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Aircraft Wake Investigation

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Abstract

THE Air Force Weapons Laboratory (AFWL) conducted a test to determine the wake characteristics of a B-52 in flight. Variations in the ambient atmosphere introduced by an aircraft wake manifested by increased wind velocities and gas constituents can cause fluctuations in laser beam propagation. By flying a B-52 upwind of a highly instrumented meteorological tower, wake vortex wind speeds and gas concentrations of the exhausts were obtained. The test was conducted in crosswinds as high as 80 ft/s which allowed the inspection of wakes 5 s in age and 2000 ft behind the aircraft. In this region, it was found that the vortex contained: 1) wind speeds in excess of 210 ft/s and 2) a 250% increase in the concentrations of CO_2. The implication of these results is that propagation of high-energy lasers through aircraft wakes could be seriously degraded.

Contents

Introduction

In developing an airborne laser weapon system, the Air Force Weapons Laboratory (AFWL) investigated methods to calculate and measure attenuation of laser radiation due to disturbances generated by the carrier aircraft. A flight test was conducted to measure aircraft generated characteristics in the flowfield that would most affect beam propagation. First, CO_2 concentrations generated by the engines were measured. CO_2 and water vapor in the laser beam's path promote molecular absorption, i.e., localized heating in the beam path resulting in a degrading lensing effect. The only relief from this heating transverse to the beam path is the aircraft's motion through the air (freestream) and the vortices shed from the wing tips which are in close proximity to the engine exhausts.

The Flight Test

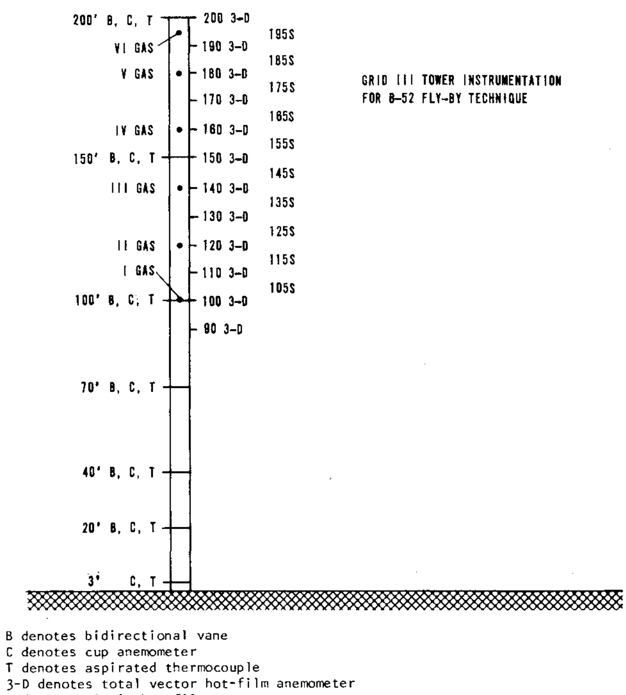
A B-52B was used as the test aircraft. The B-52 was equipped with smoke generators to mark the left wing tip and the exhaust positions of the four engines on the left wing. The method of measuring the vortex velocities involved hot wire anemometry placed on a tower located downwind of the passing aircraft. The ambient crosswind would then transport the vortex through the tower for measurement. The National Oceanic and Atmospheric Administration (NOAA) 200 ft meteorological tower near Idaho Falls, Idaho, was the tower used in this test. The top 120 ft of the tower was instrumented with a combination of 2-D and 3-D anemometers (see Fig. 1) manufactured by Thermo Systems, Inc. Because of availability, this mixture of anemometers was used. The lower 80 ft of the tower was considered to be in ground effect and was not instrumented.

In order to obtain fast, pointlike gas samples from the passing wake, an array of vacuum bottles with high speed solenoid sampling values were designed, built, and mounted on the tower. The 6×6 array of 50 ml bottles co-located with anemometers (see Fig. 1) were capable of sampling for 1/50 of a second. One tenth of a second delay between columns of bottles allowed six vertical slices of gas sampling in the vortex. As each column sampled, the solenoid opening and closing was recorded with the anemometry output to provide spatial information on sampling. Figure 2 is a sample of the anemometry with the solenoid event markers shown along the x axis as square waves.

Vortex visualization was accomplished by using the smoke generators on the B-52 and an array of color smoke grenades mounted on the tower (see Fig. 1). The combination of these smoke streams allowed the B-52 to position itself at the correct altitude such that the vortex impinged the tower. The B-52 flew a race track pattern which took the centerline of the aircraft 240 ft from the tower on the upwind leg. The B-52 maintained cruise configuration and flew at Mach numbers of 0.34 and 0.43.

Results

The test was conducted in a 38 mph average wind. The B-52 flew at a 200 ft altitude on the upwind leg. Nineteen passes by the tower were made. Of these, six were used to collect gas samples. Anemometry was run on every pass. In Fig. 2 the u-w velocity component of the vortex from a 2-D anemometer is shown for Run 16. Zero time is when the B-52 was directly upwind of the tower. From the time axis, the age of the vortices was calculated. The ages ranged from 4 to 6 s, which equates to 1600-2400 ft behind the aircraft. The peak velocity



B denotes bidirectional vane
C denotes cup anemometer
T denotes aspirated thermocouple
3-D denotes total vector hot-film anemometer
S denotes single hot-film anemometer
Gas denotes sample bottles

Fig. 1 Grid III tower instrumentation.

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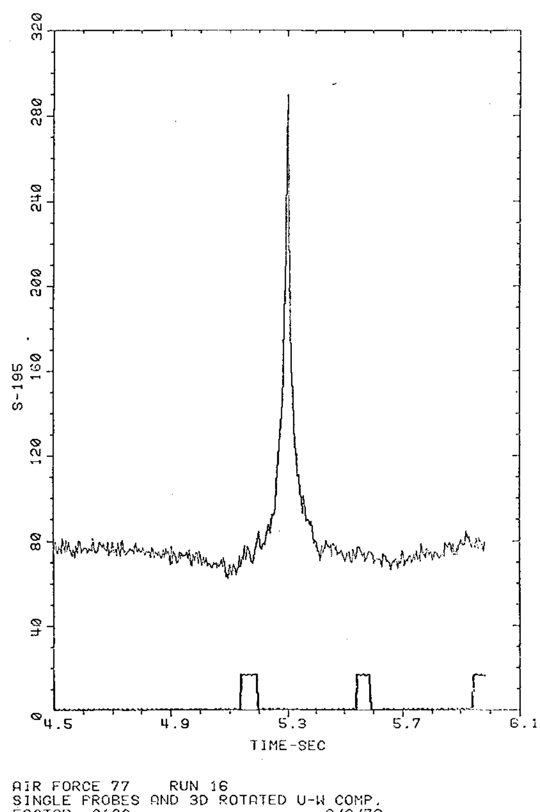

Fig. 2 Run 16 anemometry output.

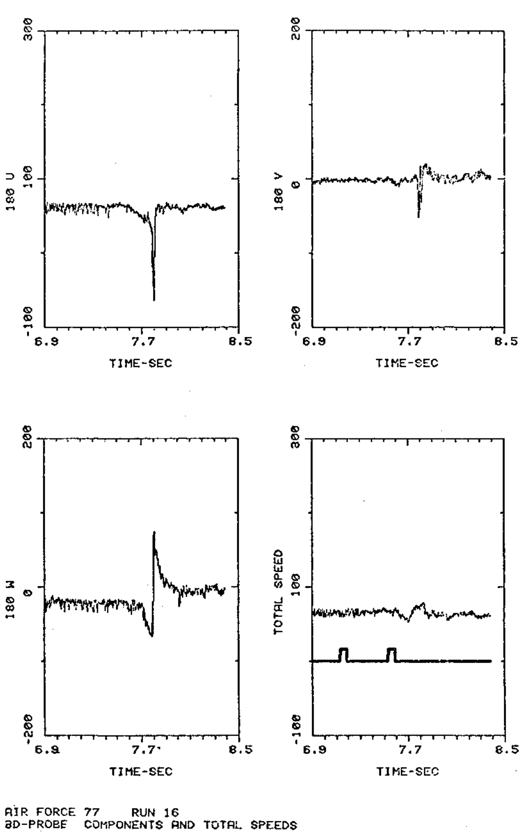

Fig. 3 Anemometry components for Run 16.

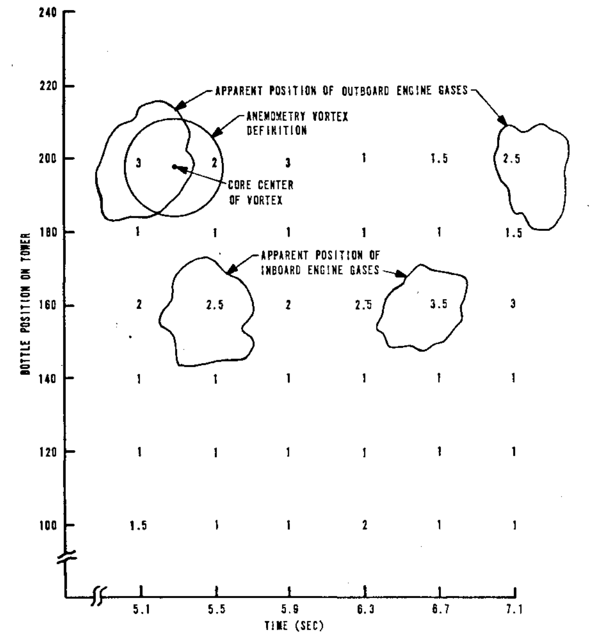

Fig. 4 CO_2 concentrations for Run 16, shown with aircraft wake (CO_2 concentrations in ppm).

encountered was 210 ft/s shown in Fig. 2. The minimum peak velocity in the vortex was 55 ft/s. Figure 3 shows Run 16 broken into its velocity components, u-component (wind direction), v-component (flight direction), and w-component (up the tower); an orthogonal system.

A mass spectrometer was used to analyze the contents of the gas sample bottles. Because of the inherent difficulty in accurate measurement of water vapor for comparisons, only the CO_2 concentrations were used for comparison. Comparisons were made to a reference sample made before each run. The CO_2 content was double that of the background readings when the engine exhausts passed through the tower. Other constituents remained the same, with the exception of water vapor, which went off scale, indicating extremely high concentrations of water. Figure 4 displays the 6×6 bottle array analyzed for Run 16. The figure shows the vortex position and the CO_2 distribution. The CO_2 concentrations are in parts per million. The increased CO_2 concentrations mark the position of the eight engine, four pod exhaust pattern of the B-52.

Conclusions

1) Anemometry revealed that the vortex span was about 40 ft. The vortex, which was expected to drop quickly, was found to remain at the flight altitude and sometimes rising higher. From the anemometry data the vortex core size was on the order of 4-6 ft across with peak velocities as high as 210 ft/s.

2) The gas samples indicate that the vortices contain higher concentrations of CO_2 and H_2O, which confirms the theory that the vortices entrain the outboard engine exhausts.

3) The CO_2 increased concentrations in the wake of the aircraft would cause thermal blooming. This coupled with the fact that the vortex entrains the engine exhausts and does not settle rapidly, i.e., less than 50 ft in 2000 ft, produces a pie-shaped region directly behind the aircraft, which is highly degrading to near-infrared laser radiation.

4) Both the anemometry and the unique gas sampling experiments proved highly successful. This type of experiment can be envisioned for any potential airborne laser platform.