall be a load cell calibrated in both compression and tension.

2) Commence countdown
3) Commence camera coverage.
4) Record the following:

a) Propellant temperature at time of firing.
b) Thrust versus time and pressure versus time.

b. Free movement tests shall be accomplished in one of the following ways:

1) Motor non-mounted (either in or out of its case):

a) Attach the applicable electrical system to ignite the motor and take motion pictures.

2) Launcher Mounted:

a) Instrument the missile and its launcher with accelerometers.

NOTE: Accelerometer data shall be transmitted by direct wire. Insure sufficient wire slack to allow freedom of movement.

b) Attach the applicable electrical system to ignite the motor.
c) Obtain complete camera coverage and record the accelerometer readings.

6.2.4 Igniter Tests

Solid propellant motor igniters, described in Appendix E, are subject to the following procedures:

6.2.4.1 Visual Inspection

a. Visually inspect the igniter and record the following:

1) Container defects

a) Damaged threads
b) Powder leaks
c) Cracks, breaks, or dents
d) Initiater insert, when applicable

2) Electrical system defects

a) Broken wires
b) Loose connections
c) Short circuits (Test using an approved continuity tester only)

6.2.4.2 X-Ray Inspection

X-ray inspection of the igniter is used to determine internal cracks or voids for all igniters, and to verify that the squib circuitry is properly imbedded in powder igniters.

NOTE: Pyrogen igniters should be considered in the same category as small scale rocket motors.

6.2.4.3 Preparation for Firing

a. Mount the igniters as follows:

1) Powder igniters shall be mounted so as to allow complete freedom of movement.
2) Pyrogen igniters shall be mounted similarly to propellant motors so as to restrain movement.

b. Prepare applicable instrumentation as described in Appendix D.
c. Connect electrical system as required.
d. Accomplish a complete check on all mechanical and electrical systems between the igniter and the instrument and control room (automatic control console).
e. Clear all personnel from the test bay.
f. Prepare motion picture camera to obtain complete camera coverage of the firing.
g. Insure the correct, short countdown has been installed in the automatic control console.
h. Insure adequate manual control in the event of a malfunction.

NOTE: For igniter tests requiring data on the volume of gas produced the igniter shall be set up in a closed chamber to allow for temperature and pressure measurements.

6.2.4.4 Firing Operation

a. Commence countdown
b. Commence camera coverage
c. Record the following during firing operation:

1) Ambient Air temperature
2) Igniter temperature at the time of firing
3) Igniter firing voltage
4) Igniter firing current, in amps
5) Time delay from application of current to igniter ignition
6) Test chamber temperature versus time, when applicable
7) Test chamber pressure versus time, when applicable

6.2.4.4.1 Environmental Firing Operations - The data required under paragraph 6.2.4.4 shall be obtained under the applicable portions of the following procedures:

a. Low Temperature Tests MTP 5-2-583
b. High Temperature Tests MTP 5-2-594

6.3 TEST DATA

6.3.1 Preparation for Test

Record the following:

a. Type motor under test
b. Propellant being used
c. Motor and propellant weight in pounds
d. Nozzle throat diameter, at a minimum of three places, in inches
e. Center of gravity of motor as required
f. Instrumentation used

6.3.2 Motor Inspections

Record the following:

a. Method of inspection (visual, x-ray, ultrasonic, etc.)
b. Presence of propellant defects such as:

1) Cracks or voids
2) Abnormal surface conditions
3) Separations between the propellant and liner or inhibitor
4) Exudate or crystal formation on the propellant and metal parts
5) Blowholes
6) Presence of foreign matter
7) Lack of perfect bond at propellant interfaces
8) Shrinkage cavities

c. Presence of motor defects such as:

1) Dents or defects in the case
2) Defects in the nozzle
3) Defects in the nozzle insert or igniter

6.3.3 Motor Static Firing

a. Record the following for all tests:

1) Temperature in degrees F
2) Propellant temperature at the time of firing in degrees F
3) Thrust, in pounds, versus time in seconds
4) Pressure, in psi, versus time in seconds
5) Igniter current, in amps
6) Igniter current at zero time, in amps
7) Temperature, in degrees F of:

a) Motor case
b) Insulation
c) Nozzle
d) Jet deflectors

8) Strain gauge readings in inch-pounds
9) Thrust components, in pounds and direction for:

a) Gimballed nozzles
b) Jet vanes
c) Gas or liquid secondary injection
d) Canted nozzles

10) Vibration, when required, in "g's" and cycles per second

b. Record applicable low temperature test data as described in MTP 5-2-583.
c. Record applicable high temperature test data as described in MTP 5-2-594.
d. Record applicable vibration test data as described in MTP 5-2-507.
e. Retain motion pictures.

6.3.4 Motor Post-Firing Operation

Record the following:

a. Weight of motor in pounds and locate center of gravity
b. Nozzle throat diameter, at a minimum of three places, in inches.

6.3.5 Motor Tactical Hazard and Destruct Tests

6.3.5.1 Open Flame Fire Test

a. Record the number of motors tested
b. Record the following for each motor tested:

1) Time from fire ignition to motor ignition, in seconds
2) Duration of propellant fires, in minutes

c. Retain motion pictures
d. Prepare blast data graph of the following:

1) Sound level pressure in psi or decibels versus distance from the blast area for specified distances at measured angles
2) Shock wave propagation, in feet per second, as determined from ultra high speed cameras, versus distance from the blast area for specified distances at photographed angles.

e. Prepare a fragment map of the area

6.3.5.2 Nozzle Exhaust Impingement Tests

a. Record the following:

1) Time from ignition of donor motor to ignition of target motor, in seconds
2) Target motor chamber pressure, in psi, versus time in seconds, if required
3) Target thrust, in pounds, versus time in seconds, if required

b. Retain motion pictures

c. Prepare blast data graph of the following:

1) Sound level pressure in psi or decibels versus distance from the blast area for specified distances at measured angles
2) Shock wave propagation, in feet per second, as determined from ultra high speed cameras, versus distance from the blast area for specified distances at photographed angles.

d. Prepare a fragment map of the area

6.3.5.3 Sympathetic Detonation Test

a. Record the time from initiation of the high explosive to initial action of the target motor, in seconds
b. Retain motion pictures
c. Prepare blast data graph of the following:

1) Sound level pressure in psi or decibels versus distance from the blast area for specified distances at measured angles
2) Shock wave propagation, in feet per second, as determined from ultra high speed cameras, versus distance from the blast area for specified distances at photographed angles.

d. Prepare a fragment map of the area

6.3.5.4 Gunfire Test

a. Record the following:

1) Weapon and ammunition type used
2) Time from firing the attacking weapon to initial action of the motor, in seconds
3) Motor chamber pressure, in psi, versus time in seconds, if required
4) Motor thrust in pounds, versus time in seconds, if required

b. Retain motion pictures
c. Prepare blast data graph of the following:

1) Sound level pressure in psi or decibels versus distance from the blast area for specified distances at measured angles
2) Shock wave propagation, in feet per second, as determined from ultra high speed cameras, versus distance from the blast area for specified distances at photographed angles

d. Prepare a fragment map of the area

6.3.5.5 Slow Heat Test

a. Record the following:

1) Time from beginning of the test to motor ignition, in hours
2) Temperature, in degrees F versus time in hours for:

a) Chamber
b) Propellant
c) Heating air

3) Motor chamber pressure, in psi, versus time in hours

b. Retain motion pictures
c. Retain closed circuit video tape
d. Prepare blast data graph of the following:

1) Sound level pressure in psi or decibels versus distance from the blast area for specified distances at measured angles
2) Shock wave propagation, in feet per second, as determined from ultra high speed cameras, versus distance from the blast area for specified distances at photographed angles

e. Prepare a fragment map of the area

6.3.5.6 Safety Destruct Test

a. Record the following:

1) Description of destruct device
2) Position, in motor, of the destruct device

b. Retain motion pictures
c. Prepare blast data graph of the following:

1) Sound level pressure in psi or decibels versus distance from the blast area for specified distances at measured angles
2) Shock wave propagation, in feet per second, as determined from ultra high speed cameras, versus distance from the blast area for specified distances at photographed angles

d. Prepare a fragment map of the area

6.3.5.7 High Level Drop Test

a. Record the following:

1) Impact shock of the motor, in "g's" and milliseconds
2) Impact shock of the container, in "g's" and milliseconds

b. Prepare a fragment map of the area, if applicable

c. Prepare blast data graph of the following (if applicable):

1) Sound level pressure in psi or decibels versus distance from the blast area for specified distances at measured angles
2) Shock wave propagation, in feet per second, as determined from ultra high speed cameras, versus distance from the blast area for specified distances at photographed angles

d. Retain motion pictures
e. Retain photographs showing damage

6.3.5.8 Thrust Neutralizer Test

6.3.5.8.1 Normal Static Tests

a. Record the following:

1) Propellant temperature at time of firing, in degrees F
2) Motor thrust, in pounds, versus time in seconds
3) Motor chamber pressure, in psi, versus time in seconds

b. Retain motion pictures

6.3.5.8.2 Free Movement Test

a. For non-mounted motors

1) Retain motion pictures

b. For launcher mounted motors

1) Record accelerometer readings in "g's" and cps

2) Retain motion pictures

6.3.6 Igniter Tests

6.3.6.1 Inspection

Record the following:

a. Method of inspection (visual or X-ray)
b. Type of igniter (powder or pyrogen)
c. Container defects such as:

1) Damaged threads
2) Powder leaks
3) Cracks, breaks, or dents
4) Defects in the initiater insert

d. Electrical system defects such as:

1) Broken wires
2) Loose connections
3) Short circuits

6.3.6.2 X-ray Inspection

Record any cracks, separations, etc. observed

6.3.6.3 Firing Operation

a. Record the following:

1) Ambient Air Temperature in degrees F
2) Igniter temperature at the time of firing in degrees F
3) Igniter firing voltage
4) Igniter firing current, in amps
5) Time delay from applying current to igniter ignition in seconds
6) Test chamber temperature, in degrees F, versus time in seconds, when applicable
7) Test chamber pressure, in psi, versus time in seconds, when applicable

b. Retain motion pictures
c. Record applicable low temperature test data as described in MTP 5-2-583.
d. Record applicable high temperature test data as described in MTP 5-2-594.

6.4 DATA REDUCTION AND PRESENTATION

Most of the information gained from a static firing shall be derived by reducing thrust versus time and pressure versus time traces. The testing agency shall be free to select pertinent times and threshold levels suitable to requirements, but for the sake of uniformity, shall always adhere to the military standard. Examination of the thrust versus time and pressure versus time traces will indicate abnormal performances such as partial propellant grain break-up, unstable burning, and poor ignition. The oscillograph traces will show clearly, the time at which catastrophic failures occur such as burn-through, case rupture, insulation failures, and many other failures which may occur.

All test results both raw and processed, shall be properly marked for identification and correlation to the respective test. Specifications that will serve as the model for a comparison of the actual test results shall be included.

Evaluation usually will include comparing the actual test results to the applicable manufacturer's specifications and the requirements imposed by the intended usage. The test results shall also be compared with the results of previous static firing tests that were conducted on the same system.

6.4.1 Thrust Versus Time

The thrust curve shall be used to determine the total impulse and specific impulse of a rocket motor. The curve is also useful in the determination of excessive vibration, nozzle burn off or nozzle burn through, and propellant breakup.

Figure 1 illustrates the values obtained from the thrust versus time curve. The example shown is general and the threshold level has been arbitrarily set at 100 pound-force units (lbf).

The primary data derived from the thrust versus time curve of Figure 1 are:

a. t_d = delay time to 100 pound thrust level, measured from the time of igniter initiation to the first sustained force of 100 pounds

b. t_a = action time between 100 pound levels

c. F_{max} = maximum sustained thrust measured at any time

d. F_{min} = minimum thrust measured at any time

e. F_{av} = average thrust during action time

f. I = impulse $\int_{t_1}^{t_2} F dt$

g. I_{sm} = motor specific impulse (measured)

$$\frac{\int F dt}{W_m} \quad (W_m = \text{weight of motor})$$

h. I_{sp} = propellant specific impulse (measured)

$$\frac{\int F dt}{W_p - W_s} \quad \begin{array}{l}(W_p = \text{weight of propellant})\\(W_s = \text{weight of slivers})\end{array}$$

i. F_{me} = Maximum Erosion Thrust. The maximum thrust which occurs early on the thrust versus time trace which is due to erosion ($F_{me} = F_{max}$).

j. F_{mp} = Maximum Progressivity Thrust. The maximum thrust which occurs late in the thrust versus time trace and is due to progressivity. Consult References 4A through 4D of this MTP for further information pertaining to thrust versus time data reduction and presentation.

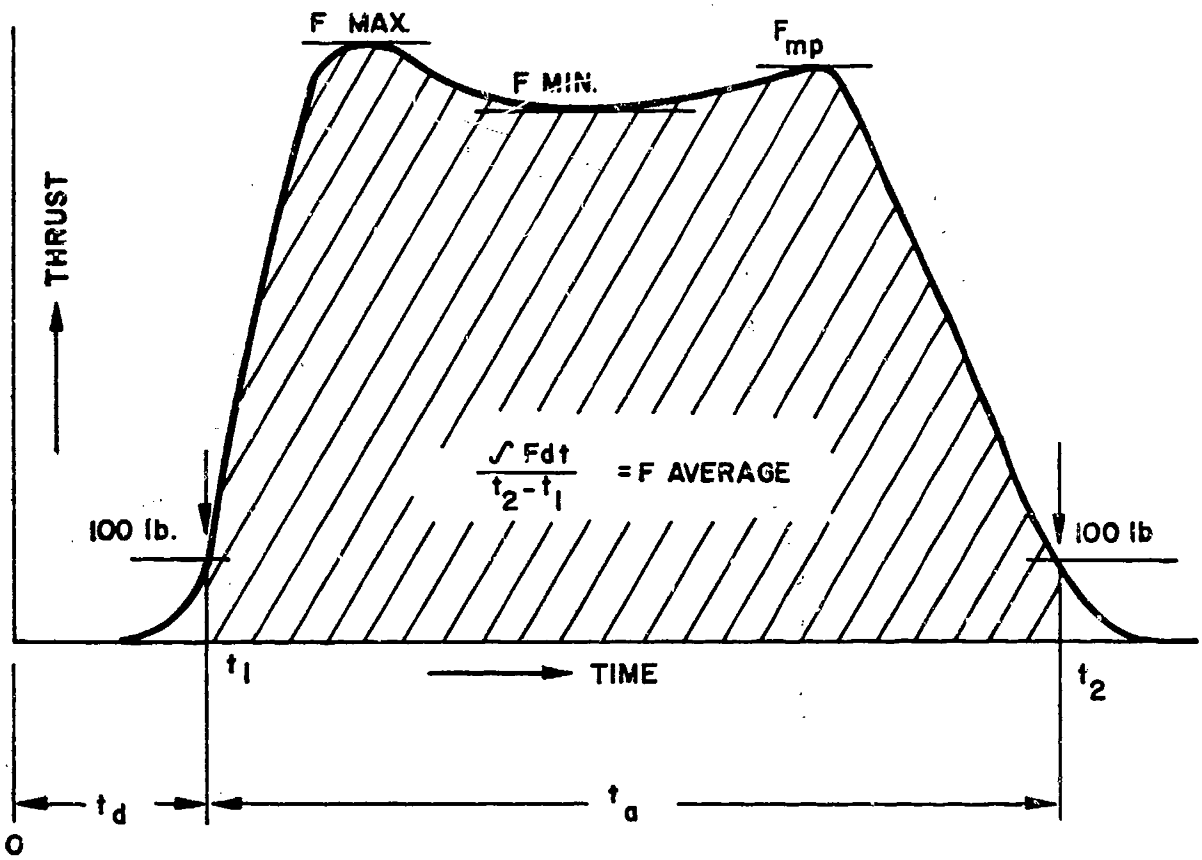


FIGURE 1. TYPICAL THRUST VERSUS TIME TRACE

6.4.2 Pressure Versus Time

The pressure versus time curve shall be used to determine a number of performance criteria for a rocket motor (unstable burning, propellant defects, etc.). The example given in Figure 2 illustrates one specialized treatment of a pressure versus time curve. All other treatments are similar but require minor changes to meet the specific test objectives. The primary data usually derived from the pressure versus time curve, as shown in Figure 2, are:

a. P = average pressure = $\int_{t_1}^{t_2} \frac{Pdt}{t_2 - t_1}$

b. P_{me} = Maximum Erosion Pressure. The maximum pressure which occurs early on the pressure-time trace which is produced by an increased propellant burning rate as a result of erosive burning during the period of low port area.

c. P_{mp} = Maximum Progressivity Pressure. The maximum pressure which occurs late in the pressure-time trace and results from an increased burning surface of the propellant.

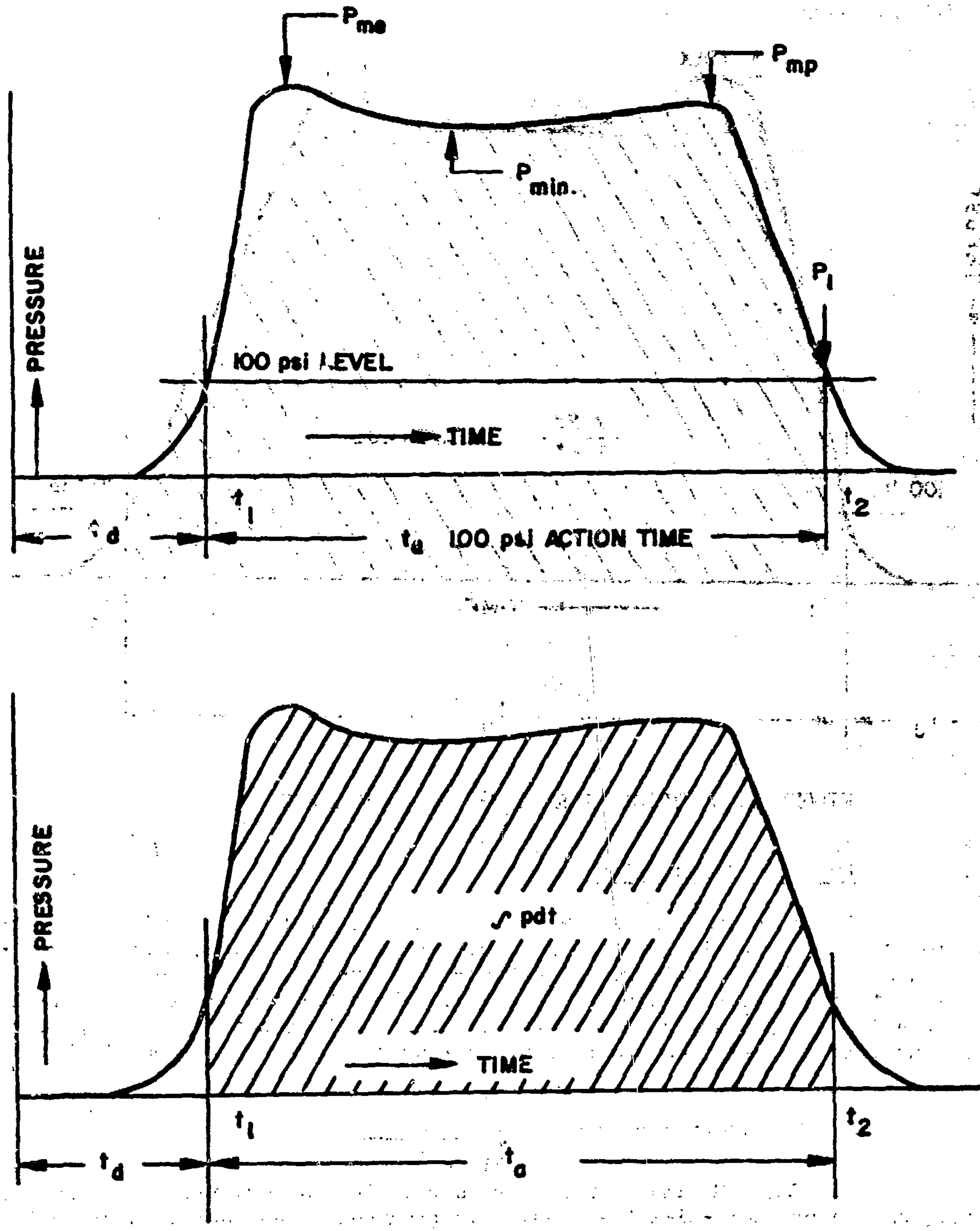


FIGURE 2. TYPICAL PRESSURE VERSUS TIME TRACE

d. t_i = Ignition Time. The time from some fixed level on the initial portion on the pressure or thrust trace to some higher level on the same trace.

e. $t(P_{me})$ = Time to Maximum Erosion Pressure. The time from zero time to the point on the pressure trace where the maximum pressure due to erosion occurs.

f. T_u = Useful Time. The time from some fixed level on the pressure or thrust trace to some higher fixed level on the decay portion of the same trace. In actual use, numerals must be associated with the subscript u to denote the levels. Example: $t_{u\,1\text{-}9p}$ is the useful time from 100 psi on the initial portion of the pressure trace to the point where the pressure has decayed to 900 psi.

g. P_{eff} = Effective Pressure. The average pressure during useful time.

$$P_{eff} = \int_{t_1}^{t_2} \frac{Pdt}{t_2 - t_1}$$

h. C* - Characteristic Exhaust Velocity = $\frac{A_t\, g}{W_p} \times \int_{t_1}^{t_2} P_{dt}$

where:

A_t = Nozzle throat area
g = gravitational constant (ft/sec^2)
W_p = Propellant weight

i. C_F = Thrust Coefficient

$$C_F = \frac{F}{A_t\, P_c} \qquad (P_c = \text{Chamber Pressure})$$

<u>NOTE</u> Consult references 4A through 4D of this MTP for further information pertaining to pressure versus time data reduction and presentation.

GLOSSARY

1. Chamber Pressure: The pressure inside the combustion chamber, expressed as pounds per square inch (PSI) usually gage (PSIG).

2. Grain: The propellant stick

3. Impulse: The integral of thrust times the derivative of time between defined limits and expressed as pounds-force-seconds (lbf-sec.)

$$\int_{t_1}^{t_2} F dt$$

4. Inhibitor: Nonflammable material bonded to the propellant grain surface to control burning surface.

5. Progressivity: Increase in chamber pressure and thrust due to grain designed to have increasing burning surface with time.

6. Sliver: Propellant remaining in the motor case after motor burnout or ejected unburned during motor burning.

7. Specific Impulse: Propellant specific impulse measured:

$$\frac{\int F dt}{W_p - W_s}$$

(W_s = weight of sliver)

(W_p = weight of propellant)

Motor specific impulse measured:

$$\frac{\int F dt}{W_m}$$

(W_m = total weight of motor)

8. Static Firing Test: The actual firing of a rocket motor in which flight is prevented by rigid mounting.

9. Thrust: Force, measured in a static test, which is produced by the rocket motor and expressed as pounds-force units (lbf)

Note: For a complete listing of terms, definitions of parameters, and letter symbols applicable to solid propellant static firings, consult References 4A through 4D of this MTP.

APPENDIX A

SPECIAL FACILITIES AND EQUIPMENT

A. Static Firing Test Facilities and Equipment

Solid propellant engine static testing facilities are equipped with thrust bulkheads which are sufficiently massive to resist the motor thrust and are as nonresonant as possible. The general practice is to construct thrust bulkheads of concrete with embedded steel rails or faced with steel plates to provide a means of connecting thrust measuring devices.

Some type of flame deflector shall be required to prevent excessive damage to the test facility due to flame erosion. The flame deflectors may be flat or dished open surfaces made from concrete or steel and may be either water cooled, or not, depending upon the thrust rating, firing duration, elevation of the motor exhaust above the deflector, and exhaust gas composition. Some deflectors are of the water-cooled elbow design and deflect the exhaust gases a full 90 degrees. Elbow deflectors generally require a large amount of cooling water and are not considered economical, expecially where process water is scarce. The facility shall have ample water, not only for cooling purposes but for fire protection as well. The fire system shall be equipped for automatic as well as emergency manual activation.

Control centers at modern facilities are usually air conditioned because of the large amount of electronic equipment which they contain. Temperature control is essential for high accuracy as well as for personnel comfort.

The static firing test facility shall contain an automatic control console capable of turning on all instrumentation at a programmed time, commencing photographic coverage at X-10, firing the engine, and shorting the firing circuit. These events shall be completely automatic but manual control shall be possible at any time in the event of malfunction. Indirect vision through mirrors and/or closed circuit television for test observation is common practice and two-way voice communication between the control center and test stand is considered essential.

Data systems shall be connected through patch panels at both the transducer and recorder ends to provide flexibility in test setups. On-site oscillogram processing shall be provided for rapid data reduction.

Supporting facilities such as machine shops, propellant storage, and supply rooms are required to prevent delays in test operations.

Ample electrical power shall be provided for both normal operation and excess load requirements.

Process water shall be ample for fire fighting and decontamination purposes in addition to all other requirements. Permanently connected and automatically controlled fog or spray nozzle systems are considered essential, as well as hand operated chemical extinguishers. Facilities shall provide remotely controlled, automatic, chemical fire fighting systems.

B. Hazard and Destruct Test Facilities and Equipment

Facilities to conduct hazard tests include an isolated area, preferably on flat ground, equipped with ample firm electrical power, an ample supply of water for fire fighting and decontamination, and a personnel shelter. In the absence of firm electrical power, gasoline or diesel generators shall be used. A communication network between the test site and base headquarters shall be established either by radio or telephone.

Equipment for conducting hazard tests shall be brought to the test site as needed. Motion picture cameras capable of a film speed of 1000 frames per second meet the requirements for the hazard tests. However, for photographing blast phenomena in case of detonation, cameras with film speeds up to 6000 frames per second are required. If possible, closed circuit television or microwave television systems equipped with zoom lenses should be employed.

C. Propulsion System Components Test Facilities and Equipment

These test facilities and equipment consist of the pneumatic, hydraulic, and electrical test facilities. The pneumatic and hydraulic test facilities are frequently used to calibrate flow meters and to set regulators. Accuracy of component testing is dependent upon the accurate calibration of the equipment contained in the test benches. Calibration of all measuring and recording instruments by a laboratory equipped with primary standards must be accomplished at regular intervals.

1. Pneumatic Test Facilities and Equipment

The major facility for pneumatic component testing is a flow bench which supplies a centralized distribution, regulation, and flow control point for high pressure gas, supplied by a large volume, high pressure, cascade system. Pressure, volume, and type of gas are determined by specifications applicable to the systems to be tested. For convenience and efficient operation, the flow bench shall be divided into a high flow system and a low flow system. Incorporated within each flow system shall be regulators to control pressure over the entire available range, flow tubes (straightening vanes), and differential pressure transducers, and the flow meters for measuring flow.

The pneumatic flow bench shall be a conveniently arranged assemblage of the apparatus required for accurately and efficiently determining the operating characteristics, calibration, reliability, and life of pneumatic components of missile systems. The bench shall contain all necessary instrumentation for controlling and recording pneumatic pressures and flows.

2. Hydraulic Test Facilities and Equipment

The hydraulic flow bench used for the testing of missile system hydraulic components provides a centralized controlled source of liquid flow and pressure.

For convenient and efficient operation, the hydraulic flow bench shall be separated into an oil flow system and water flow system. The range of flows and pressures must be known

Incorporated in the bench shall be filters, flow meters, heat exchangers, weigh tank, timing clock, antifoaming storage tank, and all instrumentation for controlling and recording hydraulic pressures and flows.

3. Electrical Test Facilities and Equipment

The electrical test bench provides a centralized distribution subpanel for the various types of electrical power that are required in evaluating and testing propulsion systems electrical components.

The bench shall provide complete instrumentation for measuring and recording the performance of electrically driven rotary components, relays, solenoids, switches, instruments, signal devices, electro-mechanical servomechanisms, and similar missile equipment.

NOTE: Simple solid propellant rocket motors require little component testing except for hydrostatic burst tests of motor cases during development and design engineering phases. Only more sophisticated systems employing thrust vectoring devices such as secondary injection systems will require tests on flow systems. Hybrid (Liquid-Solid) systems require component tests as outlined in the Liquid Propellant Systems TDP.

APPENDIX B

MOTOR MOUNTING

A motor may be mounted on any one of several types of firing stands during static firing test. Four typical methods are described as follows:

a. The motor is secured in a fixed test stand mounted to the pad. No movement is possible in relation to the motor and its tie down straps. Required movement to record thrust is permitted by the use of flexure members between motor and pad. This type of mounting is satisfactory only for recording thrust in a direction parallel to the motor axis.

b. The motor is mounted within one or more split rings with adjustable rollers forming the bed and tie down and which permit axial motion. This type of mounting provides for mounting motors of various diameters without modifications to the mount. It is suitable for thrust measurement only in the longitudinal direction.

c. The motor handling dolly or car is sometimes used as the thrust mount with the car wheels providing the limited motion necessary for recording the thrust. When this method is used, the car usually is secured with cables and a preload device is employed. Preload devices usually consist of spring loaded rods which clamp the thrust measuring device tightly against the spring tension, between the thrust adaptor and the thrust bulkhead.

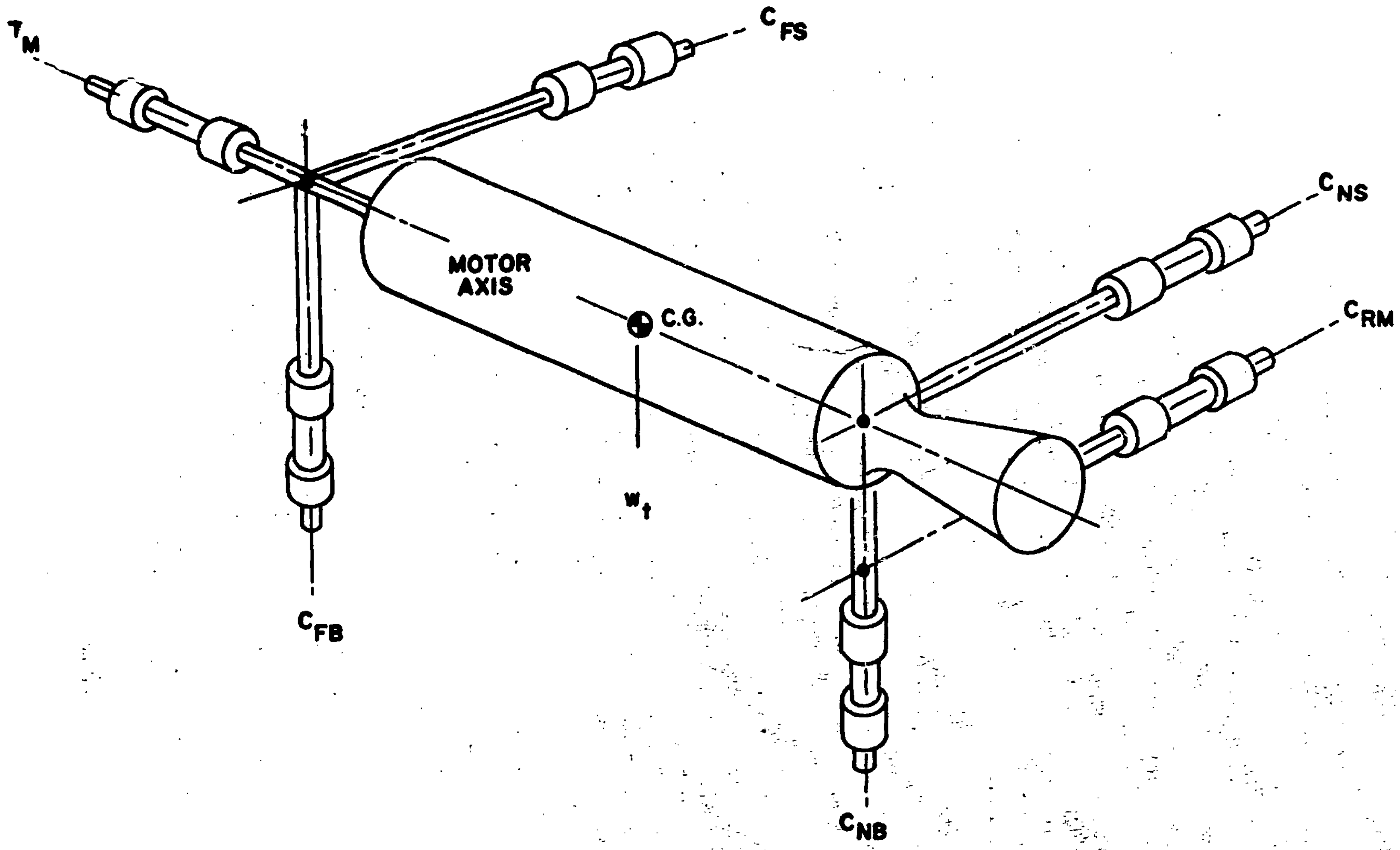
d. When motors to be tested are equipped with thrust vector control devices or have flexible or canted nozzles, it is desirable to have thrust measurements in six directions or what is commonly called a "six degree of freedom" stand. These may be devised for horizontal motor mounting but the most common practice is to mount the motor vertically. In both cases the motor must have freedom to move against load cells in any direction including roll moment about its longitudinal axis. Figure B-1 illustrates a typical horizontal mounting for multicomponent thrust measurement.

In all types of mountings it is essential to allow for thermal expansion and to ensure that all load bearing surfaces are sufficient to prevent denting or deformation of the motor case. Steel channel rolled with the flat side to the radius of the motor makes an excellent cradle, especially for the roller type of mounting.

An adapter is usually required to fasten the motor to the thrust measuring device. This adapter shall be designed according to the motor thrust and resonant frequency. It shall be sufficiently strong to transmit the thrust and sufficiently rigid so that spurious resonances will not be imparted to the force measuring device. Mounting parts to be attached to the motor shall be selected for maximum strength to transmit the thrust.

NOTES: 1. Motors that have been designed with thin cases require thrust adapters designed to fit the entire forward end of the motor to prevent crushing.

2. Integral stands built for small motors shall be engineered to avoid the presence of resonance in the data.



T_M = MAIN THRUST

C_{FS} = COMPONENT, FRONT SIDE

C_{FB} = COMPONENT, FRONT BOTTOM

C_{NS} = COMPONENT, NOZZLE SIDE

C_{NB} = COMPONENT, NOZZLE BOTTOM

C_{RM} = COMPONENT, ROLL MOMENT

FIGURE B-1. HORIZONTAL MOUNTING FOR MULTICOMPONENT THRUST MEASUREMENT

APPENDIX C

MOTOR INSPECTION METHODS

Solid propellant motor inspection is required at numerous points in the sequence of manufacturing, testing, and evaluation. There are several methods of inspection which can be employed. Each of these methods has advantages and disadvantages but, as yet no one method or technique has been found which will uncover all the flaws that are capable of causing malperformance and catastrophic failures.

The following methods are used when inspecting solid propellant motors:

Visual Inspection

Visual inspection is performed as follows:

a. Remove all possible closures to allow as much light to enter the motor as possible.

b. Additional light shall be provided by an approved safety flashlight or by mirror deflection of the sunlight.

c. A partial or total disassembly of the motor shall be performed if possible.

d. Examine the motor for and record any propellant defects such as:

1) Abnormal surface conditions
2) Cracks
3) Separations between the propellant and liner or inhibitor which may be visible from the ends.
4) Exudate or crystal formation on the propellant and metal parts.

e. Inspect the motor for any of the following:

1) Dents or defects in the case
2) Defects in nozzle
3) Defects in igniter or nozzle insert

Inspection Using a Borescope

NOTE: Borescope inspection is usually not satisfactory for propellant surface inspection because of the limited area which can be viewed and the low reflectivity of the propellant surface.

Internal inspection shall be accomplished by the use of a borescope with an explosion proof light.

CAUTION: Avoid overheating any point where the borescope light will be concentrated.

*Inspection by X-Ray

X-ray inspection is highly satisfactory for locating cracks and voids, especially in small diameter motors.

a. To obtain best results, personnel shall have considerable experience in interpreting X-rays for the determination of flaws.
b. Inspection shall be done by X-ray equipment.
c. Multiple exposures shall be made.

*Inspection by Gammagraph

The gammagraph method has given good results in determining defects such as blowholes, inclusions of foreign matter, shrinkage cavities, lack of perfect bonding, and cracks especially when used in the inspection of large diameter motors. In this method gammagraph rays emitted by a radioactive pill are similar to X-rays, but are more penetrating. Source strength and exposure time are critical factors in obtaining good resolution using this method.

Inspection by gammagraph shall be accomplished by one of the following methods:

a. Place the radioactive pill inside the propellant port and the film on the outside.
b. The pill and the film shall be placed on opposite sides of the motor.

Ultrasonic Inspection

Ultrasonic inspection depends upon a change in attenuation of an ultrasonic signal by a crack, void, or separation. Several manufacturers have had success using this method of inspection. Special techniques shall be developed through experience.

Profilometer Inspection

The profilometer essentially is a precision mounted roller which is attached to a deflecting beam. As the roller is traversed across the propellant surface all irregularities produce deflection of the beam. The beam is instrumented with strain gauges which produce a signal appearing as a pip on an oscillograph trace. When plotted against distances along the grain, these signals show the location of the surface irregularities.

*NOTE: This type of inspection may be performed only by a certified radiographer in accordance with applicable safety procedures.

APPENDIX D

INSTRUMENTATION

The specific instrumentation requirements are dependent upon the motor being fired, the static firing facility design, the solid propellant characteristics, and the specific test objectives for which the test is being conducted.

Listed below are the basic requirements and how they are accomplished:

Thrust

Thrust is usually measured with load cells of the strain gauge type. These cells have a load member, instrumented with strain gauges which may be calibrated either in compression or tension. The load cell is mounted between the motor and bulkhead to measure the force applied by the motor. The output of the strain gauge bridge circuit is fed through amplifiers to oscillograph and/or magnetic tape recorders, depending upon the requirements of the test.

NOTE: General practice is to record data both on magnetic tape and oscillographs. The oscillograph provides ready information while the tape (analog or digital) can be played into automatic data reduction systems.

Pressure

Motor chamber pressure is usually measured by attaching a calibrated transducer to a port in the head or aft end of the motor case by using a short length of stainless tubing. The transducer output is amplified and recorded in the same manner as the thrust data.

Temperature

Temperature is usually measured with appropriate thermocouples and recorded on strip-chart recorders.

WARNING

Care shall be taken when thermocouples are installed in the propellant grain to insure that there is no possibility of high voltage or stray current being applied to the thermocouple. Such an accident could result in an unexpected ignition since the thermocouple would become a resistance heater.

Photographic Coverage

Motion picture coverage shall be taken at frame rates of 1000 frames per second so that any events leading to a possible catastrophic failure, such as leaks or burn-through are recorded. Also, a careful examination of the exhaust flame can locate evidence of abnormal performance. Normally, at least two cameras are positioned at different angles to ensure that complete coverage of the motor and entire exhaust flame is obtained.

APPENDIX E

IGNITER TYPES

Solid propellant motor igniters are generally one of the two types described below:

A. Powder Igniters

These igniters, which essentially contain squibs and black powder, are normally shipped in the same container with the motor but are not installed. Installation is done prior to firing and after visual inspection and continuity checks are performed.

B. Pyrogen Igniters

These igniters are small motors that are ignited by flame producing pellets and employ removable initiators to ignite the pellets. These units usually are shipped installed in the motor, but without the initiating device.