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Aviation and Jet Contrails: Impact on Astronomy

H. Pedersen[1]

Copenhagen University Observatory, Juliane Maries Vej 30, DK 2100 Copenhagen, Denmark

Abstract. Attention is drawn to aspects of aviation that have a detrimental effect on ground-based astronomy. Depending on observing methods, science data can be influenced by an aircraft's emission of light, its thermal emission, exhaust products and condensation trail. Although these effects are mostly short-lasting for a given observing direction, they can be highly significant, and influence time-resolved astronomical observations. While the very young contrails can easily be recognized by ground-based or spaceborne observations, concern should also be given to older (hours, days) contrails, which have lost their characteristic linear shape. Contrails may grow to widths of tens of kilometers, and become almost indistinguishable from natural cirrus. As aviation increases, this may imply fewer photometric nights, in particular in the northern hemisphere, where by far the largest fuel consumption takes place.

1. Introduction

Already in 1977, the IAU recognized that airplane lights, heat, exhaust, and condensation trails could seriously degrade observational astronomy, and it was recommended (Graham Smith 1977) that aviation near observatories should be limited to below 10^o above the horizon, and that low-flying aircraft should not come closer than 5 km.

It appears that these recommendations have been successfully adopted by Spain and Australia for some of their observatories, whereas many other countries have not adopted the rules or do not enforce them.

While in principle the IAU recommendations should provide substantial protection, the volume of aviation has risen greatly, since the late 1970s. According to the International Civil Aviation Organization (ICAO), as many as 17,000 commercial jets were in operation in 1997, carrying 1.4 billion passengers [1]. To this one must add small aircraft (<9 t) and military aviation, rescue services, etc. During the coming years aviation is expected to grow significantly, with only modest gains in fuel economy or other emission standards. The Intergovernmental Panel for Climate Change (Penner et al. 1999) has discussed scenarios with up to 9 times higher fuel consumption by the year 2050, compared to 1990.

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[1]guest researcher

Some airliners already fly on routes close to astronomical observatories and in the future this may become more commonplace. This is to a large extent due to improved navigation aids, which no longer oblige a pilot to fly from one radio beacon to the next. And considering the enormous amounts of fuel combustion products, and their long residence times in the upper air, it can be expected that aviation will generate long-term effects that will slowly deteriorate general observing conditions. It is therefore becoming evident that the current IAU recommendations offer insufficient protection for astronomical observations.

2. Aircraft Lights, Heat Emission

What are the major effects on observational astronomy? Stroboscopic and fixed aircraft lights may contaminate wide-angle imaging, and with the advent of wide-angle CCD imaging, the problem will be felt more. However, this effect, and the actual appearance of aircraft in solar imaging, for example [2], is a minor problem compared to the influence of engine exhaust and the resultant condensation trail (contrail). Heat emission can be traced far behind an airliner, where it may limit good 'seeing' conditions. Using the power law dependency given by Schumann et al. (1998) it can be estimated that the temperature difference with ambient air is 0.1 K or more at a distance of 25 km behind the aircraft, corresponding to 100 seconds of flight time. During this time an exhaust plume in an orthogonal jet stream field will have swept over $\sim$1000 square degrees, as seen from a mountain top observatory.

3. Young Contrails

The condensation trail that forms in the wake of many flights is possibly the greatest threat to astronomy. As the trail sweeps over the sky, optical and infrared observations are affected by increased sky background, lesser transmission, and possibly by spectroscopic signatures.

The formation of a contrail depends on a range of parameters, which are fairly accurately described by the Schmidt-Appleman formula (see Schumann 1996). At a typical flight altitude of 10,000 m, contrails form when the air temperature is about -50 °C for 0% RH, while for 100% RH contrail formation sets in already at -40 °C. The exhaust's content of carbon soot plays an important role for contrail formation by furnishing cloud condensation nuclei. Also sulphuric aerosols may influence contrail formation. Most often the contrail evaporates after a few seconds, leaving soot in suspension. However, for supersaturated conditions the contrail may acquire water from ambient air. Under such circumstances it may persist for several hours, during which it will spread and most likely loose its linear shape. The optical thickness of the cloud may well exceed one.

Other constituents of aircraft exhaust, such as carbon oxides, nitric oxides, sulphur dioxide and unburned fuel slowly pile up in the atmosphere, or change it chemically (over the major flight corridors, anthropogenic NOx has already doubled the upper troposphere's concentration of those molecules). However, on short terms the effects are probably too small to be seen spectroscopically.

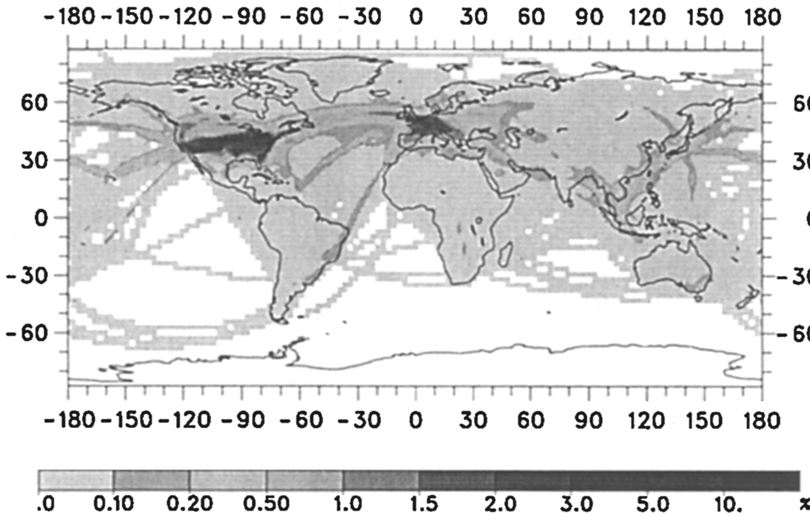

Figure 1. Time averaged global coverage by young, persistent contrails, according to modeling by the German Aerospace Centre (DLR). Apart from Antarctica, almost no land areas are protected against young contrails. Courtesy DLR.

4. Average Contrail Cover

For reason of their influence on global climate, contrails and their microphysics are being studied at several sites, in particular at the German Aerospace Centre (DLR) at Oberpfaffenhofen and the NASA centre at Langley, Virginia, USA.

To assess the amount of sky covered by contrails, systematic observations are required, and these are best carried out from space. The 1-km resolution AVHRR detector on board NOAA satellites has proven particularly useful. One image, from February 11 1999, shows as many as 70 contrails covering most of the sky over some New England states [3]. Another, from May 1995, shows a large set of contrails over southern Germany [4]. This latter image has been used to test DLR's automatic contrail recognition algorithms, which have then been applied to a much larger data set. The result is a map showing the average noon-time contrail coverage over Europe during 1996 (Figure 17 of Mannstein et al. 1998). In the most affected regions, more than 1 percent of the sky is covered by young contrails. Older, distorted contrails cannot yet be measured; this will require increased temporal and spectral resolution.

Apart from this observational approach, it is possible to model the mean contrail coverage making use of the Schmidt-Appleman criterion, knowledge of high-altitude fuel consumption and meteorological data (Sausen et al. 1998). For example, the programmes developed at DLR allow one to estimate what could be gained by changing typical flight altitudes as s function of geographic latitude. As to the time-averaged situation, Figure 1 shows that only the southern oceans are almost entirely free of young, persistent contrails, while Europe, North America, and parts of East Asia are covered by several percent. Present day modelling is, however, unable to predict the lifetime of a contrail, once generated.

5. Cirrus Formed by Contrails

Groundbased and spaceborne observations have revealed that some persistent contrails survive for many hours, and develop into extended cloud formations. An early observation was that of Georgi (1960), who described a contrail spreading into a 20^o wide cirrus band. The NOAA satellites have followed one cluster of contrails for 17 hours, during which it spread to cover 35,000 square kilometers (Minnis et al. 1998). Another contrail, imaged by the ISIR instrument (on board Space Shuttle) grew to 30 km width [5]. These results were obtained in fairly limited studies, so there is no reason to believe that they represent extremes. Existing techniques seem unable to distinguish a contrail in its late stages of development from natural cirrus. Some of these clouds may be optically thin, almost invisible to visual detection techniques, but yet have strong infrared spectral absorption (Smith et al. 1998).

This anthropogenic cloud formation has long since given rise for concern. Changnon (1981) noted a loss of sunny days over the mid-western USA, and provisionally tied this to an increased abundance of cloud condensation nuclei caused by jet aviation. A similar rise of high-level clouds over Salt Lake City around 1960 coincided in time with a rapid rise in jet aviation (Liou, Ou, & Koenig 1990). Recently, Boucher (1999), working on data from 1982 to 1991, detected a significant rise in cirrus over extended regions of the northern hemisphere, and linked this to aviation. Many others have pointed out that increased cirrus cover will lead to higher night-time temperature, hence further evaporation and cloud formation.

6. Degradation of Observing Conditions

Degradation of astronomical observing conditions has already been noticed at European observatories. Mt. Wendelstein Observatory, belonging to Munich University, is placed at 1845-m altitude in the Alps, some 75 km SE of that city. The observatory web site [6] states: *Mid 1970: Increasing air pollution caused by the increasing air traffic prevents further observations of the solar corona and worsen all other observations.* It has been shown (Schumann 1999) that the loss of coronal visibility at Mt. Wendelstein is not due to optically thick clouds, but is more likely caused by contrails. Also Pic du Midi remains affected by anthropogenic cirrus, as do many other European and North American observatories.

7. Protecting the Best Sites

It is evident from inspection of Figure 1 that the west coast of South America is strongly protected against interference by old contrails. This absence of degraded and fuzzy contrails is a valuable asset for photometric and other critical observations.

The threat from young contrails is, however, on the increase. More than 70 commercial and military flights pass daily along the Chilean coast. Typically 10 of these are at night-time. A year-long study at Paranal has tabulated their closest approach to the ESO Very Large Telescope (VLT). The vast majority pass west of the mountain, 20^o - 25^o above the horizon (Pedersen 1998). Considering the typical upper troposphere wind speed, the engine exhaust and its eventual contrail will pass the observatory's zenith $\sim$10 min later, and remain in the field-of-view for $\sim$5 sec.

This interruption of high-quality conditions may not be noticed right away by the observer, but nevertheless degrades observations with non-statistical scatter, high sky background and/or increased absorption. Usually, such data will be rejected, but if the astronomical target itself is variable, the drop in intensity caused by a contrail may pass for true data.

This is obviously not desirable, so for large ground-based observatories evasive action has to be taken, if rerouting of the aircraft corridors is not an option. Visual detection of the instantaneous aircraft positions is possible, but experience shows that contrails are hard to see against a dark sky. Also, such observations are difficult to bring into a useful, digital form. Therefore, for the ESO VLT an instrumental (all-sky CCD) system is being considered (Sarazin, private communication). All night long at one-minute intervals this would log the celestial position of any aircraft above the observatory horizon. The system could draw upon upper troposphere meteorology to derive expected moments of contrail passage, and supply these warnings to human observers and automatic telescope scheduling processes. At the same time, quantitative information is generated on the general sky conditions, i.e. natural cloudiness, extinction coefficients and sky background.

Active systems, depending on lidar or radar, are also possible, but should in general be avoided as they in themselves emit unwanted radiation. On an even more general level, it might be asked if contrail formation can be suppressed. This would limit the most immediate effects on astronomy. Careful selection of flight altitudes or routes appears as one possibility, and is already used by military aircraft. Some of these, for example the B2 Stealth bomber, are equipped with a rear looking lidar [7] to warn the pilot against 'conning', (military jargon for contrail formation). To enforce similar systems on civil aviation will not be easy, since commercial incentives seem absent. Chemical additives (e.g. chlorosulphonic acid) have the potential of achieving the same goal. They work by lowering the surface tension of water, thereby limiting droplet sizes to below 1 micron. Special fuels like CS_2 also prevent contrail formation. Unfortunately, the properties of all known contrail inhibitors are unsuitable for application in large volume.

8. Discussion

The absence of nearby air routes has long been considered a selection criterion for new observatories, and some countries have successfully adopted legislation to protect their sites accordingly. Nevertheless, the present huge volume of aviation inhibits full protection of some established sites. To some extent, observers worldwide can take preventive measures, but obviously professional observers, and for that matter amateur astronomers and the general public too, would be better served by a less contaminated sky.

It is desirable that the level of tropospheric emissions be moderated in some way, so as to limit accumulation of exhaust products. Currently, aircraft emissions are limited only for take-off and landing, and then only for NOx, CO, and unburned hydrocarbons. Emission of soot at flight level is just one of several quantities that could be limited by international agreement. Furthermore, not only commercial flights should abide to stricter standards, but also military flights.

In the mean time, astronomers have good reason to follow carefully the trends in night-time cloudiness, and to develop evasive observing strategies.

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References

Boucher, O. 1999, Nature, 397, p.30.

Changnon, S.A. 1981, Journal of Applied Meteorology, 20, p.496-508.

Georgi, J. 1960, Zeitschrift Meteorologie, 14, p.102.

Graham Smith, F. 1977, IAU/UNESCO - DG/2.1/414/44

Liou, K.N., Ou, S.C., and Koenig, G. 1990, "Air Traffic and the Environment", U.Schumann, ed., Lecture Notes in Engineering, Springer, p.154-169.

Mannstein, H., et al. 1999, Int. J. Remote Sensing 20, p.1641-1660.

Minnis, P., et al. 1998, Geophys. Res. Letters, 25, p.1157-1160.

Pedersen, H. 1998, ESO Report, Reference No. VLT-17443-1679.

Penner, J.E., et al. 1999, "Aviation and The Global Atmosphere", Cambridge University Press.

Sausen, R., et al. 1998, Theor. Appl. Climatol. 61, p.127-141.

Schumann, U. 1999, "Contrail Cirrus", Report No. 114, DLR, p.1-22; to appear in *Cirrus*, ed. D. Lynch (Oxford University Press, in press).

Schumann, U., et al. 1998, Atmospheric Environment, 32, p.3097-3103.

Smith, W.L., et al. 1998, Geophys. Res. Letters, 25, p.1137-1140.

[1] http://www.icao.int/icao/en/jr/5306_r3.htm

[2] http://physics.usc.edu/solar/direct.html

[3] http://www.osei.noaa.gov/Events/Unique/Other/UNIcontrails042_N5.jpg

[4] http://www.dfd.dlr.de/app/iom/1999_03/

[5] http://isir.gsfc.nasa.gov/main.html

[6] http://bigbang.usm.uni-muenchen.de:8002/USM/WDST/history/

[7] http://www.ophir.com/airborne.htm