A. D. ANDERSON
Lockheed Palo Alto Research Laboratory, 3251 Hanover Street, Palo Alto, Calif. 94304, U.S.A.

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Abstract. A significant number of the present long-range subsonic jet aircraft flights are in the stratosphere. Based on fuel consumption, an equivalent of 107 SST aircraft (Concorde) have been flying in the stratosphere each year from 1960 to 1970 (620 equivalent SST in 1990). Subsonic jets in 1990 will burn about 1.6 times as much fuel in the stratosphere as SST aircraft. Based on a Concorde emission index of 12.5 for NO, the amount of NO\textsubscript{x} emitted by subsonic jets in the stratosphere from 1960 to 1970 is equivalent to an average of 20 Concordes (444 Concordes in 1990).

Available information concerning mixing and transport in the atmosphere indicates that both subsonic jets and the SST will fly in the same atmospheric environment in the upper troposphere and lower stratosphere insofar as dissipation of their exhaust pollutants is concerned. The tropopause is not an effective barrier to mixing of stratospheric and tropospheric air. Many processes contribute to mixing in the lower stratosphere where the residence time of contaminants is of the order of months instead of years.

1. Introduction

The future widespread use of the stratosphere by supersonic transport (SST) aircraft, such as the Concorde and TU-144, has raised many questions regarding possible effects of SST aircraft engine emissions on the physical properties and chemical composition of the stratosphere. In particular, it has been suggested by Johnston (1971), Crutzen (1972), and others that a large volume of U.S. SST B-2707 aircraft flights will seriously pollute the stratosphere. Particularly, it is proposed that NO\textsubscript{x} exhaust products will reduce the column density of O\textsubscript{3} allowing a significant increase in UV radiation on the earth’s surface. On the other hand, the U.S. Government claimed that there will not be significant stratospheric pollution. This controversy appears to have ignored the important fact, pointed out by Jocelyn et al. (1973), that a substantial number of subsonic jet aircraft are flying in the stratosphere at the present time. Thus, it appears that there are enough aircraft exhaust products being deposited now in the stratosphere by subsonic aircraft to be able to detect any trends toward dangerous modification of the stratosphere. Thus, the suggestion that the stratosphere be carefully measured prior to SST flights may lead to more information about current depositions in the atmosphere than about truly uncontaminated air.

The chief factors affecting the concentration of aircraft pollutants in the atmosphere are the atmospheric thermodynamic structure and circulation. These in turn affect the rate of transport and mixing. The SST exhaust consists of CO\textsubscript{2}, H\textsubscript{2}O, CO, NO, SO\textsubscript{2}, particles, and hydrocarbons (Varney and McCormac, 1971). Each exhaust constituent may react with one or more of the natural atmospheric constituents. If the exhaust gases are concentrated in relatively narrow latitude and altitude bands corresponding to heavy aircraft travel routes, the resultant meteorological effects may be different than if the exhaust gases are spread throughout the stratosphere. Assuming that dif-
fusive stratospheric motions over a 25 month residence time uniformly mixes the water vapor resulting from 500 SST aircraft through the 15 to 30 km layer over the entire northern hemisphere, the mixing ratio in the stratosphere would be increased by only 0.5 ppm (Sissenwine et al., 1972). The amount of water vapor resulting from burning a given amount of SST fuel is, except for CO₂, at least an order of magnitude greater than any of the remaining pollutants.

In this paper, the available information concerning the atmospheric structure, circulation, transport and mixing will be examined in detail to try to determine how important are these factors on the residence times of contaminants resulting from subsonic jet exhausts. This will help in assessing the future impact of SST aircraft emissions on the stratosphere. First, atmospheric structure will be examined for its effect on the exchange of air between the troposphere and stratosphere. Next, the mixing and residence times of minor constituents (pollutants) in the lower stratosphere will be considered for the region where both the subsonic jets and Concorde and TU-144 will be flying. Evidence will be presented indicating that both the subsonic jets and SST aircraft will be flying in the same atmospheric environment insofar as the dispersion of their exhaust products is concerned.

2. Atmospheric Structure

The tropopause is the boundary between the troposphere (below) and the stratosphere (above). It marks a change in the vertical temperature lapse rate from rather large values in the upper troposphere to relatively small or even negative values in the lower stratosphere. According to the U.S. Standard Atmosphere Supplements (1966) (Figures 1 and 2), all latitudes are in the troposphere below 9.5 km in July (8.5 km in January). All latitudes are in the lower stratosphere above 15.0 km in July (12.2 km in January). The transition between the troposphere and the lower stratosphere varies between 9.5 and 15.0 km in mid-latitudes in July (8.5 to 12.2 km in January).

The following definition of the stratosphere was adopted by the World Meteorological Organization (WMO) in Rome, 1961:

Stratosphere – A region situated between the tropopause and the stratopause in which the temperature generally increases with height. The stratopause is the top of the inversion layer in the stratosphere, usually about 50 to 55 km.

There is, in fact, an isothermal layer in the lower portions of the stratosphere in mid and high latitudes, and at more poleward locations the thickness and importance of this segment of the stratosphere become increasingly obvious (see Figures 1 and 2). As a result according to Webb (1966), most atmospheric scientists now follow the above definition of the stratosphere in general, with a further subdivision of this principal atmospheric layer into an upper and lower stratosphere. The upper boundary of the lower stratosphere is called the stratonull. It is defined as a surface of minimum meridional temperature gradient, evidenced by a minimum or change in the gradient in the vertical wind profile. It varies in altitude, with a mean winter height of about 25 km in