The small differences between the experimental and predicted inlet performance will not have a significant effect on the engine thrust performance quoted in Ref. 4.

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Influence of Flaps and Engines on Aircraft Wake Vortices

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ALTHOUGH previous investigations have shown that the nature of aircraft wake vortices depends on the aircraft type and flap configuration, the causes for these differences have not been clearly identified. In this Note we show that observed differences in vortex core structure are related to engine placement, engine thrust and wing flap deflection angle.

Much of the quantitative information on the velocity distribution within aircraft vortices has been collected by the Federal Aviation Administration's National Aviation Facilities Experimental Center (NAFEC) in Atlantic City, N.J. In these experiments (conducted at NAFEC and Idaho Falls, Idaho) flight paths of test aircraft were selected so the vortices would drift through an instrumented smoke tower. Hot wire anemometers were used to measure vortex velocities. Smoke grenades placed at regular intervals on the tower provided flow visualization of the vortex. These tests have shown that most vortices can be divided into two general classes:[1]

1) Tubular (T): The vortex has high tangential velocities concentrated in a very tight core. Long tubular smoke streamers can be observed along the vortex axis when such a vortex passes near a smoke grenade on the tower.

2) Nontubular (NT): The vortex has substantially lower tangential velocities and a large diffused vortex core. Little axial transport of injected smoke is observed.

The types of vortices observed in NAFEC tower tests are listed in Table 1. For all configurations, the engine thrust was adjusted to maintain level flight past the tower. The vortices from aircraft with four-wing mounted engines

Received May 20, 1974. We would like to acknowledge the cooperation and assistance of NAFEC personnel and the aircraft pilots during the tower fly-by tests reported here.

Index categories: Aircraft Aerodynamics (Including Component Aerodynamics); Jets, Wakes, and Viscid-Inviscid Flow Interactions.

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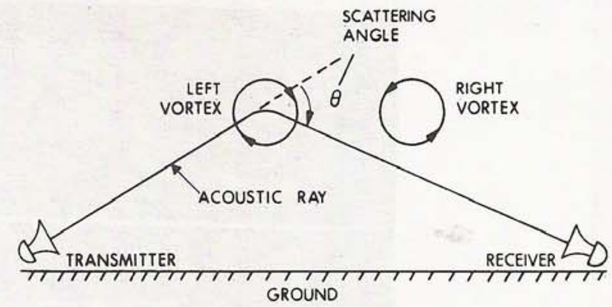


Fig. 1 Geometry for acoustic scattering from aircraft vortices.

Table 1 Vortex type[a] vs aircraft type and configuration

Aircraft type	Aircraft configuration[b] Holding	Takeoff	Landing
Propeller driven (DC-7)	T	T	T
No wing-mounted engines (B-727)	T	T	T
Four wing-mounted engines (B-707)	T	T^c	NT

[a] According to instrumented tower measurements (T = tubular, NT = nontubular).
[b] Flap extensions: Holding, none; Takeoff, partial; Landing, full.
[c] Semitubular.

configured for takeoff were designated "semitubular" (somewhat larger cores than in holding configuration). Note that the only significant differences occur in landing configuration.

An independent but consistent vortex classification can be obtained by interpreting data obtained with a pulsed bistatic acoustic vortex sensing system developed at the Transportation Systems Center.[2] In this system acoustic pulses are transmitted from one side of an aircraft flight path and received on the other. The presence of a received signal from the vortex depends on its acoustic ray-bending properties. The maximum scattering angle Θ_m (see Fig. 1) is particularly sensitive to the type of vortex core (for a given circulation, the smaller the vortex core, the larger the maximum scattering angle, Θ_m). Thus a tubular vortex would be expected to have a significantly larger value of Θ_m than a nontubular vortex. Tests conducted at several airports have shown that vortices from landing aircraft could be classified on the basis of observed Θ_m with the same results as in Table 1. Propeller driven aircraft, aircraft with no wing-mounted engines and aircraft with two wing-mounted engines (DC-10, B-737), were found to give typical values of Θ_m = 1.2 rad or higher. Aircraft with four wing-mounted engines (DC-8 and B-707) typically gave values of Θ_m = 0.5 rad. Intermediate values of Θ_m, which appeared to depend on the ambient wind conditions, were observed for the B-747 (four wing-mounted engines). Acoustic measurements made at NAFEC show that aircraft with four wing-mounted engines generate vortices with large scattering angles ($\Theta_m \geq 1.0$ rad) in both holding and takeoff configurations.

In order to explain the observed differences in core structure one must take into account the effect of flap angle on the origin of a vortex from an aircraft wing. In general, the vortex core is generated at the edge of the lift distribution, which in "holding" or "cruise" configuration (zero flap angle) is located at the tip. However, in landing configuration (full flaps) relatively little lift is generated by that portion of the wing beyond the outboard edge of the flaps. The vortex generated by the strong lift discontinuity at the flap edge is therefore likely to dominate the formation of the vortex core with relatively little pertur-

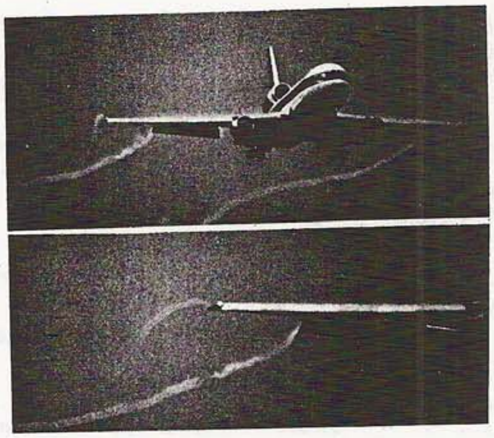


Fig. 2 Flap and wing-tip vortices of a DC-10.

bation from the wing tip vortex. This effect is evident in Fig. 2 which shows both the flap edge and wing tip vortices of a landing DC-10 under weather conditions where water vapor condensed inside the vortex cores. The flap vortex is clearly much stronger than the tip vortex. In the photographs one can observe the helical motion expected for two vortices because of their mutual induction. The weaker wing tip vortex rapidly dissipates leaving the flap vortex to form the core of the wake vortex after the roll up process is completed. This dissipation was also observed in landing configuration tests with a DC-7. The smoke from grenades mounted on the wing tips for vortex visualization was dispersed and did not enter a tubular vortex core. However, the existence of a tubular core structure was confirmed by visual observations when the core passed through the tower near a smoke grenade. The exact origin of the vortex in takeoff configuration (partial flap) is not clear at the present time since both the wing tip and flap edge probably represent significant discontinuities in the lift distribution. A short series of special tests were performed with a B-707 at NAFEC to examine this problem and will be discussed later.

Once the origin of the vortex core is known, the observed differences in core structure can be explained by considering the position and thrust of the aircraft's engines. For example, in landing configuration the exhaust blast from a wing-mounted engine located near the edge of the flap disrupts the tubular core structure during the vortex formation process. Conversely, for the first two types of aircraft in Table 1 a tubular structure can be expected in all configurations since the effects of engine blast are sufficiently removed from the point of vortex origin. The results for aircraft with four wing-mounted jet engines are explained as follows:

a) Holding configuration: The vortex origin at the wing tip is far from any engines and the engine thrust is relatively low. Consequently, the vortex core is unperturbed.

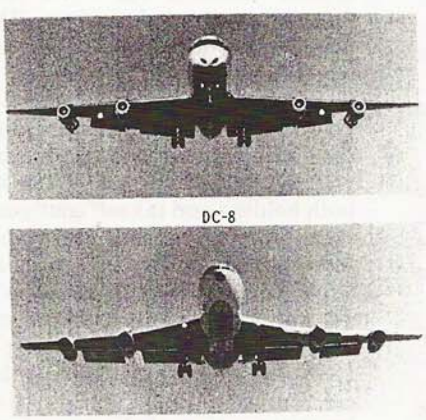
b) Landing configuration: The vortex origin at the outboard flap edge is close to an engine and the engine thrust is relatively high. Therefore, the exhaust blast has a strong effect on tubular core formation.

c) Takeoff configuration (level flight in tower tests): The vortex origin is not clearly defined, and the engine thrust is medium. Therefore, the engine blast could have some effect.

The critical nature of engine placement on vortex character was observed in the acoustic data collected at Kennedy Airport from two similar aircraft, the B-707 and the DC-8. The DC-8 consistently gave larger values of θ_m (indicating a smaller vortex core) than the B-707. This difference can be attributed to the greater separation between the flap edge and the outboard entine on the DC-8 (see Fig. 3).

In a recent series of TSC tests at NAFEC, the effect of engine thrust was tested directly by tower flybys in which one outboard engine of a B-707 in landing configuration was kept at idle. In order to avoid any systematic errors, comparisons were made with first one and then the other outboard engine at idle. The following observations were made: 1) The maximum acoustic scattering angle was substantially larger for the vortex produced by the wing with one engine at idle. 2) Smoke streamers from tower grenades could be seen along the vortex from the wing with the engine idle. These results show that tubular vortices were produced by the wing with the engine idle and that the thrust from the outboard engines destroys the tubular core under normal thrust conditions.

Consideration of engine placement and thrust could be an important factor in determining the nature of vortices generated by aircraft in takeoffs using maximum engine thrust. To investigate this operational problem, some B-707 tower flybys in recent NAFEC tests were made to simulate takeoffs. The aircraft approached the vortex tower in takeoff configuration at low altitude. Full power was applied 500 to 1000 ft before reaching the tower and the aircraft proceeded to climb out past the tower. The nontubular nature of the vortices produced was evident to the eye and was substantiated by data from the acoustic sensing system. No tubular smoke streamers were seen and, in fact, the flow within the vortex core appeared to be highly turbulent with much less core definition than in landing configuration. The acoustic data showed no scattered signal, in contrast to the excellent signals obtained in preceeding level flight "takeoff configuration" runs. It appears that vortex data collected under conditions of level flight in "takeoff configuration" cannot be used as a reliable description for the vortices generated under operational conditions. Additional information on the core structure of operational takeoff vortices was obtained from acoustic data collected at Logan Airport. Signals characteristic of tight core vortices were obtained from clean wing aircraft (B-727, DC-10) but no signals were observed for aircraft with four wing mounted engines (B-707).



B-707

Fig. 3 Comparison of flap and engine placement on the B-707 and the DC-8.

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