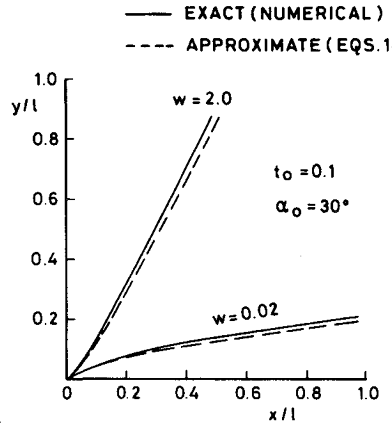

Fig. 2 Shape of towing cables.

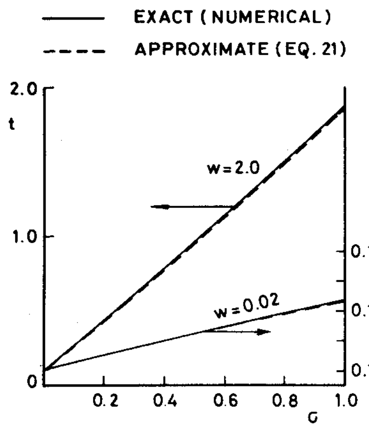

Fig. 3 Variation of tension along the cable.

following the same procedure that was taken for a, one obtains a similar solution

$$b_1 = (B_1 + B_2\sigma)^{-k} \tag{19a}$$

$$B_1 = 1 \tag{19b}$$

$$B_2 = -\frac{b'(0)}{k(b_0-b_c)} = -A_2\frac{a_0}{b_0}\,\frac{a_0-a_c}{b_0-b_c} \tag{19c}$$

from which

$$\frac{x}{l} = b_c\sigma + \frac{b_0-b_c}{(k-1)B_2}\left[1-\frac{1}{(1+B_2\sigma)^{k-1}}\right] \tag{20}$$

Finally, the tension variation along the cable may be calculated by integrating Eq. (8)

$$t = t_0 + wy/l + .0.02x/l \tag{21}$$

In practice, the exact shape of the cable is of less importance than the vertical separation and horizontal distance between the towing aircraft and the towed vehicle, and the maximal tension in the cable. All of these are obtained directly by putting $\sigma = 1$ in Eqs. (18), (20), and (21).

As was stated previously, the perturbation solution is of order $(a_0 - a_c)^2$, and might be expected to give good results even for $(a_0 - a_c)$ values that are not so small relative to a_c. To illustrate this, the approximate solution is compared to the exact (numerical) solution in Figs. 2 and 3. Calculations were carried out for typical values for towed targets, of $t_0 = 0.1$, $\alpha_0 = 30$ deg and two extreme cable weights of $w = 0.02$ and 2.0. It is seen that the approximate solution gives satisfactory results for both cable shape and tension even in these extreme conditions.

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Natural vs Man-Made Stratospheric Particulate Loading

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Introduction

THERE is abundant evidence that the earth's climate has been subject to a wide variety of fluctuations whose periods have ranged from decades to millenia.[1-6] At present, there is concern that the activities of man are influencing or even causing a global climatic change.[7-9] The main force driving the climate of the earth-atmosphere system is solar radiation. The incoming solar energy absorbed by this system is in approximate balance with the outgoing infrared radiant energy. However, variation in the radiative properties of the earth's surface and the composition of the atmosphere are very important factors, because they govern the nature and magnitude of changes in the heat balance.

Particulate Matter

Suspended particles are observed throughout the entire earth's atmosphere. These particles have an effect on the global energy budget by their modification of the atmospheric radiation balance through the scattering and absorption of light.[10] The sizes of the particles that are suspended in the atmosphere range from about 10^{-7} cm $(10^{-3}\mu)$ to 10^{-2} cm $(10^{2}\mu)$. In general, these particles cause Mie scattering, in which most of the solar radiation is scattered in the forward direction. For particles whose sizes are much less than the wavelength of light, the Mie scattering equation can be approximated by the Rayleigh scattering equation. In both situations, a component of this radiation is scattered into space, a component of it absorbed, and a component reaches the surface of the earth, where it is absorbed. Thus, these atmospheric particles can change the total sunlight that is scattered by the earth back into space. In this way, the global albedo is modified. However, these particles also radiate energy in the infrared spectrum, modifying the field of terrestrial radiation in a manner that depends on the optical properties of the particles and the temperature structure of the atmosphere.[11]

As seen in the preceding, there exists a mechanism whereby atmospheric particulate matter can produce important changes in the global heat budget. There can be natural

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feedback within this mechanism. For example, if for some reason the surfaces winds increase, more particulates are blown up into the atmosphere, which will tend to change the heat budget of the earth, which in turn may modify the wind pattern. However, there exists processes of injecting particulates into the atmosphere that are external to a natural feedback process; therefore, these processes themselves are independent of the global heat budget, but they do indeed affect the heat budget. These processes are those that are caused by man's activities. The component of atmospheric particulates due to man, and the component due to natural processes, determine the quantity and quality of soil, rock, and chemical debris within the earth's atmosphere. An evaluation of man's contribution is particularly desirable, since it is quite substantial and is amenable to control.

In the following two sections, we will discuss two of the major processes that contribute to stratospheric particulates, one natural process and one man-made process. For each of these two major processes, we will estimate their present-day rates of particulate injection into the stratosphere.

Volcanic Activity – A Natural Process

Volcanic activity probably has been the most important variable source of atmospheric particulates throughout history. Its variability strikingly correlates with climatic changes. Hamilton and Seliga[12] have shown that the temperature over the Greenland and Antarctic ice sheets decreases as the volcanic dust falling on those ice sheets increases (and vice versa) over the past hundred millenia. Bryson[13] and Reitan[14] have shown that in the last hundred years a major control of the global mean temperature in the Northern Hemisphere has been volcanic dust augmented by man's contribution. Budyko[15] has shown from direct measurements of the solar radiation normally incident at the ground under cloudless skies that the atmospheric transmittance varied during the past century in such a way that the highest values occurred in the warm period of the 1920's and 1930's when volcanic activity was at a minimum.

All of the preceding facts imply, but do not prove, that throughout history, as volcanic activity increased, more solar radiation energy was reflected into space, and the mean global temperature of the earth decreased (and vice versa). However, in the past thirty years something new has occurred. Volcanic activity was at a relatively low ebb until the 1950's, when it began to increase. One would expect that a global cooling would follow this increase in activity, but both the mean temperatures as well as the measured radiation intensity in the Northern Hemisphere began to decrease well before the 1950's. This suggests another source of atmospheric particulate loading, which became significant by 1940.[16,17]

Mitchell[8] has calculated that the average stratospheric loading of very fine particulate matter (0.1-1.0 μ), because of volcanic activity over the past century, was about 4.2 million metric tons. He assumed that only 1% of the ejected matter from the major eruptions reached the stratosphere, and he assumed a residence time of 14 months. If we assume a steady-state situation, this implies that an average of 3.6 million metric tons of volcanic particulates was injected into the stratosphere in an average year over the past century. Lamb[18] has compiled a Dust Veil Index (DVI), which is an indicator of atmospheric particulate loading due to worldwide volcanic activity. Lamb[18] obtained an average DVI of 300 over the past century, but, because of the decrease in volcanic activity after 1915 or so, he obtained an average of less than 10 for the DVI over the past three decades. If Mitchell's estimation of 3.6 million metric tons/year for an average rate of injection over the past century corresponds to a DVI of 300, we arrive at the annual average of 120,000 metric tons per year of volcanic particulates injected into the stratosphere over the past three decades, corresponding to a DVI of 10.

Jet Aircraft Stratospheric Emissions – A Man-Made Process

If the increase in man's activities is the source of increased particulate material, then there should have been a nearly exponential increase in the atmospheric loading from man's by-products in the middle third of this century. A number of observations indicate that this has been the case.[19] Recently, the explosive population growth in the drier monsoon regions of the earth has led to overuse of the land, and has resulted in extreme dust loading of the atmosphere[20]; in the wetter tropical regions, an increase in agriculture slash-and-burn rotation rates has led to increased production of smoke. Geosynchronous satellite images have shown that particulate matter from agriculture burning in Central America can be dispersed over thousands of kilometers.[21,22]

The residence time for particulate matter in the troposphere is on the order of hours or days,[23] but in the stratosphere, it is on the order of months or years.[9] It is shown below that, at the present time, commercial jet aircraft load particulate matter directly into the stratosphere at a rate of one-half of that due to volcanic activity.

Downie[24] made a study of transcontinental commercial jet aircraft flights over the United States and the North Atlantic. He found that during the winter months these aircraft were cruising above the tropopause almost 90% of the time. At these higher latitudes, the tropopause generally is at a lower altitude during the cold season. The cruise altitude for most transcontinental commercial jet aircraft is on the order of 30,000 to 35,000 ft at a speed of Mach 0.85.

First, let us consider the smaller jet engines, e.g., JT3D, such as those that power the DC-9, Boeing 727, and the Boeing 707. At 30,000 ft at 80% of maximum thrust, the fuel flow per engine is approximately 1800 kg/hr. On the average, the emission index (EI) for carbon particulates under the previous cruise condition is 0.1 g/kg of fuel. For an EI of 0.1 g/kg, the particle size distribution is as follows: 35% of the carbon particles are less than 0.01 μ; 60% less than 0.05 μ; 75% less than 0.10 μ; and 99.85% less than, 0.50 μ.

Second, let us consider the larger jet engines, e.g., JT9D, RB211, and CF6, such as those that power the DC-10, Boeing 747, and the L1011. At 30,000 ft at 80% of maximum thrust, the fuel flow per engine is approximately 2700 kg/hr. On the average, the EI for carbon particulates for the larger engines under the previous cruise conditions is 0.02 g/kg of fuel.

Not only carbon particulates, but also sulfur particulates (aerosols), are emitted. If we assume reasonably a sulfur component in the fuel of 0.05% by weight, the emission index for sulfur dioxide is 1.0 g/kg of fuel. (Also, if we assume a hydrogen-carbon ratio of 2 for the fuel, the EI for water is 1300 g/kg).

The world fleet of operational commercial jet aircraft today totals about 5000. From a study[25] by the U.S. Federal Aviation Administration, this fleet size is projected to increase 50% by 1985, and to increase by almost 300% by 1995. Of the present day commercial jet fleet of 5000, there are approximately four smaller jets for each larger jet. Let us assume 4000 for the smaller jet fleet and 1000 for the larger jet fleet. The annual average worldwide utilized flight time per day per jet aircraft is on the order of 7½ hr. In order to estimate the carbon particulates emitted into the stratosphere due to commercial jet aircraft, let us assume the following: 1) a mixture of types of engines for simplicity; a) 4000 jet aircraft with 3 engines/aircraft with 1800 kg/hr of fuel flow with an EI for carbon particulates of 0.1 g/kg, and b) 1000 jet aircraft with 4 engines/aircraft with 2700 kg/hr of fuel flow with an EI for carbon particulates of 0.02 g/kg; 2) an approximate annual average of 7½ hr flight time per day for both types of commercial jet aircraft; 3) neglect all military aircraft operations (military operations are approximately 10% of commercial operations). Let us assume that, for 90% of the time during one-third of the year, these aircraft cruise above the tropopause.[24] Then from these data, and under the previous assumptions, we arrive at 1951 metric tons of carbon particulates from commercial jets emitted directly into the stratosphere each year (1774 metric tons emitted from the smaller aircraft, and 177.4 metric tons emitted from the larger aircraft).

Engine residue also consists of sulfur dioxide and sulfur trioxide particulates, which are oxidized in the lower stratosphere through photochemical reactions. Sulfur trioxide immediately hydrolizes[26] to form sulfuric acid, H_2SO_4, and samples show that these H_2SO_4 droplets usually are on the order of tenths of a micron in size.[27] Since the EI of sulfur dioxide is twenty times that of the carbon particulates, and the H_2SO_4 weight equivalent of sulfur dioxide is 98/64 times the sulfur dioxide, this increases the loading of particulates in the stratosphere to 39,000 metric tons/year due to sulfur dioxide alone; or about 59,700 metric tons/year of H_2SO_4 particulates.

Thus, commercial jet aircraft emit over 60,000 metric tons of particulates a year into the stratosphere. This is to be compared with volcanic activity, which injects particulates into the stratosphere at approximately twice this rate (120,000 metric tons/year, see the preceding). Since there are some reasons to believe that stratospheric particulates due to volcanic activity has influenced global climatic changes in the past,[12-15] that the present-day global climate is changing,[7-9] and that the present rate of man-made stratospheric particulate loading is half that of volcanic activity, then we should be concerned.

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Technical Comments

Comments on "Experimental Investigation of Subsonic Turbulent Separated Boundary Layers on an Airfoil"

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THE authors assert, in the introduction to their experimental paper,[1], that the referenced theoretical models (Refs. 2 through 6) work reasonably well up to the onset of flow separation or at most where the separated regions are small, but that they fail with large regions of separated flow.

It seems indeed unfortunate that the authors neglected to consider the Westinghouse[7] automated algorithm for the prediction of the pressure distribution on two-dimensional noncavitating lifting hydrofoils, isolated or in cascade, even

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