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IMPACT SENSITIVITY OF MATERIALS IN CONTACT WITH LIQUID AND GASEOUS OXYGEN AT HIGH PRESSURE

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January 4, 1972

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Without a satisfactory solution to the problem of materials reaction sensitivity in liquid oxygen (LOX) and gaseous oxygen (GOX), highly reliable expendable launch vehicles and non-reusable spacecraft would not have been possible. The basic test method which accomplished this end was the ABMA and MSFC-SPEC-106B. As a result of the Apollo 13 incident, increased emphasis is being placed on materials compatibility in a high pressure GOX environment.

Besides impact sensitivity of materials, approximately adiabatic compression conditions can contrive to induce materials reactivity. Tests run at high pressure using a new MSFC tester have indicated the following:

1) The materials used in these specific tests showed an inverse relationship between thickness and impact sensitivity.

2) Several materials tested exhibited greater impact sensitivity in GOX than in LOX.

3) The impact sensitivity of the materials tested in GOX, at the pressures tested, showed enhanced impact sensitivity with higher pressure.

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While there is agreement on the syntactical basis of probability theory as it applies to LOX/GOX compatibility testing, there is disparity between the syntactics and the explanation and interpretation of these signs in terms of the real-world. Statistics can be a useful indicator if cautiously and correctly applied. There is the distinct danger of a retreat to "cure all" test methods and techniques, meanwhile disregarding the necessity for hard data acquired from statistically meaningful numbers of tests.

Future plans at MSFC include investigation and research on a variety of LOX/GOX sensitivity testing methods and techniques. It is expected that configuration testing will continue to be necessary in special situations.

Materials compatibility in LOX and GOX will continue to be a crucial consideration to the aerospace designer concerned with future space vehicles and spacecraft.

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IMPACT SENSITIVITY OF MATERIALS IN CONTACT WITH LIQUID AND GASEOUS OXYGEN AT HIGH PRESSURE

INTRODUCTION

The accomplishments of the Space program over the past decade and a half have been possible largely because of the availability of highly reliable expendable launch vehicles, and non-reusable spacecraft. The Saturn series of launch vehicles has accummulated an enviable series of successful performances during this period. A sizeable contributory factor in the successful flights of the Saturn vehicles was the early recognition of the critical nature of the storage, handling and use of the oxidizer, liquid oxygen.

However, the next generation space transportation system involves a reusable vehicle called the Space Shuttle. This vehicle will be designed to support a wide range of scientific and commercial uses of space such as earth resources work, satellite placement, repair and servicing, materials processing in space and many other tasks. The vehicle will probably use both liquid hydrogen and liquid oxygen, have two stages, with both stages being intrinsically both space vehicles and aircraft having complete recovery capability. Of considerable interest to those concerned with liquid oxygen/gaseous oxygen (LOX/GOX) compatibility considerations is the fact that one current design shows the booster stage may have on the order of twelve 8700 psi liquid hydrogen/liquid oxygen engines, while the orbiter may have one or two similar engines. The practicality of a two-stage Space Shuttle type vehicle is somewhat dependent upon achieving high efficiencies in propulsion. Such a rocket propelled vehicle can use to good advantage a specific impulse (I_{sp}) on the order of 450 to 460 seconds if the lift-off weight and the size of the vehicle are to be kept low. The extensive development and operational experience on the large liquid hydrogen/liquid oxygen rocket engines of the Saturn vehicle, together with about ten years of technology and advanced development programs on liquid oxygen/liquid hydrogen engines, now gives us the confidence that the required high pressure LOX/GOX systems can be developed. To implement this development we expect to employ certain new equipment and techniques such as the MSFC High Pressure LOX and GOX Tester. We have already begun our testing relative to Shuttle requirements, and we find that there is no more

logical beginning nor more useful initial screening techniques than the use of MSFC-SPEC-106B (ASTM Standard D2512), a test procedure which uses the familiar ABMA impact sensitivity tester. For this reason some background information and a description of this system follows.

BACKGROUND

As early as 1957 an impact sensitivity measuring instrument was developed by Lucas and Riehl[1] at the Army Ballistic Missile Agency, and it was used to acquire impact sensitivity data for use by designers concerned with the design of the LOX and GOX systems in the Saturn vehicles. The criticality with which the Marshall Space Flight Center currently views the task of materials selection in design can be noted from the fact that a materials compatibility sign-off is required by the responsible materials engineer before design drawings can be released. Hence there should be no unacceptable LOX or GOX system materials specified in the design.

The diagnostic machine which finally evolved from the Lucas-Riehl effort came to be known as the "ABMA Tester," and is shown in Figure 1. Over 220,000 individual tests have been made on 3,000 different materials at the Marshall Space Flight Center using this tester.

The actual test procedure involves dropping a 20 pound (9.04 Kg) weight from known heights up to 43.3 inches (1.1 meters), under "near-frictionless" conditions. It has been found that even very minimal sliding friction can indeed mask the very low energy level reaction thresholds, and can contribute to erratic results. Consequently, a system for measuring precisely the energy impacted on each "drop" is currently being developed. It should be mentioned however, that standard specified test level of 72 ft-lbs (10 Kg-M) energy, frictional effects are not an important factor with a properly designed system. The test specifies that maximum permissable frictional deviation from free fall is 3 percent.

To continue, during operation the plummet strikes a plunger which delivers a blow to the material being tested in the bottom of an expendable aluminum cup. In preparing the cup for a test, the remainder of the cup is filled with liquid oxygen after the test sample is in place. Details of the striker cup and the sample arrangement are shown in Figure 2.

Any resulting reactions are observed visually, and are categorized as follows:

1. Audible detonation
2. Visible flash in darkened room
3. Evidence of burning (charring).

Using the maximum energy input of 72 ft-lbs (10 Kg-M), the absence of any indication of a reaction in twenty trials is considered an indication of acceptability of the material under test. A reaction occurring during the twenty drops requires forty additional drops without any evidence of a single reaction if the material under test is to be considered acceptable. More than one reaction during the twenty drops is cause for immediate rejection[2].

CRUCIAL TEST PARAMETERS

A decade or more ago, investigators learned through experience the extreme importance of proper sample preparation, if reproducible test results are to be obtained. Cleanliness is extremely important, and a special specification (MSFC-SPEC-164) must be met in cleaning parts used in the tests. In LOX, the impact sensitivity usually varies somewhat with thickness. Factors such as energy rate and density delivered to the sample, hardness, resilience, ductility and other factors are involved in the reaction. Maintaining as near constant test conditions as possible eliminates some of the variables but several others remain.

In the ABMA Tester (MSFC-SPEC-106B test) all solid materials are tested in the form of 11/16 inch diameter discs in the specific thickness intended for use. Pressure sensitive tapes, coatings, surface treatments, etc., are tested only after applying them to test discs made of the material upon which they will be used in service. A 347 stainless steel insert is used as a false bottom in each sample cup when hard or granular materials are tested, because hard materials under test can be driven into the sample cup thereby penetrating the cup material oxide and creating high intensity localized heating which can be sufficient to trigger a detectable reaction between the cup and the LOX.

In testing liquids, where a "use thickness" is not specified, these are tested in 0.050 inch (0.127 cm) thicknesses. Semi-solids such as greases, caulking compounds and other semi-solid materials are tested in 0.050 inch (0.127 cm) thicknesses using special cup inserts. The inserts are made of 5052 aluminum. The test material is pressed into the 5052 cups with a clean stainless steel spatula. The insert cups are then placed in the regular specimen cups with clean tweezers. References 1 through 6 give complete details on the LOX impact tester, data taken over the years, and general data on materials compatibility.

The fact that the above described equipment, techniques, and tests have been used successfully for well over a decade offers ample testimony to the sound engineering judgement involved in the design of that system for use in Saturn vehicle compatibility testing. Fate has since intervened however, and the near tragedy of Apollo 13 gave us some unprecedented insight into the next generation of problems to be solved in the operation of the high pressure LOX/GOX systems to be expected on the Space Shuttle vehicle.

HIGH PRESSURE OXYGEN CONSIDERATIONS

The Apollo Command and Service Module (CSM) carries supercritical oxygen in two tanks in the service module to provide crew breathing oxygen, drinking water and to feed the fuel cells which generate electrical power. About 55 hours and 43 minutes after liftoff of Apollo 13, oxygen tank number two in the service module ruptured which in turn blew the number four bay service module skin, or cover, off. Events of the rest of the mission are now history.

In the aftermath, however, a high level investigation board was convened to ascertain the reason for the failure. The board activities were conducted at a fever pitch, and continued for some several months. Oxygen compatibility considerations came to the forefront almost immediately, and as a consequence, crash test programs were initiated and executed at a number of industrial and government testing facilities all over the U. S. It was finally determined that the most probable cause of the failure was electrical ignition of polytetrafluoroethylene insulation inside the supercritical tank.

In the meantime, impressive test data on materials in high pressure oxygen were being acquired. In many cases investigators, spurred by the data they were getting, tested at pressures well beyond

those associated with CSM operating conditions. This was the case at the Marshall Space Flight Center, and the apparatus used in these tests and some typical test data will be discussed later.

LOX/GOX IMPACT REACTION THEORY

According to a prevalent theory which attempts to explain the phenomenon of LOX/GOX impact sensitivity, the high temperatures resulting from nearly adiabatic compression can be considered the cause of ignition in an impact tester. These same conditions can also be obtained from the rapid pressurization of a GOX system if the conditions surrounding the pressurization approximate adiabatic conditions. It is helpful to consider the properties of a perfect adiabatic gas to envision what happens. The temperature attainable by compression of a perfect adiabatic gas can be assessed by means of the following relationship:

$$TV^{\gamma - 1} = \text{Constant},$$

giving the variation of T and V along an adiabat, where T is temperature, V is volume, and γ is the ratio of specific heats at constant pressure and constant volume. From this simple relationship, it can be shown for example, that an adiabatic compression of a gas initially at 27°C (300°K), to a volume of one tenth the original volume, there is an eighteen fold increase in temperature on the centigrade scale. In this example the final temperature after such adiabatic compression is about 477°C (750°K). Such conditions are by no means unknown in actual practice, and adiabatic compression phenomena are realities which must be faced in many of the LOX/GOX system designs today. This rapid heating of the gas increases its activity greatly and also gives rise to localized conditions which certain of the materials in the system may not be able to withstand without a reaction. In general then, adiabatic compression phenomena constitute another source of energy for reactions in LOX or GOX in complete systems, as well as constituting a prime mechanism locally at the interface of the striker pin and the material under test during impact testing.

Admittedly, the precise description of the mechanism prevailing at the instant of impact of the striker pin is less well understood than are classic adiabatic compression cases involving rapid pressurization effects. In fact, there is a growing suspicion that shock wave propagation and interaction phenomena in the striker-material-cup-base system may in part account for some of the anomalous results occasionally attained in LOX/GOX impact testing. This theory will be pursued in greater depth in the near future in an attempt to better correlate the results of tests made using different types of apparatus. In the meantime, partly as a result of the Apollo 13 incident mentioned earlier, and in an attempt to extend our knowledge to accommodate Space Shuttle requirements, we have developed a unique impact tester currently capable of testing to 1500 psia (10.3×10^6 Newtons/m^2) with a 10,000 psia (68×10^6 Newtons/m^2) eventual upper limit to be attained. A description of the 1500 psia (10.3×10^6 Newtons/m^2) system follows.

MSFC HIGH PRESSURE GOX TESTER

The GOX tester utilizes the basic ABMA Tester assembly with the addition of a specially designed pressurized sample holder. The tester is designed to allow a 20 pound (9.04 Kg) plummet to fall through a distance of 43.3 inches (1.1 meters). The maximum deviation from free fall allowed is 3 percent. The plummet lands upon the striker pin which protrudes from the sample holder. Figure 3 shows details and orientation of striker pin and sample. The basic instrument as shown consists of a plummet guided in its vertical fall by two sets of bearings, one set at each end of the plummet. The bearings arranged at the vertices of equilateral triangles roll freely in tracks milled in steel bars. These tracks are bolted rigidly to steel tubing supports and are accurately aligned with shims so that uniform contact with the ball bearings is maintained at all points along the length of the track. The supports are securely anchored to the top, and base plate. The 1 inch (2.54 cm) thick base plate is anchored in an 8 cubic foot (0.23 cubic meter) cube of concrete.

The control panel is separated from the instrument by a reinforced concrete wall containing an observation window in line with the viewing port of the sample holder so the operator has a view of the sample. Figure 4 shows the testing arrangement in use at the Marshall Space Flight Center. A second viewing port is located on the sample holder

for photographic coverage of test evaluation if required. The room is darkened to a predetermined level during the tests to enhance the observation of reactions.

The plummet is held at the desired height by an electromagnet and a safety catch spring loaded in holding position except when power is delivered to the solenoid releasing the safety catch. The drop height may be varied from 0 to 43.4 inches (0 to 1.1 meters). A height indicator is located on the electromagnet support strut and must be set to zero with the plummet resting on the striker pin and the sample when drop height and/or sample thickness is changed.

The plummet is released by activating two switches on the control panel. One of these switches releases the safety catch and the other reverses the electromagnetic field which releases the plummet as the field collapses. The plummet delivers the impact to a stainless steel striker pin resting on the sample. The sample holder is pressurized to the desired pressure by a remotely controlled solenoid valve.

The striker pin is 8.13 inches (20.65 cm) long with a 0.50 inch (1.27 cm) diameter impacting surface. The position striker assembly has a 12.4 to 1 pressure ratio to balance the system. This provides a method of decreasing the stable friction losses of the system to less than 2.25 ft-lbs (0.31 Kg-M).

PROCEDURE FOR TEST EVALUATION

The same basic test philosophy is employed as used previously with the ABMA Tester. The physical nature of the sample determines the manner in which it is prepared for test evaluation. Solids and sheet materials are cut in 0.75 inch (1.90 cm) to 1 inch (2.54 cm) diameter discs. Oils, greases and other semi-solids are evaluated as thin films in the bottom of the sample holder. Again it should be emphasized that it is imperative that samples and sample holders be precleaned prior to test. After each test, the sample holder is dismantled and cleaned with a pure chlorinated hydrocarbon solvent and dried. A clean striker pin is used for each test. The face of the striker pin must be free of pits and scratches. The striker pin is cleaned by vapor degreasing and alkaline soak, followed by rinsing in water and drying. A pre-cleaned sample is placed in the sample holder. The cap is placed on

the sample holder and bolted in place. The system is purged and pressurized to the desired pressure with the test fluid. Twenty samples are tested at a given impact level starting at 72 ft-lbs (10 Kg-M) and the level decreased until there is no evidence of reaction at each pressure of interest. An evidence of reaction is defined as one of the following:

a. An audible explosion
b. A visible flash in a darkened room
c. Evidence of burning (charring).

The approximate threshold value is obtained by testing 20 samples at each of the drop heights listed in Table I. The first height at which no reactions are obtained in 20 drops is the approximate threshold value. The definitive threshold value is determined by 20 tests at drop-height increments of 3 inches (7.62 cm) starting at a height of 6 inches (14.24 cm) above the approximate threshold value. The definitive threshold value is the higher of the two adjacent heights at which no reaction was obtained.

TEST RESULTS

Effect of Sample Thickness

A series of test evaluations were made to determine the effect of sample thickness of selected materials at pressures up to 1000 psia (6.8×10^6 Newtons/m^2) in room temperature gaseous oxygen. The results are tabulated in Table II.

For the materials listed in Table II, statistical tests of the validity of relationships between the two variables, thickness and percent reaction, are presently underway involving calculation of the correlation coefficients to determine the measure of the strength of the relationship between the two variables. By inspection there appears to be an ordinal association in the inverse relationship. The practical significance of the above data is that, in order to get usable compatibility design data, materials must be tested in the actual thickness contemplated for use in the design.

Effect of Pressure

The effect of variable pressure on test samples was determined using the standard 20 pound (9.04 Kg) plummet falling through a distance of 43.3 inches (1.1 meters). The results are tabulated in Table III.

By inspection, the impact sensitivity of the materials evaluated appears to increase with increased pressure. Statistical analyses are also underway using these data to ascertain the strength of that relationship, and these studies will be reported in the future.

Comparison of LOX versus GOX Sensitivity

The Apollo 13 incident, as noted earlier, caused increased attention to be focused on GOX testing at high pressure. Due to the beneficial heat sink effects of LOX, and the generally higher activity of GOX it could be intuitively guessed that materials sensitivity in GOX may be higher, and in truth, it appears to be so. A series of test evaluations was conducted to determine the relative differences in materials sensitivity between LOX and GOX using 72 ft-lbs (10 Kg-M) impact energy. The results are tabulated in Table IV. These results indicate enhanced materials sensitivity in GOX at higher pressures.

LOX/GOX COMPATIBILITY STATISTICS AND BATCH TESTING

A word about the statistical techniques appropriate to LOX/GOX testing seems in order. Few statisticians challenge the syntactical basis of probability theory (the rules by which the special signs or symbols of probability theory are manipulated), but the actual explanation of these signs in terms of the real-world phenomena is a subject of unending discussion and debate. For instance, in a recent article[7] the authors took rather violent issue with the basic specification MSFC-SPEC-106B and the ASTM Test Method D2512-69. The issue concerned batch testing of materials - a problem which has indeed been a source of difficulty since the beginning of LOX/GOX impact sensitivity testing. The treatment by the authors purported to

show that the probability of obtaining zero reactions in 20 trials (the test criteria) was about 36 percent whether the material of the batch under test was good or bad. Unfortunately, some gross oversights were evident in the logic employed. The binomial probability distribution theory was arbitrarily applied, in a way which violated the fundamental premise that the variable under observation must constitute a theoretical frequency distribution, where discrete, rather than continuous variables are involved. Discrete variables must be precisely that, and license taken with the interpretation of discrete variables can easily invalidate the statistical analysis. Similarly, the event (reaction) must be defined or described in a way which will guarantee a mutually exclusive event - the reaction judging criteria must guarantee that one, and only one, "outcome" can take place at a time. It is therefore possible to be syntactically correct, but decidedly incorrect in terms of the real-world situation being observed.

In relating to the real-world situation, it has been our experience at the Marshall Space Flight Center that materials requiring batch test typically will exhibit reasonably well defined differences in sensitivity, i.e., a bad batch might typically exhibit 20 percent reactions when test data over a large statistical population with many samples, is considered.

Now if one assumes that:

1) Reaction sensitivity testing is synonomous with the discrete variable approach of the binomial theoretical frequency distribution

2) All samples can be counted on to be independent

3) The basic probability of a reaction, or no reaction, is the same for all samples

4) Random sampling conditions are satisfied,

then the probabilities with a binomial distribution can be estimated by employing certain well known statistical techniques. A typical example follows:

Given a batch of material typically exhibiting about 20 percent probability of a reaction on any single attempt, as described above, what then is the probability that in a given test series of 20 drops,

a rejectable material might inadvertently pass the acceptability requirements of zero reactions in 20 drops? Using the binomial probability distribution:

$$P(O) = \frac{n!}{x!\,(n - x)}\, p^x q^{n-x}$$

Where P(O) is the probability of zero reactions, x is the number of reactions in n trials, n is the number of independent trials, or number of drops, p is the probability of a reaction on a single trial, and q is the probability of having no reaction on a single trial. Substituting the numbers, one finds that there is only about a 1 percent probability that a batch test material which had been exhibiting 20 percent reactions over a large population could possibly pass the 20 drop test. Or to put it another way, there is a 99 percent probability that there would be a reaction at some time during the test series of 20 drops, and the material would be rejected, as it should. In actual practice, if there is any question whatever of marginality, the full series of 60 drops is run. In this situation the probability of getting only one reaction, or to say it another way, the probability of passing a rejectable batch, can be shown to be a vanishingly small percentage if the probability of a reaction on a single trial has been running on the order of 20 percent over a large population.

Even if, in a given batch of material, the probability of a reaction in a single trial has been averaging as low as 5 percent, it can be shown by means of the binomial distribution theory that zero reactions in 225 drops constitutes a significant improvement in the batch, that from 1 to 21 reactions are most probable to occur if the batch is running true to form, and that reactions in excess of 21 are indicative of a batch worse than the average batch, which has been exhibiting 5 percent probability of a reaction on a single trial. In actual practice, it is not at all uncommon to run 200 to 300 drops on naturally marginal batches of material. This practice, coupled with the fact that the selected energy level of 72 ft-lbs (10 Kg-M) is basically a conservative limit, gives us the confidence that our batch testing procedures are statistically and practically meaningful in terms of final hardware acceptance criteria. Emphasis on, and preoccupation with, "cure all" test methods and techniques can never supplant the hard data from statistically meaningful numbers of tests.

FUTURE PLANS

As noted earlier, at the Marshall Space Flight Center materials compatibility in LOX and GOX has been a major consideration in space vehicle design, and no doubt will continue to be of key importance in future designs. In addition to those tests and procedures mentioned earlier, several other testing methods are either being used currently, or are in various stages of development. Figure 5 shows a simplified schematic of the various testing techniques being used and developed. With such a wide diversity of test methods it can be readily seen that the problem of cross correlation between the methods employed is indeed a most difficult one. Future plans include systematic and continuing assessment of correlation factors between the various methods, where appropriate.

The conductor arc-over and the wire burn-thru tests are typically resorted to when configuration testing is required. Much of the testing following the Apollo 13 incident was of the configuration test variety, and the resulting data were system peculiar and of value almost exclusively only with regard to the system under test. This is, of course, the nature of configuration testing. In spite of the lack of correlation of tests resulting from configuration testing data, there sometimes are real world circumstances in which the full configuration test is the most expeditious and meaningful technique to use. Such occasions arise, for example, when synergistic effects of materials combinations yield systems or components which must be verified as to overall compatibility.

In general, it should be mentioned again that we have not found any exceptions to the rule to date that impact sensitivity rank ordering of materials by testing according to MSFC-SPEC-106B, rank orders materials correctly.

CONCLUSIONS

Without a satisfactory solution to the problem of materials reaction sensitivity in LOX and GOX, highly reliable expendable launch vehicles and non-reusable spacecraft would not have been possible. The basic test method which accomplished this end was

the ABMA and MSFC-SPEC-106B. As a result of the Apollo 13 incident, increased emphasis is being placed on materials compatibility in a high pressure GOX environment.

Besides impact sensitivity of materials, approximately adiabatic compression conditions can contrive to induce materials reactivity. Tests run at high pressure using a new MSFC tester have so far shown that:

1) The materials used in the tests cited in Table II showed an inverse relationship between thickness and impact sensitivity.

2) Of the materials tested to date several tend to indicate that impact sensitivity in GOX is more pressure dependent than in LOX.

3) The impact sensitivity of the materials tested to date in GOX at the pressures tested showed enhanced impact sensitivity with higher pressure.

4) The rank ordering of the materials tested so far in LOX up to 1000 psia (6.8×10^6 Newtons/m^2) is the same as the rank ordering resulting from tests in LOX at 14.7 psia (9.5×10^4 Newtons/m^2).

While there is agreement on the syntactical basis of probability theory as it applies to LOX/GOX compatibility testing, there is indeed the danger of a disparity between the syntactics and the explanation and interpretation of these signs in terms of the real-world. Statistics can be a useful indicator if cautiously and correctly applied. There is the distinct danger of a retreat to, or a preoccupation with, "cure all" test methods and techniques, meanwhile disregarding the necessity for hard data acquired from statistically meaningful numbers of tests.

Future plans at the Marshall Space Flight Center include investigation and research on a variety of LOX/GOX sensitivity testing methods and techniques. It is expected that configuration testing will continue to be necessary in special situations.

In the final analysis, the many questions of materials compatibility in LOX and GOX will undoubtedly continue to be crucial considerations to the aerospace designer concerned with our future space vehicles and spacecraft.

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TABLE I. DROP HEIGHT SCHEDULE FOR APPROXIMATE THRESHOLD VALUE DETERMINATION

MEASUREMENT	DROP HEIGHT, INCH (CM)
FIRST HEIGHT	43.3 (109.98)
SECOND HEIGHT	33.0 (83.82)
THIRD HEIGHT	24.0 (60.96)
FOURTH HEIGHT	15.0 (38.10)
FIFTH HEIGHT	6.0 (15.24)

TABLE II. EFFECT OF SAMPLE THICKNESS OF VARIOUS MATERIALS AT 72 FT-LBS (10 Kg-M) IMPACT ENERGY

MATERIAL	THICKNESS, INCH (CM)	PRESSURE, PSIA (N/M^2)	% REACTION	INCREASE IN SENSITIVITY
SILICONE RUBBER	0.060 (0.015)	50 (34×10^4)	55	–
SILICONE RUBBER	0.020 (0.050)	50 (34×10^4)	100	1.8
POLYTETRA-FLUOROETHYLENE	0.062 (0.157)	1000 (6.8×10^6)	10	–
POLYTETRA-FLUOROETHYLENE	0.034 (0.086)	1000 (6.8×10^6)	20	2
FLUORINATED RUBBER	0.090 (0.229)	1000 (6.8×10^6)	10	–
FLUORINATED RUBBER	0.060 (0.152)	1000 (6.8×10^6)	33.3	3.3
POLYIMIDE #1	0.075 (0.189)	1000 (6.8×10^6)	66.7	–
POLYIMIDE #2	0.060 (0.152)	1000 (6.8×10^6)	100	1.5

TABLE III. EFFECT OF PRESSURE ON IMPACT SENSITIVITY IN GASEOUS OXYGEN

MATERIAL	THICKNESS, INCH (CM)	% REACTION AT PRESSURE, PSIA (N/M^2)			
		50 (34×10^4)	100 (68×10^4)	500 (3.4×10^6)	1000 (6.8×10^6)
FLUORINATED HYDROCARBON	0.074 (0.188)	0	20	50	66.6
FLUORINATED SILICONE	0.129 (0.328)	50	50	100	100
SILICONE	0.060 (0.152)	50	100	100	–
POLYIMIDE #3	0.032 (0.081)	–	29	100	100

TABLE IV. IMPACT SENSITIVITY OF SELECTED MATERIALS IN LIQUID AND GASEOUS OXYGEN AT 72 FT-LBS (10 Kg-M)

MATERIAL	THICKNESS, INCH (CM)	PRESSURE, PSIA (N/M^2)	% REACTION IN	
			LOX	GOX
NYLON	0.003 (0.008)	500 (3.4×10^6)	20	50
SILICONE	0.060 (0.152)	100 (68×10^4)	100	100
POLYTETRAFLUORO-ETHYLENE	0.065 (0.165)	500 (3.4×10^6)	0	10
CHLOROTRIFLUORO-CARBON PLASTIC	0.125 (0.317)	1000 (6.8×10^6)	0	0
POLYIMIDE #2	0.090 (0.229)	1000 (6.8×10^6)	6.67	66.7
PROPRIETARY THREAD SEAL	0.030 (0.0762)	1500 (10.3×10^6)	0	25.0

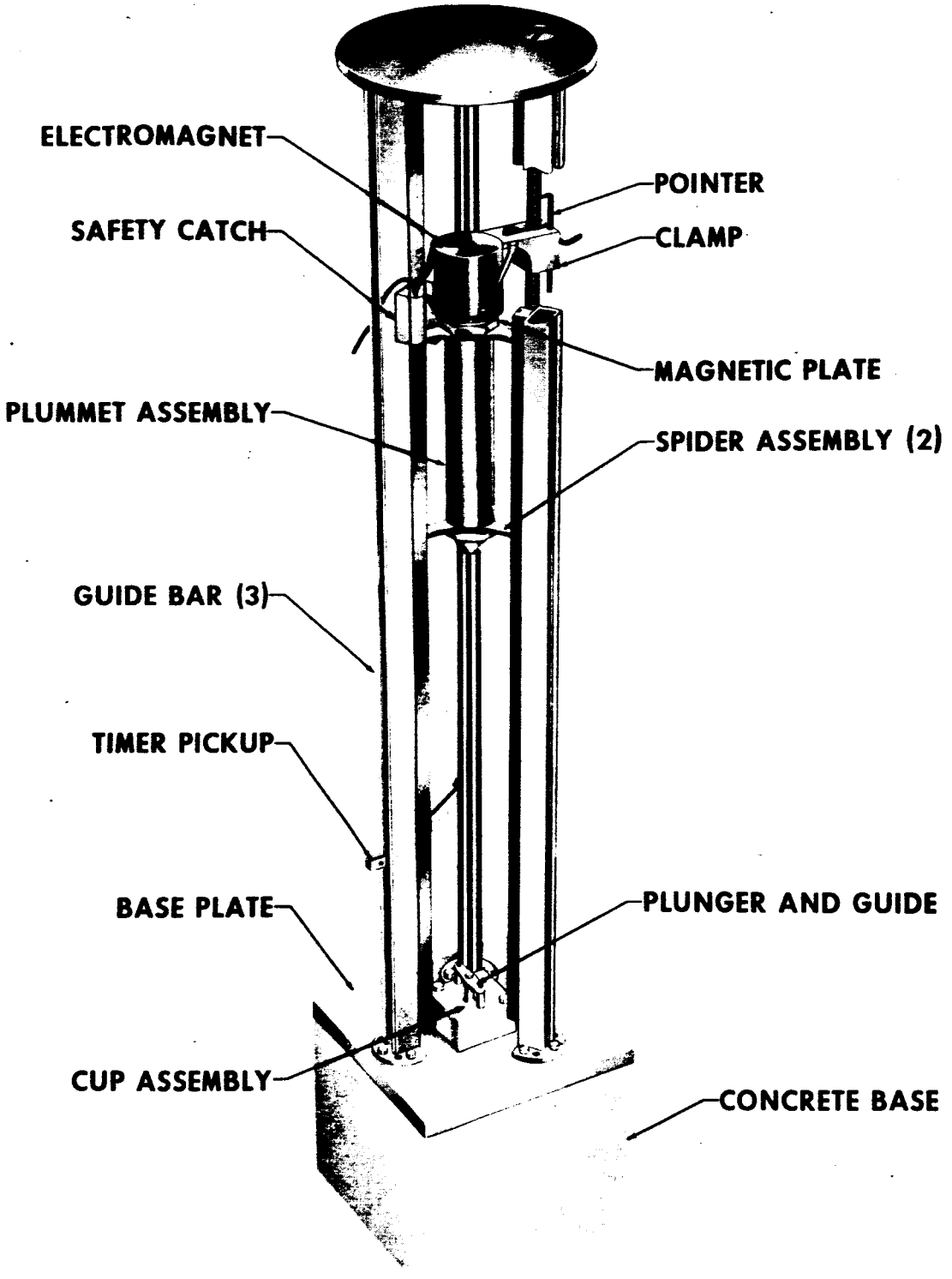

FIGURE 1. ABMA TESTER

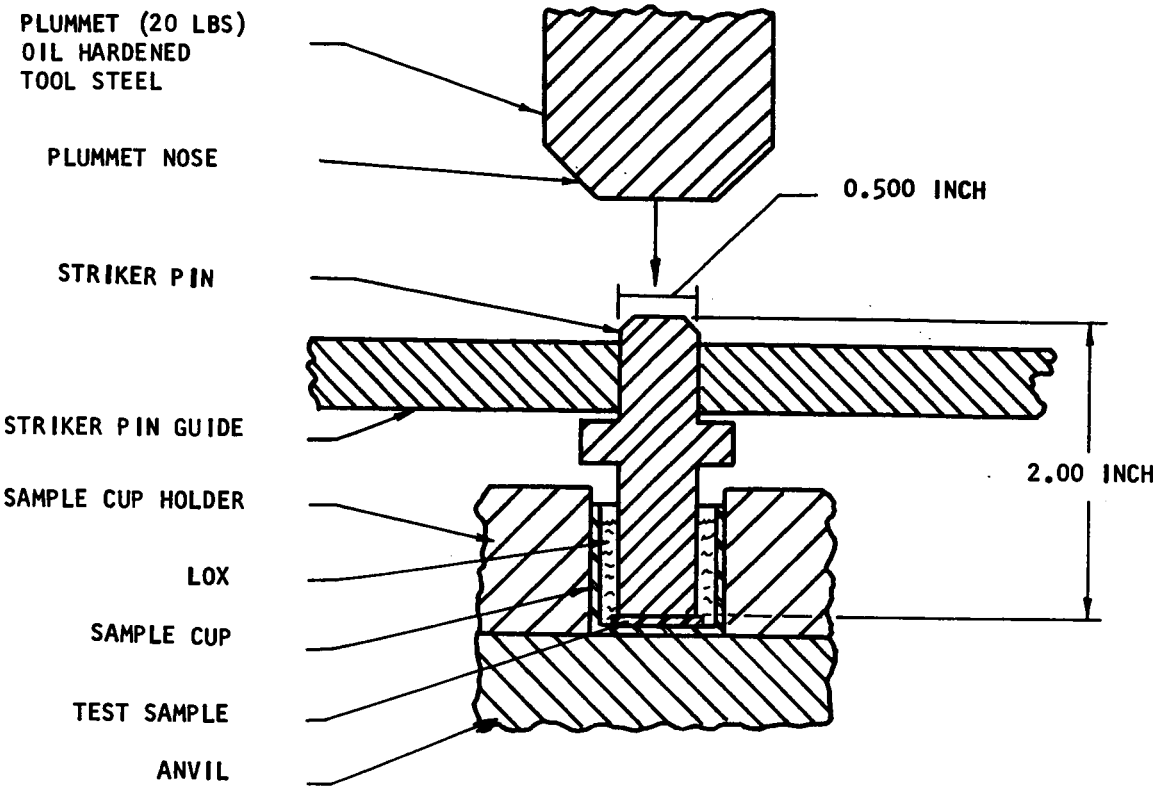

FIGURE 2. STRICKER, CUP, AND SAMPLE ARRANGEMENT

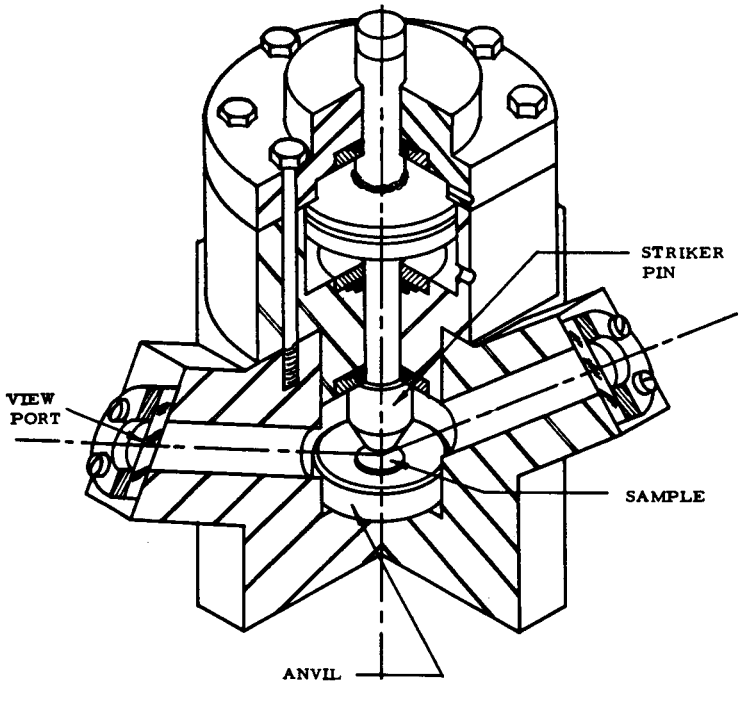

FIGURE 3. HIGH PRESSURE O_2 TESTER

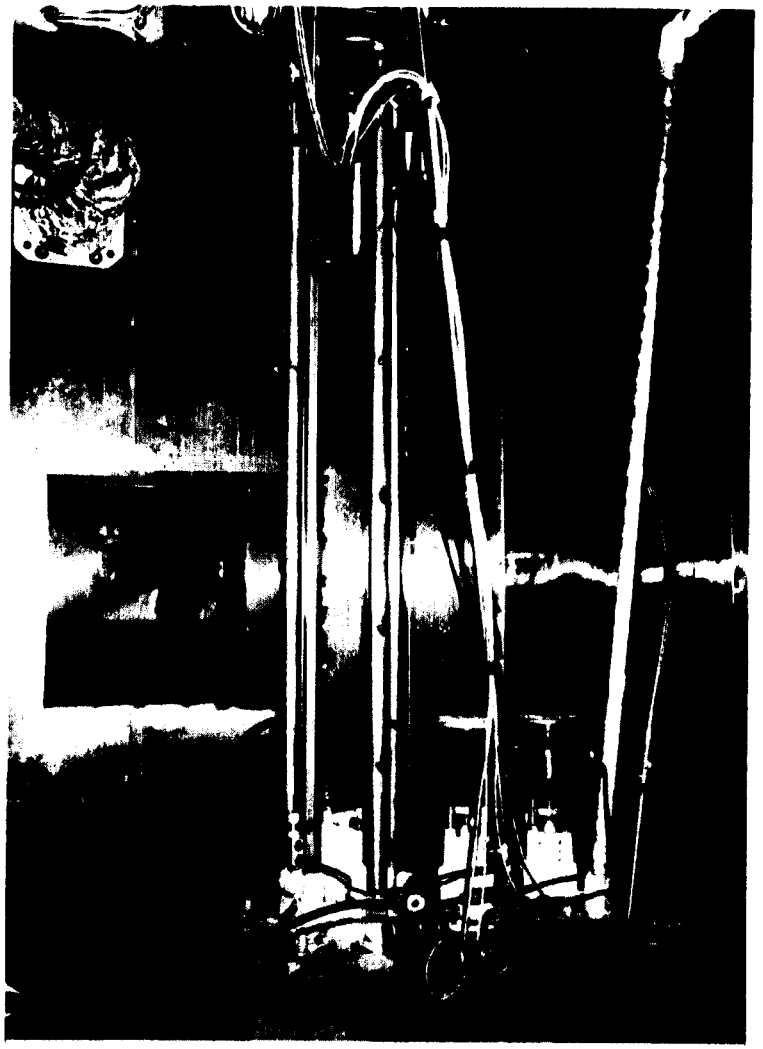

FIGURE 4. MSFC HIGH PRESSURE LOX/GOX TESTER

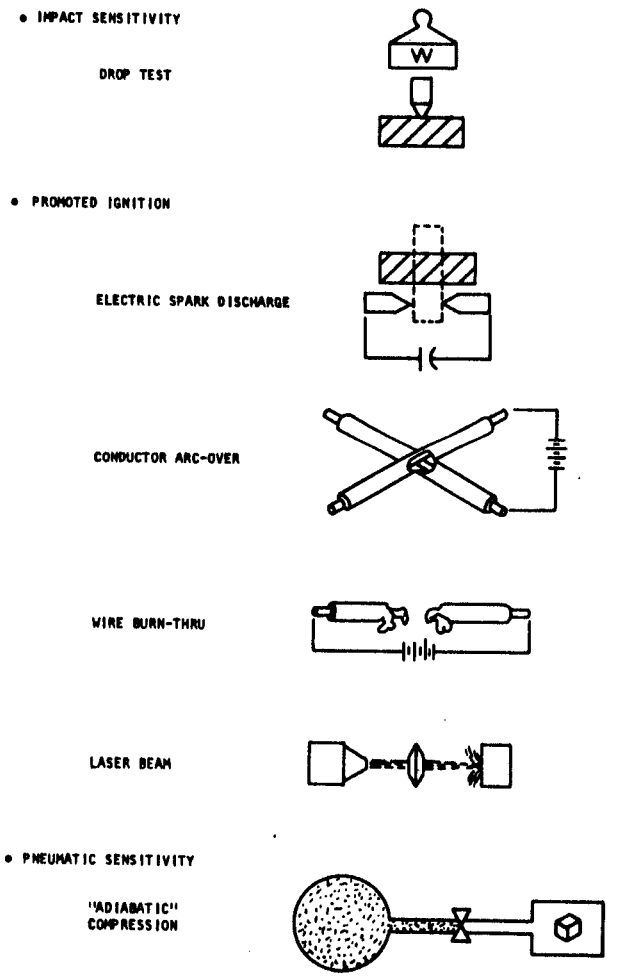

FIGURE 5. METHODS OF LOX/GOX MATERIALS COMPATIBILITY TESTING

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APPROVAL

IMPACT SENSITIVITY OF MATERIALS IN CONTACT WITH LIQUID AND GASEOUS OXYGEN AT HIGH PRESSURE

By

R. J. Schwinghamer

The information in this report has been reviewed for security classification. Review of any information concerning Department of Defense or Atomic Energy Commission programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

This document has also been reviewed and approved for technical accuracy.

Karl L. Heimburg
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