Computational Investigation of Early-Stage Condensation Trails of a Subsonic Transport Aircraft

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Description: Our research focuses on highly resolved simulations of a typical subsonic transport aircraft with an aim to understand the sensitivities of aircraft condensation trails (contrails) to various atmospheric conditions and aircraft parameters. Depending on the atmospheric relative humidity (RH), persistent contrails can potentially evolve into cirrus clouds via processes not yet well understood. Persistent contrails and contrail-induced cirrus clouds were identified as significant contributors to radiative balance from aviation-associated processes (IPCC, 1999). Parametrization of these processes is also noted to have a high degree of uncertainty.

The specific question this research effort hopes to address is how the amount of ice and its size distribution in aircraft contrails vary with the atmospheric relative humidity and temperature. The approach taken uses Large Eddy Simulations (LES) of the vortex-wake and turbulent exhaust jet along with Lagrangian tracking of soot-ice particles. Contrail growth for 1-2 minutes after the aircraft passage is simulated in the initial study. Figure 1 shows the schematic of the contrail development regimes. Our study focuses on the interaction regime where the vortex wake and exhaust jets interact strongly. Figure 2 shows the distribution of ice in the wake of the aircraft. In this case the ambient humidity was significantly lower than the RH in the jet exhaust. As a result the jet water vapor drives the ice growth.

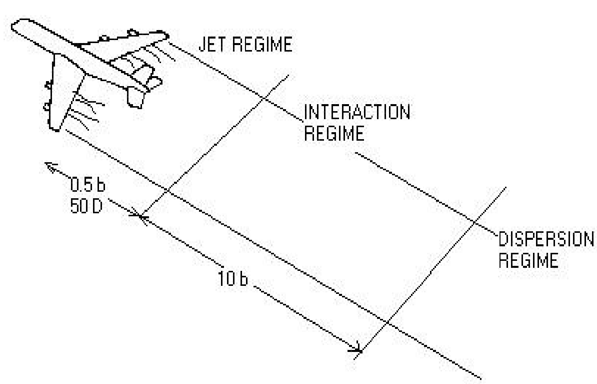


Figure 1: Schematic of wake-jet development regimes behind a transport aircraft. b is wing span

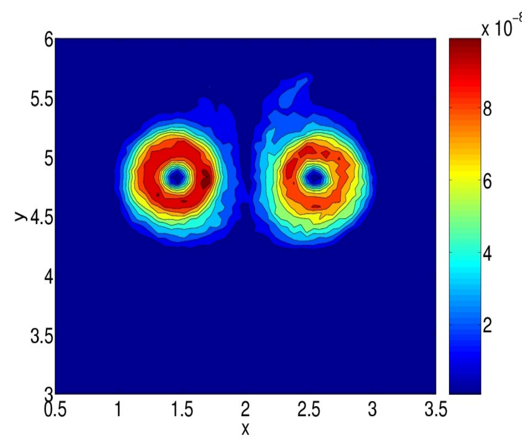
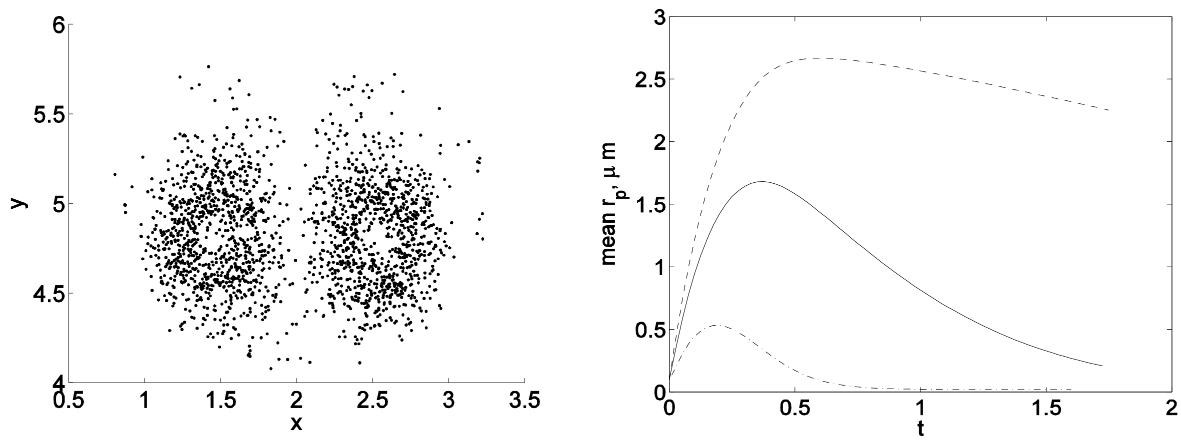


Figure 2: Ice mass density in kg/m^3, averaged in the flight direction

In addition to the baseline case with T_{amb}=220K, higher and lower values of 227K and 213K were simulated. The time evolution of the mean ice particle radius (Figure 3b) shows the general feature that first, due to the jet exhaust super saturation, ice growth takes place on the soot particles, but at later times as the jet exhaust diffuses into the unsaturated ambient air, the ice sublimates.

Furthermore, lower temperature causes increased freezing of water vapor on the droplet surfaces. Figure 3a shows the distribution of the ice particles as they are advected by the vortex pair. Simulations were also carried out at different levels of ambient stratification and it was found that the sensitivity of contrail growth to stratification in the early stage is quite small.



(a) (b)

Figure 3: (a) Ice distribution at t = 45sec (b) Evolution of mean particle size for T_{amb}=220K (solid), T_{amb}=213K (dashed), T_{amb}=227K (dash-dot)

To summarize, we have developed a code to perform three-dimensional LES of the early evolution of contrails using high order spatio-temporal schemes. During the first 1-2 minutes after the aircraft passage, ambient temperature has a dominant effect on the ice growth but stratification is relatively unimportant. Studies of contrails in an atmosphere which is supersaturated with respect to ice are continuing and persistent contrail growth is expected.

Status: This work is continuing with support from the FAA PARTNER Center of Excellence in collaboration with Boeing and Aerodyne Inc. Our next step is to incorporate the numerical interpolations into larger computational domains which are necessary for carrying out the simulations to longer contrail evolution times. Another item of development is the comparison/calibration of the simple ice-microphysics model with detailed ice-microphysics simulation. Also under development is a simulation for a Boeing 767 aircraft under realistic cruise conditions. Using the LES database, the contrails will be analyzed for optical properties which are crucial in assessing the effect of contrails on the radiative forcing.

Reference: Aviation and the global atmosphere, IPCC, 1999.

Publications:

A. Shirgaonkar and S. Lele, "High-resolution Simulations of Aircraft Wake-Exhaust Mixing With Applications to Contrail Formation", AIAA Paper 2005-4909.

A. Shirgaonkar and S. Lele, "Large Eddy Simulation of Contrails: Effect of Atmospheric Properties", AIAA Paper 2006-1414, 44th AIAA Aerospace Sciences Meeting, Reno, 2006 (In preparation).

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