[redacted]

INSTRUMENTATION AND COMMUNICATIONS CONSIDERATIONS FOR DYNA-SOAR

By Gerald M. Truszynski
Flight Research Center

and Paul O. Lindfors
Air Force Flight Test Center

L
1
1
2
9

INTRODUCTION

The Dyna-Soar vehicle, when considered in terms of the regime of flight to be traversed and the length of test time available at extreme velocities while still within the atmosphere, becomes a research facility of unique value. Many of the flight conditions to be encountered are extremely difficult to duplicate satisfactorily in ground test facilities and, as a consequence, the vehicle itself becomes a primary means of obtaining the information required in validating hypersonic aerodynamic theory and the correctness of the vehicle design approach.

The previous paper by Harold G. Russell, B. Lyle Schofield, and Thomas F. Baker, has indicated a number of areas wherein research investigations will be conducted during flight tests of the Dyna-Soar glider. This paper discusses some of the measurements required in conducting the investigations, the possible general approaches to be taken in obtaining these measurements, and the system planned for the main data acquisition. Finally, the electromagnetic transmission problem is discussed as it directly affects the Dyna-Soar Step I tests.

DISCUSSION

Some of the measurements required to conduct the desired investigations with the Dyna-Soar vehicle and the general approach which will be taken in obtaining these measurements are shown in figures 1 and 2. Many of the measurements can be obtained by the extension of techniques presently in use, and, although a number of installation problems concerned with local internal environmental conditions in various parts of the vehicle, such as low pressure, acceleration levels, and high structural temperatures, will be encountered, it is felt that these problems

[redacted]

[redacted]

can be adequately solved during the course of development of the specific vehicle. However, some measurements - those noted in figure 2 - present difficulties mainly because of the external environmental conditions surrounding the Dyna-Soar vehicle at hypersonic velocity and extreme altitudes.

The measurement of skin and internal structural temperatures is required for verification of the structural and thermal design approaches and to obtain heat-transfer data for the vehicle. Thermocouple materials capable of withstanding a temperature environment of the order of 3,500° F are available which will be sufficient for all but a few of the very forward locations on the vehicle. These materials consist of iridium-rhodium sensing wire and utilize magnesium oxide and beryllium oxide insulating material, all enclosed in a metal sheath capable of withstanding the local temperature environments. Platinum sheathing will be required at the higher temperature locations. Thermocouples utilizing these materials have, with a proper preconditioning procedure, provided temperature measurements to 3,500° F and have maintained calibration through repeated exposures to these temperatures. For temperatures above 3,500° F and as a means of rapidly viewing broad structural areas, the adaptation of infrared detection methods to the measurement of temperature appears feasible and will be investigated for specific application to the Dyna-Soar vehicle.

L
1
1
2
9

The area of measurement encompassing static structural strains on the Dyna-Soar vehicle is one which presents formidable temperature problems, particularly if these measurements are to be made during the entire flight regime. Weldable-type strain gages are available which allow static strain measurements to the order of 800° F. However, even in this temperature range, careful consideration must be given to the problem of compensation of the gage outputs for the effects of thermal expansion of the airframe if reasonable accuracy is to be obtained. Studies indicate that temperature levels above 1,000° F will exist during portions of the flight trajectory on structural members where strain measurements would be desirable. The outlook for static strain measurements above 800° F is pessimistic unless suitable developments can be realized in the near future. Dynamic strain measurements appear to be feasible to the order of 1,500° F for short time durations.

The measurement of angles of attack and sideslip is a very important requirement, both for proper control of the vehicle in the flight corridor and for interpretation of the flight data. These quantities can be derived from the stable platform and associated computer to be installed in the vehicle to perform the energy management and navigation function. However, an aerodynamic means of measurement is felt to be extremely important, both as the primary approach to assure measurement of this basic parameter and as a means of evaluating the platform's capability during the buildup flights. On the X-15 research airplane, this

[redacted]

[redacted]

measurement is obtained through the use of a null-seeking servo nose sphere. Figure 3 illustrates this particular device, which is constructed of Inconel and incorporates internal liquid nitrogen cooling. The device has satisfactorily undergone thermal shock tests to a stagnation temperature of 3,400° F and an impact pressure of 2,000 pounds per square foot. Investigations indicate that flow problems would not limit the use of this approach to the measurement of flow angles at hypersonic velocity and that sufficient sensitivity of the differential pressure obtained is maintained through the operational altitude and velocity range of the Dyna-Soar vehicle. The primary problem of extending this technique to higher velocities is, of course, that of maintaining structural integrity at the elevated temperatures which will be encountered. It appears that a suitable design, utilizing a ceramic nose-cap material such as beryllium oxide or alumina and cooled through the use of expendable coolant, may be possible for the Dyna-Soar vehicle even at the extreme flight conditions. In any event, the use of a servo nose sphere is desirable through as high a velocity range as possible during the buildup flights.

Surface pressure distribution will be measured by utilizing two types of transducers; this procedure was necessitated by the extreme variation of the range of pressure encountered during the altitude excursions of the Dyna-Soar. The range, limitations, and problem areas for these measurements are shown in the following table:

Approach	Range, mm Hg.	Limitations	Problem areas
Standard transducer	10 to 20	Low range	Temperature environment
Heat conducting transducer	10^{-3}	Real-gas effects	Temperature environment, outgassing, pressure equilibrium

Standard transducers can be utilized down to the order of 10 to 20 millimeters of mercury full scale. Below this pressure range and down to the order of 10^{-3} millimeters of mercury full scale, which corresponds to the static-pressure level at 260,000 feet, a heat-conducting transducer can be utilized. This type has been constructed in thermocouple, thermistor, and wire-resistance, or Pirani configurations. Figure 4 illustrates a small Pirani gage which has been used by the National Aeronautics and Space Administration for low-range pressure measurements in hypersonic tunnels and are adaptable to flight use. The internal volume of this instrument is extremely small and internal

[redacted]

lag is of the order of 0.25 second at pressure levels of 2 millimeters of mercury. The structural temperature levels to be encountered on the vehicle will require the installation of pressure transducers in a protected environment and the use of tubing leading from the measurement orifice to the transducer; under these conditions, lag will be experienced. Representative values for these lag factors in a typical Dyna-Soar installation are about 5 seconds at pressure levels of 0.1 millimeter of mercury and about 7 seconds at pressure levels of 0.01 millimeter of mercury. These lag values are not considered to be unduly restrictive in terms of the investigations contemplated.

L1129

The use of heat-conducting, extremely low-range pressure transducers, however, presents some specialized problems. Their principle of operation requires a knowledge of the specific heat of the gas of which the pressure is being measured; hence, if large variations in the real-gas properties are experienced, the calibration will be affected. Also, at pressure levels where the mean free path becomes of the order of the size of the measuring apparatus, pressure equilibrium is not established and temperature measurements of the environment at the orifice and transducer locations must be made so that proper corrections can be applied. Finally, outgassing problems at extremely low-pressure levels will require a critical monitoring of all materials used in the pressure-measurement subsystem.

The measurement of shock-layer ionization levels is extremely desirable in order to correlate the analytical investigations of the problem of electromagnetic transmission through an ionized layer. Flush-mounted ionization probes can probably be installed to provide some information on the ionization level directly at the aircraft surface. Experimental determination of the degree of ionization within this layer is a more desirable measurement, but the problem of design of a probe which will withstand near-stagnation temperature and also minimize the effect of the probe itself on the desired measurement remains to be solved. The Dyna-Soar vehicle does, however, provide a good means for the investigation of the overall effects of the ionized shock layer on the various communication systems in terms of total attenuation, noise, antenna breakdown and mismatch, and signal distortion and refraction. Multifrequency transmitting and receiving equipment properly instrumented for measurements of these effects will be installed to perform research tests in this specific area of interest.

The range of flight latitudes traversed by the Dyna-Soar vehicle and the duration of flight at extreme altitudes while still within the atmosphere make it a valuable means of obtaining a variety of geophysical measurements such as atmospheric density, composition, and lower ionospheric properties. Equipment is under development by the Air Force Cambridge Research Center (AFCRC) to obtain these measurements and will be integrated in the Dyna-Soar vehicle as part of the overall research program.

[redacted]

The number of areas of developmental and research interest to be investigated with the Dyna-Soar vehicle, coupled with the relatively small number of flights contemplated, demands a maximum return of recorded data for each flight. For the program presently planned, the instrumentation system must be capable of recording on the order of 800 individual channels of information. Most of the parameters to be recorded are quasi-static in nature, although a requirement exists for a small number of high-frequency information channels for specialized purposes.

L
1
1
2
9

It is planned to use a dual data-acquisition system in the Dyna-Soar vehicle: a pulse code modulation (PCM) system as the main high-capacity data system, and a frequency modulation (FM-FM) system to provide the required high-frequency capability. (See fig. 5.) Both systems will record on a single onboard magnetic tape which will be the primary recording medium. All information will also be telemetered to the ground to provide for real-time monitoring of certain critical vehicle and pilot reaction quantities and for data assurance in the event of loss of the vehicle during the boost or recovery phases of the flight.

Since much of the data to be acquired on Dyna-Soar flights will be utilized for research purposes, the accuracy provided by the instrumentation system is of importance. The pulse code modulation system, by analog-to-digital conversion of all data at their source, provides higher data-acquisition accuracy by eliminating many intermediate modulation-demodulation links found in other conventional tape systems. In addition, the digital form of the data minimizes degradation during the subsequent processing cycle. In order to satisfy the multitude of data requirements, the instrumentation system must be flexible and easily modified to meet specific requirements on each flight. The PCM system will be designed with versatility as one of the prime criteria to allow for rapid and relatively simple expansion or contraction of the number of parameters sampled and the sampling rates, or both.

The problem of electromagnetic transmission through the ionized shock layer surrounding the Dyna-Soar vehicle affects three primary functions: (1) voice communications to and from the vehicle, (2) transmission of research and operational information from the vehicle to the ground through the telemetry system, and (3) tracking the vehicle with precision ground radar equipment utilizing a beacon transponder. Although the vehicle itself provides the best means of performing detailed investigations of the problem over broad frequency ranges, the immediate problem for the Dyna-Soar is the determination of the frequencies of transmission which will allow satisfactory conduct of the Step I tests in light of these three functions. In terms of program cost, it would be desirable to utilize, where possible, equipment and systems which are already installed or programed for the Atlantic Missile Range where the Step I tests will be conducted. At present, voice communications and telemetry functions are generally conducted

[redacted]

in the UHF band (225 to 260 megacycles), whereas instrumentation radar tracking equipment operates on the S and C bands, at approximately 3,000 and 5,500 megacycles, respectively. It is desirable to examine the specific Dyna-Soar Step I flight program to determine where transmission difficulty in these frequency bands will occur and whether, from an operational standpoint, these "blackout" areas are tolerable. Figure 6 illustrates a Dyna-Soar trajectory in which the most severe conditions, from an ionization standpoint, at a rearward antenna location will occur. These conditions are for a vehicle with a wing loading of 27 pounds per square foot. Indicated on the trajectory are the calculated areas of blackout which are expected to occur on the UHF, S, and C bands. As noted, a very small gap appears on the C band and a large area of blackout on the UHF bands. Operationally, it is believed that it is extremely important to maintain continuous radar tracking over the entire trajectory, and this capability appears to be feasible with the existing C band equipment. Since all data are being recorded onboard, a telemetry gap of the extent indicated may possibly be tolerated, depending on the final requirement for real-time monitoring; however, a voice-communication blackout of this same extent is not acceptable and communications equipment operating in at least the C band is indicated. It is planned to obtain verification of these analytical results through the use of free-flight rocket-model tests to be conducted by the NASA Langley Research Center. These tests are required to provide the necessary level of confidence to proceed with the procurement of equipment for the Dyna-Soar Step I tests.

L 1 1 2 9

CONCLUDING REMARKS

In summary, it is felt that most of the measurements required for the developmental and research investigations contemplated with the Dyna-Soar vehicle can be accomplished. Specific installation problems will require continuing development of wire and insulating materials capable of withstanding higher temperature environments. A strong development effort is also required to obtain strain-measuring devices suitable for use at higher temperatures. Effort toward the practical adaptation of present infrared-sensing techniques to the measurement of high-level structural temperatures is necessary. Finally, research must continue into practical methods of obtaining in-flight measurements of ionization and dissociation levels necessary for a better understanding of the shock-layer phenomena to be encountered on this and subsequent hypervelocity vehicles.

[redacted]

MEASUREMENT	APPROACH
1. Altitude, velocity, attitude.	Stable platform.
2. Accelerations, angular velocity, control positions, forces, moments.	Standard transducer methods.
3. Vibration	Strain gages and Accelerometers.
4. Structural deformation.	Cameras.

Figure 1

MEASUREMENT	APPROACH
1. Temperature.	Thermocouples, Infra-red.
2. Structural strain.	Strain gages.
3. Angle of attack, Angle of sideslip.	Stable platform, Nose sphere.
4. Surface pressure.	Specialized transducers.
5. Electromagnetic transmission phenomena.	Total attenuation, noise, antenna effects, refraction.

Figure 2

[redacted]

[redacted]

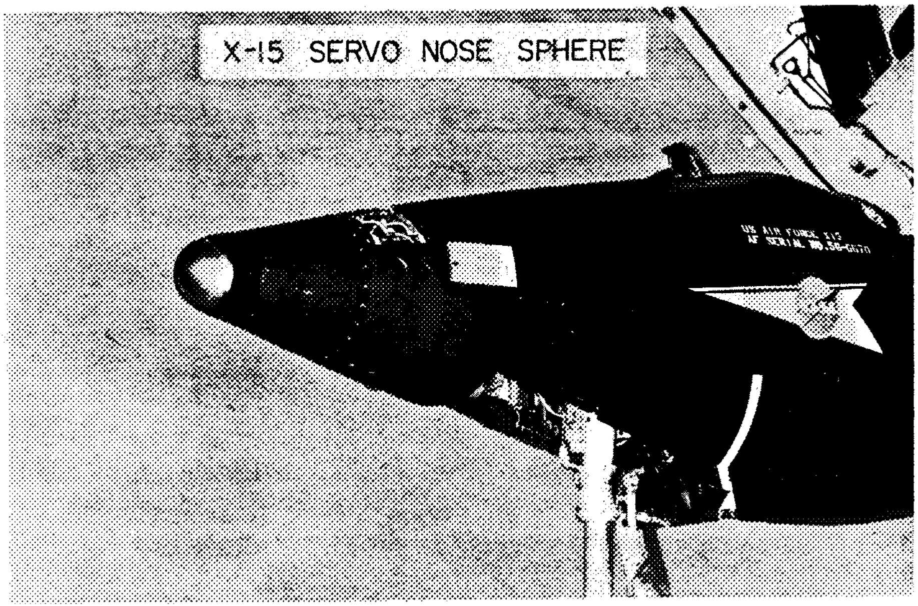

Figure 3

PIRANI PRESSURE TRANSDUCER

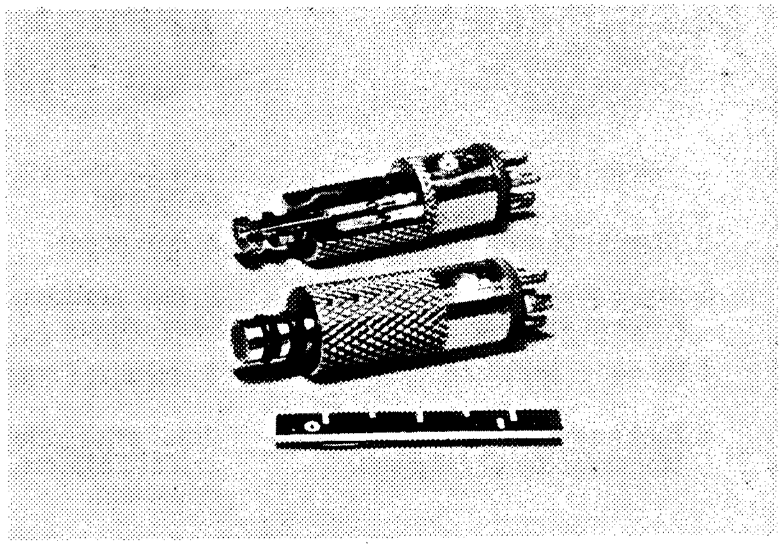

Figure 4

[redacted]

[redacted]

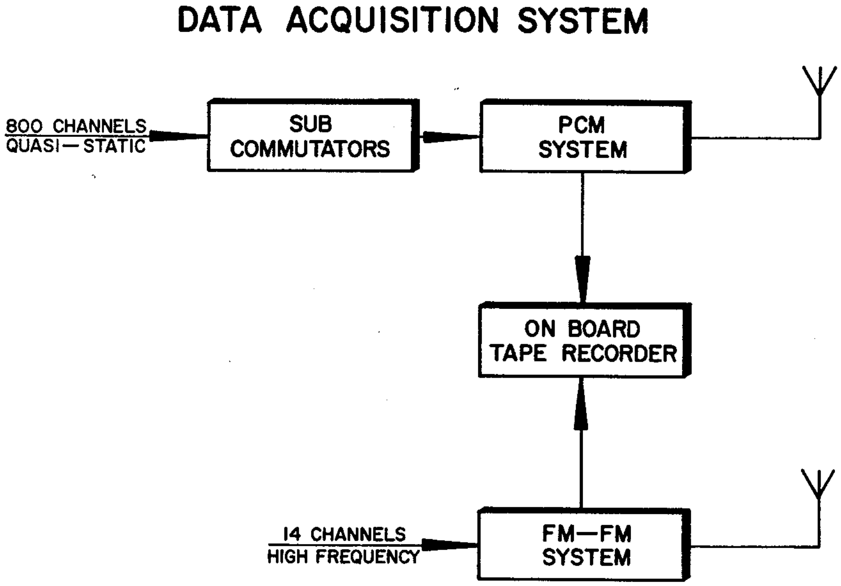

Figure 5

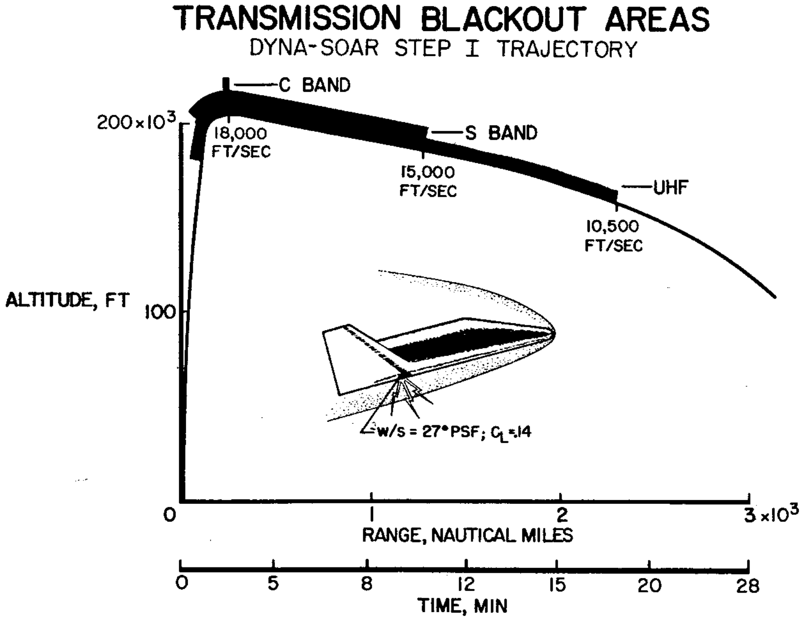

Figure 6

[redacted]