S37-02

Modeling of the Expected Lidar Return Signal for Wake Vortex Experiments

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Abstract

A computer program that models the Lidar return signal for Wake Vortex experiments conducted by the Aerosol Research Branch was written. The specifications of the program and basic theory behind the calculations are briefly discussed. Results of the research and possible future improvements on it are also discussed.

Introduction

Recently, the Aerosol Research Branch of the Atmospheric Sciences Division at Langley Research Center began undertaking Lidar based measurements of the Wake Vortex regime of an airplane. This research is of significant interest for many reasons. First, the entrainment of the exhaust plumes by the wingtip vortices of the airplane effects the dilution of the exhaust gases into the atmosphere. It can also result in chemical reactions that can lead to the formation of highly reactive species such as sulfur oxides and nitrogen oxides. These can in turn effect the atmosphere. Increased knowledge of wake vortex phenomena is also of interest for airplane safety since aircraft vortices have been linked to several airplane crashes. Much of the work done on vortex phenomena has been in the area of numerical modeling, such as Continuum Dynamics' UNIWAKE program. There has been very little experimental verification of these models. The Lidar based investigations hope to provide such verification, as well as other information such as the types and sizes of exhaust particles. In conducting these experiments it is obviously useful to know how high the quality of the data can be expected to be for different experimental setups. For this reason it is useful to have a working model that can provide such information and which agree well with experimental data.

Summary of Research

The goal of this research has been to create a computer program that would produce a theoretical Lidar return signal that is as realistic as possible. It is hoped that this can provide information about the experimental setups that will yield the best data, and what kind of data quality can be expected from them. The program models the scattering of a laser pulse off atmospheric molecules and the exhaust particles of the aircraft plume, which has been entrained into the wingtip vortices. The program is written in the Interactive Data Language (IDL) version 3.6.1 for use on a PC.

The problem is approached primarily from a theoretical standpoint. Given a laser with a certain wavelength and power, the power elastically backscattered off the atmospheric molecules into a particular light detector is calculated using the formulae for Rayleigh backscattering coefficients as provided in Raymond Measure's, <u>Laser Remote Sensing: Fundamentals and</u>

Applications. The amount of backscattered light is sampled every 1.5m, which is the same sampling interval the detectors in the actual experiments use. The molecular density of atmospheric molecules is also required for this calculation. This is calculated for the different altitudes using the methods described in U.S Standard Atmosphere, 1976. The program also calculates the amount of Mie backscattered power scattered off the particles in the exhaust plume of an aircraft. The plume is assumed to have a gaussian vertical distribution with a full width half maximum given by the program user and centered about an altitude also given by the user. The particle size distributions are taken from previous work done by June E. Rickey, but the program allows for other size distributions to be used. The amount of Mie backscattered power is calculated using a Mie scattering program from C.F. Bohren and D.R. Huffman's Absorption and Scattering of Light by Small Particles. To determine how much of the backscattered radiation is detected the radius of the telescope is required, as well as the reflectances and transmissions of the various mirrors and beam splitters in the detector system. These can all be entered and altered by the user.

Once the amount of backscattered power is known, this can be converted to the number of photons per second detected by dividing by the individual photon energy. Also, the total number of photons detected in each 1.5m range bin can be calculated. Multiplying this number by the efficiency of the Photomultuplier tubes in the detector assembly yields the number of photoelectrons detected in each range interval. At this point, synthetic noise is added to make the model more realistic. This is done using the random number generator provided by IDL. The resulting model return signal looks qualitatively like an actual return signal.

This signal is then compared with an actual return signal to determine how realistic the model is. The model is found to give a significantly higher signal to noise ratio than the experimental signal. Thus an additional factor must be added to the model to downgrade the performance of its detector assembly. This is still in the process of being done.

In conclusion, this program produces model Lidar return signals that qualitatively resemble experimental Lidar return signals. With further work the programs output will more closely resemble an experimental signal and hence will be more useful. There are many improvements that can still be made to it. For example, a more user-friendly interface is being added making the program easier, as well as simplifying the process of changing the different input values. Also, better results might be obtained by changing the vertical plume distribution from a gaussian to one predicted by the UNIWAKE model or some similar one. Unfortunately, time has run out to incorporate this into the program.