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AN IMPROVED TECHNIQUE FOR THE CALIBRATION OF SOLAR CELLS USING A HIGH ALTITUDE AIRCRAFT

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ABSTRACT

A description of a newly developed technique for the airborne calibration of solar cells is given. Aircraft modifications and data supporting the inherent advantages of this technique are discussed.

INTRODUCTION

The NASA Lewis Research Center began calibrating solar cells utilizing a high altitude aircraft in 1963. Semilogarithmic plots of the measured solar cell short circuit current (Isc), as a function of air mass, yields the predicted outer space Isc, except for corrections for the earth-sun distance and ozone absorption,(ref. 1). A B-57B aircraft was initially used as described in (ref. 1), however it was replaced with an F-106B aircraft, (fig. 1), in 1972. Reduced endurance limitations of the F-106B aircraft necessitated a flight profile change and therefore a data acquisition system with improved capabilities.

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AIRCRAFT MODIFICATIONS AND EQUIPMENT

The B-57B experimental equipment included a collimating tube located in the aft fuselage, a pilot sight mounted in the forward cockpit and aligned parallel to the collimating tube, and a manually operated data acquisition system located in the aft cockpit. A temperature controlled mounting plate attached to the collimating tube base was capable of holding six (6) 2 x 2 centimeter solar cells.

The collimating tube assembly used in the B-57B aircraft, (fig. 2), was installed in the forward portion of the F-106B, just aft of the radome. Minor modifications of the assembly were required due to F-106B space limitations and required structural mounting differences. This resulted in a collimating ratio of 5:1 and angular displacement limits normal to the aircraft's longitudinal axis of 20 to 60 degrees above the horizon. A fuselage cutout, (fig. 3), was made to permit illumination of the solar cells and was provided with a ground installed cover plate for other aircraft missions. A pilot controlled hatch, (fig. 4), capable of being opened or closed in-flight, was added to protect the solar cells from atmospheric contaminants during climb and transport to the test area.

An optical sight, (fig. 5), mounted in the forward cockpit, provides steering information to ensure illumination of the solar cells during data collection. The sight is aligned parallel to the collimating tube and the angular elevation of both are preset prior to take-off to correspond to the calculated solar elevation angle (Hc). The relative location of the optical sight and collimating tube, along with the sight detail, are depicted in (fig. 6).

A remotely controlled, pilot operated, 20 channel digital voltmeter, (fig. 7), capable of measuring at a rate of 0.8 channels/sec., records the data on a paper tape. Only 12 channels are utilized which permits each solar cell Isc to be measured once each scan.

In-flight effects of the fuselage cutout on engine inlet airflow distortion and generated noise levels, with the cover plate removed, were examined throughout a restricted flight envelope. In addition, over-pressurization of the compartment enclosing the collimating tube, due to ram air inflow, was monitored during the flight test series. Results indicated that the cutout had no adverse affects on engine operation and produced negligible ram inflow. The distance between the cutout and engine inlet, approximately 5.2 meters (17 feet), was apparently sufficient to damp any boundry layer disturbances prior to inlet injestion. Also, maximum compartment pressure recorded was only 1.379×10^4 dynes/cm^2 (0.2 psi) above ambient. A slight howl was barely preceptible during certain flight conditions and was considered uneventful.

PROCEDURE

Flight data are collected over a period of about eight (8) months, September through April, to take advantage of lower tropopause heights. During this period the solar elevation angle at solar noon varies through a range of approximately 22 to 59 degrees, calculated for the test site area of 45° N latitude.

During the B-57B operation, the aircraft was flown to an altitude of approximately 15,240 meters (50,000 ft.) and data was gathered at 1524 meter (5,000 ft.) intervals, flying a racetrack pattern described in (ref. 1). Data was usually acquired at 4 to 6 altitudes depending on atmospheric conditions. Two crewmembers were required, a pilot and research observer, because of the manually operated data recording system located in the aft cockpit. Nominal flight time required for a typical B-57B mission, to include cell measurements over a 6096 meter (20,000 ft.) altitude range, was 2 hours and 30 minutes. Approximately 1 hour and 30 minutes was required to gather the data, which in this example would be 5 measurements/cell.

To reduce the time of data collection using the F-106B aircraft, a controlled rate of descent is established at an altitude of 15,240 meters (50,000 ft.) and continued to about 1000 meters below the reported altitude of the tropopause. This procedure is used to positively identify the tropopause location due to its effects on cell output, as described in (ref. 2).

Comparing with the B-57B method, only about 1 hour and thirty minutes is required for an identical mission as described, of which approximately 10 minutes is required to complete the descent maneuver, assuming a rate of 610 meters/min (2000 ft/min).

Sun angle computations are identical to those described in (ref. 1), and the corrections defined in (ref. 1), Appendix, are applicable but of slightly different values. Usually these corrections are ignored because of their small magnitude, and with pilot proficiency the Sun's image can be acquired on the sight and held centered with the following procedure.

Aircraft control inputs displace the Sun's image on the optical sight along skewed axes, as a function of Hc. Fig. 8 depicts the skewed axes for an Hc value of about 45°, along with image displacement resulting from control inputs. For example, if the image were displaced along the roll axis, only an aileron input would be required for centering. Conversely, if displaced along the pitch/yaw axis, either a pitch or heading change could be employed for centering. Further, since pitch changes alter the aircraft's rate of descent, at a constant airspeed, it becomes possible to control the descent rate by a combination of pitch and heading inputs. Once established only minor corrections are required, therefore heading changes are made with rudder inputs to prevent image displacement along the roll axis.

Establishing a controlled descent rate provides a direct control over the number of cell Isc measurements, for a given altitude change. Figure 9 is a plot of measured atmospheric pressure as a function of time when a constant rate of 610 meters/min (2000feet/minute) was attempted. The plot curvature is primarily due to the approximate exponential pressure distribution of the atmosphere. By converting the pressure measurements to meters, using standard atmospheric tables and replotting, it can be seen that an accurate control of the descent rate is possible. This is shown in (fig. 9) as an approximate straight line. Since each cell output is measured every 15 seconds(12x1/0.8), the cell Isc is recorded every 152 meters (500 ft) in this example. For a sampling altitude range of 6096 meters (20,000 ft.), 40 measurements are recorded/cell as compared to 5/cell using the B-57B aircraft.

SUMMARY

The controlled, continuous descent method of calibrating solar cells offers distinct advantages of cost and accuracy when compared to the method described in (ref. 1). Actual time of data collection was reduced approximately 85-90% with a total mission flight time reduction of approximately 40%. This is accomplished even though the test site area currently used is almost 2-1/2 times farther from the aircraft's operating base. Perhaps more importantly, the number of individual cell Isc measurements recorded during each flight increased dramatically by about 800%, thereby promoting a more accurate prediction of solar cell performance in outer space.

REFERENCES

1. Brandhorst, Henry W., Jr.; and Boyer, Earle O.: Calibration of Solar Cells Using High Altitude Aircraft. NASA TN D-2508, 1965.

2. Brandhorst, Henery W., Jr.: Calibration of Solar Cells Using High Altitude Aircraft. NASA TM X-52145, 1965.

Figure 1. - F-106B test aircraft.

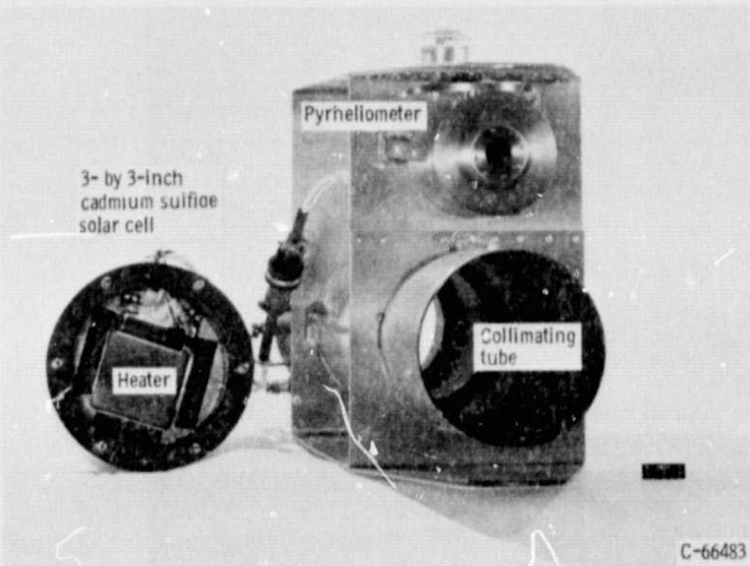

Figure 2. - Unmodified collimating tube assembly.

Figure 3. - Fuselage cutout with tube assembly.

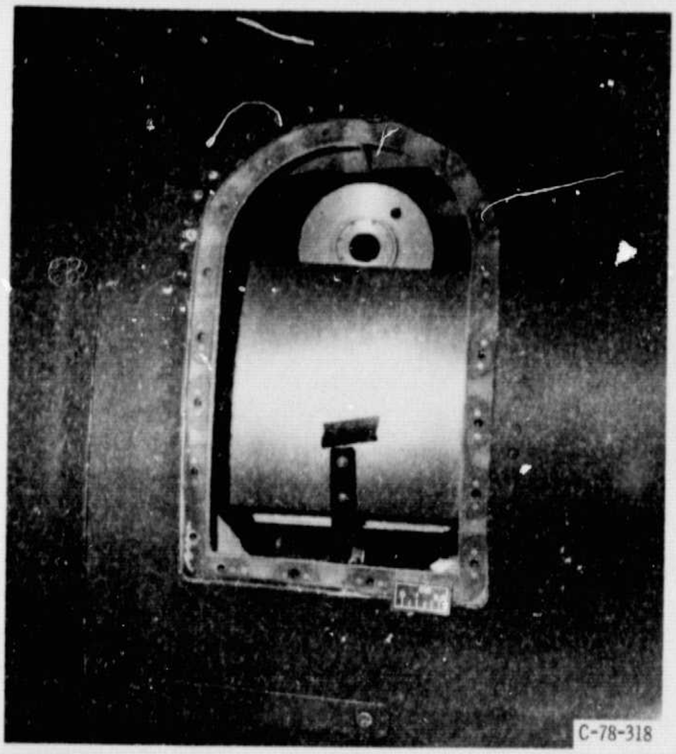

Figure 4. - Collimating tube cover hatch.

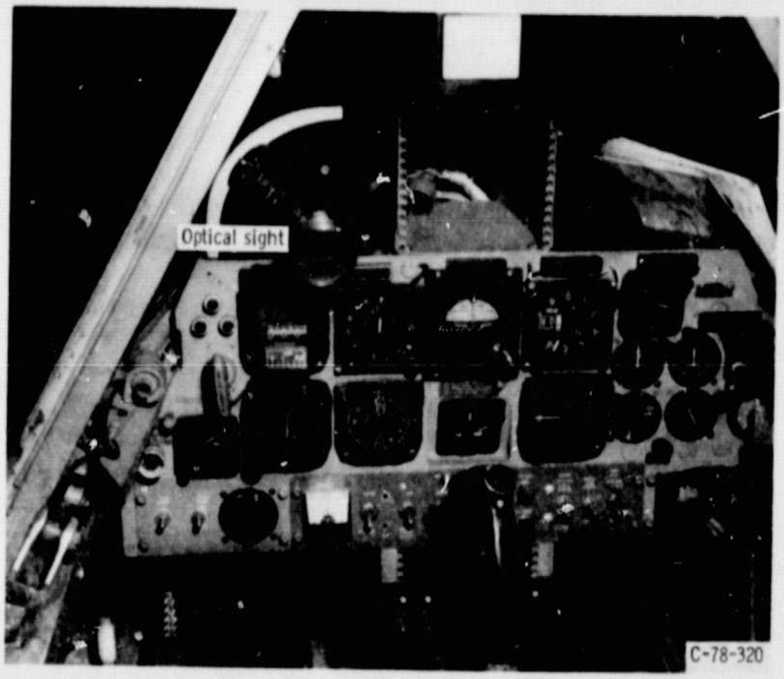

Figure 5. - Optical sight.

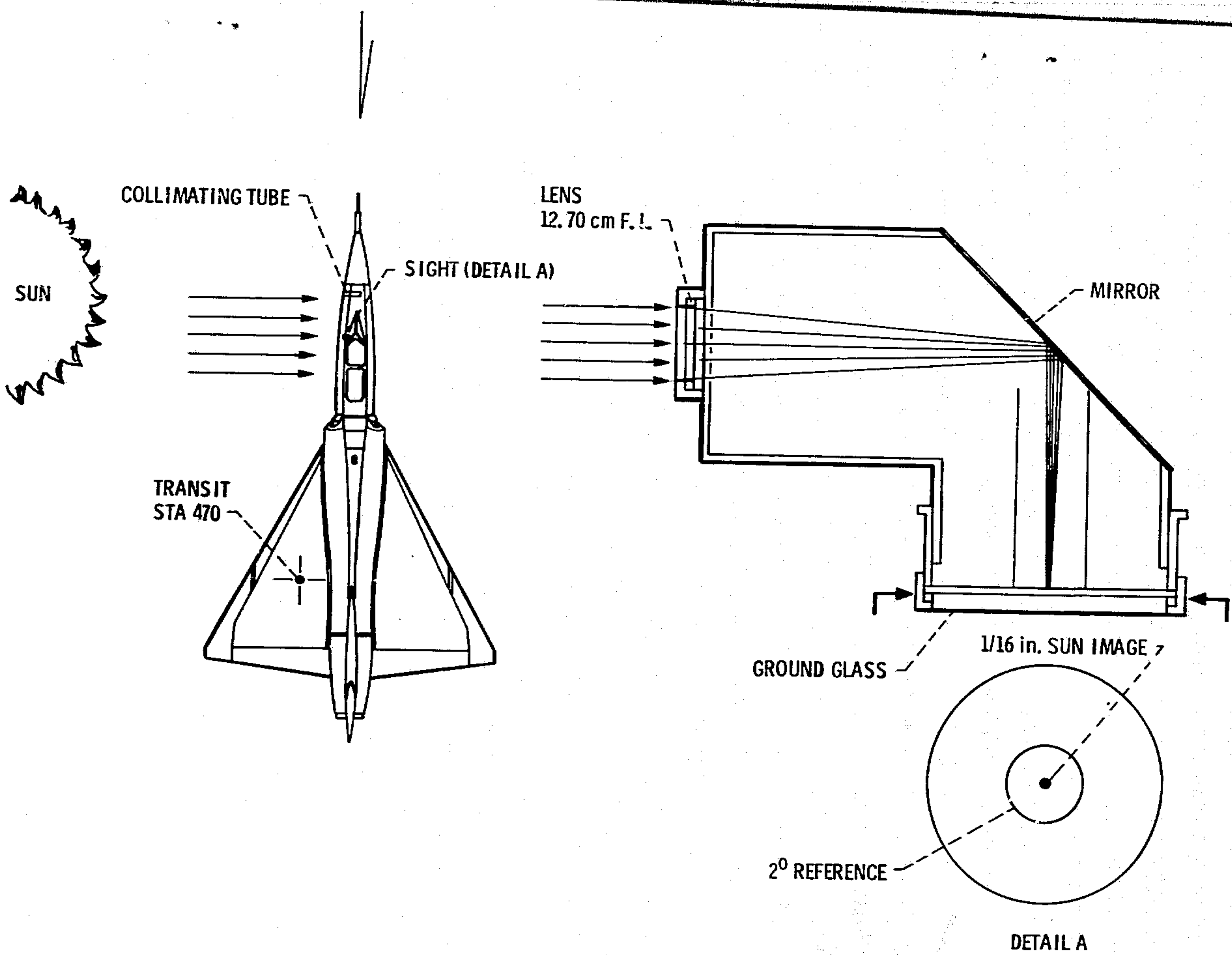

Figure 6. - Aircraft configuration and sight detail.

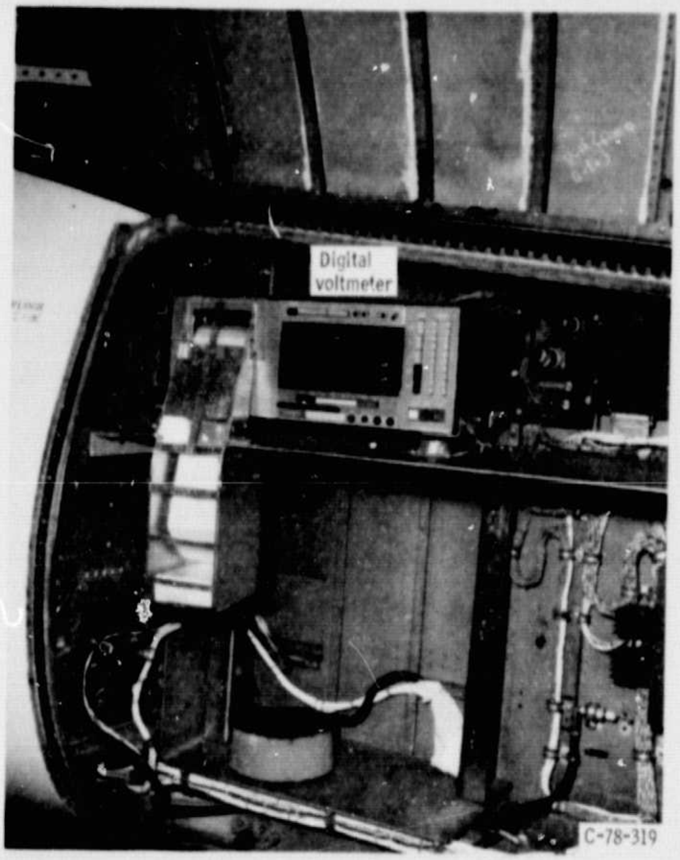

Figure 7. - 20 Channel digital voltmeter.

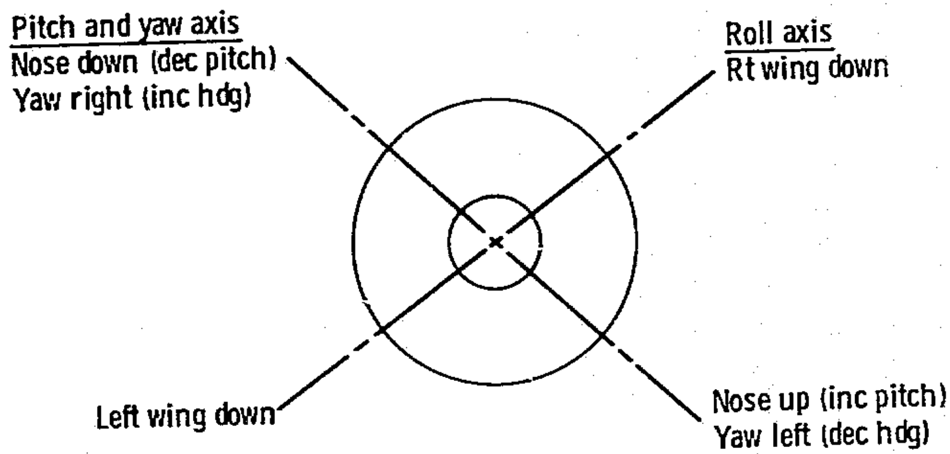

Figure 8. - Optical sight control axes.

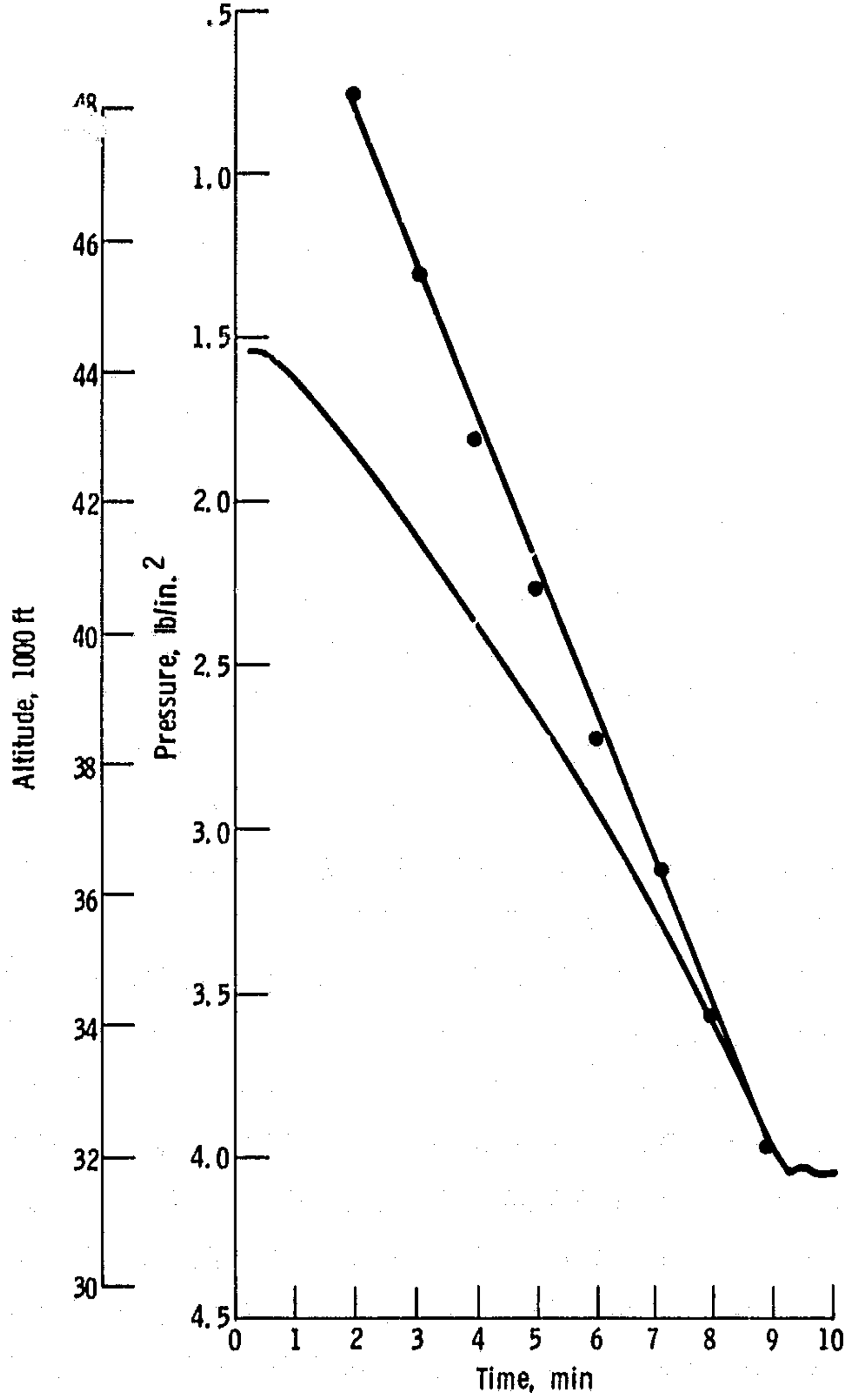

Figure 9. - Aircraft descent rates.

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