A Technique for Instrumenting Sub-gravity Flights

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THE PROBLEM of physiologic and psychologic effects of exposure to sub-gravity and weightlessness is an important aspect of space medical research. There has been speculation on the effects of prolonged exposure to uninterrupted weightlessness,[1] and work has been done during sub-gravity and weightlessness which have lasted for periods up to thirty seconds. [2,4] One method of producing sub-gravity and weightless conditions for medical research purposes is by the use of jet aircraft flying ballistic trajectories.[3] Theoretically, it is possible to realize uninterrupted weightlessness for a period of thirty seconds; this time period is dependent upon angle of entry into the parabola, and speed of aircraft upon entering the parabola which must be selected so that forward velocity of the aircraft is below stalling speed at apogee.

Research flights at the Aero Medical Field Laboratory, Holloman Air Force Base, have shown that individual pilots vary in their skill in achieving the maximum duration of the weightless state during flying of the ballistic trajectory. The instrumentation to be described was designed as an aid to the pilot in obtaining the maximum duration of the weightlessness state and to record quantitatively the G forces acting on the subject and on the aircraft frame. A further purpose of the instrumentation was to permit evaluation of the border line between sub-gravity effects and those associated with weightlessness. An incidental use of the instrumentation is to permit accurate exposure of subjects to a specific value of sub-gravity for any desired period of time within the aircraft's capability.

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DESCRIPTION OF THE INSTRUMENTATION

Prior to the design of the instrumentation, sub-gravity flights showed that the principal G forces experienced by the subject were those of vertical and longitudinal G forces. These G forces are in respect to the vertical axis and the longitudinal axis of the aircraft. In early experiments the aircraft G meters were used in flying the sub-gravity trajectories. However, it soon became apparent that these meters were too insensitive for realizing the maximum duration of weightlessness possible for each parabola. Another devise for indicating sub- and zero G conditions was a golf ball tied to a string suspended from the top of the canopy. While it was a novel use for the golf ball, it nonetheless provided the pilot and the observer with a method for indicating qualitatively the presence or absence of true weightlessness. As the aircraft oscillated from weightlessness to sub-gravity conditions the ball would rise and fall, indicating with extreme sensitivity the presence of weightlessness, but when forced to one extreme of its tether gave no indication of the amount of G being experienced.

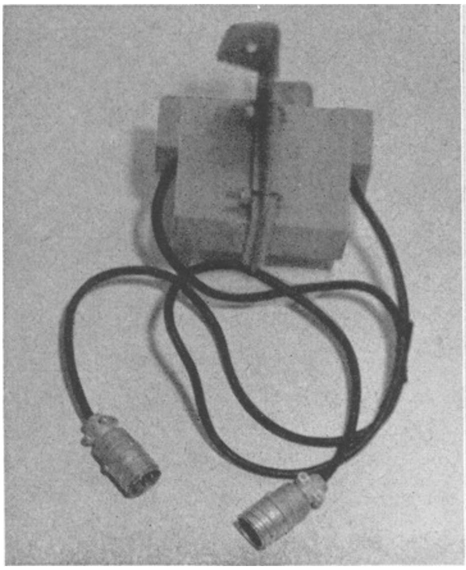

Fig. 1. Statham ±0.5 G accelerometer and bracket used for mounting on aircraft frame.

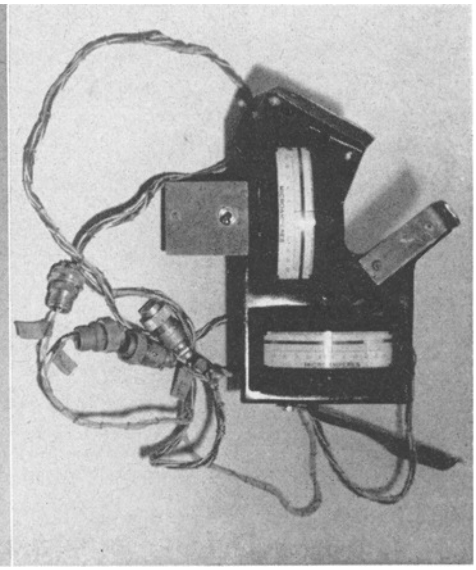

Fig. 2. Microammeters with range of 25-0-25 microamperes and bracket for installation in pilot's compartment of F-94 type aircraft.

In designing instrumentation the need for a sensitive gravity-indicating device was resolved by the use of the Statham accelerometer with a range of ±0.5 G. One accelerometer was mounted to indicate the forces acting in the vertical axis of the aircraft, and the other oriented to indicate longitudinal G forces—forces acting along the longitudinal axis of the aircraft. (Fig. 1).

As a visual aid to the pilot in realizing the maximum duration of weightlessness, two sensitive microammeters were installed in the pilot's compartment, within his field of vision and each was connected directly to the corresponding accelerometer oriented in the vertical and longitudinal axes of the aircraft. (Fig. 2).

The microammeters have a range of 25-0-25 microamperes. The microammeter connected in parallel with the vertical G accelerometer is on the right; the longitudinal G accelerometer is connected to the microammeter on the left. The accelerometers act as null indicators, that is, the electrical output of the accelerometers during weightlessness is zero so the needle of each microammeter rests in the 0 position. During positive vertical G the right microammeter records, or follows, the current output of the accelerometer and the pilot has an indication of being in positive G. If the aircraft enters negative G the needles swing the other way. During the positive vertical sub-gravity state the needle swings down from 0 and during the negative G state swings up from 0. Longitudinal acceleration or deceleration is indicated by a swing in the left microammeter needle to the right or left. For realizing the maximum duration of 0 G it is necessary for the pilot to keep the individual needles riding in the 0 position for as long as possible, or as long as the capability of the aircraft permits.

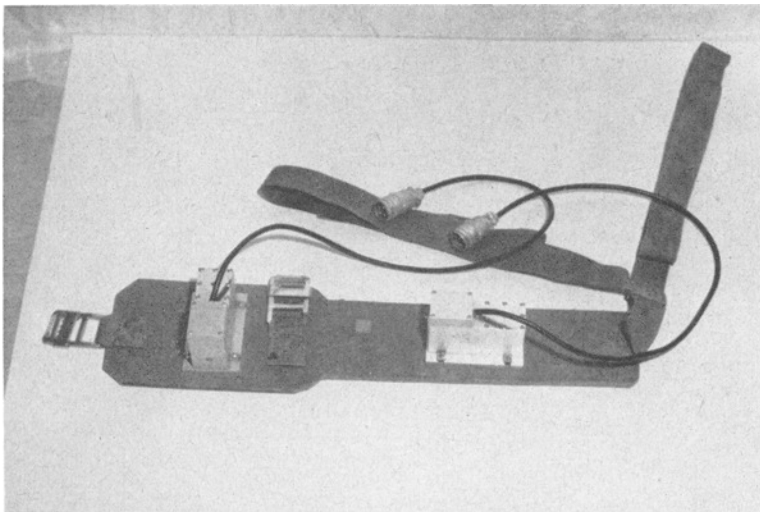

Fig. 3. Statham accelerometers mounted on chest band for recording quantitatively G forces on subjects during sub-gravity trajectory. Accelerometer at left is oriented to record longitudinal G forces, and at right, vertical forces.

To record vertical G forces and longitudinal G forces acting on subject, since there was some doubt that the subject and the aircraft are submitted to the same forces, two Statham accelerometers were mounted on a leather band which was strapped to the chest of the subject. Figure 3 shows the chest band and accelerometers. The output of these accelerometers is fed into a Century model 409 recording oscillograph (Fig. 4), a galvanometer type oscillograph recorder sensitive enough to record the output of the accelerometers without further amplification.

To record reactions of the subject on film, part of the instrumentation package was a gun sight aiming point gun camera equipped with an 84° wide angle lens. This has since been changed to a camera, equipped with the same lens, but with a larger film magazine. To correlate the reactions of the subject with the amount of G imposed upon him, the film record and the oscillograph record are synchronized. This is accomplished by means of lights which appear every half second on the face of the camera and recorded as bright lights on the film. These lights are also recorded by the oscillograph recorder in the form of half-second timing traces (Fig. 5).

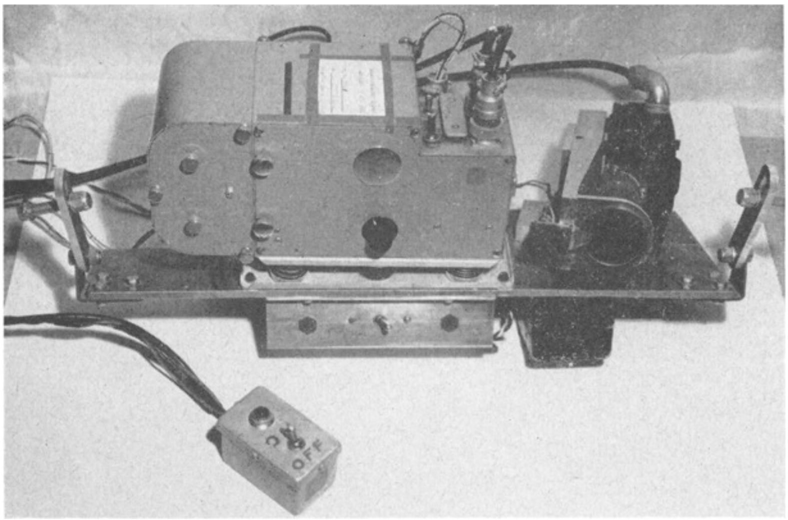

Fig. 4. Century model 409 oscillograph recorder and gun sight aiming point gun camera with 84° wide angle lens.

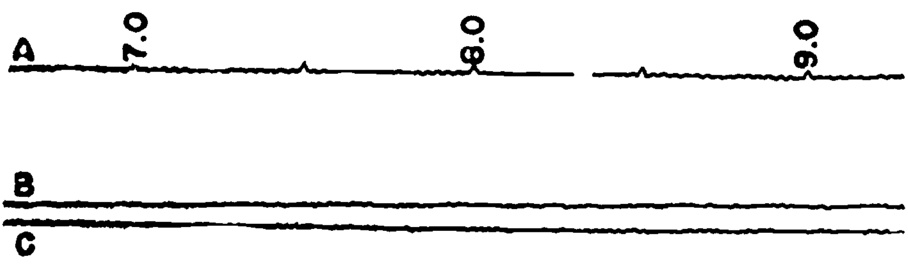

Fig. 5. A segment of oscillograph record of sub-gravity flight, showing: (A) timing in seconds, (B) vertical G force, (C) longitudinal G force, and (D) 100 cps timing tracing.

A block diagram of the instrumentation appears in Figure 6. The instrumentation consists of two units, the microammeters and accelerometers on the aircraft frame comprising the unit used to provide the pilot with an aid for realizing the maximum duration of zero G, and the accelerometers, on the subject, and oscillograph recorder comprising the unit used to record quantitatively the duration the subject is in zero gravity or sub-gravity conditions. The camera provides a film record of the subject's reactions to zero and sub-gravity conditions.

microammeters is equivalent to ±0.014 G.

The accelerometers on the subject are calibrated by the use of known re-

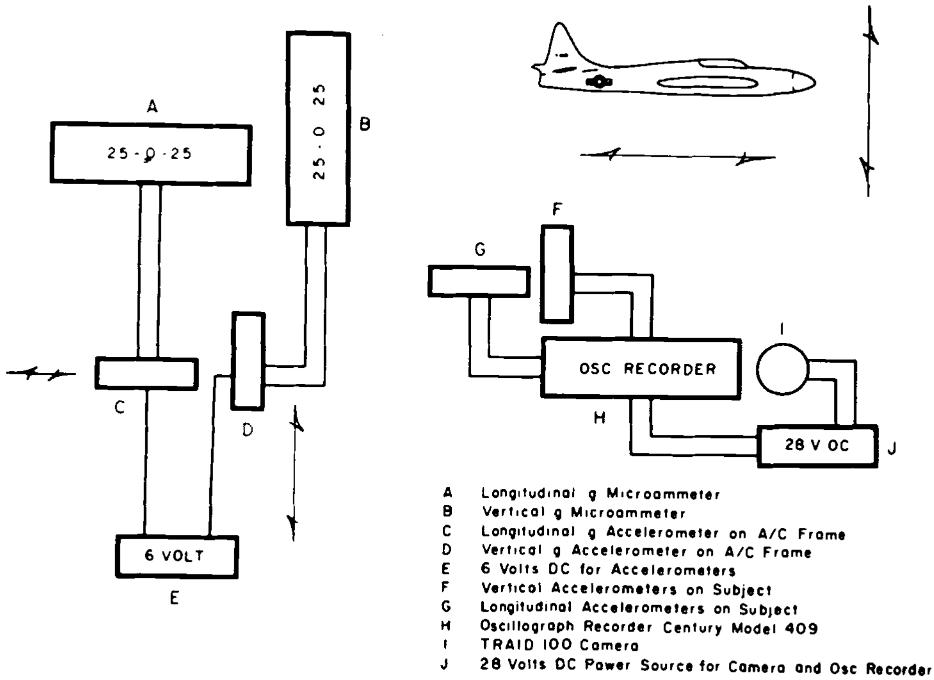

Fig. 6. Block diagram of instrumentation used in sub-gravity tests.

sistance values. If a resistor is placed across one arm of the accelerometer bridge, a deflection in the output circuit results which simulates the effect of combined resistance change in the active bridge arms due to changes in acceleration. Calibration resistors of predetermined value gave values of simulated accelerations (Fig. 7).

We see that the accelerometers are calibrated in steps of +0.125, +0.250, +0.395, and +0.5 G. One half G is the full range output of the accelerometers. Calibrating for negative G values is done by reversing the

CALIBRATION

Calibration of the instrumentation is done in two steps. First the microammeters are calibrated so that each division on the scale corresponds to a known amount of gravity. This is accomplished by the use of the familiar machinist sine-bar and Johanson blocks. Each accelerometer is tilted in 5° increments to an angle of 45° from the horizontal. Placed horizontally the accelerometer is at zero G, and being tilted 30° places +0.5 G on the accelerometer. Calibration in this manner discloses that each division on the polarity of the calibration circuitry. We see from the trace the steps of calibration, the one-half-second timing trace, and the 100 cps timing trace provided by the oscillograph recorder.

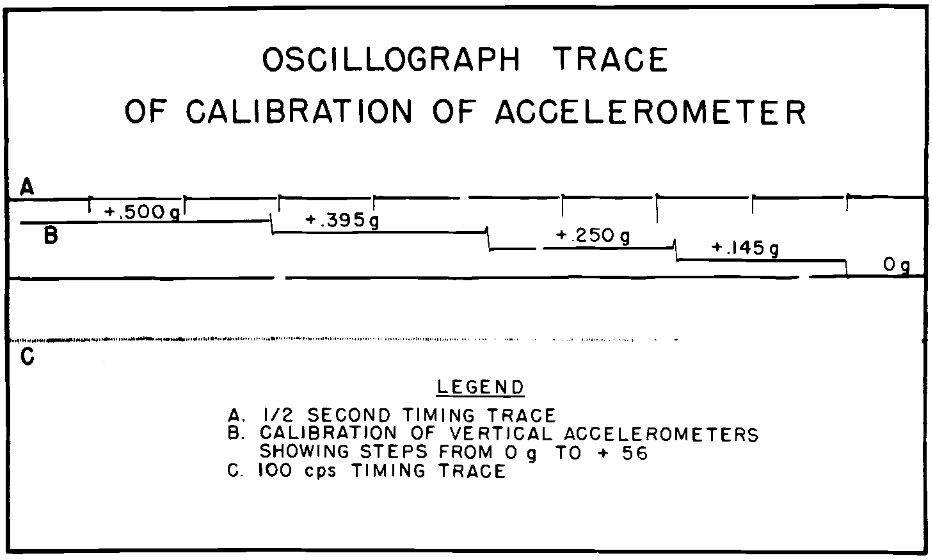

Fig. 7. Oscillographic tracing of calibration of accelerometer, showing: (A) timing in ½ second units; (B) steps in vertical accelerometer from zero G to +0.56 G, and (C) 100 cps timing tracing.

RESULTS AND DISCUSSION

Reduced data from flights conducted during the past year emphasize that individual pilots vary in their skill in obtaining the maximum duration of zero G from each ballistic trajectory flown. Repeated flights using the technique described greatly increases pilot skill. The longest consecutive period of zero G obtained has been seven seconds. Periods of less than +0.025 G last for as long as 22.5 seconds, with intermittent periods of zero gravity of four to five seconds. Complete trajectories of less than +0.1 G for thirty seconds or more can be easily realized.

Incidental problems arising in the use of F-94 jet aircraft as test platforms in sub-gravity research has been: (1) the loss of engine oil pressure, (2) loss of hydraulic fluid from the reservoir, and (3) loss of trim tab action. The loss of engine oil pressure lasts only during the zero G trajectory and is not harmful to the engine. The oil rises in the chamber during reduced gravity conditions causing a loss of hydrostatic pressure at the oil sump located in the bottom of the reservoir. This loss of pressure is reflected in the oil pressure indicating needle dropping to zero and remaining there as long as the oil is floating in the chamber. The same conditions prevail for the hydraulic fluid, except in the F-94, with returned longitudinal acceleration the fluid tends to flow out the overflow vent located at the top of the reservoir and is dumped overboard. The loss of trim tab action is explained in the overheating of the trim tab actuator motor due to loss of air currents in the zero G state. With returned air currents the trim tab actuator motor cools and become operational.

The equipment designed to instrument sub-gravity flights is uncomplicated and has the advantages of light weight and compactness. The complete package weighs less than 15 pounds and can be fitted easily in the observer's compartment of an F-94C aircraft.

Some of the more interesting observations of recent flights have been an incident of extreme vertigo and disorientation in a pilot with more than 3,000 flying hours, observations on the behavior of different fluids under sub- and zero-gravity conditions, and a high incidence of motion sickness. Preliminary experiments indicate that a study of fluid behavior under extended periods of true zero G will be valuable in the planning and design of future space vehicles.

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The Unknown Measurements of a Jet Pilot

From accident data, it is apparent that we do not have, at present, adequate objective measurements of the task imposed upon the pilot in high performance aircraft nor do we have adequate information regarding the pilot's ability to cope with these tasks. The design and arrangement of instruments and controls in a jet cockpit are predicated upon subjective evaluations by operational people. What objective data are available for design of instruments and controls were collected in reciprocating engine aircraft. The task imposed upon the jet pilot is entirely different. It is not known how many tasks the pilot can adequately perform in a given period of time or how much ordinary tasks, such as moving handles or levers, can be complicated when such objects are placed in positions that are difficult to reach or locate. It is not known how long the pilot looks at essential instruments in order to fully comprehend their significance. It is not known how long it takes the pilot who has been flying by outside visual reference suddenly to make the transition to instrument flying, especially if the aircraft is in an unusual attitude. With the increasing performance of aircraft, any demand that exceeds the pilot's ability to adequately react in the time interval for action is calculated to result in an accident and loss of the pilot.—The Need for Aeromedical Research in the Field, *USAF Medical Service Digest,* September, 1957.