Jets, haze, and the strato-sphere

Twenty kilometres high in the sky sounds a long way up—commercial jet airliners only cruise half as high. So it seems astonishing that tiny particles less than a millionth of a metre across so far up in the stratosphere may affect us. Yet very possibly they may.

The debate on how high-flying supersonic aircraft will affect the stratosphere created a lot of heat, but not too much light. One of the few firm conclusions to come out of it was that we know so little about the natural processes occurring at those altitudes that we can't make more than educated guesses about the effects of jet engine pollution.

Concern about the effects on the stratosphere of supersonic airliners like the Concorde and the Russian TU-144 has centred on two main problems: could the exhausts of the aircraft weaken the earth's ozone shield, allowing more ultraviolet radiation to reach the ground, and could the particulate material and water vapour that their engines throw out so alter the amount of radiation reaching and leaving the earth that changes in the climate will result?

In *Ecos* 2 we looked at ozone. We reported that it's unlikely that supersonic jets flying at 20 km would weaken the ozone shield, but the possibility cannot be ruled out. (To be on the safe side the Australian Academy of Science has recommended that they fly below 18 km.) In this article we discuss the effects of particles and water vapour.

In the Southern Hemisphere very few aircraft fly in the stratosphere. However, north of the equator a much larger number, especially military ones, do. Studies of how radioactive fall-out moves have told us that, up to 40 km, very little mixing of the stratospheric air occurs across the equator. So comparing the relatively pristine Southern Hemisphere with the Northern one may reveal the effects of pollution.

Twilight glows

Remember those twilight glows that you've seen on a cloudless night about 20 minutes after sunset or before sunrise? At an altitude of 10 km they look even more spectacular, becoming a brilliant yellow or orange. At 20 km most of this spectacular colour has gone.

Mount Agung, the holy mountain of Bali, quiet again after the 1963 eruption in which it hurled vast amounts of dust high into the stratosphere.

More than 50 years ago scientists realized that light from the sun scattering off tiny particles located in the stratosphere caused this effect. Dr Keith Bigg, at what is now the CSIRO Division of Cloud Physics at Epping near Sydney, was fascinated by these glows. He began studying them in 1954.

In his early experiments, Dr Bigg measured from the ground the rate at which the light intensity changed during twilight. These experiments revealed the location of the particles—about 20 km above the earth near the equator, but somewhat lower at latitude 34°S, the latitude of Sydney—and gave some idea of their size and numbers.

The German scientist C. E. Junge obtained the first direct samples of these particles 4 years later in 1958, using instruments suspended beneath balloons over the United States. These samples revealed that, in the Northern Hemisphere at least, the particles consisted of ammonium sulphate. During the next 3 years further samples taken using balloons and the now-notorious U-2 aircraft confirmed both the particles' chemical make-up, and that they occur in a narrow band.

It happened that several U-2 aircraft were stationed in Australia between 1962 and 1964 to sample radioactive fall-out from nuclear tests. Dr Stan Mossop, a colleague of Dr Bigg, approached the United States Air Force asking if samples of the stratospheric particles could be taken from the aircraft using his instruments. His request was readily agreed to. As a result he was able to obtain samples from altitudes of up to 21 km from an area stretching from Cairns to Antarctica.

Mount Agung erupts

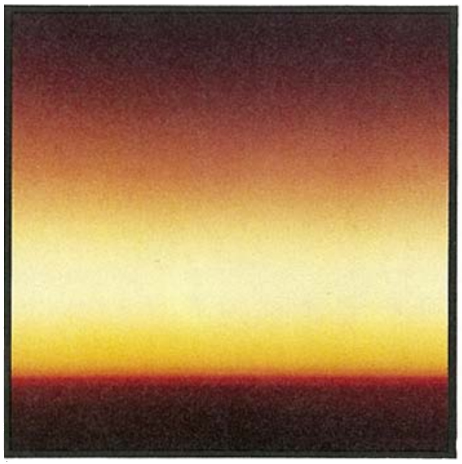
Dr Mossop's first chemical analyses revealed that, as in the Northern Hemisphere, stratospheric particles to the south of the equator consisted mainly of ammonium sulphate. But right in the middle of this sampling period the largest volcanic eruption for more than 70 years occurred at Mount Agung on the Indonesian island of Bali. Mount Agung threw huge quantities of dust and gases high into the stratosphere. Within a month this debris began to drift over Australia, giving at first spectacular twilights, but later extinguishing the colours altogether and producing a dirty brown sky instead.

The U-2 samples revealed that the stratospheric particles were changing too. As the twilight glows became more brilliant, Dr Mossop began picking up particles that contained relatively large chunks of volcanic dust surrounded by a coating of ammonium sulphate. A few months later the large dust particles had become far fewer, but now they were coated with sulphuric acid, not ammonium sulphate. By the time the U-2s departed early in 1964, the particle band consisted almost exclusively of sulphuric acid.

With the departure of the U-2s went Dr Mossop's means of taking samples. The Division didn't attempt to take any more until 1968. For several years the Australian Department of Supply had been launching large helium-filled balloons from Mildura and Longreach for the United States Atomic Energy Commission—once again to monitor radioactive fall-out. Dr Bigg approached the Commission late in 1967, and it agreed to let him have space on these balloons, so sampling began once more.

Perhaps the most surprising result coming from this work is that even now, more than 12 years after the eruption of Mount Agung, the majority of particles in the southern stratosphere consist of sulphuric acid. So far, Dr Bigg has no idea whether this change from ammonium sulphate to sulphuric acid has had any effect on the world below.

Recently, in America, with the help of the University of Wyoming and the National Centre for Atmospheric Research (who flew his instruments), Dr Bigg was able to compare the situation locally with that to the north of the



Twilight 10 km up.

Relatively colourless twilight glow higher up at 20 km.

Preparing a helium-filled balloon before dawn.

Dr Bigg thinks that the natural variations are so great that it will be very difficult to tell if aircraft are having an effect.

equator. He and his American colleagues could detect hardly any differences—in the Northern Hemisphere too the predominating particles have changed from ammonium sulphate during the late 1950s to sulphuric acid, possibly as a result of the Mount Agung explosion. This eruption could be the cause, since above 40 km considerable mixing of the air of the two hemispheres does occur, and we know that debris went that high.

Fewer particles now

Dr Bigg has observed other changes in the particle band too. Photographs taken in 1968 with cameras mounted on the balloons revealed clearly visible layers of particles within the band. Two years ago these layers could still be clearly seen, but now they have gone. The layers have become so blurred that they can't be seen at all. At the same time the actual number of particles in the stratosphere seems to have gone down.

In Dr Bigg's opinion, these results suggest that the natural variations occurring within the particle band are so great that it will be very difficult to tell if aircraft are having an effect. He also thinks it will take another 10 years to document even seasonal changes, or those produced by minor volcanic eruptions. Perhaps the fact that relatively few supersonic aircraft will be flying in the Southern Hemisphere for some years yet will allow him sufficient time to build up enough background information for us to detect any changes that may occur should these aircraft become common.

Jet engines throw out solid soot particles and gases—mainly unburnt fuel, sulphur dioxide, oxides of nitrogen, carbon dioxide, and water. Sulphur dioxide would react with the oxygen in the air in a matter of seconds to become sulphur trioxide, and then with water vapour to become sulphuric acid. So in fact the engines are laying a trail of sulphuric acid particles. In addition, the oxides of nitrogen give nitric acid. At the height that commercial airliners currently fly this probably doesn't matter very much, since the strong up-and-down circulation at those altitudes rapidly disperses these pollutants and rain washes them out. But higher up in the stratosphere where they would remain on average for about $1\frac{1}{2}$ years, they would disappear only very slowly.

To get the problem of particle pollution into perspective, it's worth remembering that the Academy of Science estimated that the total stratospheric build-up of carbon and sulphuric acid particles likely to be emitted from supersonic aircraft flying in 1985 is only 0·7% of the total weight of particles occurring there naturally. The Academy was unable to calculate the weight of particles likely to be formed from nitrogen oxides.

Influencing climate

So why worry about particles at all?

Enough particles spewed out in the stratosphere may be expected to cool the climate simply because their bulk interferes with the sun's radiation as it passes through the atmosphere.

A far-fetched idea? Not really, when one realizes that there is evidence that temporary cooling caused by the increased dust load in the stratosphere may occur following volcanic eruptions. In addition, the particles may trigger the formation of cirrus clouds in the bottom levels of the stratosphere—similar particles certainly appear to affect cloud formation at lower altitudes. Water vapour thrown out from the jet engines of many high-flying aircraft may have the same effect, by so increasing the level of water vapour in the stratosphere that cloud haze forms. The engines may also form vapour trails, which again may spread out and form a cloud haze.

Such cloud hazes from any cause would interfere with radiation reaching and leaving the earth—either by preventing it from reaching the earth, or by the opposite effect of reducing heat radiation from the atmosphere. There is a good deal of dispute within the scientific community about which of these opposite effects would be the greater, and the extent to which they will occur depends on the amount of water vapour naturally existing in the stratosphere.

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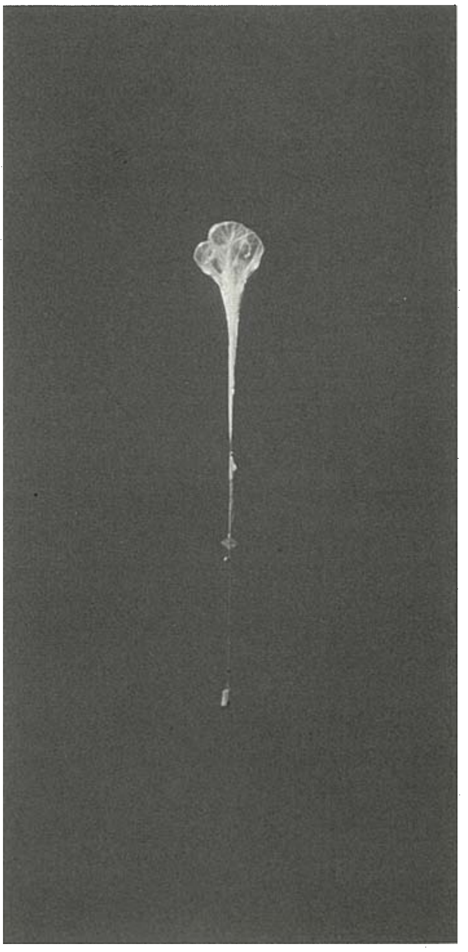


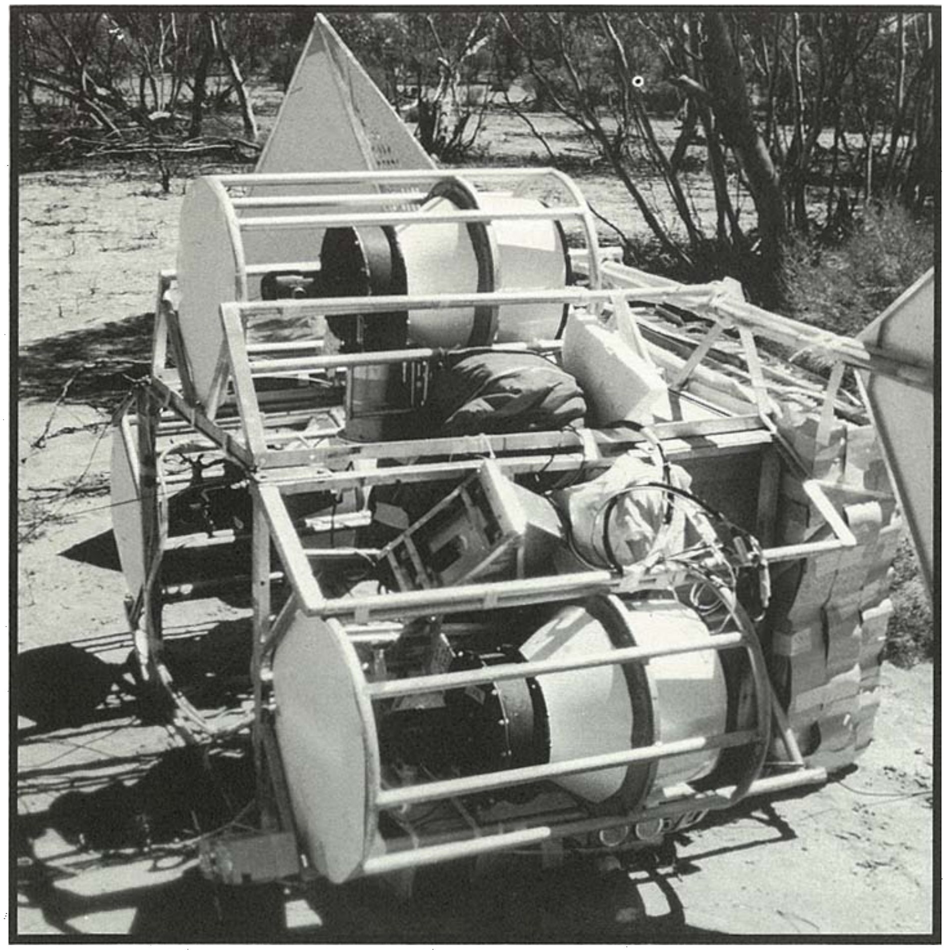
There it goes!

For the last 2 years, Mr Peter Hyson of the CSIRO Division of Atmospheric Physics at Aspendale, near Melbourne, has been investigating how much water vapour the stratosphere contains. Like Dr Bigg, he has been attaching instrument loads to balloons belonging to the United States Atomic Energy Commission launched from Mildura and Longreach. The RAAF has also been flying one of his instruments in a Canberra bomber.

The consensus of opinion among scientists in the Northern Hemisphere is that the stratosphere contains very little water vapour—only about 2–4 p.p.m. Mr Hyson's results agree.

After 10 years of study, H. J. Mastenbrook at the Naval Research Laboratory, Washington, D.C., has shown that this level does vary a little with the time of year, but it's still too early to know if similar cycles occur in the Southern Hemisphere.

For clouds to form, the relative humidity would need to approach 100%, but at latitude 34°S over Sydney, a water vapour content of 2–4 p.p.m. at a height of 15 km gives a relative humidity of only about 6%. The Academy of Science suggested that, by 1985, water vapour emitted by



The balloon's instrument package has come back to earth.

supersonic transport aircraft in the stratosphere could increase the world-wide level by about 10%. So, over the latitudes of Australia at least, cloud formation would be extremely unlikely.

Polar haze

Nevertheless, the stratospheric air in Australian latitudes may be particularly dry. During winter, extremely high cirrus clouds have been seen over Norway—suggesting that in polar regions the water vapour concentration may at times reach saturation at 15–20 p.p.m. A cold band also occurs over the tropics, and there too less humidity would be required to cause saturation. Even so, the Academy concluded that an average global increase of 0·2 p.p.m. of water vapour caused by aircraft 'would be unlikely to cause any considerable change in cloud amount in either polar or equatorial zones'.

As to the effects of vapour trails, the Academy 'expected that supersonic aircraft will produce contrails which may last for several minutes, but which will be more likely to disappear within 30 seconds on most occasions'. The Academy even went so far as to suggest that it may be preferable from this point of view for the heavy air traffic now flying at 8–12 km in the troposphere to transfer to the stratosphere, since over the United States jet vapour trails spreading out into extensive cirrus cloud sheets has apparently become a familiar sight.

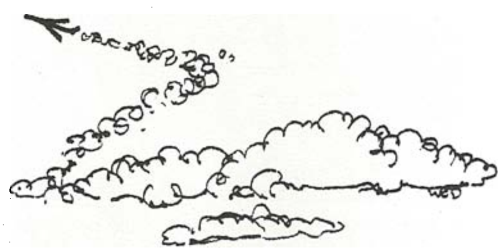
To date, all calculations done have assumed that clouds will only form if the relative humidity is close to 100%. However, it may be that, if enough atmospheric particles are present, clouds will form when the humidity is lower—a point worth bearing in mind when making future calculations.

The high wispy cirrus clouds you see are composed entirely of ice crystals; and, once formed, these crystals may continue to grow in humidities of 70% or less. (This explains why jet vapour trails in relatively cloudless skies can spread out into cirrus cloud sheets.) In clean air, not many ice crystals form until the humidity is close on 100%.

In experiments carried out from an aircraft flying in clean air at altitudes of up to 8 km over Tasmania, Dr Bigg tried to create clouds by dropping trails of dry ice pellets laid in patterns into cold and humid but cloudless air patches. Frequently, above 6 km, sizeable clouds formed in the shapes of the original seeding patterns.

City atmospheres contain particles that behave like dry ice in that they cause ice crystals to form at humidities of less than 100%. No research has yet been done to see if the particles thrown out by jet engines behave in the same way, but if high-flying aircraft do produce large numbers of such particles then they may cause clouds to form. The most likely time when such clouds would form is when a weather change approaches. High cirrus clouds would appear earlier than they do at present, and this might alter the course of events that accompany the change.

The United States Atomic Energy Commission ceased financing the Australian balloon launchings early last year, but the Department of Supply's launching team has continued its work (at least for the time being) with the support of the Australian government. The Divisions of Atmospheric and Cloud Physics have now bought their own smaller balloons, and Mr Hyson and Dr Bigg will join forces and launch their instruments on the same balloon. So Australian research into water vapour and particles in the stratosphere will continue.



More about the topic

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