# Assessment of Future Solid Rocket Motor Flight Instrumentation/Data Needs

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**An assessment of the differences seen in static vs flight testing of solid rocket motors has been evaluated to provide the designer with better data, and the currently available nondestructive testing, static, and flight test instrumentation has been identified and discussed, along with the most promising new approaches for use during flight testing. These new approaches are microwave horns, ultrasonics, thermovision, in situ transensors, and isotopes, along with a parachute recovery concept to confirm postfiring flight test results. The major aspects of the problems with these concepts are addressed and a preliminary estimate of the development problems, time, and funding requirements are presented.**

## Introduction

SINCE it has become increasingly apparent in recent years that the designer needs more help than ever as technology advances, an assessment of future solid rocket motor instrumentation/data needs has been made. Furthermore, it has recently been found that data obtained during full-scale solid rocket static testing do not agree with data obtained from subsequent flight testing of motors. In light of that concern, this paper describes the results of an assessment of the designer's data needs, basic state-of-the-art instrumentation available today, and specialized instrumentation used to date. The paper identifies the most promising new flight test instrumentation/data techniques for future flight programs. Areas of concern with respect to these potential new instrumentation/data items are also addressed. The conclusions and recommendations of this assessment are provided, and a summary of this effort is included.

## Discussion

The assessment of future solid rocket motor flight instrumentation needs is addressed from the point of view of what the design engineer needs to adequately evaluate his design with respect to the system requirements. This is especially true since designers have had to design with reduced margins of safety in order to maximize the performance gains. Advanced propulsion system technology has also had to be used to provide the desired performance gains to minimize the number of launchers required in order for a weapon system to be cost-effective. To be able to accomplish this task, an evaluation of today's available instrumentation is discussed, and the most promising future instrumentation capabilities are presented. This paper addresses expected major problem areas in bringing future instrumentation to optimum usefulness. This instrumentation should be brought to a point where it can be used to give the designer confidence that his design complies with all system needs.

## Design Engineer's Data Needs

The solid rocket design engineer requires a multitude of data during the static and flight test phases of a development program to evaluate his design with respect to the program requirements. Figure 1 shows major areas of technology, which require evaluation for comparing design compliance in flight with that demonstrated during static test. These areas of concern have been developed as a result of the knowledge obtained from numerous flight programs, where differences have been seen between static and flight test results due to such potential effects as spin, acceleration, and gravity.

Other areas of interest are such aspects as: What is the internal pressure down the bore of the motor? What is the flap gap and how much flap remains at a given time during the motor action time? Where is the flame front at any interval during motor operation? What is the insulator thickness at any given moment and, more generally, what are the nozzle material erosion rates and temperatures during the test? Also, position and acceleration data of the components are required for compliance analysis purposes.

One specific example of the problem seen between static and flight test results has been the variation of the thickness of insulation seen in poststatic tests vs that observed after an insulated chamber was recovered subsequent to a flight test. These data are shown in Fig. 2. Analysis of these data indicates, in the worst case, as much as 140% more erosion is seen as a result of the flight environment than is seen for a similar static test. The rationale as to why such a difference exists rests in the fact that the static test environment cannot fully duplicate the flight test environment due to physical phenomena differences, or the exact conditions at the time of the burnout of the flight test motor are not really those seen from the measurements taken from the recovered insulated chamber. In any event, it can readily be seen that a need exists for flight test instrumentation that can adequately and accurately measure the erosion of such a component as an insulator during flight as well as during static test.

Other examples of differences seen during flight testing and those experienced in static testing were the problems with particle erosion due to spin effects during flight testing of a solid rocket motor and aluminum agglomeration problems in another solid rocket motor test program.

## Basic Instrumentation

The standard instrumentation available to the designer today to obtain static test data is: pressure, temperature, acceleration, strain, vibration, calorimeter, and break wire.

A tabulation showing a comparison of today's typical static test instrumentation channels vs flight instrumentation channels is shown in Table 1. An analysis of this tabulation shows the limited amount of data that the designer can obtain from flight test instrumentation compared to the data available from a static test.

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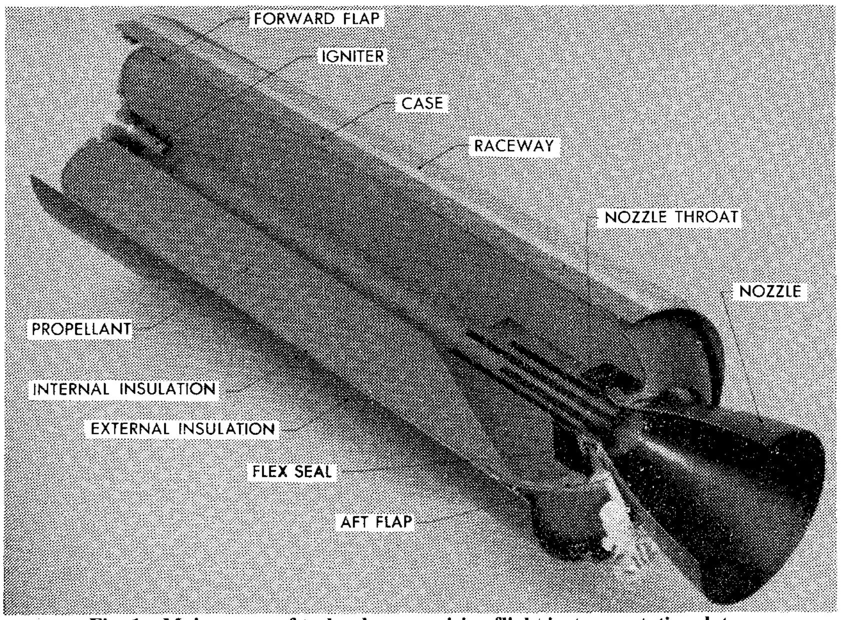


**Fig. 1 Major areas of technology requiring flight instrumentation data.**

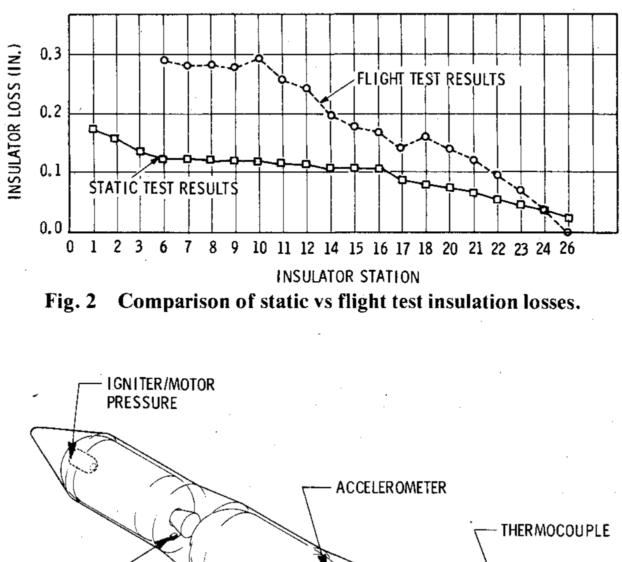


**Fig. 2 Comparison of static vs flight test insulation losses.**

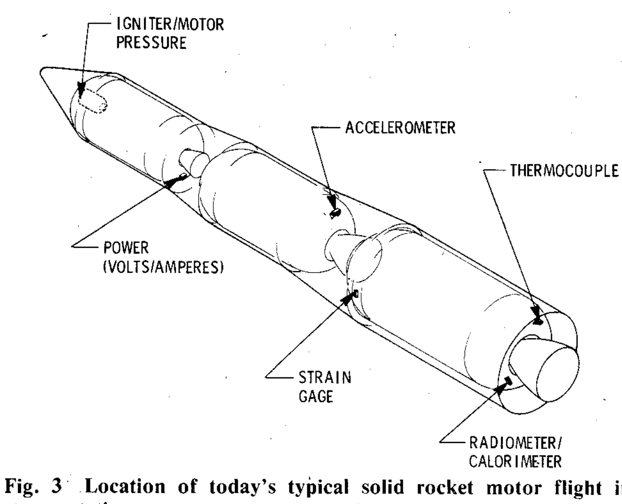


**Fig. 3 Location of today's typical solid rocket motor flight instrumentation.**

**Table 1 Comparison of today's typical static vs flight instrumentation**

| Static test instrumentation | Flight test instrumentation |
|---|---|
| Force (thrust) | Accelerometer (vibration) |
| Pressure | Pressure |
| Power | Power |
| Time | Temperature |
| Position | Strain |
| Strain | Radiometer |
| Accelerometer (vibration) | Calorimeter |
| Temperature | |
| Radiometer | |
| Calorimeter | |
| Break wire | |
| Photographic | |

**Table 2 Tabulation of specialized NDT and static test instrumentation**

| Name of instrumentation | Type of data |
|---|---|
| Microwave horn | Flame front location |
| Ultrasonics | Structural separations |
| Thermovision | Temperature measurements |
| Flash X-ray | Thickness measurements |
| Holography | Cracks and debonds |
| Eddy current | Thickness measurements |
| In situ transensor | Stress and temperature measurements |

Figure 3 shows the location of today's flight test instrumentation on a solid rocket motor.

## Specialized Instrumentation

A number of specialized types of instrumentation have been used for nondestructive testing (NDT) and/or static testing. These concepts are shown in Table 2 and the instrumentation concepts and usefulness of the data are subsequently discussed in more detail.

### Microwave Horns

Microwave horns have been successfully used during static testing of solid rocket motors to establish the flame front location as it progresses within the motor.[1] These data are exceptionally useful in determining if the flame front has progressed in locations prematurely due to cracking and/or separations of the grain from the case bond/insulation system.

The use of a microwave horn as a flame front detection device found its origin as an extension of a transceiver used for measuring automobile velocity. Thus the hot gas of the

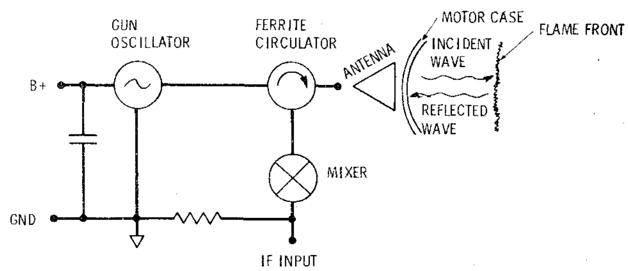


Fig. 4 Microwave horn instrumentation arrangement.

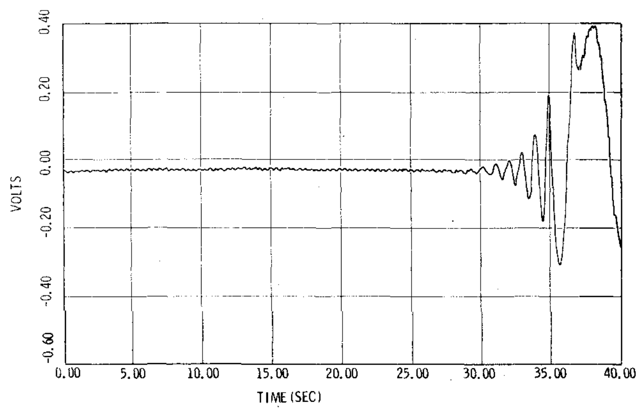


Fig. 5 Typical microwave horn data.

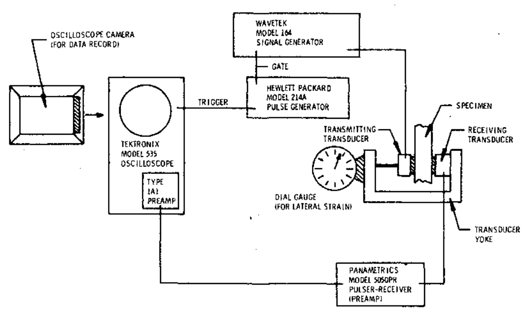


Fig. 6 Typical ultrasonic instrumentation setup.

flame front in the solid rocket motor reflects the signal much like the metal of a car. A schematic of the microwave horn is shown in Fig. 4.

One of the limitations of this concept is that the flame must be within approximately 6 in. of the chamber wall before a sufficient signal is reflected back from the flame front and into the mixer diode. The incident wave and reflected wave then beat together to produce a signal whose frequency is nearly directly proportional to the velocity of the approaching flame. Typical microwave horn data are shown in Fig. 5.

Analysis of these data readily provides the designer with the exact time that the flame reaches a specific location inside the solid rocket case and this can then be compared to the analytical predictions in order to evaluate compliance of the design.

### Ultrasonics

The use of ultrasonics, to date, has been restricted to NDT; however, it is felt that the concept is a viable candidate for both static and flight testing.[2] A schematic showing the ultrasonic instrumentation arrangement is given in Fig. 6.

An example of an anomalous condition that has been observed in the cylindrical section of solid rocket motor cases using ultrasonics is shown in Fig. 7. Observation of the control area data and the damaged area results shows how the damaged area attenuates the signal, thus indicating a

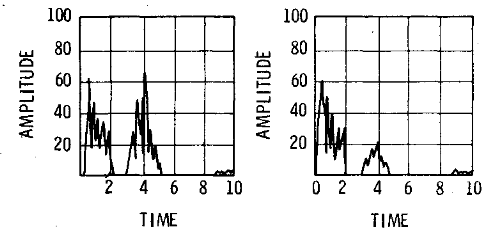


Fig. 7 Typical ultrasonic data.

separation within the structure. These data were obtained using an 0.75-in.-diam transducer.

Another new ultrasonic technique is one of measuring dewetting and internal damage in filled polymers such as solid rocket propellants.[3] This work showed that ultrasonic measurements of dewetting correlate well with volume dilatation data in tension, as well as damage measurements performed in uniaxial compression and in shear. It was experimentally shown that for a filled polymer, a universal relation exists between acoustic measures of damage and the principal tensile strain for fairly general states of strain. Also, a quantitative physical model relating the observed ultrasonic effects to specific damage events has been developed. The estimates of the size of vacuoles arising from dewetting obtained by applying these model data were shown to be in excellent agreement with independent microscopic evidence. Time-dependent void growth at constant strain has also been observed by ultrasonic techniques.

Ultrasonics has also been used to investigate mechanical properties of double-based rocket propellants.[4] Data were developed about different moduli and the Poisson's ratio at short loading times.

A total description of the polymer characteristics also involved measurement of long loading items, e.g., standard tensile testing, creep testing, etc.

The ultrasonic measurements were limited by the thickness of the sample and by the requirement that the sample and the contact liquid affect each other. These requirements can be potentially overcome by using a suspension of ground propellant particles.

Still another example of ultrasonic application was one of measuring ethylene propylene diene monomer (EPDM) insulation thickness in a solid rocket motor Kevlar case before and after firing has been accomplished.[5] This work has shown that insulator thicknesses can be measured ultrasonically from the outside surface of the motor case. However, not enough measurements were made to establish accuracy limits, but there can be reasonable confidence in measurements made at exactly the same place before and after firing.

### Thermovision

To date, thermovision has been used mainly in nonrocket motor applications such as measuring surface properties of building structures, and for nondestructive testing of various solid rocket components such as filament wound cases.[6]

The concept was also used for an NDT methods investigation. This investigation was completed using thermography as a tool to determine subsurface defects in materials and components centered around a specific equipment system.[7]

The minimum success of thermography studies for material inspection applications previous to the referenced investigation was attributed to lack of a suitable scanning system in such studies.

Besides an infrared (i.r.) sensing system, a heating/cooling system was required for the material inspection applications investigated. Unlike the sensing system, the heating/cooling system had to be developed since it could not be simply procured. Radiative, conductive, and convective systems were investigated. The conductive system produced the most successful results.

Initial feasibility studies were conducted on material samples having programmed defects. All samples were flat plates having a 6×6-in. cross section and a thickness varying from 0.1 to 1.0 in. Experimental results definitely established that voids, unbonds, and delaminations could be detected in the samples. Resolution capability was also investigated and supporting data accumulated. Results from the feasibility studies involving simple geometric samples have been published.

Because emissivity and geometry were considered important factors, feasibility studies progressed to an actual motor component. Another evaluation used a nozzle exit cone having known unbonds between the phenolic liner and aluminum shell. The unbond areas were mapped with ultrasonic methods and verified with plugs taken from the exit cone.

Results of thermographic inspection correlated precisely with the ultrasonic results. Several different heating conditions were successfully imposed. The most successful condition involved heat applied to the inward side by hot air currents, with the i.r. signature viewed on the inside cone while residual heat dissipated. The results were significant because the unbond area was detectable through 0.75 in. of liner and was only approximately 0.010 in. thick in certain areas.

A further study of thermographic inspection was conducted using subscale solid rocket motors. The objective was to detect case unbonds. In such motors, the case was a phenolic beaker and the propellant was a high-energy formulation. Again, precise agreement was obtained between thermographic results and results of X-ray examination. Certain subscale units were cut up to verify results.

More recently, a thermovision camera was used to obtain static motor firing data, as shown in Fig. 8.[8] A typical equipment setup consisted of an infrared scanning camera, a processor, and a black and white CRT display.

Thermal mapping of a solid rocket motor forward dome was accomplished with good resolution. Colored isotherm plots (thermograms) were recorded on movie film. Also, magnetic recording of the video signal data permitted detail temperature plots to be made. Analyses of these data indicate very vividly the usefulness of such data to the designer, since knowing the exact location of an anomaly, and the transient temperature situation leading up to the anomaly, can be directly used to establish the adequacy of a design.

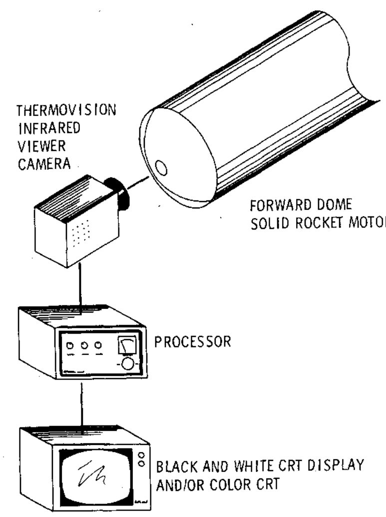


**Fig. 8 Thermovision test arrangement.**

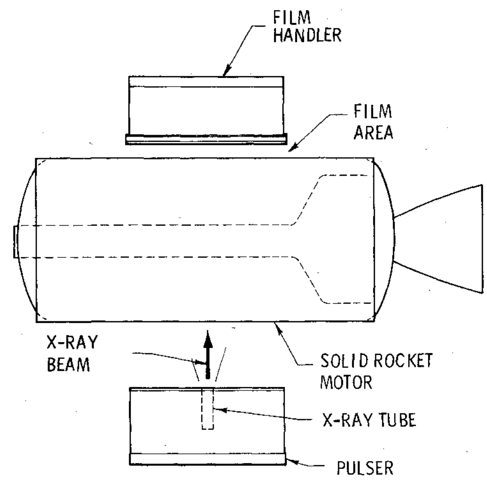


**Fig. 9 Flash X-ray setup.**

### Flash X-ray

Flash X-ray has been used to determine the position of the forward flap in a solid rocket motor during the conduct of a static test. The test setup, used to obtain flash X-ray data during the test, is shown in Fig. 9.

Detection of solid rocket propellant surface regression with respect to burning abnormalities has been evaluated with considerable success.[9] Due to the size of the equipment, however, this technique appears to have no potential for being adapted to flight.

Still another application of X ray has been the diagnostic evaluation of elemental particle concentrations in a solid rocket motor exhaust plume.[10] Preliminary data from this investigation indicate this new application has a high feasibility of determining particle concentration within a 10% accuracy, with approximately 1 $mm^3$ resolution of at least some preferential constituents such as Al and Cl.

### Holography

Holography has been used as a nondestructive technique to inspect large solid rocket motors for separations between case/liner/propellant interfaces.[11] This concept has been under development since the early 1960s and has been used to replace X-ray techniques in many areas, since it has the potential to detect 1 $in.^2$ solid rocket case/liner/propellant separations and 1×1×0.002 in. thick cracks deep in solid rocket propellant.

Operation of this technique is accomplished by sending an acoustical signal into the propellant using a transmitting transducer, as shown in Fig. 10. Signals are reflected back through the propellant from anomalies (such as cracks and debonds) to a scanning receiver. The receiver picks up the signals and transmits them to a storage unit and/or for visual interpretation.

More recently, diversification of acoustical holography as a nondestructive inspection technique has been used to evaluate Titan III-C-type propellant.[12]

Based on a review of the preliminary NDT data available to date, it is concluded that the concept would not be practical for static or flight test applications, since correlation of the acoustic data and conditions that might exist in the motor would be highly speculative.

### Eddy Current

The use of an eddy current concept has been demonstrated by measuring insulator thickness.[13] The tests were conducted on EPDM rubber samples from 0.025 to 1.0 in. thick. Also, steel and aluminum were used for calibration purposes, since the objective of the evaluation was to determine a method of measuring insulator thickness while on a mandrel. A schematic of the eddy current setup is shown in Fig. 11.

The studies revealed that consistent calibration was difficult to obtain, and many reading problems existed. Actual in-

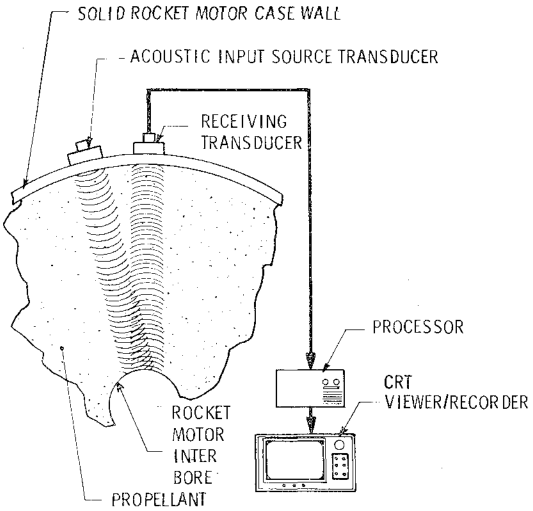


Fig. 10 Typical holography concept illustration.

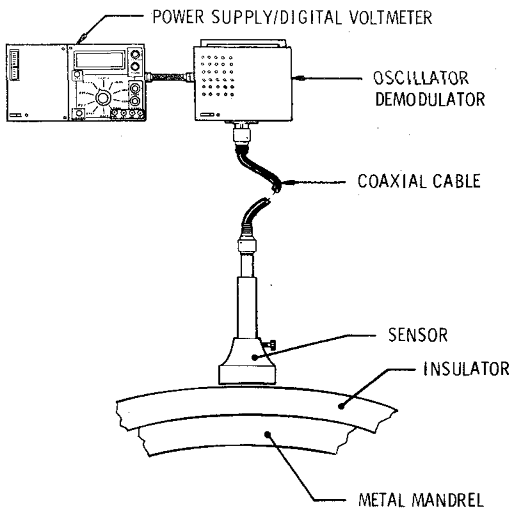


Fig. 11 Schematic of eddy current setup.

sulator thickness measurement data were obtained using a flat sensor, and it is obvious that this contributes to the data scatter, and a contoured sensor is desired when working with contoured components.

It must be remembered that this concept must have a conductive backing to permit it to work, and that relatively large sensors are required when the material being measured is greater than 0.100 in. Therefore, it is felt that the concept is not useful for a flight application.

#### In Situ Transensor

The first use of a wireless in situ transensor in a solid rocket motor was demonstrated in a Navy Polaris A-3 application.[14] Such an application permits monitoring of normal stresses and temperatures within the motor, which permits an evaluation of normal case bond stress and internal propellant temperature changes caused by motor aging and environmental testing. Also, the gages can provide motor design data for exposure to shock, vibration, and solar radiation.[15]

A schematic of an in situ transensor arrangement is shown in Fig. 12; typical in situ motor temperature and pressure data are seen in Fig. 13.

## Most Promising New Flight Instrumentation/Data Techniques

A detailed evaluation was conducted with respect to all types of instrumentation available to the designer. This evaluation considered the basic and specialized instrumentations that have been used for NDT, static, or flight testing of solid rocket motors. Also, another means of obtaining data useful to the designer, such as recovering the hardware after flight testing, was considered. The results of this evaluation have identified six of the most promising new flight instrumentation data techniques and their usage, as shown in Table 3.

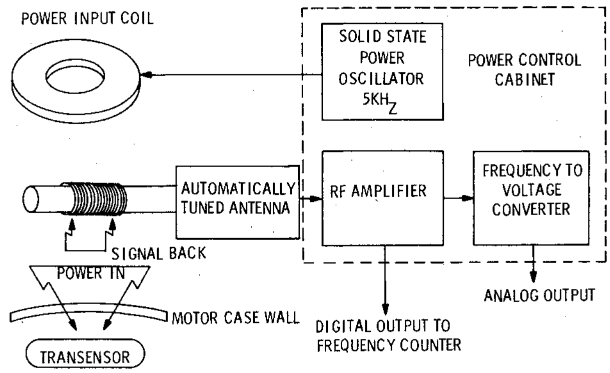


Fig. 12 In situ transensor system.

**Table 3 Tabulation of most promising new flight instrumentation/data techniques**

| Name of technique | Usage |
|---|---|
| Microwave horn | Flame front location |
| Ultrasonics | Structural abnormalities and thickness measurements |
| Thermovision | Location of hot spots |
| In situ transensors | Propellant stress and temperature data |
| Isotopes | Material loss rate |
| Parachute recovery | Structural abnormalities, material loss rate, and hot spots |

## Areas of Concern with Potential New Instrumentation

Even though three of the four most promising new flight instrumentation techniques have been evaluated in either NDT or static tests of solid rocket motors (the latter two concepts have been used in the military and/or industry for obtaining design information), there is still a major concern with respect to being able to utilize the potential new instrumentation technique for flight from the viewpoint of the following: miniaturization, power requirements, reliability, development time, and cost.

Therefore, each of these areas is addressed in the subsequent discussions for each of the most promising new flight instrumentation concepts.

#### Microwave Horns

Microwave horns can be used to monitor the location of the flame front during the rocket motor operation; however, the vertical height of the current horns limits the application to the domes of the motors unless significant miniaturization can be accomplished. Upon evaluation of this concept, it has been determined that the horns can be miniaturized to the point that it is felt that they could be located on the cylindrical portion of the solid rocket chamber, under a raceway, thus making the concept more viable for flight.

A development time in the order of 6-12 months is foreseen in order to accomplish the miniaturization, and a development cost of less than $50,000 is projected. Subsequently, the unit cost of a horn is relatively low since they are projected to cost about $200 each. However, the processor system cost will be approximately $30,000.

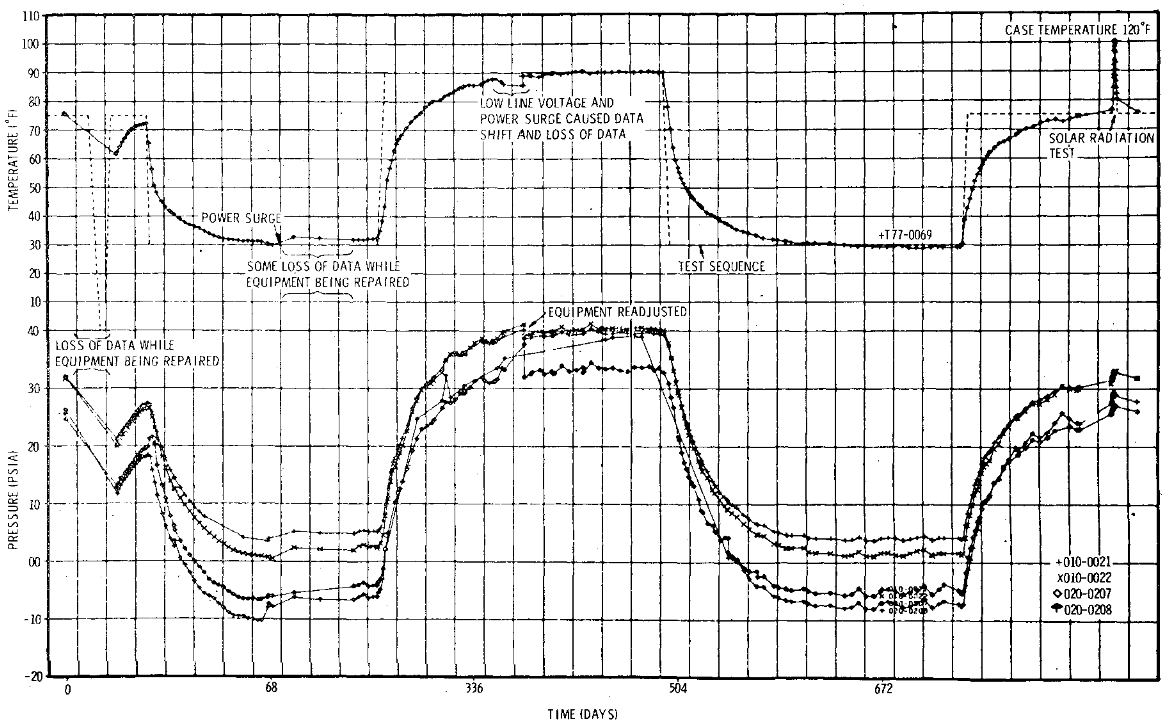


Fig. 13 Typical in situ transensor data.

### Ultrasonics

The use of ultrasonics to measure anomalies and the thickness of the insulation during flight offers the designer a potential for real-time data during static and flight testing. However, the high propellant temperature inside the rocket motor presents a major development problem. The problem may be overcome by increasing the power of the detection system in order to be able to read a change in thickness of the insulator. Furthermore, it will be necessary to develop a low-frequency system ($\simeq 1$ MHz).

One of the biggest problems has been that the material density and modulus of such rocket motor case materials as Kevlar seem to vary so much that they affect the propagation of the signal within the materials from calibration to testing.

Relatively speaking, the technology now exists for this concept to be used; however, it will take at least a year's development effort to identify once and for all whether the concept is really ready for use in a flight test mode.

Currently, a standard floor model ultrasonic piece of equipment costs $8000, and it is projected that it could cost as much as $20,000 to $30,000 for a system that is capable of being flown. It is projected also that something in the order of $200,000 of development costs will be required to make this concept viable for use in a flight test program.

### Thermovision

Thermovision offers the designer, as a minimum, a potential for a gross-type diagnostic measurement during flight testing in the dome areas of the solid rocket motor; however, the results will probably not be quantitative even though an anomaly occurs. Nevertheless, the fact that the location of an anomaly can be pinpointed is of great value to the designer.

The field of vision of a single camera is one of the limiting concerns with this system. However, multiple cameras can be potentially used, depending on the complexity of the packaging in the interstage areas.

The technology exists for using this concept for obtaining flight data and it can readily be demonstrated in less than a year's time.

Currently, a camera and the readout equipment cost $15,000 to $30,000, depending on the unit, where the camera is only in the order of $15,000. Thus if more than one camera were required, excessive costs would not be a problem. In addition to the basic equipment costs, something less than $100,000 would probably be required in basic development costs.

### In Situ Transensors

One of the major concerns with this concept is the fact that the pickup must be directly over the transensor, and the vertical height of the current transensor is in the order of 8 in. in diameter and 2 in. in height. It is thought that the transensor can be miniaturized to where it is only 0.5 in. in height, thus being able to be used in a raceway. Also, another limitation is the fact that the in situ pickup must be within 1 ft of the transensor.

Power requirements are relatively low, such as 50 W per transensor, and the output is in the order of 3 to 5 MHz.

The reliability of this concept may be slightly sensitive, since it must be tuned before a flight, and there is some concern about how long the instruments will remain calibrated or if a shift in calibration would occur during flight.

The development of such a concept will probably require 1 to 2 yr and may cost anywhere from $100,000 to $500,000. However, the standard readout unit itself only costs in the order of $5000 at the present time and transensors only cost $800 to $1000 each. Thus the use of a number of them during a flight would not create excessive costs.

### Isotopes

The use of isotopes probably represents the newest concept available for the designer to obtain insulation erosion information during a flight, yet the basic technology has been around for some time and has been used to measure wear loss of large steel gun barrels.[16]

The concept would utilize small wafers of iron which are in the order of 0.005 in. thick and are 0.25 in.$^2$ in shape. These wafers would be subjected to a bombardment with a beam of protons, whereupon a nuclear reaction takes place that causes a free neutron and the radioactive isotope $^{56}Co$ to be produced. The reaction is endothermic and requires a proton energy in excess of 5.45 MeV. A $^{56}Co$ concentration of less than 1 ppm is easily produced by this method. Neither this amount of $^{56}Co$ nor the amount of hydrogen produced by the beam is sufficient to have a significant effect on the characteristics of the steel. Furthermore, this reaction does not result in a material that is a health problem, since the gamma rays given off are in the order of micro "curies."

Each wafer would require a detector and these laboratory detectors are typically a 3-in.-diam right cylinder by about 12 in. long. Therefore, it may be desirable to miniaturize these detectors, and it is felt that they can be developed to operate properly when they are as small as 0.5 in. in diameter and are only 4-6 in. long. Vibration is a concern with that type of equipment, but is is felt that it can be satisfactorily isolated from any motor shock.

Still another concern is the fact that the half-life of $^{56}Co$ is in the order of 77 days; however, a rule of thumb exists that detection is still acceptable for as long as 10 half-lives. Therefore, the measurement should be made to later than 9 months after the material has been submitted to a nuclear reaction.

It is projected that such a concept could be developed within a year's time for less than $200,000. Further, current amplifiers only cost approximately $200 each (one is needed per wafer), and a laboratory detector only costs in the order of $1000 and an analyzer runs $10,000 to $15,000; however, only one of these is required. The wafer radiation would probably cost about $500 each. Thus, the use of a number of the wafers and amplifiers on a flight could be foreseen without excessively large costs.

#### Parachute Recovery

On a few occasions during the flight testing of a new propulsion system that used solid rocket motors, the expended rocket motor cases were recovered from the ocean after they had either been found after washing up on land or were picked up at sea by a ship. Data obtained from these recoveries were most beneficial and certainly the idea of recovery should be considered as an excellent aid to the designer. It should further be noted that this technique is being used in the Space Shuttle program to permit reusage of the rocket motor cases and nozzles, and the concept could potentially confirm postfiring flight test results.

Miniaturizing the parachute recovery concept used for Space Shuttle is the primary development concern, since it must be packaged in the interstage area where very little volume exists with advanced technology solid rocket motors mated into a propulsion system. Nevertheless, it is felt that a parachute recovery system can be packaged in approximately 10 $ft^3$ of volume, thus making the concept feasible.

A concern exists also with respect to the initial angle capability required for deployment of the parachute as a function of the missile trajectory angle at the time when deployment is possible, but based on the fact that the Shuttle has overcome this problem, it is felt that this would not be a problem that could not be handled.

An exact estimate of the development time and cost of this concept is not readily obtainable; however, it is felt that a recovery concept could be developed within a year's time at a development cost of less than $250,000, and that a parachute recovery package would cost less than $100,000 per solid rocket motor stage.

In any event, if the most promising new flight test instrumentation techniques are to be available for the designer to use as an improved tool during the development of a future solid rocket motor, then these techniques must be pursued from the very beginning of a development program, just as any basic propulsion system technology area is pursued, such as a new propellant, nozzle, or an extendible exit cone. Further, it will be necessary to perform analytical, laboratory, and bench testing prior to actual evaluation of these techniques in static testing, and they must subsequently be proven useful before they can even be considered for flight testing usage.

## Conclusions and Recommendations

It has been determined, in some cases, that solid rocket motor data obtained during static testing do not agree with flight test data and that more quantitative flight test data are needed in order that, in the future, the designer can adequately do his job.

Up until the present time there has been minimal flight test instrumentation capable of providing the needed information to the designer, and the advent of lower margins of safety and the use of advanced technology make it even more imperative that more quantitative static and flight test data are obtained.

More recently, a number of new concepts have been developed for either NDT and/or static solid rocket motor testing that have potential application for obtaining data during flight testing. These concepts are microwave horns, ultrasonics, thermovision, in situ transensors, isotopes, and parachute recovery of flight hardware.

In order to be able to obtain the needed flight test data, it will be necessary to advance the development of the most promising new concepts in parallel with the development of the basic solid rocket motor technology so that these data will be available in a timely manner. This will permit the designer to gain confidence in the correlations needed during static testing to make the concepts usable during flight testing. Therefore, it is recommended that the system contractors and the Government support the propulsion industry in this endeavor to provide better tools for the designer and in turn help maximize the performance of any new propulsion systems which will, in turn, minimize the cost of these systems.

There will be problems encountered during the development of any new flight test instrumentation concept, but is is felt that in a year or two, and with the expenditure of reasonable amounts of development funding, reliable instrumentation can be developed that will provide extremely important data to the designer.

## Summary

It has become increasingly apparent in recent years that significant differences exist within a solid rocket motor during static testing from what happens during flight testing and that the designer needs better data during all phases of a development program in order to maximize performance goals and minimize the cost of propulsion systems.

Advances have been made in the area of instrumentation technology for solid rocket motor data gathering from an NDT and/or static test point of view, and some of these same technologies can be very useful to the designer if they can be developed for flight test application. It is felt that the development of these concepts will aid the designer tremendously as he works with reduced margins of safety and advanced propulsion system technology in the future.

The most quantitative potential instrumentation concepts that have been identified for potential use during flight testing are microwave horns, ultrasonics, thermovision, in situ transensors, and isotopes, along with using parachute recovery as a means of confirming the postfiring test results. It is noted that a concerted development effort (minimum of 1 to 2 yr) and the expenditure of reasonable funding will be required in order to have these concepts available for the designer to use on any future propulsion system utilizing solid rocket motors.

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