Any noncondensable gases are collected by a Toepler pump and measured manometrically. These usually total less than 0.001 μmole per milligram of sample. Water is separated from other condensables by warming the trap to −78.5°C. The amount of noncondensable gas evolved ranges from 0.001 to 0.02 μmole per milligram. With this procedure, any CH_4 and H_2S, present in the salt, would be separated from the water before reaction of the water with the uranium. The sample water is reacted with uranium metal at 700°C as described by J. D. Godfrey [*Geochim. Cosmochim. Acta* **26**, 1215 (1962)]. Hydrogen liberated in this reaction is collected into a calibrated volume by a mercury Toepler pump and the amount of gas measured manometrically. Background water yields from the apparatus are less than 1 μmole, as determined by repeated analysis of sample blanks. Absolute water yields from the samples ranged from 30 to 950 μmole, depending on the sample size.
3. The experiment in Fig. 1 differed from the normal procedure described in (*2*) in that the salt sample was loaded into the furnace tube under laboratory air rather than under dry nitrogen. The water released below 218°C undoubtedly included atmospheric water vapor adsorbed on the interior surfaces of the apparatus during loading. Samples loaded under dry nitrogen yield no measurable water between 23° and 218°C, provided the samples are exposed to high vacuum for at least 30 minutes.
4. Oil was removed from sample RK-10 after sawing by soaking the sample in organic solvent Furfasol (John B. Moore Corp.).
5. The origin of the water responsible for such mine leaks is discussed in L. P. Knauth, M. B. Kumar, J. D. Martinez, *J. Geophys. Res.* **85**, 4863 (1980).
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7. This work was supported by DOE contract DC-AC-97-80ET46616. We thank J. D. Martinez and R. Wilcox for helpful suggestions. J. Stirling prepared the samples from Rayburn's dome. G. Smith, M. Beeunas, and M. Haimson assisted in the laboratory. A critical review by E. Roedder resulted in a substantial improvement of the manuscript.

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Clear Air Turbulence: An Airborne Alert System

Abstract. *An infrared radiometer system has been developed that can alert a pilot of an aircraft 2 to 9 minutes in advance of an encounter with clear air turbulence. The time between the warning and the clear air turbulence event varies with the flight altitude of the aircraft. In turbulence-free areas, the incidence of false alarms is found to be less than one in 3.4 hours of flight time compared to less than one per 10 hours of flight time in areas with turbulence.*

Clear air turbulence (CAT) constitutes a hazard to air safety, and a pilot warning in advance of a CAT encounter has become important to the welfare of aircraft passengers and crew. The CAT-related average economic loss of commercial and military aviation worldwide is more than $25 million annually (*1*). Forecasting CAT is difficult, since it is often a microscale phenomenon not usually apparent on synoptic-scale weather charts. An on-board detection device could warn the pilot of this phenomenon.

A high frequency of CAT and large changes in water vapor content are often associated with stable layers in the atmosphere. This is especially true at the tropopause, where dry, ozone-rich, stratospheric air comes in contact with relatively moist, ozone-poor, tropospheric air. Clear air turbulence produces marked variations in the distribution of water vapor, through which its presence can be detected with an infrared sensor that is sensitive to radiation in the molecular water vapor band.

Some atmospheric conditions that foster CAT are predictable—for example, a sloping tropopause or a standing wave in the lee of a mountain. However, there are conditions under which CAT is unpredictable. Vertical wind shear in stable layers can intensify until a critical value is exceeded locally. Spontaneously, Kelvin-Helmholtz waves can form, amplify, become gravitationally unstable, and give rise to CAT (*2–4*). Under these conditions, an on-board sensor may provide the only warning.

An infrared radiometer system has been developed by the NOAA Environmental Research Laboratories and NASA Ames Research Center that alerts the pilot to the onset of turbulence (*2*). It consists of an infrared radiometer with appropriate optics (*5*) mounted in a fixed forward-looking position on the aircraft. The voltage output response of the radiometer is received by a microprocessor, which computes the standard deviation of the stream of voltages over a prescribed time interval. If the deviation exceeds a certain threshold, a flashing light warns the pilot of the subsequent onset of turbulence. Cloud effects can be eliminated by use of a second channel of the radiometer in the portion of the spectrum from 9.5 to 11.5 μm (870 to 1050 cm^{-1}), so that the system responds only to CAT.

The system was tested in NASA jet aircraft flying at altitudes ranging from 5.8 to 12.5 km. The distance from which the radiometer can detect atmospheric emission anomalies increases with height, due to the decreased concentration of absorbing gas (water vapor) in the atmosphere at higher altitudes. Figure 1 shows an envelope of the alert time before a CAT encounter. The solid line is the maximum alert time based on experimental data. The dashed line indicates 70 percent values; that is, 70 percent of the alarms are received during the time period up to the curve. Figure 1 was produced empirically from the data for 367 encounters in all types of atmospheres. The edge of the envelope is not linear since atmospheric absorption is not linear.

Table 1 shows the results of compila-

Table 1. Results of CAT alert system tests based on all data obtained during CAT-dedicated missions in 1978 and 1979.

Category	Number	Percent
Total encounters	367	
Alert given	327	89.1
No alert given	40	10.9
Total alarms	380	
True alarms	327	86.1
False alarms	53	13.9

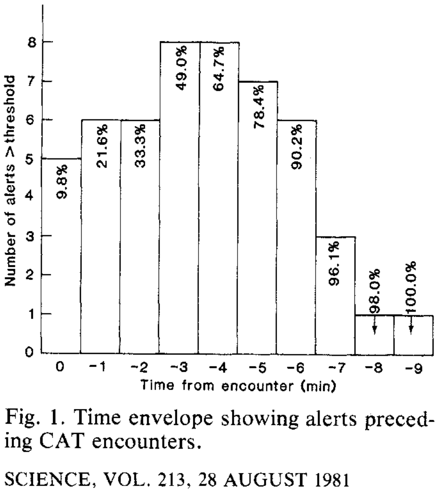

Fig. 1. Time envelope showing alerts preceding CAT encounters.

Table 2. Results of CAT alert system tests in nonturbulent areas with and without clouds.

Date in 1979	Cirrus included		Cirrus excluded	
	Hours	False alarms	Hours	False alarms
20 June	3.5	5	3.0	2
11 July	2.5	0	2.5	0
13 July	6.5	0	6.5	0
29 July	4.0	13	1.5	2
Totals	16.5	18	13.5	4

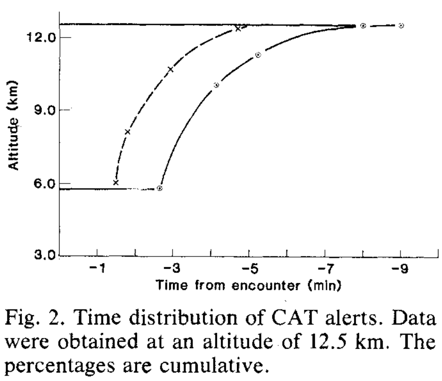

Fig. 2. Time distribution of CAT alerts. Data were obtained at an altitude of 12.5 km. The percentages are cumulative.

tion and analysis of all the data obtained under clear or cloudy conditions. The upper half of Table 1 shows the success of the system in alerting the pilot to subsequent encounters; the lower half shows the veracity of the alarms given. The false alarms include early data obtained when instrumentation and system problems were being experienced. The most recent data are from the 1979 CAT-dedicated missions carried out from the NASA Convair 990 aircraft. During these missions 36 turbulence events were encountered and alerts were given for 34 (94.4 percent). A total of 39 alarms were given, of which only five were false (12.8 percent). A comparison of the data from this last period with the total of all data shows a significant improvement in the system.

A typical time distribution of CAT alerts at a fixed altitude is illustrated in Fig. 2. Multiple alerts were received for each event. In 25 CAT encounters at an altitude of 12.5 km, the greatest number of alarms (31 percent) occurred between 2.5 and 4.5 minutes. More than half (57 percent) of the alarms were given between 2.5 and 6.5 minutes. This lead time is adequate for the pilot to warn the passengers and crew or to reduce the speed of the aircraft in order to minimize the impact of the turbulent area.

The CAT missions were flown without a cloud-detecting channel. The importance of eliminating cloud effects in future sensors is illustrated by the data of Table 2, which represent four nonturbulent flights with and without cloud effects. Fourteen false alarms were caused by clouds. On the basis of these results we conclude that the expected number of false alarms in cloud-free areas is about one per 3½ hours of flight time.

The results of these tests of the infrared radiometer system indicated that CAT may be detected from 2 to 9 minutes before an encounter at least 89 percent of the time at altitudes of 5.8 to 12.5 km. In the absence of general models for accurate ground prediction of CAT, on-board warning of nonconvective turbulence events is the most practical means of obtaining operational air safety.

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13 April 1981

Photochemical Oxidants Potentiate Yield Losses in Snap Beans Attributable to Sulfur Dioxide

Abstract. *Field-grown snap beans (*Phaseolus vulgaris*) were given recurring midday exposures to sulfur dioxide in open-top field chambers containing ambient photochemical oxidants. There was a linear correlation (correlation coefficient = −.99) between increasing concentrations of sulfur dioxide and the yields of snap beans. Synergism was indicated for the mixtures of ambient ozone plus sulfur dioxide, leading to threefold greater yield losses in nonfiltered air than in charcoal-filtered air (to remove the ozone). Even the lowest sulfur dioxide dose in nonfiltered air reduced the yields of Astro, a cultivar that exhibited no visible pollutant-induced foliar injury.*

It is projected that sulfur oxide pollution will become increasingly important as more coal is burned to satisfy the demand for electricity and industrial energy (*1*). Sulfur dioxide (SO_2), presently the second most important plant-damaging pollutant in the United States (*2*), is primarily a point-source pollutant. Ozone (O_3), the most ubiquitous and serious phytotoxic air pollutant affecting crop growth, originates from the action of sunlight on nitrogen oxides and hydrocarbons, products of automobile exhaust (*2, 3*). Only limited data are available on the impact of mixtures of SO_2 and O_3 on the yields of field-grown crops. Most data relate to foliar injury.

In 1966, O_3 and SO_2 mixtures were first reported to cause synergistic effects with respect to leaf injury on tobacco (*Nicotiana tabacum* L.) (*4*). Subsequent reports indicate that plant responses to $SO_2 + O_3$ may be additive, more than additive, or less than additive, depending upon the species tested and the conditions of the experiments (*5*). Tingey *et al.* (*6*) found that only 3 of 11 species tested showed synergistic responses. Pollutant concentrations and SO_2/O_3 ratios also influenced the plant response.

In a field study, Oshima (*7*) observed a significant exposure dose–response interaction for mixtures of SO_2 and O_3 when the O_3 concentrations were just below the threshold value required to reduce the yield of red kidney bean (*Phaseolus vulgaris* L.). He added SO_2 at the rate of 0.10 part per million (ppm) or 262 $\mu g\ m^{-3}$, about 6 hours per day on 45 days over an 11-week period to Los Angeles Basin air. The enhanced toxicity resulted when SO_2 was added to a 50:50 mix of carbon-filtered (CF) and nonfiltered (NF) air providing a total O_3 dose of 95 hours $\geq$ 0.10 ppm (196 $\mu g\ m^{-3}$) (filtration through carbon removes O_3). In another field study, soybean [*Glycine max* (L.) Merr.] plants were exposed to 0.10 ppm of SO_2 in CF air for 6 hours per day for 133 days beginning 14 days after emergence; their yields were not reduced when compared to plants grown in exclusively CF air (*8*).

We report here results obtained in 1979 at Beltsville, Maryland, using open-top chambers in the field to assess the impact of low SO_2 doses added to Washington, D.C., metropolitan air on the yields of three snap bean (*P. vulgaris*) cultivars. The cultivars were selected because of their known differences in resistance to ambient oxidants. An 8-year field study investigating the susceptibilities of 387 snap bean cultivars and breeding lines to oxidant-induced leaf injury had shown that 70 percent were resistant to the exposures, 22 percent were intermediate, and 8 percent were highly susceptible (*9*). Open-top chamber experiments, initiated in 1972, indicated that endemic oxidant concentrations in suburban Washington, D.C., lowered the yields of five plant species tested (including snap beans) by an average of 10 percent (*10*). Mean yields of four snap bean cultivars were reduced 4 percent by ambient oxidants during the 5-year period from 1972 to 1976 (*11*). We used three of these cultivars, Astro, Bush Blue Lake 274 (BBL 274), and BBL 290, which, based on the yield response, were oxidant-resistant, oxidant-intermediate, and oxidant-susceptible, respectively. Cultivar BBL 290