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INSTRUMENTATION FOR THE X-15

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The development of a research airplane which extends manned flight into regions where extremes of temperature and pressure are reached requires the simultaneous development of new instrumentation techniques not only to insure safe operation of the airplane but also to derive a maximum of research data throughout the operational range of the aircraft. The instrumentation required for the North American X-15 airplane project consists of a ground range and its associated equipment and airborne equipment required for pilot's displays and for research measurements.

This paper will outline a plan for a ground range, which is based upon developed equipment already in use, and also will discuss the airborne instrumentation and some of the special airborne devices which are made necessary by the extended performance capabilities of this airplane.

A ground range is required for various reasons, some of these are:

(a) To assist the mother and research aircraft in navigation

(b) To aid the pilot by means of telemetered data and voice communication when necessary

(c) To provide search facilities in the event of an emergency landing

(d) To determine accurately aircraft trajectory for research purposes

The ground range which is required to handle most of the high-speed flight plans covers a distance of about 400 miles in length. Figure 1 indicates the approximate location of the three radar-equipped ground stations which comprise the range facility. These stations, which are near Ely, Nevada, Beatty, Nevada, and at the NACA High-Speed Flight Station at Edwards, Calif., are located along a selected flight path and are appropriately spaced, so that adequate overlapping of tracking is secured. Also indicated in this figure are the locations of lake beds which may be used as emergency landing areas.

The tracking equipment will consist of radars similar to those now being used at the Air Force Missile Test Center in Cocoa, Florida. Figure 2 indicates the flow of information to and from each of the ground stations. The information coming from the airplane consists of vehicle

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range, elevation and azimuth data as secured by the tracking radar, telemetered engine and aerodynamic data, and voice communication. Received from an up-range station are timing signals, voice communication, and radar acquisition data. Recorded at each station on magnetic tape or on film are the precision radar data, the telemetered information, timing, and the voice channels. The telemetered quantities which must be monitored are also directly displayed. The outgoing information consists of station-to-station and ground-to-air voice, timing, and radar acquisition data. The radar information when received at a down-range station is corrected for parallax and earth curvature, and these data are then used to train the down-range radar on the target. The timing signals emanate from a timing system at Edwards and are relayed to each of the stations.

The detail design and fabrication of this range are being undertaken by the Electronic Engineering Co., Los Angeles, California, and it is estimated that the range will be ready for use sometime in 1958.

The airborne equipment required for piloting aids and research measurements will now be considered. Figure 3 gives a side view of the airplane showing the instrument compartments. A small compartment near the nose permits installation of a pressure recorder. The tubing leading to this recorder will be short so that reasonable lags are encountered at low absolute pressures. The main instrument compartment is immediately behind the pilot. The midsection of this compartment consists of a removal rack which can be placed on a convenient surface outside the airplane. Removal of this rack allows access to the remainder of the instruments which are mounted on shelving surrounding the rack well. Another compartment adjacent to the center of gravity is used for center-of-gravity accelerometers and some other small sensing elements. All of the compartments will be pressure and temperature controlled.

The measurements which are required for the X-15 are: accelerations; attitude angles; angular velocities; control positions; engine pressures and temperatures; structural strains, temperatures, and deformations; velocity; altitude; air temperature; Mach number; and air-flow angles. At moderate speeds and altitudes these quantities will be sensed by conventional means, recorded on NACA developed recorders, and indicated to the pilot, as necessary, by standard panel instruments. No difficulty is forseen at high Mach numbers with the instrumentation which can be protected within the airplane. These are the devices which will record accelerations, attitude angles, angular velocities, control positions, engine pressures, and engine temperatures. Structural strains, temperatures, and deformations will have to be measured in order to study heat transfer and to determine the effect of high temperatures on the structure. It is estimated that approximately 500 measurements of various strains and temperatures will be required. A method of making accurate strain measurements at the temperatures which this airplane will ultimately reach is not yet known; however, some development work is underway at the Langley Laboratory as well as at many other agencies in regard to this problem.

It is planned to secure the structural temperature measurements with thermocouples which are spot welded to the structure. This technique provides good heat transfer to the thermocouple and results in a minimum of mass connected to the aircraft skin. A good measurement of local skin temperature can thereby be secured, as changes in the heat capacity of the skin are minimized. The thermocouples have been tested with leads supported 3 to 5 inches away from the junction, at temperatures up to 1400° F, and under intense vibration, with satisfactory results. A severe data workup problem exists if many local temperatures and strains are to be measured and analyzed in detail. At present, work is being done to reduce this problem. A laboratory setup is now under test which would enable this mass of data to be sampled and recorded on magnetic tape. This technique will be used if satisfactory results are secured. It is also possible that commercial equipment suitable for recording low-level signals on magnetic tape will become available for use on the airplane.

Structural deformations of the wings and tail surfaces will be viewed by cameras which will be enclosed in pressure- and temperature-controlled compartments.

Present techniques for measuring velocity, altitude, and Mach number depend upon an accurate determination of static pressure. It will be extremely difficult to sense static pressure accurately at high speeds because of the conditions which are indicated in figure 4. Plotted against Mach number is the ratio of impact pressure behind a normal shock to the stream static pressure and the stagnation temperature in increments of 100° R. The values are based on an ambient temperature of 400° R and real gas properties. One of the difficulties in sensing static pressure is caused by the fact that the ratio of impact pressure behind a normal shock to the stream pressure increases rapidly as the Mach number increases, varying from about 1 at sonic speeds to over 60 at a Mach number of 7. A static-pressure probe with a 1-percent impact-pressure error could sense static pressure to 1 percent at sonic speeds. At a Mach number of 7, however, if the same percentage of impact pressure leaks into the static-pressure measurement, an error of over 60 percent in static pressure would result.

The second difficulty encountered is that the temperature rise encountered at high speeds greatly limits the probe configurations which should be used to minimize pressure errors. The thermal problem has been sufficiently discussed with respect to the airplane. Similar structural problems exist in the design of a probe and are aggravated by the high heat-transfer coefficients which would exist on the nose and along the length of a probe of reasonable diameter. In order to extend the measurement of velocity and altitude to high speeds, a stable platform-integrating accelerometer system will be used instead of pressure methods. Equipment similar to that proposed is already available for navigational purposes. This equipment is in general heavy and of large size because of extreme navigational accuracy requirements. Also, only horizontal velocities and displacements are measured, since altitude is usually determined by pressure methods.

A three-axis system is being proposed for use in the X-15. Specifications for the platform and computing elements have been prepared which are based on current manufacturing capabilities, and manufacturers' proposals are now being reviewed.

The proposed platform system is a three-gyro assembly which is oriented tangent to the earth and along a planned great-circle path. Three accelerometers are borne by the platform. These measure accelerations in the coordinate system which is indicated in figure 5. The coordinate axes are: any selected great-circle path, an axis perpendicular to this path, and local vertical. The outputs of the 3 accelerometers are inserted into computing networks which apply corrections for earth rotation and curvature and Coriolis accelerations. The accelerations are then integrated and summed with proper initial conditions to produce horizontal and vertical velocities. The velocities are vectorially summed to provide total velocity which is furnished to a pilot's indicator. Vertical velocity is available from the vertical integrator and is again integrated to secure altitude. Pitch, yaw, and roll angles are available from pickoffs on the platform gimbals and will be supplied to a pilot's indicator and recorded for research purposes. It is believed that this apparatus will be extremely valuable for the control and investigation of hypersonic aircraft.

The measurement of air temperature from the airplane is difficult. In order to secure accurate measurements, it is necessary to design the temperature probe so that full stagnation temperature is reached by the sensing element, and yet the probe supports and radiation shields must retain adequate strength under high pressure and acceleration loads. Some high-temperature probes have been designed for measuring exhaust jet temperatures; however, no apparatus is available which is suitable for the X-15 airplane. It is planned at present to secure air temperature from a radiosonde survey. These data, in combination with data secured from the airplane, can be used to compute Mach number and also stagnation temperature. It is unfortunate that balloon-sounding techniques are at present limited to altitudes of about 100,000 feet and therefore these derived quantities will be similarly limited.

A device which will be suitable for the determination of angle of attack and sideslip is now being investigated. Although these flow angles are not normally considered basic to the control of an airplane, the X-15 is faced with unusual problems of flight-path control, both on leaving the effective atmosphere and also upon reentry after ballistic flight.

There are various criteria for the design of this sensing element. The sensing element must

(a) Be forward of aircraft flow disturbances

(b) Be structurally sound at elevated temperatures

(c) Operate with reasonable accuracy at extremely low pressures to provide angle information well before reentry

(d) Introduce a minimum flow disturbance so that heat-transfer phenomena on the forward portion of the aircraft can be studied.

These criteria lead to the consideration of the null-balance sensing device shown in figure 6. The sensing element is a sphere located in the nose of the airplane. It is on appropriate gimbals and is servo driven in two planes. The sphere has 5 orifices, one at the stagnation point and pairs of orifices at about 30° or 40° from the stagnation point in the pitch and yaw planes. Each pair of orifices produces a pressure difference which is proportional to the misalinement of the sphere with the relative air flow. The pressure differences are sensed and guide the servos to realine the sphere into the relative wind. Computations have been made which indicate that a 6-inch-diameter spherical nose, constructed of Inconel, can be made of reasonable thickness so that its surface temperature will not exceed 1,200° F under the proposed flight plans. When based upon sphere pressure distributions and the sensitivity of an available differential pressure sensor, the resolution of the device is estimated to be about 0.6° at 200,000 feet for a typical flight plan. This resolution would increase by about a factor of 10 for each 50,000 feet decrease of altitude. These computations indicate that sufficient accuracy is available to allow making successful reentry into the atmosphere upon completion of ballistic flight.

No static source is available on this configuration. In order to provide indicated airspeed to the pilot during the landing condition, an alternate pitot-static source will be provided, which will be calibrated for use at landing speeds. At the present time, various sphere-cone configurations are being tested to determine heat-transfer characteristics along the fuselage and at the lip and some of the pressure characteristics of the sphere at high angles of attack. Some of the heat-transfer data have been presented by William V. Feller in a previous paper, and these data indicate that there are severe thermal problems to be overcome in the design of the external configuration. Many technical difficulties will also be encountered in designing the mechanism which drives this device; however, it is felt that a workable unit can be made available for the X-15 airplane.

This paper has described the ground range and airborne equipment which is to be used with the [redacted]irplane. Some of the instruments

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required are now in use. However, as has been pointed out, new measurement problems introduced by the increased performance characteristics of the airplane will require novel approaches. Means of obtaining these new measurements have been decided upon; however, much further development work is necessary before suitable apparatus can be made available.

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LOCATION OF X-15 GROUND RANGE

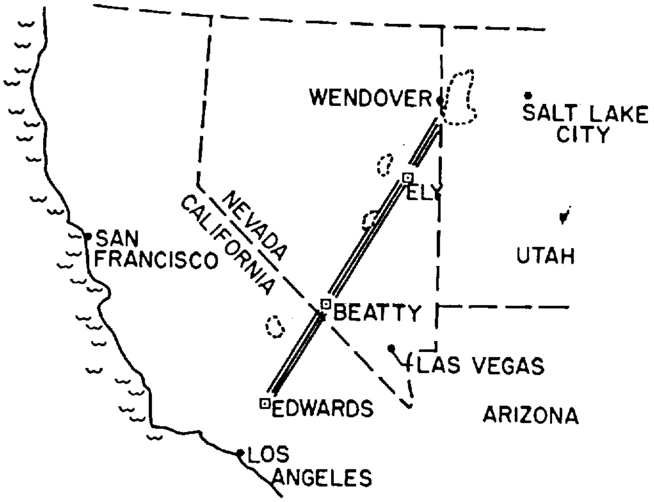

Figure 1

INFORMATION FLOW ON X-15 RANGE

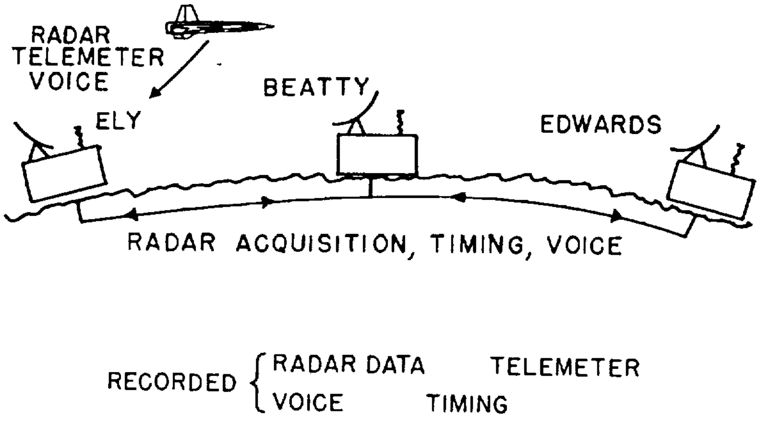

Figure 2

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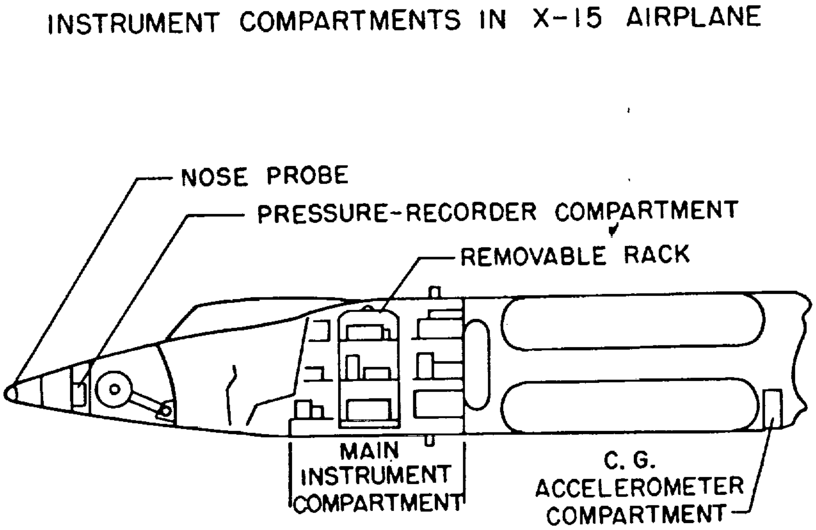

Figure 3

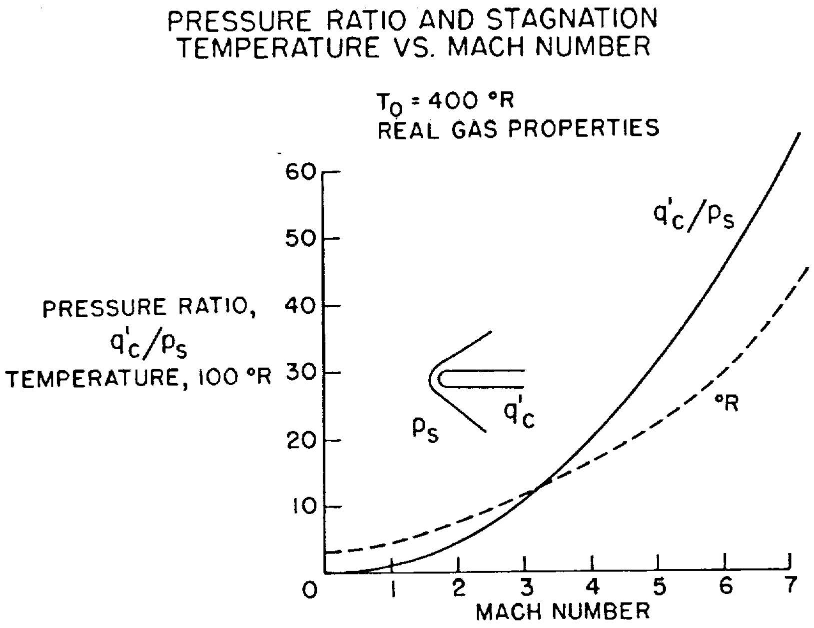

Figure 4

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STABLE-PLATFORM SYSTEM FOR X-15 AIRPLANE

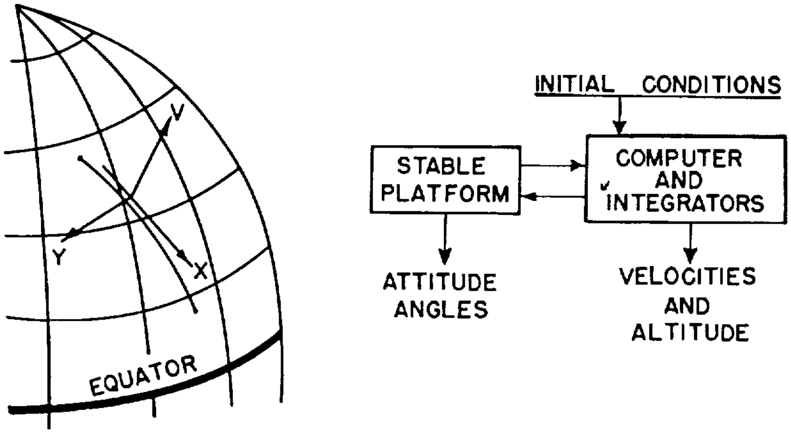

Figure 5

ANGLE-OF-ATTACK AND YAW SENSOR FOR X-15

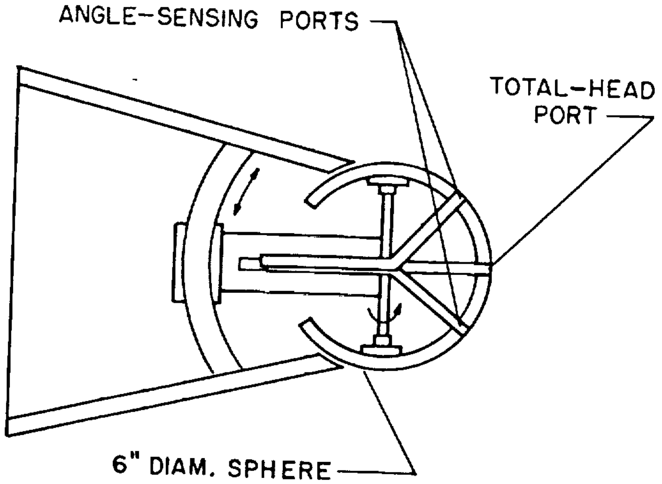

Figure 6