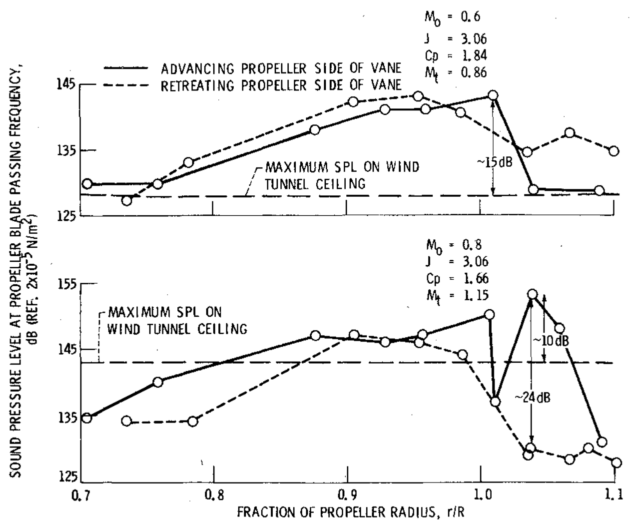

Fig. 4 Radial variation of vane surface sound pressure level at propeller blade passing frequency.

A comparison of the maximum sound pressure level spectra measured on the tunnel ceiling with that obtained by placing the vane transducer in the tip vortex is shown by Fig. 3. At the propeller blade passing frequency of approximately 1000 Hz, the sound pressure level measured on the vane surface due to the action of the tip vortex is about 15 dB higher than the maximum propeller noise measured on the wind-tunnel ceiling. The tip vortex spectra is rich in higher harmonics, showing even larger increases in sound pressure level compared with the ceiling transducer. This suggests that the tip vortex is highly compact and subjects the vane surface to a sharp "slap"—or nearly impulsive excitation—as opposed to a sinusoidal excitation at the blade passing frequency. Somewhat similar results were obtained at Mach 0.8, although the higher harmonics in the tip vortex were usually significantly below the level of the fundamental.

A summary of the blade passing frequency sound pressure level measured in the propeller wake plotted as a function of radial position is shown by Fig. 4. Measurements obtained on both sides, or surfaces, of the vane are shown, as is the maximum blade passing sound pressure level measured on the tunnel ceiling.

At Mach 0.6, the vane surface measurements significantly exceed the wind-tunnel ceiling values for radial positions between $r/R \approx 0.75$ and the propeller tip. Little difference was noted between the two surfaces of the vane, excepting the region beyond the propeller tip. This effect beyond the blade tip may have resulted from the vane being set at 6 deg incidence angle relative to the undisturbed tunnel flow, and thus not aligned with the local flow.

At the Mach 0.8 condition, the advancing propeller side of the vane experienced higher sound pressure levels than the other side of the vane. This is especially evident in the region beyond the propeller tip, where measurements were obtained in or near to the tip vortex. At this radial location the transducers on the advancing propeller surface of the vane experienced a sound pressure level approximately 24 dB higher than the other surface. Maximum vane surface sound pressure levels were about 10 dB greater than the maximum levels measured on the wind-tunnel ceiling.

Concluding Remarks

Model test results support the hypothesis that a well-defined propeller tip vortex exists that can subject a downstream wing surface to a much greater excitation than might be experienced by the aircraft fuselage side wall exposed to propeller generated noise. If the assumption is made that fuselage and wing surfaces are equally responsive to the incident dynamic pressure, and ultimately transmit this response with equal efficiency to the cabin interior, it follows that passenger cabin noise levels may well be governed, at least in some instances, by the action of the propeller tip vortex striking the wing or other portions of the airframe. Indeed, even if structural borne excitations were less efficient than airborne excitations in creating cabin noise, the higher level of the former could still govern cabin noise levels.

Spectral analysis indicates that the vortex may subject the wing surface to a sharp "slapping" excitation rich in high-order harmonics. This maximum excitation exists over a relatively narrow radial extent and could easily be missed or overlooked in a test that relied on microphones at fixed radial positions.

At higher speed, where the blade tip is supersonic, large differences were found in the sound pressure level between the two sides of the vane. This has potential significance relative to preferred directions for propeller rotation, as well as use of the wing or other surfaces to shield the cabin side wall from propeller noise.[8]

The need for more work is clearly indicated to further explore the character of propeller wakes and their potential acoustic interactions with the airframe. Wing surface response to propeller tip vortex induced excitations, and the effectiveness of this response in radiating noise to the cabin interior, must be established to assess the full significance of the results presented here.

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Estimate of Human Control over Mid-Air Collisions

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Introduction

IN the albeit sometimes too complex world of today, it is sometimes refreshing (and sometimes alarming) to stand off at a distance and view the behavior of man and his

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machines from a mathematical viewpoint. The interactions and rules of behavior seem so complex as the number of interactions increases that one sometimes wonders if social behavior becomes dominated by sheer numbers. It was this curiosity that motivated the author of this Note to investigate collision frequency between man-made, man-driven machines. The most common of these machine interactions are automobile collisions, ship collisions, and aircraft collisions. When a large number of vehicles are roaming in a space, constrained only by a few limiting boundaries, they could appear to an observer from afar as a somewhat randomly moving group of particles. Those in the physical sciences are well aware of the consequences of random motion: *inevitable and predictable collisions.* The thought behind the analysis presented in this article was to study aircraft mid-air collision accidents treated from the standpoint of random collision theory to determine (or at least to estimate) the effectiveness of human control in this case over the sheer numbers game. As will be shown from the following analysis, the results of this approach are encouraging in one case (air-carrier travel) and somewhat discouraging in another case (general aviation).

To provide the necessary theoretical background for such an analysis, this Note first presents the results of random collision theory, then molds it to the case at hand of mid-air collisions. This background is followed by presentation of data for a ten-year span (1969-1978) on aircraft, air travel, and mid-air collision accidents. Fortunately, relatively few mid-air collisions occur, so to make the analysis statistically more meaningful, average values of quantities were used, averaged over the above-stated ten-year period. The article concludes with a comparison of the predictions of random collision theory with the reported mid-air collision data.

Random Collision Theory

When bodies of number density n_1 collide with bodies of number density n_2, random collision theory predicts[1] a collision rate

$$C_{12}=n_1 n_2 \sigma_{12} v_{12} V \qquad (1)$$

collisions per unit time, where σ_{12} is the collision cross section between the bodies, v_{12} is their relative velocity, and V is the volume containing all the bodies. Translating this theory to the case of mid-air collisions, and considering only two groups of aircraft: "small" (general aviation) and "large" (air carrier), results in a predicted collision rate of

$$C_{sl}=\left(\begin{array}{c}\text{collision per year}\\ \text{in the U.S. between}\\ \text{small and large planes}\end{array}\right)=\frac{N_s N_l \sigma_{sl} v_{sl}}{V_{sl}} \qquad (2)$$

where N_i is the average number of plane species types in the air at any given time, V_{sl} is the volume over which these two species roam, and σ_{sl} is the effective collision cross section given as

$$\sigma_{sl}=\pi(r_s+r_l)^2 \qquad (3)$$

where r_s (or r_l) is the "diameter" D divided by 2, where D is a characteristic dimension given by

$$D=\frac{\text{length}+\text{width}+\text{height}}{3} \qquad (4)$$

and v_{sl} is the relative velocity between the planes

$$v_{sl}=\tfrac{1}{2}(v_s+v_l) \qquad (5)$$

Table 1 Registered U.S. civil aircraft on record with FAA

Year	Total air carrier	Total general aviation	Total registered civil aircraft
1969	3008[a]	130,806[a]	133,814[a]
1970	2796[a]	131,743[a]	134,539[a]
1971	2722[a]	131,148[a]	133,870[a]
1972	2685	168,115	170,800
1973	2667	177,086	179,759
1974	2658	185,350	188,008
1975	2681	193,661	196,342
1976	2549	203,332	205,881
1977	2546	212,735	215,281
1978	2549	234,190	236,789
Average since 1971	2626	196,353	198,979

[a] Listed as active U.S. civil aircraft.

Table 2 Civilian air-carrier miles flown annually

Year	ϕ, miles/yr
1969	2,736,596,000
1970	2,684,552,000
1971	2,660,731,000
1972	2,619,043,000
1973	2,646,669,000
1974	2,464,295,000
1975	2,477,764,000
1976	2,568,113,000
1977	2,684,072,000
1978	2,797,000,000

When one is considering interactions between planes of the same species (either small or large), Eq. (2) is modified by a factor of ½ to become

$$C_{ii}=\tfrac{1}{2}N_i^2\sigma_{ii}v_{ii}/V_{ii} \qquad (6)$$

Data on Aircraft, Air Travel, and Mid-Air Collision Rates

To compare the predictions of Eq. (2) or (6) with actual mid-air collision rates, data for the ten-year period 1969-1978 were used. Table 1 presents data on the number of aircraft of the two categories on record with the FAA.[2,3] Note that 98.7% of all registered U.S. civil aircraft are general-aviation (private) aircraft. Thus analyses of this particular group will be emphasized.

Table 2 presents data on civilian carrier aircraft miles flown annually during the ten-year period.[4] The annual miles traveled has been denoted by the symbol ϕ, which, in terms of the previous nomenclature of the previous section, is simply $\phi=N_l v_l$, where v_l is the average velocity of carrier aircraft (expressed in units of miles/yr). The value is rather strikingly constant, the average over these ten years being $\phi=2.63\times10^9$ miles/yr.

For general-aviation aircraft, data are logged on the aircraft *hours* flown per year, and are presented in Table 3.[4] Since there are 8760 hours per (365 day) year, the average number of general-aviation aircraft in the air at any given time is

$$N_s=\frac{30,359,000}{8760}=3466 \text{ aircraft}$$

Table 3 General-aviation aircraft hours flown

Year	Aircraft hours
1969	25,351,000
1970	26,030,000
1971	25,512,000
1972	26,974,000
1973	29,974,000
1974	31,413,000
1975	32,024,000
1976	33,922,000
1977	35,792,000
1978	36,600,000
Average	30,359,000

Table 4 Mid-air collision accidents, U.S. civil aviation (1969-1978)

Year	General aviation with general aviation	General aviation with air carrier	Air carrier with air carrier
1969	23	3	0
1970	32[b]	0	0
1971	27	3	0
1972	24[b]	1	0
1973	24	0	0
1974	32	0	0
1975	28	0	0
1976	30	0	0
1977	34	0	0
1978 (partial)[a]	33	1	0
Average	28.7	0.80	0

[a] 1978 files as of Sept. 26, 1978.
[b] Includes one U.S. general-aviation vs foreign aircraft.

Table 5 Comparison of random collision theory predictions with reported data (1969-1978)

Type of collision	Predicted rate collisions/yr	Actual rate collisions/yr	Factor by which human control influences rates
(General aviation / General aviation)	34.3	28.7	1.20
(General aviation / Air carrier)	590	0.80	738
(Air carrier / Air carrier)	99.4	0	∞

Comparing this number with the total number of registered general-aviation aircraft (Table 1) shows that at any given time on the average over the ten-year span 1.77% of the registered aircraft are in flight.

The final data of concern are the actual (recorded) number of mid-air collision accidents in U.S. civil aviation. These data of interest are presented in Table 4.[5] It is seen that the largest number of collisions occur between general-aviation aircraft.

The question arises as to what type of aircraft are characteristic of each of the two groups (general aviation and air carrier). To accurately determine these characteristics, a detailed analysis of the dimensions, speeds, and service ceilings of all aircraft is required. Lacking such input, the author has chosen the following aircraft as representative:

General aviation (small)—Cessna Model 150; 33-ft 2-in. wingspan; 23-ft 8-in. long; 9-ft 7-in. high; average cruising speed 117 mph; service ceiling 14,000 ft.

Air carrier (large)—Boeing Model 747; 195-ft 8-in. wingspan; 231-ft 10-in. long; 63-ft 5-in. high; average cruising speed 450 mph; service ceiling 39,000 ft.

While this exact choice may be disputed, the general features should be reasonably representative. The volume of the space is taken as the product of the service ceiling and the land area of the United States (3.60×10^6 miles^2).

Results and Discussion

Given the previous data, Eqs. (2) and (6) were used to predict the collision rate for comparison with the data of Table 4. A summary of the results is given in Table 5.

The comparisons between random collision theoretical predictions and the actual cases shown in Table 5 clearly show that insofar as mid-air collision accidents are concerned, human control is very effective in air-carrier travel, but relatively ineffective in general aviation. The reasons for this rather striking difference may possibly be in traffic control, pilot training, instrumentation, or whatever, but the analysis of such causes are not within the scope of this Note. Nevertheless, they should give cause for credit to air-carrier aviation and cause for concerns to general aviation.

Probably the weakest link in the previous analysis is the rather arbitrary choice of representative aircraft for the two groups considered. In this respect, a more detailed analysis is required for general-aviation aircraft. However, the comparisons for air carriers are relatively insensitive to the choice. For those trained in the physical sciences, the fact that random collision theory predictions are close to the "real world" for general aviation is, in itself, a remarkable revelation. It is the hope of this author that the information presented in this Note will have a positive influence on the marvelous, manmade world of aviation.

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Subsonic Flow over Airborne Optical Turrets

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Introduction

FOR a number of applications, the telescope of an airborne optical system is housed within a turret mounted atop the aircraft fuselage. The interaction of the turret with the high

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