NOTES AND CORRESPONDENCE

Airborne Tracking Sunphotometer

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ABSTRACT

An airborne tracking sunphotometer, mounted on the outside top surface of an aircraft has been developed to provide unrestricted viewing of the Sun. This instrument will substantially increase the data that scientists can gather for atmospheric studies. The instrument has six wavelength channels and an automatic data gathering system. The instrument's optical features, tracking capability, mechanical features, and data gathering system are described.

1. Introduction

An airborne tracking sunphotometer has been developed at NASA Ames Research Center for the purpose of obtaining accurate multispectral atmospheric extinction measurements at different altitudes. The limitations of ground based sunphotometers are discussed in Pitts (1977). This new instrument is designed to be mounted on the top of an aircraft and outside the cabin in a configuration allowing an unobstructed view of the sun. Previous measurements were made by observing the sun through an aircraft window; this configuration severely restricted the viewing angle to the sun. Moreover, an additional calibration of the window had to be done to account for attenuation and angular effects.

2. Instrument

The instrument consists of a solar-tracking system, detector module, temperature-control system, nitrogen-purge system, mechanical drive chain, and data-collection system. A block diagram is shown in Fig. 1.

The two-axis solar-tracking system can be seen in Fig. 2. The solar-tracking system was designed to achieve two objectives: first, to be able to acquire the sun starting from a position several degrees away; and second, to track the sun with an accuracy of $\pm 0.1^\circ$ in the presence of aircraft movements. A large field of view (FOV) is required because the initial pointing is manually controlled until solar acquisition occurs. The large FOV simplifies the initial pointing and, in addition, enables the system to reacquire the sun if tracking is lost because of abrupt movements by the aircraft. To accomplish the two objectives under normal cir-

cumstances is not too difficult, but in this case the sensor was restricted in size and location. It was designed to fit into the detector module surrounded by the science detectors; the sensor design is shown in Fig. 3. The sensors used are Clairex photoresistors that have been matched to track each other over the operational range of sun intensities. The sensing technique uses a shadow mask that bisects each detector when the system is in balance. This design allows for very accurate tracking, yet at the same time provides a FOV of $\pm 25^\circ$. This unique design resulted in a sensor with a wide FOV and accurate tracking in a very compact package. The dome rotation is referred to as azimuth motion. The central section of the dome is free to rotate within the dome, perpendicular to the azimuth, and is referred to as elevation motion. The control system is designed to compensate for the flight characteristics of the Convair 990 aircraft and acceleration/vibration limits have not been determined. The flight conditions are benign, except during a turn. During cruise, the typical roll rate is ± 40 arc min in 30 sec, typical yaw is ± 10 arc min in 30 sec, and typical pitch is ± 6 arc min in 30 sec. The worst-case conditions occur during a turn; the time required to turn 360° at 400 kt is 8.2 min for an azimuth rate of $0.73 \text{ deg sec}^{-1}$. The system is designed to move in elevation or azimuth at 8 deg sec^{-1} . The acceleration that may occur during a turn is estimated to be 1.0 rad s^{-2} . If the instrument should lose lock the reacquisition occurs very rapidly as long as the sun is in the FOV of the instrument. The tracking system responds quickly because it uses a single rate of 8 deg sec^{-1} for tracking.

The detector module, shown in Fig. 4, is a cylindrical unit that plugs into the main unit through a connector.

FIG. 1. Airborne sunphotometer block diagram.

The module is easily removable for maintenance and repair. It contains six separate silicon photodetectors, each with its own optical filter, which are replaceable; a sun sensor for sun-tracking purposes; and a temperature sensor and heater to control the temperature inside the module. The filters range from 380 to 1020 nm with a nominal bandwidth of 10 nm. The detectors used are Silicon Detector Corporation devices that combine a detector and preamplifier inside a TO-5 style can. The FOV of each detector is set by the entrance aperture to 2° , the inside surfaces of the aperture assembly are anodized a dull black to reduce internal reflections, and a baffle is included to further reduce reflections. The 2° FOV was selected to allow for $\pm 1^\circ$ of tracking error without affecting the solar-radiation signal. The entrance aperture is protected from the airstream with a fused quartz window; no lenses are used in the system. Much of this design borrows from earlier work done by Tomasi (1978) and Russell (1978).

The temperature-control system uses a combination of accurate electronic feedback control and simple bimetallic thermostat controls. The reasoning behind this approach is that parts of the system require heating,

but not absolute temperature control. The six detectors located inside the detector module require absolute temperature control and are temperature controlled to $45^\circ \pm 1^\circ\text{C}$ by an analog temperature control system located inside the aircraft cabin. The position control electronics can withstand -55°C , but the stepper motors cannot operate below -10°C . The heating requirements here are easily served by heater blankets controlled by bimetallic switches. To reduce heat loss the dome shell and the detector module are constructed of fiberglass. The system was tested in an environmental chamber at -55°C ; the detector temperature dropped to 44.5°C and the stepper motor temperature dropped to 26°C .

To prevent condensation from forming on the window, a dry-nitrogen purge system is included. A small flexible tube is used to route the nitrogen into the detector module, as can be seen in Fig. 2. The nitrogen is continuously on during each flight from takeoff to landing.

The mechanical drive train was designed to provide a mechanical torque multiplication of 80 for the stepper motors and to prevent external forces from driving the

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FIG. 2. Airborne sunphotometer.

FIG. 3. Solar tracker sun sensor.

gear train backward. The torque multiplication was needed because the size of the stepper motors was limited by the size of the overall dome, which was purposely kept small to minimize aerodynamic drag. Stepper motors were chosen for the drive power because of their inherent reliability and adaptability to digital-control systems. Their reliability is due in large part to the fact that they do not contain brushes, a common source of mechanical failure, and their adaptability to digital control systems because they are digital devices that move in discrete steps. The gear train includes a nonslip drive belt that connects the stepper motors to a worm which in turn drives a worm gear. A characteristic of worm/worm gear combinations is that they cannot be driven backward by external forces. This desirable characteristic was specifically

FIG. 4. Detector module.

chosen to prevent aerodynamic forces from setting up mechanical oscillation. Backlash is present in the gear train, but is small enough to be ignored.

3. Data collection

The data-collection system is based on a Hewlett-Packard HP9816 computer with floppy disc and printer. A data-collection, data-processing, and printing program, which is interactive and easy to use, was written for the HP9816. Besides the computer, the data-collection system includes a multiplexer, a 12-bit analog-to-digital converter, and electronics to process the aircraft inertial navigation data. The data are sampled approximately every 2 sec and are synchronized with the aircraft data system which provides the altitude, longitude, and latitude data. The science dataset includes the six detector signals, detector temperature, tracking error, sun tracker azimuth angle, sun tracker elevation angle, and UTC time. The computer stores the data on 3.5 in. floppy disks, each of which can hold 270 kilobytes of data. The data are also printed out for real-time check and backup. Besides the data-collection program, additional programs are being written to process the data and display Langley and optical-depth plots. Future plans are to integrate some of the processing and plotting programs to operate in near real time to provide graphical display of atmospheric conditions during a flight.

4. Calibration and flight tests

The system was test-flown in December 1984, and in April 1985 it was flown in a validation mission for the SAGE 2 satellite. The 1985 mission was based in Brazil, and results were presented at the SAGE 2 Science Team Meeting at Ames Research Center in May 1985. Preparations were made to operate the sunphotometer in a second SAGE 2 validation mission in August 1985. However, the mission was canceled by the loss of the CV990 aircraft. In place of the lost mission, the system was taken to Mauna Loa Observatory to

obtain calibration data simultaneously with the University of Arizona calibrated sunphotometer. The instrument is designed to retain its calibration. The detectors are temperature controlled and the amplifier gains are set with precision resistors. The resolution of the detector signals is limited by the 12 bit analog—digital converter that can resolve 1 part out of 2048 of the 0 to +10v detector signals. The instrument is designed to operate in clear skies and it is also assumed that over the period of a flight profile there are no solar fluctuations. There is evidence in the literature that in the wavelength region of interest solar fluctuations would account for less than a 1% variation of the data. On the matter of clear skies, it is possible that the instrument could be used to look through patchy cirrus clouds by controlling the pointing with the data collection computer (assuming that the computer is fast enough to gather data and control the instrument) by utilizing the attitude, longitude, and time of day data. Several future missions are planned for this instrument.

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