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BALLOON-BORNE RADIOMETER PROFILER: FIELD OBSERVATIONS

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Project Objective:

The objective of this project is to develop the capability of making routine soundings of broadband radiative fluxes and radiative flux divergences to heights of 1500 m AGL. Using this capability, soundings will be made under different cloudiness conditions and will be compared to radiative transfer models.

The Radiometer Profiler:

To meet these objectives radiometers are carried on a stabilized platform (see Figure 1) in a harness inserted in the tetherline of a tethered balloon meteorological sounding system, approximately 30 m below the balloon. The platform is leveled by an automatic control loop stabilization system in which the level sensors are two single-axis solid-state rotation rate sensors. These sensors use vibrating micro-machined quartz tuning forks to sense angular rate. Rate sensor drift is corrected periodically by a long-term-average measurement of the earth's gravity vector as sensed using a pair of single-axis linear accelerometers.

The rate sensor/accelerometer leveling system is a new design completed in 1994. Other modifications were made to the prototype platform - the automatic control loop was modified to use the new sensors, the breadboarded electronic circuits were made into finished printed circuit boards, new radiometers (total hemispherical radiometers and pyranometers) were installed and tested, improved pulley housings were installed, the platform structure was stiffened, and platform components were miniaturized and relocated in a weatherproof housing. Initial field tests were also performed.

Leveling Measurements

The radiometer platform stabilizes itself using feedback loops involving a pair of acclerometers and rate gyros active on axes separated by 60 degrees. The accelerometers are sensitive to lateral accelerations as well as the gravitation acceleration component when the platform is not level. They are, therefore, lowpass-filtered for use as a mean level indicator. The rate gyros measure angular velocity, but become insensitive to low-amplitude long-period rotations.

They are high-pass filtered and are used to measure oscillations of the platform about its mean orientation.

It is important to know the inherent accuracy of the leveling system components, which can be estimated as follows. For the rate gyros, the full-scale (± 5V) is 100° s^{-1}. The analog outputs from these sensors are sampled using a 12-bit A/D converter, yielding a sampling resolution of $\dot{\theta}_{res} = 0.024° s^{-1}$. The angular displacement at a given frequency can be represented by

$$\theta = \theta_o \sin(2\pi f t)$$

where θ_o is the displacement amplitude. The rotation rate is then

$$\dot{\theta} = 2\pi f \theta_o \cos(2\pi f t)$$

Therefore, the displacement resolution at a given frequency (or period T) is

$$\theta_{res} = \frac{\dot{\theta}_{res}}{2\pi f} = \frac{\dot{\theta}_{res} T}{2\pi}$$

For a nominal period of 60 s, this gives $\theta_{res} = 0.06°$, which is well within the accuracy required to validate leveling requirements of 0.5° rms deviation from zenith. For the accelerometers, which measure mean departures from level, the acceleration due to an angular displacement is, to a first approximation,

$$a = g \sin\theta$$

The full-scale range of 4 g through a 12-bit A/D converter gives a resolution of 0.001 m s^{-2}, which corresponds through the above relation to 0.06°. As noted previously, the accelerometer measurements of angular displacement can be contaminated by lateral accelerations. As an estimate of this effect, consider that a reasonable maximum platform lateral velocity change over 60 s of 3 m s^{-1} yields an average acceleration of 0.05 m s^{-2}. This corresponds to an error in the measurement of average displacement of 0.29°, which is comparable to mean leveling requirement for the platform. Thus, as long as the balloon is reasonably stable, the accelerometers are adequate to establish the required mean leveling.

Results of Flight Tests

The new rate sensors proved to be very sensitive, and the platform sides had to be stiffened to reduce the sensitivity of the control system to flexures of the structural members of the platform. These structural modifications increased the mass of the platform to about 2.5 kg. Flight experience showed that a low-speed 7.5 m^3 balloon should have adequate lift to carry the platform to its design atitude of 1500 m AGL. A 7 m^3 high-speed balloon with rigid tail fins should allow flights to this altitude in winds up to 35 kts.

An initial series of balloon-borne test flights was performed under waivers obtained from the Federal Aviation Administration. Figures 2 and 3 present the test results during a period of continuous ascent with a low-lift balloon on June 28, 1994. During this flight segment, the mean tilt of the radiometer profiler from horizontal on axis 1 was 0.5° with a standard deviation of 1.2°. The tilt on axis 2 was -1.7° with a standard deviation of 0.6°. We should be able to improve on these initial results with better pre-flight leveling adjustments and with control loop filters and sensitivity adjustments. Further test flights will concentrate on stabilization system performance, better sensitivity matching of the two axes, flight profiles (continuous versus stepped ascents), testing of a new high speed balloon, calibration and testing of the radiometers, development of operating procedures, etc.

Field experiments were used to test the stable platform radiometers against transfer standards. Discrepancies between the airborne radiometers and the standard radiometers suggest that the airborne radiometers should, in the future, be calibrated while they are in position on the Radiometer Profiler; this will allow us to correct for the thermal conductivity of the platform radiometer mounts.

This project is cooperating with National Science Foundation and Office of Naval Research-funded investigators as part of the Surface Heat Balance of the Arctic (SHEBA) program to develop new tethered balloon technologies for atmospheric research in the Arctic. Plans are being made to make data flights with the Radiometer Profiler at Point Barrow, Alaska, in the summer of 1995.

Acknowledgement

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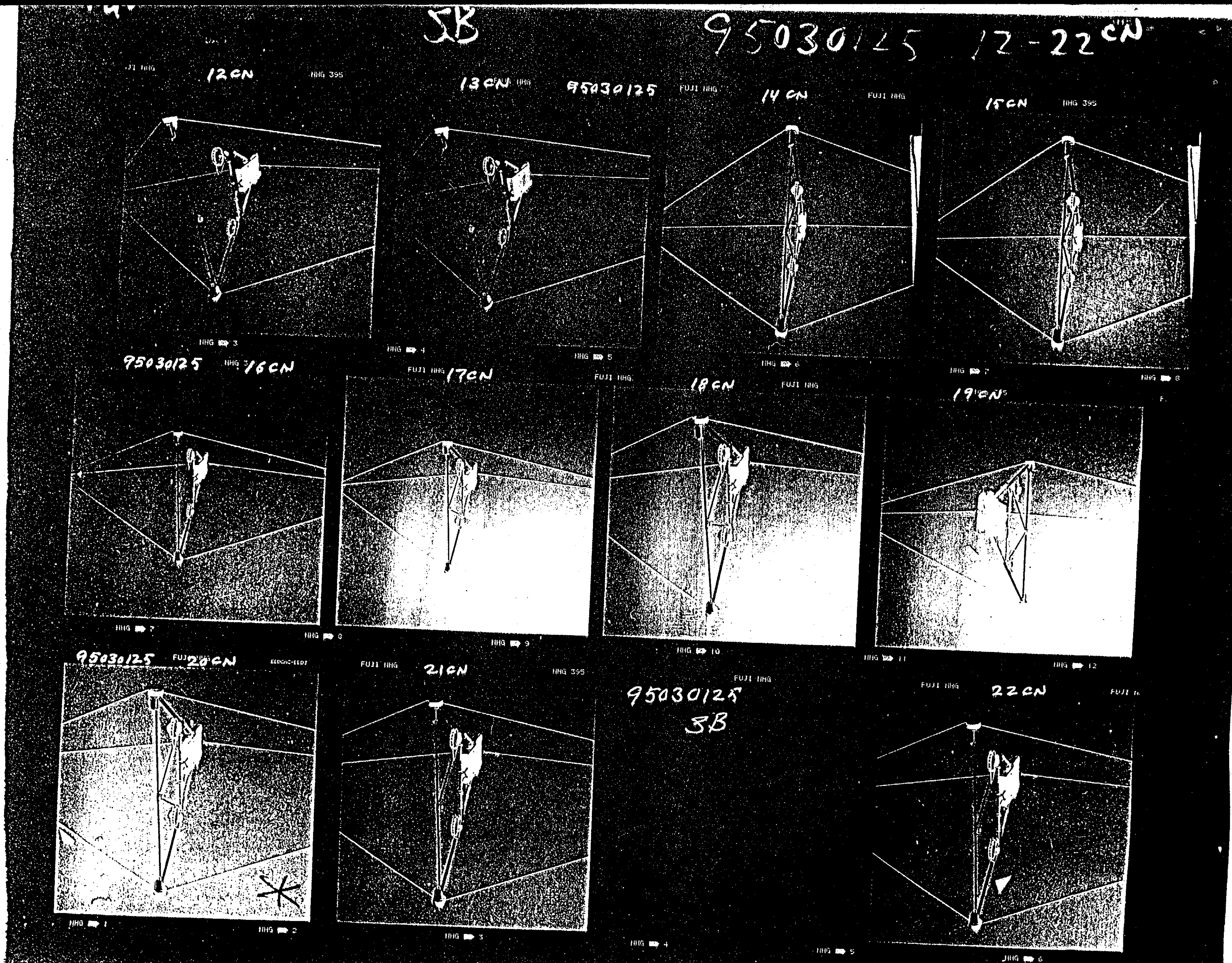
FIGURES

Figure 1. Photograph of prototype self-leveling balloon-borne radiometer platform.

Figure 2. Time series from rate gyro 1. These data were collected during a steady ascent. The deviation is the instantaneous departure from level. It is obtained by removing periods longer than 30 s in the deviation rate and then

integrating over time. The first 130 s of the flight were affected by wake turbulence from nearby buildings. The increased unsteadiness about 400 s into the flight corresponds, we believe, to early battery failure. The period between 150 s and 350 s is the period for which statistics have been calculated.

Figure 3. Time series for rate gyro 2. Same treatment as data presented for the rate gyro on Axis 1. For this flight, there was more oscillation at low frequencies on this axis. From the results for the other axis, we believe that this can readily be improved.



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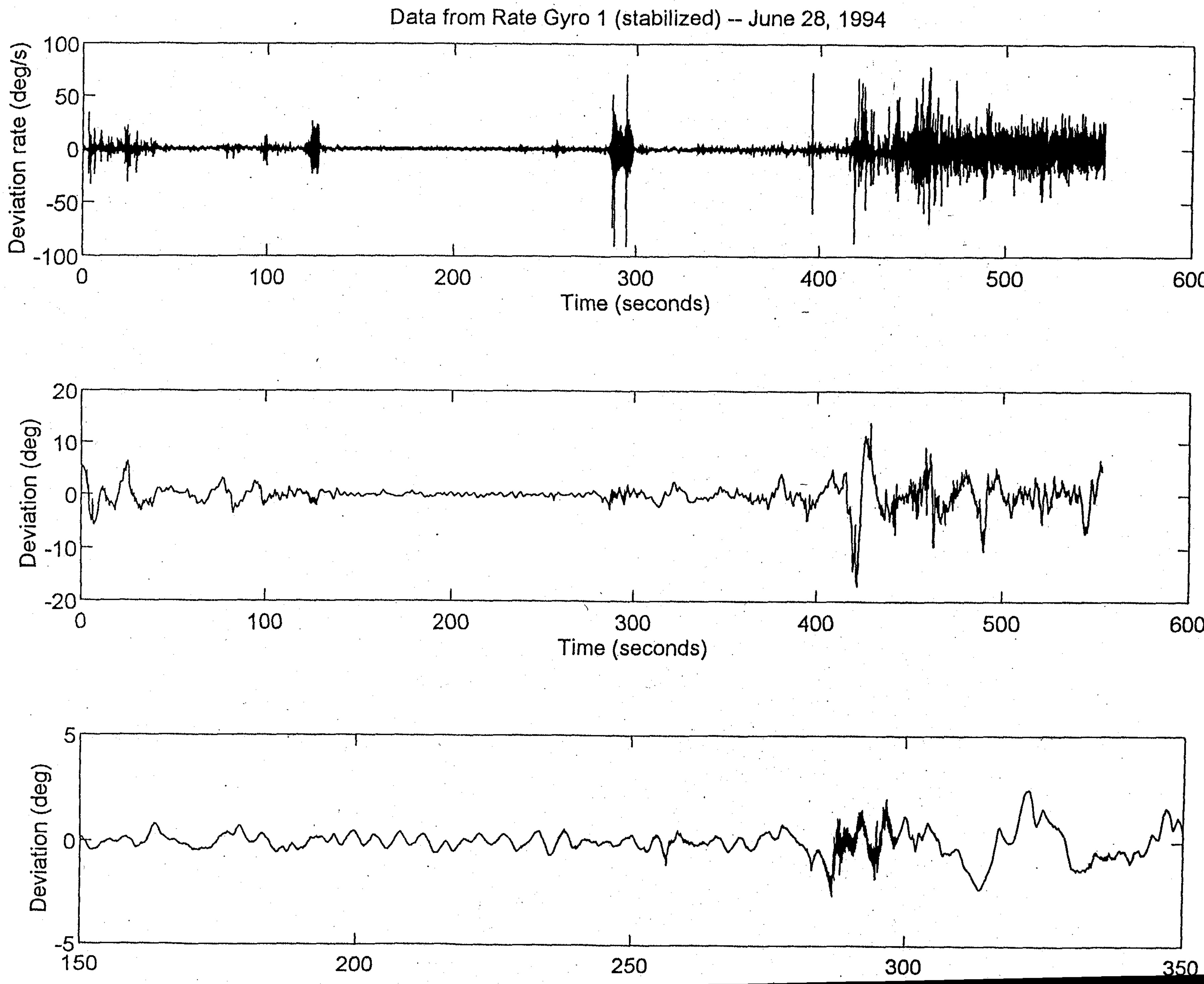
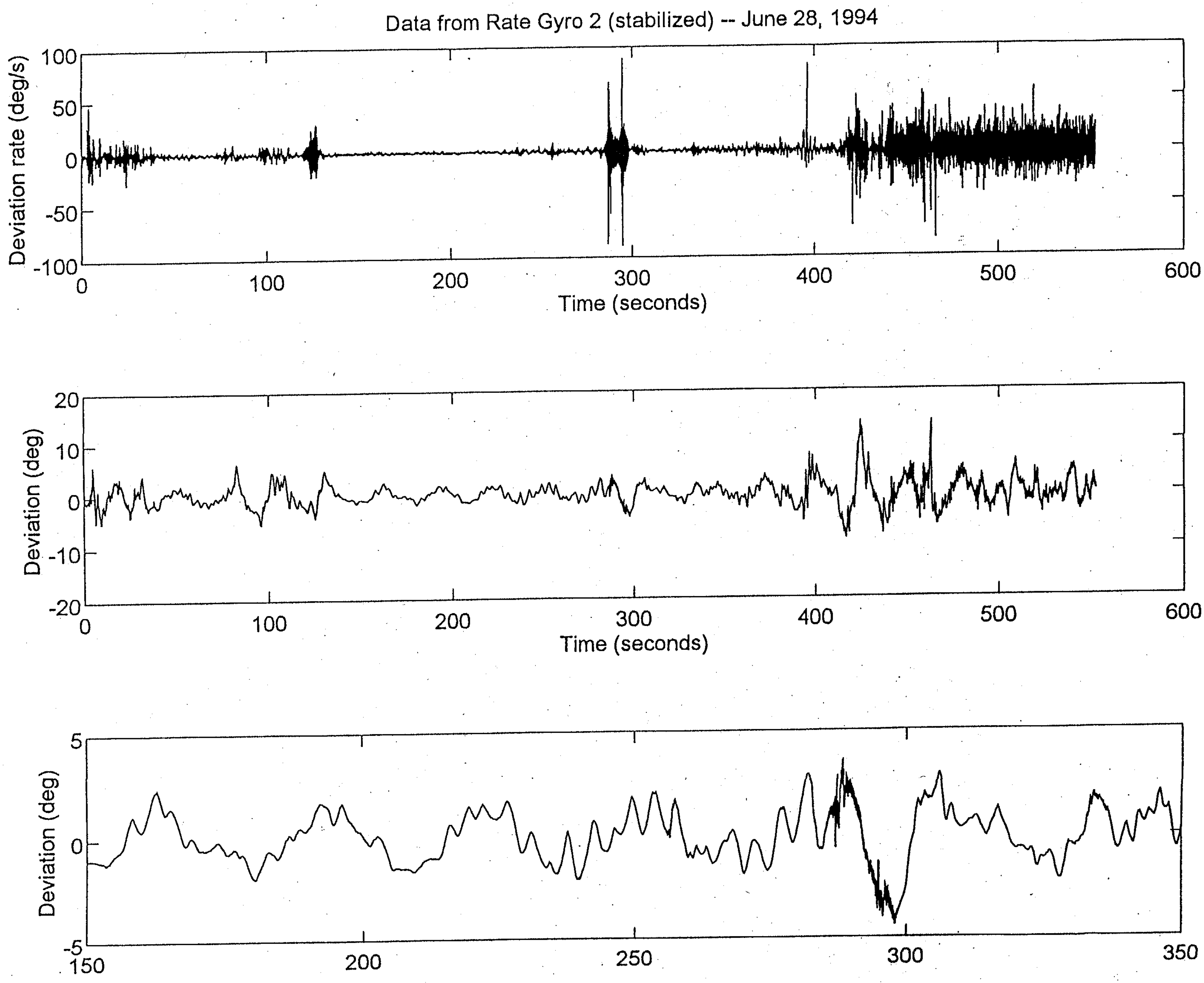

Data from Rate Gyro 1 (stabilized) -- June 28, 1994
Deviation rate (deg/s)
100
50
0
-50
-100
0
100
200
300
400
500
600
Time (seconds)
Deviation (deg)
20
10
0
-10
-20
0
100
200
300
400
500
600
Time (seconds)
Deviation (deg)
5
0
-5
150
200
250
300
350

Fig. 2



Data from Rate Gyro 2 (stabilized) -- June 28, 1994
Deviation rate (deg/s)
100
50
0
-50
-100
0
100
200
300
400
500
600
Time (seconds)
Deviation (deg)
20
10
0
-10
-20
0
100
200
300
400
500
600
Time (seconds)
Deviation (deg)
5
0
-5
150
200
250
300
350

Fig. 3