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Explosion - Proof Testing Techniques

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FOREWORD

This report is a result of work done under Task 130903 (580), Control No. ASTEV-62-51. The work was done in the Environmental Division of the Directorate of Engineering Test, Deputy for Test and Support, Aeronautical Systems Division.

The studies presented began on 15 May 1962 and were concluded on 14 November 1962.

This report concludes the work of Task 130903 (580).

ABSTRACT

This report briefly discusses ignition properties of gaseous fuel-air mixtures with application of these properties to explosion-proof testing technique. Present test methods are discussed, and possible changes in test procedure are suggested. A suggested testing specification is presented. This specification contains several changes from older specifications.

This technical documentary report has been reviewed and is approved.



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INTRODUCTION

In the Air Force the purpose of explosion-proof testing is to insure that equipment used in and around flight vehicles will not cause an explosion if exposed to fuel vapors. The equipment is tested by operating it in an explosive fuel-air mixture. If the equipment does not cause an explosion, it is said to be explosion-proof.

Many questions have arisen concerning test methods and validity of test results. This report is intended to answer some of those questions and to suggest certain new test procedures.

Explosion-proof testing conducted at Wright-Patterson Air Force Base has consisted primarily of testing electrical and electronic equipment for airborne use. For this reason, this report will be particularly concerned with explosion-proof testing of electrical and electronic components and equipments.

IGNITION PROPERTIES

When a proper amount of combustible fuel is mixed with an oxidant, it is possible for combustion to occur. Unless the mixture is hypergolic, a small amount of energy must be supplied to the fuel-oxidant mixture in order to initiate the combustion. The amount of energy required depends on the pressure, the temperature, the mixture composition, the inert gases present, and the method in which the energy is delivered to the flammable mixture.

Heterogeneous Ignition

This type of ignition occurs when an ignition source is introduced into a combustible mixture. Examples of such ignition sources are spark plugs and hot wires that do not uniformly heat the entire mixture before the mixture burns or explodes.

Homogenous Ignition

This type of ignition occurs when the total mixture in a container is uniformly heated to the ignition point.

Minimum Spontaneous Ignition Temperature

The lowest temperature which will cause homogeneous ignition of a given fuel/oxidant mixture is known as the minimum spontaneous ignition temperature.

Whether or not homogeneous ignition occurs depends on the temperature, the pressure, the volume of the container, the surface to volume ratio, the mixture composition, and the composition of the heated surface.

An example will show the difference between heterogeneous and homogeneous ignition. A large block of wood in contact with a 1000 °F match flame may be charred where the flame has made contact, but the block will not continue to burn after the match is removed. The same block of wood will spontaneously burst into flame after a sufficient time in a 500° F oven and will continue to burn as long as sufficient oxygen is available.

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Tests using a cartridge heater as a heterogeneous ignition source showed that a temperature of $1450 \pm 20^\circ\text{F}$ was required to ignite a mixture of 100/130 octane aviation gasoline and air (ref 1). An identical fuel-air mixture placed in a glass flask, which was uniformly heated, required a temperature of 824°F for ignition (ref 6).

A fuel having a lower spontaneous ignition temperature than another fuel may or may not require less spark energy for ignition. For example, aviation gasoline grade 100/130 octane has a minimum spontaneous ignition temperature of 824°F while JP-4 fuel has a corresponding ignition temperature of 468°F . However, only about half as much spark energy is required to ignite aviation gasoline as is required to ignite JP-4 fuel. Hexane on the other hand has a minimum ignition temperature of 453°F (lower than JP-4) but requires the same spark energy for ignition that aviation gasoline does.

Many conditions influence the ease of ignition of fuel-air mixtures. The most important of these conditions is the air to fuel ratio, or more precisely the oxygen to fuel ratio. Analysis of various experimental results reveals that the air to fuel ratio requiring the lowest spark energy for ignition is also the ratio which gives the lowest spontaneous ignition temperature for that fuel.

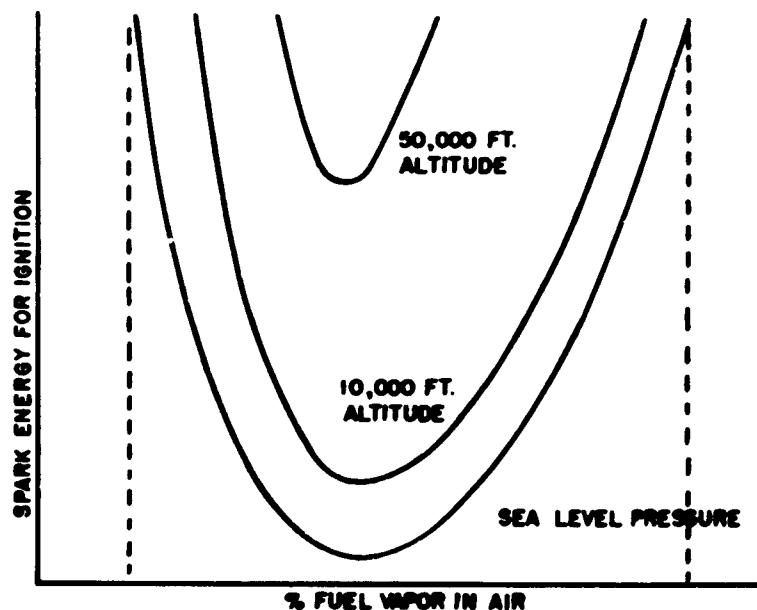


Figure 1. Minimum Spark Energies for Ignition

Figure 1 shows the effects of fuel-air ratio and pressure changes for a typical fuel. For a given fuel, the fuel-air ratio requiring the least energy input for ignition may be called the optimum ratio. It is apparent that this optimum ratio must be used in explosion-proof tests if valid test results are to be obtained. An item of equipment which contains a weak ignition source might not cause an explosion when tested with a non-optimum fuel-air ratio and yet might cause an explosion when accidentally exposed to the optimum ratio during operational use.

The dotted lines in figure 1 represent the flammable concentration limits for the fuel at sea level atmospheric pressure and a given temperature. Fuel concentration above and below these limits cannot be ignited.

The pressure of the fuel-air mixture also affects the ease of ignition. Spark energies and temperatures required for ignition increase as pressure decreases. Pressures used in explosion-proof testing do not exceed ground level atmospheric pressure. A pressure-equivalent altitude of 55,000 feet represents the lowest pressure currently used in routine tests. The greater possibility of arcing and corona at lower air densities makes altitude simulation a necessary part of the test procedure.

It might be noted in passing that the fuel used in explosion-proof tests need not be the same fuel as that to which the item tested may be exposed in operational use. All that is required however, is that the energy input necessary for the ignition of the test fuel be as low or lower than that needed for the operational fuel. Such factors as comparative ease of flame propagation through small holes and fuel volatility should also be considered when selecting a test fuel.

The temperature of the fuel-air mixture is another factor influencing the ease of ignition. Increasing the fuel-air mixture temperature widens the concentration limits between which the mixture is ignitable, and decreases the amount of input energy required for ignition. Higher temperatures also cause the flame to propagate at a more rapid rate. When conducting explosion-proof tests, effort should be made to use a temperature equal to or higher than that to which the test item will be exposed in actual normal operating use.

The degree of turbulence of a fuel-air mixture affects its burning and ignition properties. Flame arrestors are less effective in turbulent mixtures than in quiescent mixtures. Spark energies required for ignition are not changed by turbulence unless there is a high airflow rate past the ignition source. Convection currents and turbulence do affect hot surface temperatures required for ignition. In explosion test chambers the mixture must be sufficiently turbulent to insure uniformity, but not so turbulent that ignition properties are seriously affected. An air velocity of 200 feet per minute in the test area appears to be practical.

Water vapor in the fuel-air mixture can affect the mixture ignition and burning properties. It is presently believed that ordinary atmospheric humidity has very little effect on ignition properties. Increasing the humidity does decrease the burning rate.

Increasing the oxygen concentration above that of the usual fuel-air mixtures lowers considerably the amount of energy required to cause ignition. Equipment which is to operate in oxygen rich atmospheres should be tested in such atmospheres.

Valid explosion-proof test results are obtained when equipment is operated in the most easily ignitable explosive environment to which it will be exposed in actual use.

CURRENT TEST PROCEDURES

This test procedure meets the explosion-proof test requirements of Specifications No. MIL-E-5272C and MIL-T-5422E for determining the explosion producing characteristics of items of equipment not hermetically sealed and not contained in cases designed to prevent flame and explosion propagation.

The equipment to be tested is installed in the explosion test chamber and connections are made for normal electrical operation. The test item controls are operated by mechanical devices manipulated from outside the test chamber. External covers of the test items are removed or opened in order to insure adequate circulation of the explosive mixture. Figure 2 shows a typical test installation in a three foot diameter chamber.

Before scaling the test chamber the equipment is operated to determine proper and normal functioning. The chamber is then sealed and the air temperature within is raised to $160 \pm 5^{\circ}\text{F}$ or to the maximum temperature (if lower than 160°F) at which the test item is designed to operate at an altitude of 50,000 feet.

A pressure equivalent to that at an altitude of 55,000 feet is obtained in the test chamber, and a predetermined quantity of fuel is injected into the chamber. This quantity of fuel is such that the optimum fuel-air ratio should be achieved at the designated test altitude of 50,000 feet. By varying the altitude from 55,000 feet to 45,000 feet, rich, intermediate, and lean fuel-air mixtures are obtained within 5,000 feet of the test altitude. Experience has shown that the most easily ignited fuel-air ratio is actually reached at some altitude within 2,000 feet of the test altitude.

The above procedure is repeated at various test altitudes of 40,000, 30,000, 20,000, 10,000 and 5,000 feet to ground level.

The equipment under test is operated continuously during the test, and all making and breaking electrical contacts are actuated as frequently as possible while the altitude is varied from 5,000 feet above to 5,000 feet below each test altitude. If high temperature components are present, a sufficient warm-up time is permitted.

As the altitude is decreased, the air temperature in the test chamber is maintained at $160 \pm 5^{\circ}\text{F}$ or is maintained at the maximum temperature to which the test item is designed to operate (if lower than 160°F).

A sampling device with a spark plug is used to verify the explosiveness of the fuel-air mixtures.

Grade 100/130 octane aviation gasoline is used as the fuel for obtaining explosive atmospheres, and experimentally, it has been shown that the most easily ignited fuel-air ratio consists of one part of gasoline to 13 parts of air by weight.

If an explosion occurs within the chamber, the test item is considered to have failed the test. If no explosion occurs, the item is considered to be explosion-proof.

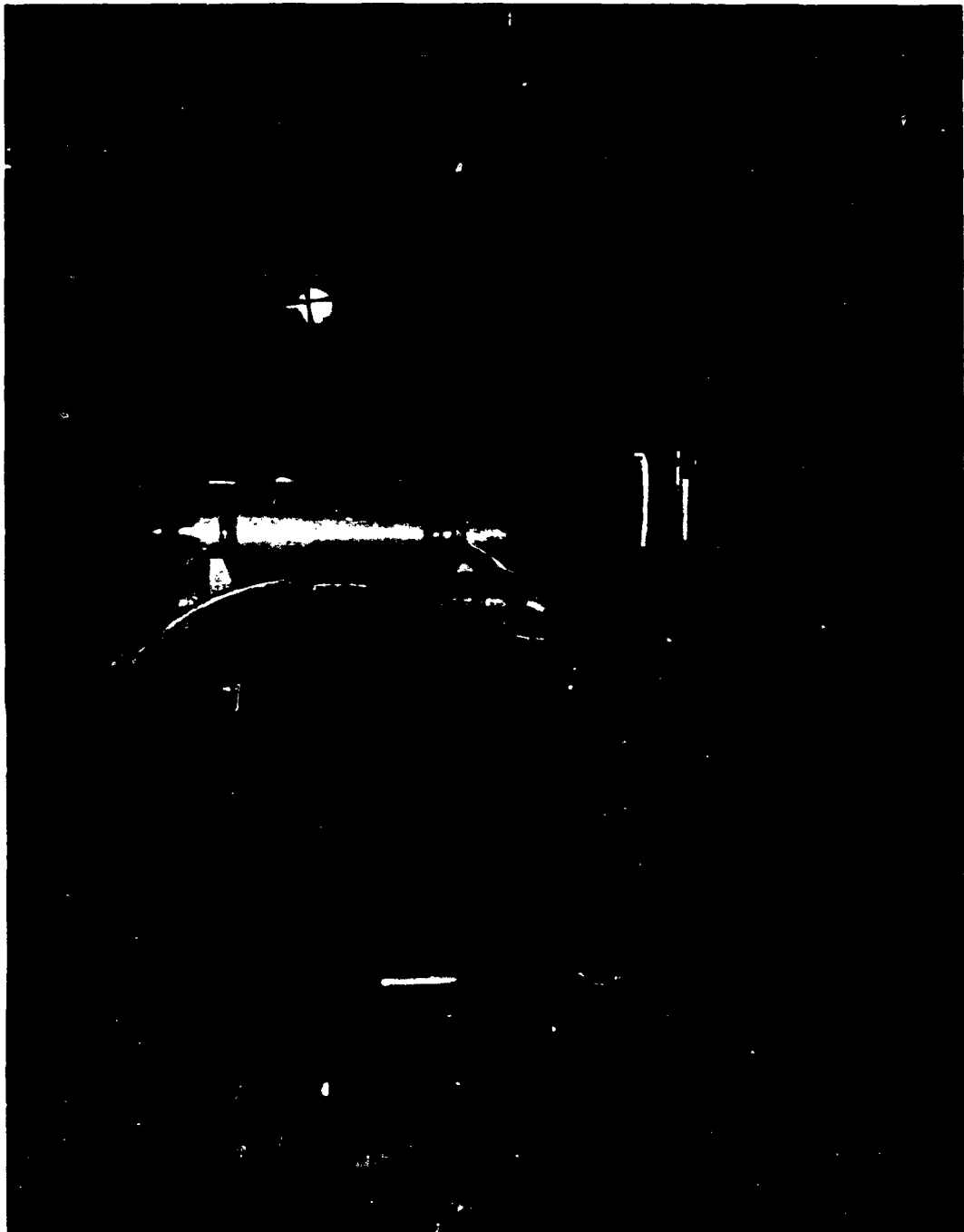


Figure 2. Typical Test Set-Up

DISCUSSION OF CURRENT TEST PROCEDURE

By injecting fuel into the test chamber at a pressure altitude 5,000 feet above each test altitude, the fuel-air mixture is sure to diffuse into partially confined spaces in the test equipment. This procedure also aids full vaporization.

The method of varying the altitude from 5,000 feet above to 5,000 feet below each test altitude insures that the equipment being tested has been exposed to the most easily ignited fuel-air ratio at an altitude within 2,000 feet of each test altitude. This method guarantees that the optimum ratio is achieved even though slight errors may exist in the values used to calculate the fuel quantity which should be used. The altitude is varied slowly enough to allow switches, relays, and other components to operate many times while the altitude is within 2,000 feet above or below the test altitude.

The test item, which has thus been operated in the most easily ignited fuel-air ratio at the various test altitudes, should not cause an explosion when exposed to any fuel-air ratio of the same fuel, or when exposed to any fuel which is less easily ignited.

As stated previously, only about half as much spark energy is required to ignite aviation gasoline (grade 100/130 octane) as is required to ignite JP-4 jet fuel. Using aviation gasoline as a test fuel thus provides a very critical test for most kinds of electronic equipment carried in jet aircraft.

Even though JP-4 jet fuel has a minimum spontaneous ignition temperature of 468°F, a considerably higher temperature is necessary in most cases to ignite this fuel. As explained earlier, a hot source which does not uniformly heat a fuel-air mixture will require a temperature much higher than the minimum spontaneous ignition temperature in order to ignite the mixture. For a fuel-air mixture to explode at its minimum spontaneous ignition temperature, the mixture would have to be confined and heated in an item of equipment. Most equipment components do not contain spaces where fuel vapors could penetrate, be confined, and heated to sufficiently high temperatures.

It is possible for a flowing fuel-air mixture to be ignited by contact with hot surfaces, but the ignition temperature increases rapidly as the mixture flow rate increases (ref 7). Blowers are provided for adequate air circulation around many high temperature electronic components. In addition, parts of equipment which reach temperatures above 460°F are seldom exposed to the air.

The spontaneous ignition temperature of most fuels increases rapidly as the pressure of the fuel-air mixture decreases. Certain electronic components become warm at increased altitude because of lack of air cooling. They may still not cause an explosion because higher temperatures are necessary for ignition at higher altitudes.

The above paragraphs indicate that using a test fuel with a low spontaneous ignition temperature is not necessary when testing most kinds of electrical and electronic equipment since the usual causes of explosions are sparks and corona. Aviation gasoline is an adequate test fuel for these ignition sources.

There may, however, be some items of equipment which should be tested with a fuel which has a spontaneous ignition temperature as low as that of the fuel to which the equipment may be exposed during service operation. The next section of this report will show that hexane is a fuel which is quite well suited for testing the equipment used in or around jet powered aircraft.

POSSIBLE VARIATIONS IN TEST PROCEDURE

Test Fuel

Aviation gasoline has been used as a test fuel because of its ease of handling, its volatility, and its low spark energy required for ignition. However, jet fuels are used in modern jet propelled aircraft. The jet fuels have lower spontaneous ignition temperatures but need greater spark energy for ignition than aviation gasoline. The high spark energy requirement and low volatility of jet fuels make them unsuitable for use in explosion-proof testing.

It is desirable however, to have a test fuel with a spontaneous ignition temperature as low as that for jet fuel, and a spark energy ignition requirement as low as that for gasoline. Hexane appears to be such a fuel.

An important disadvantage of fuel blends such as gasoline and jet fuel is that their actual detailed composition varies from time to time. Figure 3, which is reproduced from reference 5, shows that the fuel-air ratio requiring the least input energy for ignition, changes as the molecular weight of the fuel changes. The optimum gasoline-air ratio varies slightly as quantities of gasoline are obtained at different times and different places, and to analyse and test each quantity of fuel used is impractical. Use of a standard, single component test fuel would be a better solution to the problem. Hexane again appears to be the fuel for explosive testing.

Use of a fuel of known molecular weight simplifies and renders more exact the calculation of quantities of test fuel needed. Liquid fuels simplify actual quantity measurement for tests.

In addition to the above characteristics, hexane has flame and explosion propagation characteristics similar to those of the fuel blends. This means that testing of containers which are designed to prevent an internal explosion from propagating to the outside ignitable mixture could be accomplished with hexane.

Since during testing no fuel condensation should occur on chamber walls or on test equipment itself, hexane is ideally suited because of its high volatility.

No special precautions are needed for handling and storing hexane other than those precautions normally employed when using flammable liquids. Hexane should be stored at temperatures under 140°F.

Tests at the Explosives Research Laboratory of the Bureau of Mines have shown that 95 percent purity is sufficient to maintain nearly constant ignition characteristics of a fuel providing the 5 percent of impurities is composed mostly of other hydrocarbon fuels. Hexane of 95 percent purity is available from chemical suppliers throughout the country.

Although the cost of 95 percent pure hexane is high compared to the cost of gasoline, it is economical compared to the cost of testing apparatus and manpower requirements. Hexane makes possible a somewhat shorter test procedure and therefore the time saved may be sufficient to offset the increased fuel cost.

The appendix of this report offers for consideration, a testing specification utilizing hexane. We believe that this specification provides a very practical test procedure which

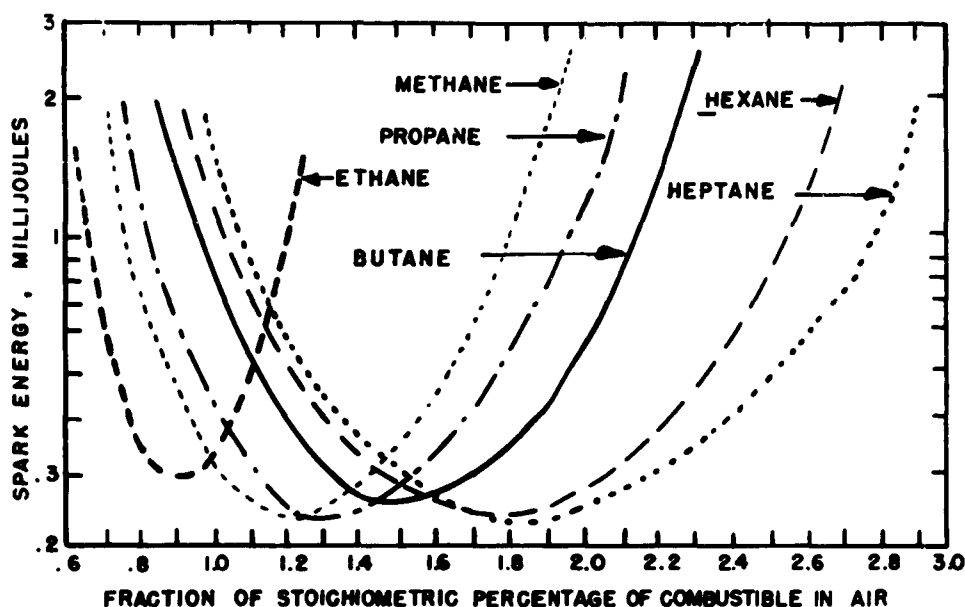


Figure 3. Minimum Spark Energies for Ignition

yields valid results for equipment which will be used in aircraft or in aerospace vehicles having safety hazards similar to those of aircraft.

Sampling Devices

Even though it is possible to calculate fairly accurately how much fuel should be injected into a test chamber for the production of an ignitable mixture, there is still some doubt as to whether the optimum fuel-air ratio is actually obtained. For this reason, various sampling methods have been proposed to verify the explosiveness of the fuel-air mixture.

One method of sampling is to measure the spark energy required to ignite the fuel-air mixture. Experimentation would establish the minimum energy value necessary to ignite an optimum fuel-air ratio under different conditions of pressure and temperature. Samples of the mixture taken during a test should then ignite with equal minimum energies.

Unfortunately, the spark energy sampling method is too complicated and time consuming for use in routine testing. The equipment required to create and measure variable energy sparks is complicated, and spark energy repeatability is difficult to maintain. Extensive experimentation would be required to establish the minimum energy values for all of the pressure and temperature conditions which might occur during various tests. If a sample taken during a test did not ignite with the minimum energy value designated, there would still be no indication as to whether the mixture was rich or lean. Test chamber leakage adds to the difficulties.

A Bendix Model 2528 Variable Ignition Test Unit has been procured. Although the operation of the ignition unit is relatively simple, actual measurement of the spark energy

is quite cumbersome. A modified integrator such as that used in reference 3 would simplify energy measurement, but is a costly item of equipment.

Hot wire sampling devices have many of the disadvantages of the variable energy spark devices. In addition, a rather long time is required for the wire to reach its final temperature, and the actual temperature which causes ignition depends very much upon the exact construction of the sampling device.

Investigation of a type of sampling which would not involve the measurement of ignition energies or temperatures may make it possible to measure the fuel-air ratio in such a way that the ratio is read continuously on a meter or recording instrument. Results of this investigation will be presented in a later report.

A factor worth considering is the lack of penetration of the mixture to partially enclosed spaces of the test items. Extreme turbulence or long times for circulation would be necessary to insure complete uniformity of the mixture throughout the test chamber. However, varying the altitude above and below the test altitude will produce the optimum mixture at some point within the vicinity of the test altitude.

The method of varying the altitude above and below the test altitude actually eliminates the need for exact sampling during routine tests. If the quantity of fuel which should be injected into the test chamber is calculated with a reasonable degree of accuracy, the fuel-air mixture will be ignitable in the vicinity of the test altitude. Varying the altitude ensures that the most easily ignited fuel-air ratio is achieved, at some point in the vicinity of the test altitude. Sampling the mixture with an ordinary spark plug ignition source will verify that an explosive mixture has been achieved. Therefore, sampling with an ordinary spark or glow plug ignition source is considered satisfactory for routine testing.

Since exact knowledge of the fuel-air ratio present in the test chamber is often required when conducting research experiments, there is justification for the development of precise sampling techniques.

Special Test Requirements

The rapid development of new aerospace systems creates safety problems which must be solved as they arise. Equipment which will be exposed to explosive conditions that are more severe than those encountered in aircraft should be tested under those severe conditions. Knowledge of these conditions and knowledge of the relative ease of ignition of flammable substances is required for valid testing.

Hydrogen is an example of a fuel which causes very hazardous operating conditions. Equipment which will be operated in hydrogen-air or hydrogen-oxygen mixtures should be tested in such mixtures. Hydrogen will ignite with less spark energy than is required for ignition of hydrocarbon fuels. In addition, flames and explosions will propagate more readily even through small holes, in the presence of hydrogen fuel than when a hydrocarbon is present.

Hydrogen should not be used as a test fuel when the equipment being tested will not be exposed to hydrogen. The spontaneous ignition temperature of hydrogen is higher than that of many hydrocarbon fuels. A second consideration is that the very low spark energy required for ignition of hydrogen will place an undue burden on the equipment manufacturer if hydrogen would be used as a test fuel for all testing.

The oxygen concentration greatly influences the ease of ignition of fuels. Equipment which will be exposed to both high oxygen concentrations and fuel vapors should be tested in such fuel-oxygen mixtures. The temperature, pressure and amounts of other substances such as nitrogen which might be present should be controlled so that operational conditions are simulated.

The testing of equipment in high oxygen concentration mixtures presents the hazards of destructive detonations. Precautions should be taken therefore to ensure the safety of personnel. One precaution would be to surround the test item itself with a secondary structure, which would contain large rupture discs capable of rupturing at very low pressures. The test item enclosed within this structure is placed in the explosion test chamber. The explosive mixture is admitted only to the inside of the precautionary structure which surrounds the test item.

Although a considerable amount of research has been done with fuel-oxygen mixtures, little or no actual testing of equipment in these mixtures has been accomplished. The exact conditions under which detonations may occur in test chamber are not well known. Further study is needed of this type of testing.

Some equipment will be operated in ambient temperatures higher than the 160°F prescribed in the present testing specifications. The high temperature is a safety problem where there is a possibility that the equipment may be exposed to ignitable vapors. Temperatures during tests of equipment should be at least as high as those to which the equipment will be exposed in operation. As long as this temperature is safely below the minimum spontaneous ignition temperature of the test fuel, valid results can be obtained.

New fuels may or may not be more easily ignited than present jet fuels. Comparison of spontaneous ignition temperatures and spark energies required for ignition will indicate whether a standard explosion-proof test is sufficient or whether special test conditions are required. Equipment should be tested in the most easily ignited mixture to which it may be exposed during operational use, but the equipment should not be required to pass tests more severe than those which may actually be encountered under operational environments.

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APPENDIX-SUGGESTED TESTING SPECIFICATION

This specification is presented only for the exchange and stimulation of ideas and should not be used as an approved specification.

Section 1: Testing

1.1 **General** - This test is composed of the following two procedures. The applicable procedure shall be used.

I. Procedure for determining explosion producing characteristics of items of equipment not hermetically sealed and not contained in cases designed to prevent flame and explosion propagation.

II. Procedure for determining the flame and explosion arresting characteristics of equipment cases or covers designed for that purpose

1.2 **Apparatus** - The test chamber shall be equivalent to or conform to Specification MIL-C-9433B (ASG).

1.3 **Fuel** - Fuel used shall be hexane of 95 percent purity or greater.

1.4 **Procedure I** -

1.4.1 **Preparation for Test**

a. The equipment to be tested shall be installed in the test chamber in such a manner that normal electrical operation is possible and mechanical controls may be operated through the pressure seals from the exterior of the chamber. All external covers of the test item shall be removed or opened to insure adequate circulation of the explosive mixture. Large equipment may be tested one or more units at a time by extending electrical connections through the cable port to the remainder of the equipment located externally.

b. The equipment shall be operated to determine that it is functioning properly and to observe the location of any sparking or high temperature components which may constitute potential explosion hazards.

c. Mechanical loads on drive assemblies and servomechanical and electrical loads on switches and relays may be simulated when necessary if proper precaution is given to duplicating the normal load in respect to torque, voltage, current, inductive reactance, etc. In all instances, it is preferable to operate the equipment as it normally functions in the system during service use.

1.4.2 **Test Procedure** - The test shall be conducted as follows at 10,000 foot interval test altitudes of ground level to 5,000 feet, 10,000 feet, 20,000 feet, 30,000 feet, etc. up to the highest altitude at which the equipment will operate in service or to 80,000 feet, whichever is the lower altitude.

a. The test chamber shall be sealed and the ambient temperature within shall be raised to the maximum normal in-service ambient operating temperature of the equipment or to 350°F, whichever is the lower temperature. No test shall be conducted at tem-

peratures lower than 80°F. Chamber internal wall temperatures must not be lower than 20°F below nor higher than 70°F above chamber air temperature. These temperatures shall be achieved prior to the introduction of fuel vapors. High temperature components of the test item shall be operated during this period.

b. The internal test chamber pressure shall be reduced sufficiently to simulate an altitude 5,000 feet above the highest test altitude to be used during the test. A sufficient quantity of hexane shall be introduced into the chamber to produce a fuel-air mixture containing $3.63 \pm .1$ percent hexane vapor by volume. The quantity of fuel required shall be determined from consideration of the fuel specific gravity, chamber volume, temperature, pressure, etc. (see Section 2). A time of 3 ± 1 minutes shall be allowed for introduction and vaporization of the fuel. Air shall be admitted into the chamber until an altitude of 3,000 feet above the test altitude is obtained.

c. Operation of the test item shall at this time be started. If no explosion results, air shall be admitted into the chamber so that the altitude may be reduced slowly downward past the test altitude to an altitude 3,000 feet below the test altitude. The test item shall be operated continuously throughout the period of altitude reduction, and all making and breaking electrical contacts shall be operated as frequently as possible. When practical, a switch should be operated rapidly several times, and then each of the other switches should be operated rapidly several times. This cycle should be repeated at least five times while varying the chamber altitude above and below each test altitude. Rotating electrical equipment once started should be allowed to come to full operating speed, and when turned off, should be permitted to come to a complete stop before re-starting.

d. The ignitibility of the fuel-air mixture in the test chamber shall be verified by igniting a sample of the mixture at each test altitude, by a spark gap or glow plug ignition source having sufficient energy to ignite a $3.63 \pm .1$ percent hexane mixture at the highest altitude used in the test. For test altitudes of 20,000 feet and higher, attainment of ignition at any point within 2,000 feet of the test altitude shall be considered satisfactory evidence that the mixture is ignitable even though ignition is not obtained at some other point within the vicinity of the test altitude. For any test altitude below 20,000 feet, the mixture sample should ignite immediately at any point within 3,000 feet above or below the test altitude. Failure to obtain ignition of the sample as described will void the test, and a new mixture must be produced in the test chamber.

e. If, by the time the chamber altitude has been reduced to 3,000 feet below the test altitude, no explosion has occurred during the operation of the equipment, preparations for testing at the next lower test altitude may be started. At 5,000 feet above the lower test altitude, an additional quantity of fuel shall be injected into the chamber so that a $3.63 \pm .1$ percent hexane mixture (by volume) will be obtained at the lower test altitude. This quantity of fuel will be the difference between the quantity of fuel already in the chamber and the total quantity needed for the lower test altitude. At 3,000 feet above the new test altitude, operation of the test item shall begin as described in 1.4.2c. This procedure is repeated at each test altitude until the lowest test altitude is reached.

f. If the ground level atmospheric pressure at the test location is greater than 733 mm. of Hg., the following procedure may be used for accomplishing the test at the lowest test altitude. The test at the 10,000 feet test altitude shall be accomplished as described in 1.4.2c and 1.4.2e. At a chamber altitude of 7,000 feet an additional quantity of fuel shall be injected into the chamber so that a $3.63 \pm .1$ percent hexane mixture (by

volume) is obtained at a pressure equivalent to 4,000 feet altitude. The test shall then be conducted as described above with the chamber altitude being slowly reduced from 7,000 feet to ground level.

g. If the ground level atmospheric pressure at the test location is between 633 mm. of Hg. and 733 mm. of Hg., the following procedure shall be used for accomplishing the test at the lowest test altitude. After the test at the 10,000 feet altitude, a quantity of fuel shall be injected into the chamber so that a $3.63 \pm .1$ percent hexane mixture is obtained at a simulated altitude of 5,000 feet. The test is conducted with the chamber altitude being gradually reduced from 7,000 feet to ground level. After the chamber pressure has reached ground level pressure, the chamber shall be purged and then evacuated to a simulated altitude of 10,000 feet. A quantity of fuel, which is 1 percent greater than the total quantity previously used to achieve the $3.63 \pm .1$ percent hexane mixture at a simulated altitude of 5,000 feet shall then be injected into the chamber. The test shall then be conducted while gradually reducing the chamber altitude from 8,000 feet to ground level. The chamber shall then be purged, and the test repeated using a quantity of fuel 1 percent less than the quantity used to achieve the $3.63 \pm .1$ percent hexane mixture at a simulated altitude of 5,000 feet.

h. If the ground level atmospheric pressure at the test location is less than 633 mm. of Hg., provision must be made to pressurize the test chamber to at least 633 mm. of Hg. pressure, and the applicable procedure of 1.4.2f or 1.4.2g then followed.

1.4.3 Failure Criteria - If the test item caused an explosion or flame at any time during the test, the test item shall be considered to have failed, and no further trials need be attempted. Conditions existing in the chamber at the time of failure should be obtained a second time with the test item not operating, so that this removes the possibility of chamber equipment causing the explosion.

1.5 Procedure II -

1.5.1 Preparation for Test -

a. The case with either the equipment or a model of the equipment of the same volume and configuration in position within, shall be installed in the explosion chamber.

b. Provision will be made to circulate the fuel-air mixture into the case being tested. If it is necessary to drill the case for insertion of a hose from a blower, adequate precaution must be taken to prevent ignition of the ambient mixture by backfire or release of pressure through the supply hose. The case volume shall not be altered by more than ± 5 percent by any modification to facilitate the introduction of ignitable vapor.

c. A positive means of igniting the explosive mixture within the case shall be provided. The case may be drilled and tapped for a spark gap, or a spark gap may be mounted internally. Points of ignition should be not more than 1/2 inch from any vent holes or flame arresting devices, and as many of such ignition sources should be installed within the case as there are vent holes or flame arresting devices. Where the design of equipment makes this impractical, use as many points of ignition as are practical.

d. A thermocouple inserted into the case and attached to a sensitive galvanometer may be used to detect explosions within the case.

e. Provision shall be made to insure that the air within the test chamber has a water vapor dewpoint lower than 67°F.

f. If the ground level atmospheric pressure at the test location is not equal to or greater than 633 mm. of Hg., provision shall be made to pressurize the test chamber to at least 633 mm. of Hg. Ground level pressures referred to in 1.5.2 shall consist of pressures greater than or equal to 633 mm. of Hg. but not greater than 800 mm. of Hg.

1.5.2 Test Procedure - The test shall be conducted as follows:

a. The chamber shall be sealed, and the ambient temperature within adjusted as in 1.4.2a. The chamber shall then be evacuated to an altitude 5,000 feet above ground level. A quantity of hexane capable of producing a $3.63 \pm .1$ percent hexane mixture at ground level pressure shall then be injected into the chamber. While reducing the chamber altitude to ground level, adequate time shall be allowed to insure complete circulation of the mixture through the component being tested.

b. After the chamber altitude has reached ground level, one of the internal case ignition sources shall be energized in order to cause an explosion within the case. If ignition of the mixture within the case does not occur immediately, the test shall be considered void and shall be repeated with a new explosive charge.

c. At least five internal case explosions shall be accomplished. If five or more internal ignition sources exist, one explosion caused by each source shall be sufficient. If the case under test is small (not in excess of 2 percent of the chamber volume) and if the reaction within the case upon ignition is of an explosive nature, without continued burning of the mixture as it circulates into the case, more than one internal case explosion may be produced without recharging the entire chamber. The number of such explosions shall not exceed the number which is equal to one tenth of the chamber volume divided by the case volume. Ample time must be allowed between internal case explosions for replacement of burnt gases by fresh explosive mixture within the case. If the internal case explosions produced did not cause a main chamber explosion, the explosiveness of the fuel-air mixture in the main chamber shall be verified as in 1.4.2d. If the air-vapor mixture in the main chamber is not found to be explosive, the test shall be considered void and the entire procedure repeated.

d. The test of 1.5.2a., b., and c. shall be twice repeated in its entirety. During the first repetition a quantity of fuel 1 percent greater than the quantity used in 1.5.2a. shall be used. During the second repetition a quantity of fuel 1 percent less than the quantity first used in 1.5.2a. shall be used.

1.5.3 Failure Criteria - If the case being tested allows a flame or explosion to propagate to the main chamber at any time, the case shall be considered to have failed the test, and no further trials need be attempted. Significant change in the shape of the case due to internal explosions shall also constitute a failure even though these explosions did not propagate to the main test chamber.

Section 2: Calculation of Quantity of Hexane Needed to Obtain Ignitable Hexane -

Air Mixtures

2.1 General - The hexane-air- mixture requiring the lowest input of energy for ignition is a mixture containing 1.7 times the stoichiometric percentage of hexane, or 3.63 percent

hexane by volume. The quantity of liquid hexane needed to produce this mixture in a test chamber may be calculated when the following information is known:

- a. Net gaseous volume of test chamber
- b. Test altitude pressure.
- c. Air temperature in chamber.
- d. Molecular weight of hexane.
- e. Density of liquid hexane.
- f. Percentage of water vapor in air.

2.2 Simplified Calculation - The calculation of the quantity of hexane required may be simplified by use of Charts A and B which yield the quantity of hexane required for a chamber having a gaseous volume of one cubic foot. These charts are based on the simplified formula $V = 2.11 \frac{P}{T} = kP$ in which V is the required volume of liquid hexane in

cubic centimeters, P is the pressure of the test altitude in mm. of Hg., and T is the absolute air temperature inside the chamber in °K. The appropriate value of k from Chart A is used to find V on Chart B. Multiplication of the ordinate of Chart B by the actual gaseous volume (in cubic feet) of a test chamber will yield quantities of hexane needed for that chamber.

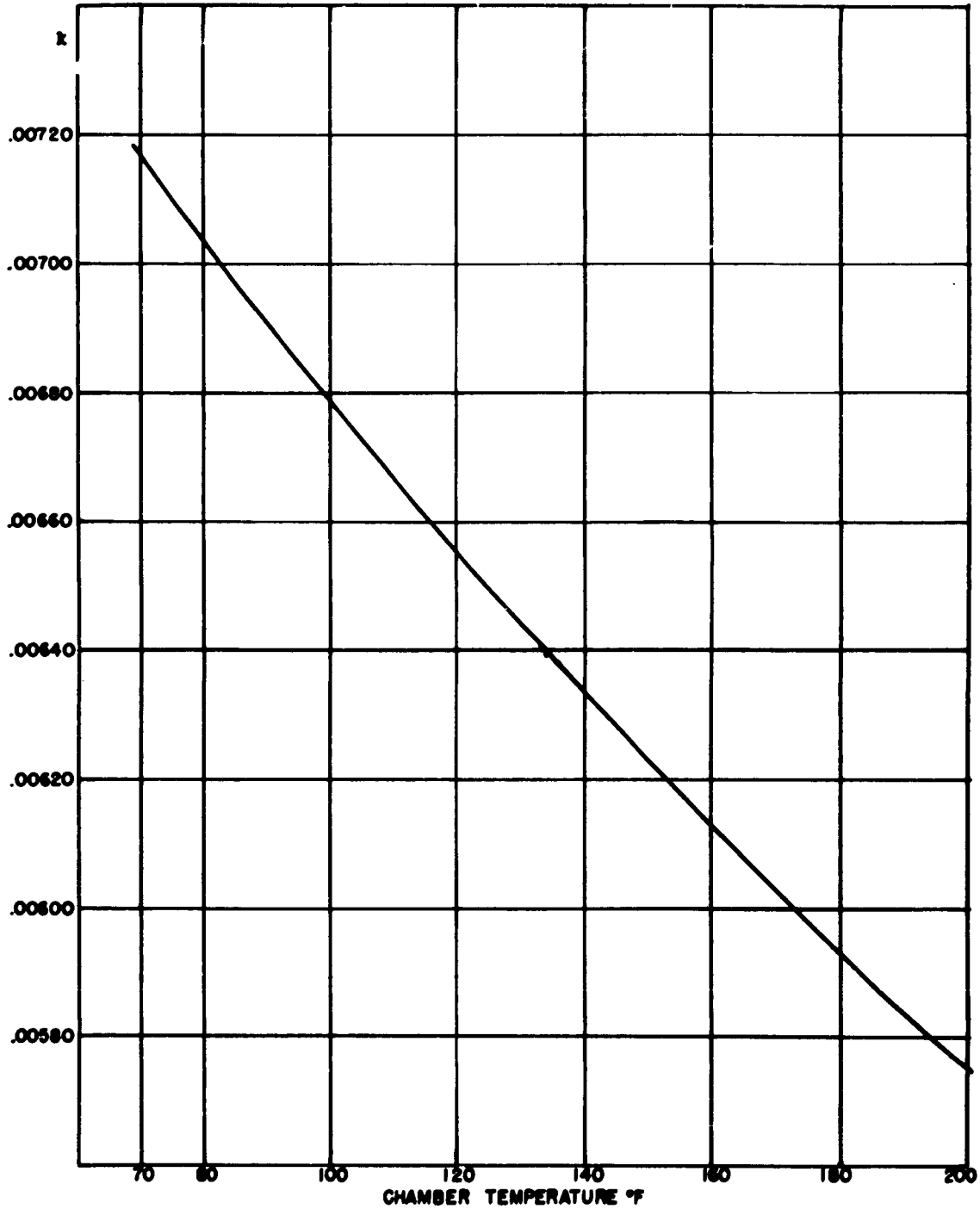


Chart A Calculations of Fuel Required for Tests

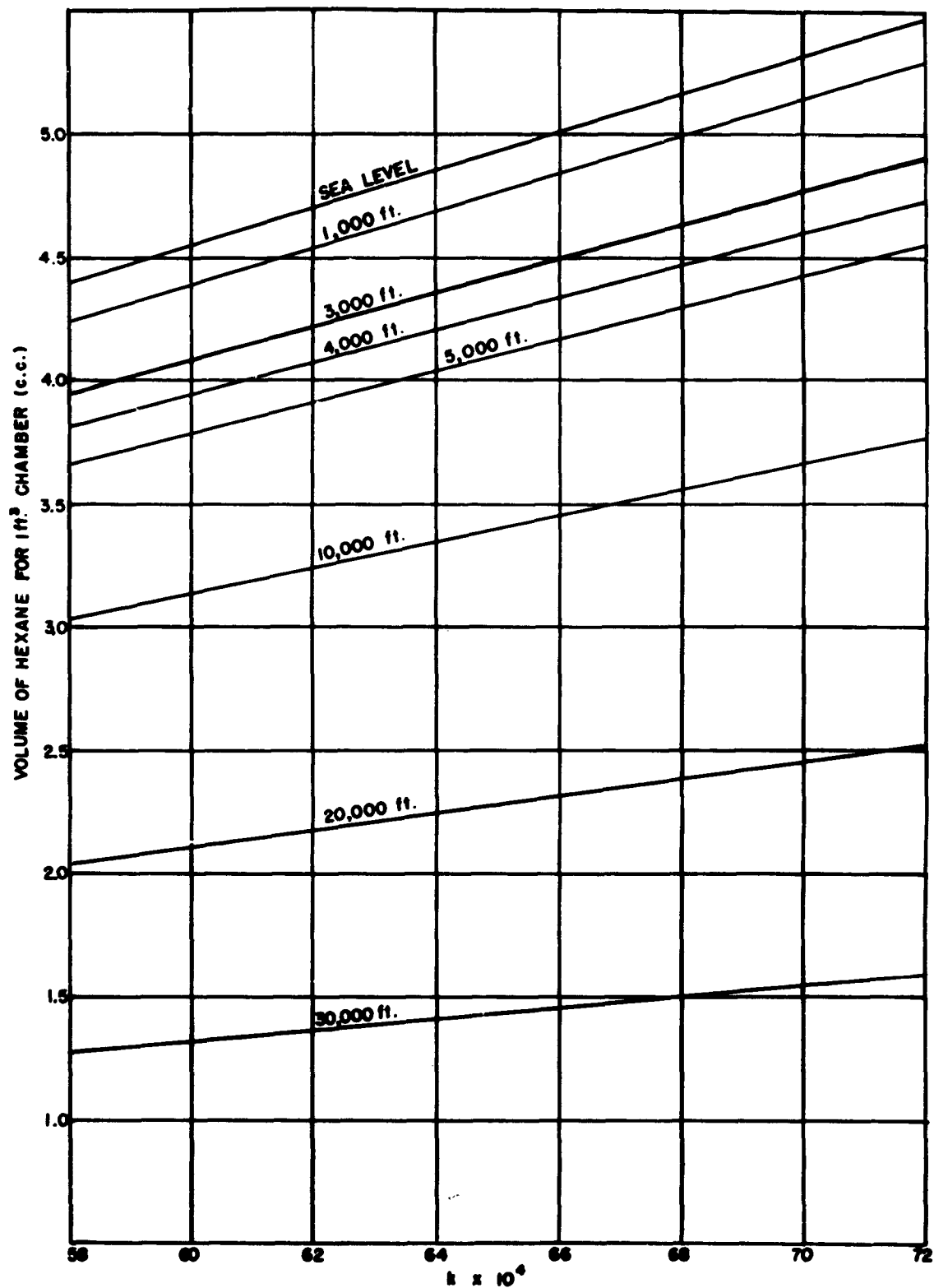
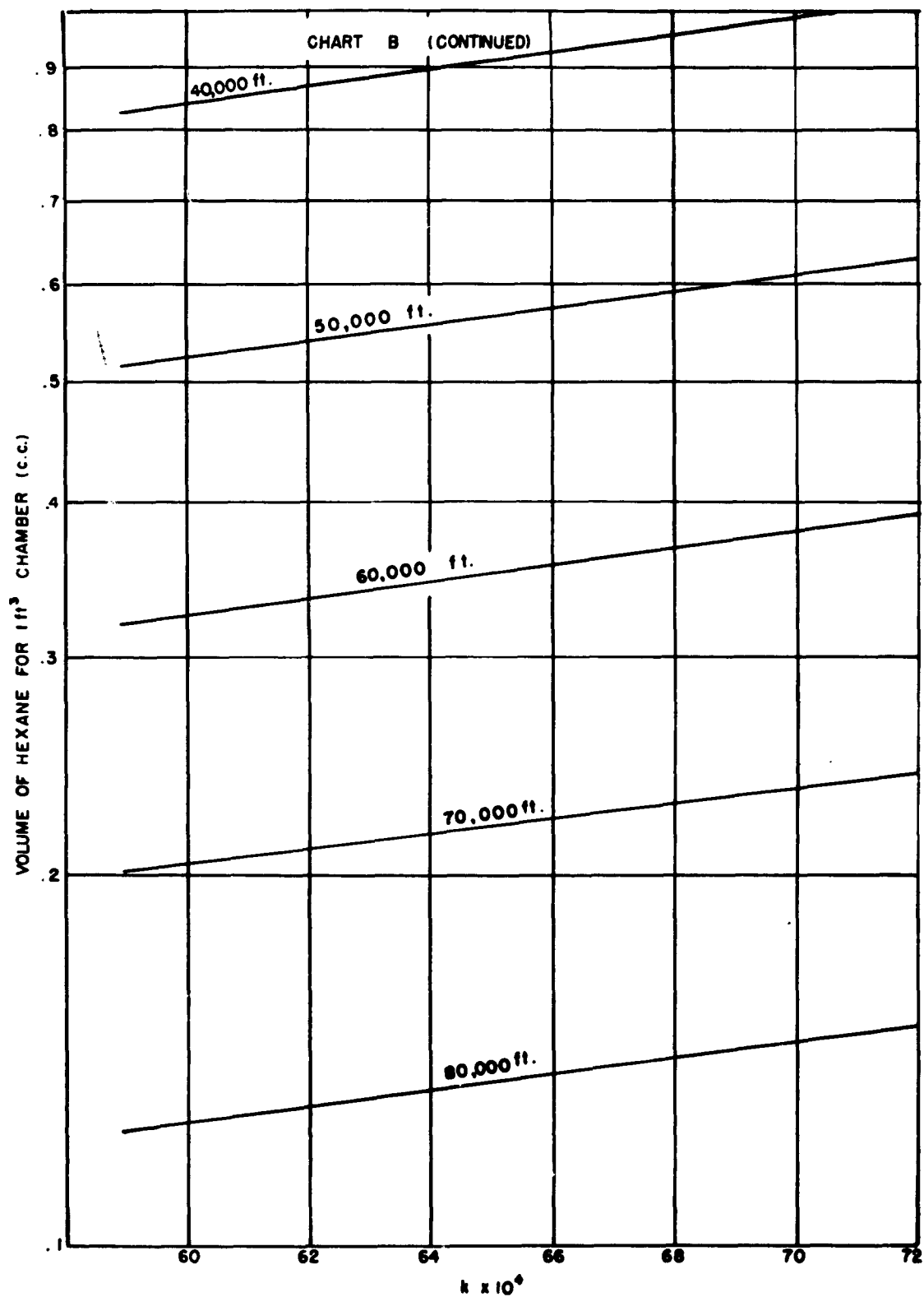


Chart B Calculations of Fuel Required for Tests



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Test, Deputy for Test and Support, Wright-Patterson AFB, Ohio.
Rpt No. ASD-TDR-62-1081. EXPLOSION-PROOF
TESTING TECHNIQUES. Final report, Feb. 63,
16 pages incl illus., 6 refs.

Unclassified Report

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3. Fuel
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