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Fuselage Ventilation Due to Wind Flow About a Postcrash Aircraft

Jay W. Stuart

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ABSTRACT

Postcrash aircraft-fuselage fire development is inherently dependent on the internal and external fluid dynamics besides the combustion, pyrolysis, and heat transfer of the environment. The natural ventilation rate, a major factor in the internal flow patterns and fire development, is inherently related to the external fluid mechanics--the flow about the fuselage as affected by the wind and external fire. An analysis has been performed that can be used to estimate the rates of ventilation produced by the wind for a limited idealized environmental configuration. The simulation utilizes the empirical pressure-coefficient distribution of an infinite circular cylinder near a wall with its boundary-layer flow to represent the atmospheric boundary-layer. The resulting maximum ventilation rate for two door-size openings, with varying circumferential location in a common 10-mph wind is an order of magnitude greater than the forced ventilation specified in full-scale fire testing. The method was verified roughly by comparison with test results.

It is recommended that the analytical method be verified by systematic full-scale testing. Furthermore, extended investigation of the real influencing parameters (1) fuselage size and shape, (2) fuselage orientation and proximity to the ground, (3) fuselage-openings size and location, (4) wind speed and direction, and (5) induced flow of the external fire plume is recommended. Finally, fire testing should be conducted to a maximum ventilation rate at least an order of magnitude greater than the inflight air-conditioning rates nominally used in testing.

ACKNOWLEDGMENT

DEFINITION OF SYMBOLS

Abbreviation	Definition
a	radius of fuselage[1]
A	area of fuselage[1] opening
A_f	area of fuselage[1] interior cross section, 6.51 m^2 (70 ft^2)
C	orifice coefficient of fuselage[1] openings
D	diameter of fuselage[1], 3.76 m (12.33 ft)
G	gap displacement of bottom of fuselage[1] from the ground
p	static pressure
q	dynamic pressure of normal component of wind velocity
Q	volumetric flow
U	velocity at a location
$\bar{U}$	average ventilation flow speed in fuselage[1]
ρ	density of air at standard conditions
ν	kinematic viscosity of air at standard conditions
θ	polar angle of fuselage[1]

Coefficient

C_p	p/q, pressure coefficient on the surface of a fuselage[1]
K	shear coefficient in uniform shear flow in the free stream
R_D	$DU_{\infty n}/\nu$ Reynolds number based on fuselage[1] diameter

Subscript

$(\ )_\infty$	free-stream value
$(\ )_{\infty n}$	normal component of free-stream value

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[1]"Fuselage" here is synonymous with "cylinder."

$(\ )_{\sim t}$	tangential component of free-stream value
$(\ )_1$	value immediately external to opening number 1
$(\ )_2$	value immediately external to opening number 2
$(\ )_i$	value in interior of fuselage[2]
$(\ )D_{cr}$	critical value for transition flow
$(\ )D_e$	empirical value

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[2]"Fuselage" here is synonymous with "cylinder."

CONTENTS

Figures

SUMMARY

Postcrash aircraft-fuselage fires are inherently dependent on the fluid dynamics of the environment both internal and external to the fuselage besides the combustion, pyrolysis, and heat transfer. The natural ventilation rate, which is one of the principal driving forces of the internal fluid mechanics, is inherently dependent on the external fluid mechanics--the effect of the wind and external fire on the flow about the fuselage. Hence, the ventilation rates, including the influence of the external flow, are functions of various parameters: (1) fuselage size and shape, (2) fuselage orientation and proximity to ground, (3) fuselage-openings size and location, and (4) wind speed and direction. The influence of the external fire plume is omitted in this treatment. The formulation developed in the analysis presented here can be used to estimate these natural ventilation rates based on idealized assumptions stated subsequently.

The results show possible free ventilation rates between two openings in the fuselage to be an order of magnitude greater than in-flight air-conditioning rates. And, they over predict by 25 percent the one roughly scaled recent full-scale measurement of the free ventilation rate at NASA/JSC under somewhat different conditions. The results of this analysis are based on normal door-size openings in a 10-mph perpendicular wind. Another result is that the ventilation direction can change or be in the opposite direction inside the fuselage depending on the changing direction of the wind or the circumferential locations of the two openings. The ventilation rates are determined from wind-tunnel data for the pressure-coefficient distributions around a fuselage-simulating infinite circular cylinder oriented normal to the wind and displaced away from a parallel wall with its boundary layer, the flow being laminar.

The magnitude of the ventilation rates is directly proportional to the normal component of the free-stream wind velocity, the opening area, and the opening orifice coefficient. Furthermore, the rate is increased or decreased by 20 or 30 percent by the increase or decrease respectively of the opening-area or orifice-coefficient ratio by a factor of two. Similar but more subtle pressure-distribution effects are shown for various fuselage locations above the ground, including the particular case of a fuselage in contact with the ground.

In conclusion, the wind-about-fuselage flow can have varied and strong effects on the fuselage ventilation rates. The complete real effects await the further investigation of the other essential parameters: (1) large-scale turbulent Reynolds numbers, (2) orientation or incidence of fuselage to the ground, (3) finite length or three-dimensional effects, and (4) the induced velocity or circulation simulating the effects of the external fire plume.

As a result of this analysis, test programs, using forced ventilation to simulate fuselage natural ventilation, should conservatively provide volumetric flow-rates proportioned to the 12,000-cfm capability of the common 10-mph wind by the component of the wind velocity normal to the fuselage.

SECTION I

INTRODUCTION

Ventilation is an essential factor in an internal aircraft fire. It basically supplies oxygen for the combustion of exposed materials after the available oxygen in the enclosure has been consumed. Also, the rate of flow and the positions of the inlets and outlets for ventilation have a basic effect on the three-dimensional flow patterns and spatial distribution of oxygen concentration in the enclosure. Consequently, the basic characteristics of fire development (i.e., flame-spread rates and fuel-surface burning rates) are dependent on ventilation and can be generally and locally constrained by ventilation.

During a small in-flight fire, ventilation is predominantly determined by the air-conditioning controls, the designed system of inlets and outlets, and the configuration of the furnishings. In a postcrash aircraft fire, the ventilation in the cabin is further influenced by the opening of any part of the fuselage, whether it is a door, a window, or a fuselage-skin rupture or a breech. If a wind exists, it inherently controls the rate of ventilation which, in turn, influences the internal flow patterns and spatial distribution of oxygen. For the initial stage of interior fire development, the fire-induced free-ventilation effects are considered secondary. Besides the wind speed and direction, the circumferential position of the fuselage openings may have an equally important influence on the strength of the resulting ventilation. The circumferential position of an opening is essentially defined, not relative to the fuselage, but relative to the wind velocity in a plane normal to the fuselage axis or to the resulting polar pressure distribution. The implication in principle is that the circumferential position of the openings relative to the wind vector after a crash (after the fuselage may have rolled somewhat) is the determining condition.

Furthermore, if a postcrash fire is external to the fuselage and adjacent to an opening, the following three inherent aspects occur:

(1)   The ventilation rate and direction through the adjacent opening will determine the transport of flames through the opening and the degree of internal propagation by heat transfer and flame spread.

(2)   The buoyant effects of the fire produce convective mass transport which induces fluid flow about the fuselage which, in turn, alters the pressure distribution.

(3)   The basic wind flow pattern about the fuselage and its alteration by the presence of the external fire basically influence flow entrainment and the external fire character-istics and development.

All of these aspects influence the nature and progress of fire development in the cabin interior. Therefore, the fire hazards to cabin occupants are greatly dependent on ventilation. These hazards

are the spreading of the flame, the intensity of the heat, the smoke
density which may obscure safety and exit signs, and the presence and
concentration of toxic products of combustion. Knowledge of the quanti-
tative dependence of these hazards on ventilation in conjunction with
the combustion of exposed materials would permit the specification
of the proper test ventilation for screening materials. The prime
objective is to properly select aircraft interior materials that will
maximize the evacuation time during threats from these hazards.

The specific objective of this report is the approximate deter-
mination of the ventilation rates through the openings of a postcrash
aircraft fuselage due solely to the ambient wind. Hence, the three
influences on or by the external fire are not treated.

SECTION II

ANALYSIS

In this analysis, the approach is to apply the continuity equa-
tion to the system of two fuselage openings and the conservation of
momentum to each opening by using the orifice discharge relation. The
pressure difference across each opening is determined from the pressure-
coefficient distributions for flows about cylinders with simulated bound-
aries and then related to the wind velocity. Finally, the volumetric
flow and average speed of the ventilation in the cabin can be calculated
for various circumferential positions of the openings and other common
parameters. An approximate comparison is made with a ventilation mea-
surement having somewhat different conditions.

A.   FLUID MECHANICS OF FUSELAGE VENTILATION

Consider the ventilation flow at two openings, 1 and 2, in a
control volume--a finite cylinder as an expeditious representation
of a fuselage--see Figure 1. The continuity equation for incompressible
flow, $\Delta\rho = 0$, is

$$U_1 A_1 = U_2 A_2$$

where U_1 and U_2 and A_1 and A_2 are the average speed through and the
area of each opening, respectively. Application of the orifice discharge
relation in terms of the pressure difference across each opening provides
an equation in terms of the internal pressure, p_i,

$$A_1 C_1 \sqrt{2(p_1 - p_i)/\rho} = A_2 C_2 \sqrt{2(p_i - p_2)/\rho}$$

where all other quantities are assumed known and p_1 and p_2 are the
pressures external to the corresponding openings. Solving for p_i and
substituting it back into either side of the continuity equation yields
a formula for the volumetric flow rate in terms of conditions at the
selected opening. The pressure change related to the internal flow
resistance along the fuselage is neglected in this analysis.

Before the substitution, however, the pressures are normalized
into coefficients for the convenience of relating to empirical data
and the wind speed, $C_p = p/q$, where $q = \frac{\rho}{2} U_\infty^2$. The normalizing dynamic
pressure is defined by the component of the wind in the plane of the
cylinder axis and normal to the surface, as shown in Figure 1. The
resulting volumetric-rate formula is a dimensionless function of pressure
coefficients as well as area- and orifice-coefficient ratios,

$$Q = C_1 A_1 U_{\infty n} \sqrt{c_{p_1} - \left[c_{p_1} + c_{p_2}\left(\frac{A_2 C_2}{A_1 C_1}\right)^2\right] \bigg/ \left[\left(\frac{A_2 C_2}{A_1 C_1}\right)^2 + 1\right]}$$

The pressure coefficients, in turn, depend upon Reynolds number, dimensionless distance from the ground, and atmospheric boundary layer.

The dimensional form of the volumetric rate, Q, emphasizes the proportional dependence on the orifice coefficient, C, and the area, A, of the opening and on the normal component of the free-stream velocity. In addition, the average speed, $\overline{U}$, of the internal ventilation is expressed by spreading the interior flow uniformly across the cross-section of a fuselage, A_f,

$$\overline{U} = \frac{Q}{A_f}$$

B.   PRESSURE DISTRIBUTIONS FOR FLOWS AROUND INFINITE CIRCULAR CYLINDERS

The problem is essentially to determine the pressure-coefficient distribution circumferentially around the fuselage. As a first approximation, the openings or orifices are assumed to be relatively small and to be located sufficiently far from the ends of the fuselage, when compared to the fuselage diameter, so that three-dimensional interference effects can be neglected. Thus, the fuselage is treated as being an infinite cylinder and the field of flow as being two-dimensional. Also, the openings are considered to be orifices having sharp edges and right-angle faces through the outer surface of the fuselage.

Pressure-coefficient distributions for infinite circular cylinders are available in the literature. The actual situation, however, is a full-scale fuselage near the ground with the approaching stream being an atmospheric boundary layer. Furthermore, the fuselage may be inclined to the ground and at an angle of yaw to the wind. In the absence of an actual pressure distribution, a sequence of empirical distribtuions varying from the ideal toward the real is considered. In Figure 2, the pressure-coefficient distributions of this sequence are presented in polar and Cartesian graphs. For the single or isolated cylinder, three sets of pressure-coefficient distributions are presented. For the uniform flow in the free stream, the inviscid solution from potential theory is symmetrical about the x and y axes (Reference 2-1). At $\theta = 0$ and 180 degrees, stagnation values of $C_p = 1.0$ result, and the accelerating flow from 0 to 90 degrees gives values continually decreasing from plus to minus to a minimum of $C_p = -3.0$. The introduction of uniform shear $U_\infty = U_0 (1 + Ky/a)$ in the free stream (U_0 is the velocity at the streamline projected far upstream from the cylinder axis, K is the shear coefficient, y is the distance from the streamline, and a is the radius of the cylinder) to indicate the effect of an atmospheric boundary layer away from the ground, suppresses and augments the surface

velocities on the lower ($\theta < 0$) and upper ($\theta > 0$) surfaces respectively, according to an analytical solution in Reference 2-2. For an extreme shear, $K = 0.6$, the minimum pressure coefficient at $\theta = 90$ degrees reaches $C_p = -7.0$, as shown only in the Cartesian graph; the lower-surface value (not shown) is greatly depressed. The distributions for this inviscid flow around the cylinder are symmetrical only about the y axis.

The natural viscous flow around the cylinder in a uniform free stream (Figure 2) produces two types of pressure-coefficient distributions; both exhibit boundary-layer separation and nearly constant and negative values throughout the wakes (Reference 2-1). The laminar boundary layer (L) separates near $\theta = 75$ degrees just downstream of the location of the minimum value of approximately $C_p = -1.10$ at $\theta = 67$ degrees and produces a wake value of slightly more than $C_p = -0.8$. The turbulent boundary layer (T) delays separation to about $\theta = 125$ degrees, which allows more pressure recovery in the wake to a coefficient value of about $C_p = -0.3$. The minimum pressure coefficient at $\theta = 90$ degrees decreases to near the potential-theory value, $C_p \simeq -2.5 < -3.0$. Hence, whether the boundary-layer flow is laminar or turbulent--the Reynolds number $R_D \gtrless R_{D_{cr}} \simeq 3 \times 10^5$ respectively--makes a significant difference in the pressure distribution and its magnitude.

The closest simulation of the actual flow about a horizontal fuse-lage displaced from the ground (Figure 2) is indicated by the empirical pressure-coefficient distribution for a two-dimensional cylinder displaced 0.4 of its diameter ($G/D = 0.4$) from a wall with a boundary layer, which is parallel to the free-stream velocity; the Reynolds number is $R_{D_e} = 4.25 \times 10^4$ (Reference 2-3). Since the $R_{D_e} < R_{D_{cr}} \simeq 3 \times 10^5$ for a uniform free-stream flow, the boundary-layer flow on the cylinder surface is probably laminar even though the wall and its boundary layer have some influence. This influence moves the stagnation point to a slightly negative incidence, as can be seen from the pressure-coefficient distribution (Figure 2) and reduces the corresponding pressure coefficient to 0.95. Otherwise, the pressure-coefficient distribution is similar to the single cylinder in a uniform free stream with laminar flow except for the lower minimum coefficient induced by the proximity of the ground at $\theta = -90$ degrees. In the absence of more realistic turbulent-flow data, these data were utilized for the principal ventilation estimates here.

At a closer proximity to the ground, with a gap-to-diameter ratio of $G/D = 0.10$, the wall boundary layer creates greater interference and impresses its dissipated energy on the flow around the cylinder. The resulting pressure-coefficient distribution is generally less marked. The stagnation region is moved to a more negative angle and broadened, and its pressure coefficient is reduced to about $C_p = 0.50$. The upper-surface minimum pressure coefficient at $\theta = 65$ degrees is increased only slightly to nearly $C_p = -1.0$, and the lower minimum is shifted to $\theta = -125$ degrees and increased greatly to $C_p = -0.66$. Also, in the wake C_p becomes -0.50. Ventilation estimates were also made using these data.

As G/D approaches zero, the cylinder touches the wall and the pressure coefficient distribution becomes vastly changed. This case will

be discussed in combination with the empirical data for two cylinders normal to a uniform viscid stream for $G/D = 0.5$ and 0 respectively (Reference 2-4). The latter are useful to compare the effectiveness of the wall with and without a boundary layer. These distributions and comparisons are discussed to enhance the understanding of the various parameters effecting the real simulation.

For $G/D = 0$, the stagnation region extends from $\theta = -30$ to -90 degrees at the point or line of contact, where $C_p = 1.0$ for the two touching cylinders but becomes $C_p = 0.50$ for the cylinder touching the wall because of the dissipated energy in the wall boundary layer. Consistently then, the low pressure in the wake extends over the entire rearward surfaces to $\theta = -90$ degrees, where $C_p = -1.25$ for the two cylinders and $C_p = -0.60$ for the cylinder touching the wall. The minimum pressure coefficients are slightly reduced to $C_p = -1.65$ for the two cylinders and $C_p = -1.10$ for the cylinder touching the wall, while the polar angle remains about the same and is moved forward about 25 degrees to $\theta = 45$ degrees, respectively. Hence, a fuselage lying on the ground has a greatly different flow and pressure distribution than if it were located above the ground. Likewise, the ventilation is affected.

When $G/D = 0.5$ for the two cylinders, the stagnation pressure remains $C_p = 1.0$ while its location is lowered to a small negative angle. The wake pressure coefficient is about $C_p = -1.20$, which indicates laminar boundary-layer separation, and is less than for a single cylinder when either isolated or near a wall. The minimum pressure coefficients are reduced even more than $C_p = -1.10$ for the cylinder near a wall to $C_p = -1.45$ at both $\theta = 67$ and -90 degrees.

C.   VENTILATION PERFORMANCE COMPARISONS

Now, having a conservative representation of the pressure-coefficient distribution, the ventilation formula may be applied by considering a configuration with two openings which represent doors, vents, and/or breaches caused by a crash. Since doors have the nominal size of 3 by 6 ft, the opening areas are both assumed to be 2 m^2 (about 21 ft^2) for convenience. Also, the sharp-edge orifice coefficients are assumed to be $C_1 = C_2 = 0.60$, a typical value. A 10-mph (14.7-ft/sec) normal component of the free-stream velocity is assumed, which is convenient and nominally representative of a probable wind. The only remaining variable is the essential one--the circumferential location of each opening. Since the critical criterion is for the maximum ventilation flow--the locations yielding the maximum pressure differences--the greatest positive and the least negative values are sought. They correspond to the stagnation point and the minimum pressure-coefficient or maximum local-induced-speed point. It is illustrative to show this maximum as part of a variation. So, one location is fixed at the location of one extreme pressure--the stagnation point, labeled "S" at the slightly negative polar angle in Figure 3, where the door is commonly located. The other location is varied circumferentially, passing through the other extreme pressure location and, thereby, establishing the value of the maximum ventilation rate.

The resulting ventilation performance is shown graphically in Figure 3 for a cylinder located 0.4 of its diameter from the ground (G/D = 0.4). The maximum volumetric rate is slightly above Q = 200 cfs (12,000 cfm) corresponding to the minimum pressures at the polar angles of approximately θ = 67 and -90 degrees. This rate is nearly an order of magnitude greater than in-flight ventilation, and 25 percent higher than values roughly scaled from measurements in the somewhat different full-scale configuration at JSC, as described below. The corresponding maximum average-ventilation speed in the fuselage is almost $\overline{U}$ = 3 fps. For any opening on the leeward side of the fuselage, 80 < θ < 180 and -180 < θ < -90 degrees, i.e., in the wake, the values are only slightly less. Since these wake locations are usually door and window locations, these large ventilation rates are possible, depending on the wind speed and direction. Hence, such large ventilation rates should be included in any test where natural ventilation is a prominent feature.

Also indicated in Figure 3 is the ventilation performance of another set of opening locations which were selected as extreme for the fuselage located a smaller distance from the ground, G/D = 0.10. Placing the fixed opening in the wake, labelled "W" in Figure 3, and varying the other opening location, the other ventilation performance curve in Figure 3 is presented for comparison. The maxima of the volumetric flow rate and of the average fuselage-flow speed are not as great as they were for the larger gap (G/D = 0.4). However, and most significant, the signs or directions of the ventilation flow in the cabin can change depending on the circumferential location of the second opening. It cannot be overemphasized that the two openings can be arbitrarily located at any place on the circumference.

Figure 4 indicates the influence of the opening-area and orifice-coefficients ratios for the cylinder located 0.4 of its diameter from the ground. An increase or decrease of the opening-area ratio, A_2/A_1, by a factor of two effects an increase of 20 percent or a decrease of 30 percent, respectively, in the volumetric flow rate and the average fuselage flow speed. This influence for the area ratio is equally valid for the orifice-coefficient ratio, C_2/C_1, since the volumetric flow rate depends upon the product ratio, A_2C_2/A_1C_1. Thus, the ventilation performance is also significantly affected by these parameters.

D. FULL-SCALE VENTILATION MEASUREMENTS

The basis of the comparison with the full-scale natural ventilation rate measured in the NASA/JSC Boeing standard-body 737 test fuselage is described here. Using the one set of received test data having a significant wind, the wind velocity was measured to have a magnitude of U_∞ = 17 $\pm$5 mph and a direction toward the front and 10 degrees to the left of the fuselage orientation, as sketched in Figure 5. No directional variation is noted; but some variation is generally present. Resolving the velocity into the normal component yields $U_{\infty n}$ = 3.0 $\pm$0.9 mph ($\pm$30 percent). Proportioning the predicted volumetric rate, Q = 12,000 cfm, in a 10-mph wind relative to the measured cross-flow speeds yields a scaled Q = 3,600 cfm. The configuration has openings

on opposite sides of the fuselage at the stagnation line and in the wake. The volumetric rate Q = 2870 ±570 cfm was determined from flow speeds, 188 ±37 and 250 ±50 fpm, measured respectively with hand-held anemometers at the top and bottom points at one-third of the height of the aft-bulkhead door on a vertical line of symmetry; the door area was 13.1 ft^2. The analysis overestimates this averaged measured Q = 2870 cfm by 25 percent, which is a correlation, though coarse.

Furthermore, the configuration and instrumentation of this test is significantly inconsistent with those indicated by the analysis:

(1) The longitudinal location of the openings are where end effects of the fuselage exist. The front door is in the region of the fuselage nose, and the rear vents are very near the square cut-off base of the fuselage. This rear-opening location is particularly suspect because of the slight 10-degree angle of wind approaching from the rear and possibly flowing over and separating from the sharp base edges; Figure 5 shows a sketch of the wind and ventilation for the test situation.

(2) The opening or orifice system is much more complex. The front inlet door is the same as in this analysis. However, there are two rear vents: one vent is appropriately located on the wake side, but the other vent is near the stagnation line. These dual rear vents may allow some flow to bypass the cabin and alter the flow rate through the cabin. In addition, the two bulkheads with center openings divide the fuselage into three chambers, instead of one chamber as in the analysis. Furthermore, the front bulkhead opening has an attached flow straightener.

Hence, a complex analysis of this test system with appropriate orifice-area and orifice-coefficient values for each opening would be more appropriate for the estimate. Such an analysis can be done and is recommended for any operational fire-hazard application. Also, a correction for the flow velocity profile across the rear bulkhead was not made for the empirical volumetric flow rate calculation.

SECTION III

ADDITIONAL GENERAL OBSERVATIONS

General implications and limitations are discussed here. First, the flow and pressure-coefficient distribution for each set of conditions are defined relative to the ground plane or direction of the wind. Consequently, the postcrash rotation of the fuselage does not change the flow or pressure distribution relative to the wind or ground axes. However, the openings, which are located relative to the fuselage reference axes, may be rotated with the fuselage to other locations relative to the pressure distribution (i.e., a door normally located on the stagnation line at $\theta = 0$ near the maximum pressure may be rotated 67 degrees to the location of the minimum pressure in accordance with a postcrash rotational orientation of the fuselage). This relative rotation can have a strong influence on the ventilation rates.

The presence of an external fire near an opening can induce large convective velocities which cause changes in the adjacent local pressure coefficients and may cause a rotation or distortion of the distribution. This effect may be simulated by a change in the flow-field circulation about the fuselage; hence, the pressures may be affected at all circumferential locations. How the effects of the interaction of the fire convection and wind flow about the fuselage are quantitatively related requires future investigation. A first attempt at modeling this effect might be the simulation of the fire-convected velocity by the superposition of circulation which would induce such a velocity. The altered flow and pressure distribution about the cylinder would cause changes in ventilation. Such pressure distributions resulting from circulation exist in the literature.

The effect of the wind over the fuselage on the external fire and plume dynamics may be more important. Fundamentally, the combustion process and resulting heat-flux distribution of a fire contiguous to the fuselage are inherently and intimately affected by this flow interaction. A less fundamental but significant effect on the fire plume and dynamics is the influence of the ventilation direction and magnitude on whether the flames enter an opening into the fuselage. This effect, in turn, is dependent on the pressure difference at the openings as determined from the circumferential pressure distribution.

Other predominantly three-dimensional influences are more or less secondary. Consider the orientation or incidence of the fuselage to the ground or the location of an opening near the end of a finite cylinder or of a real fuselage nose, tail, or appendage shape. These usually small, but occasionally large, effects can be measured in small-scale, large Reynolds number wind-tunnel tests or estimated in some situations by established methods and empirical data. The limiting size of the opening relative to the fuselage diameter that does not affect the local pressure distribution is another such item. Then, of course, there is the variation of the orifice-discharge coefficient with the opening configuration, such as surface shape, opening outline shape, and edge sharpness.

All of these effects of the various parameters could be improved by a general program of investigation. Such a program would include an extensive literature search, analytical methods and applications, scaled wind-tunnel tests, and some full-scale validation tests. The minimum test effort would be the full-scale validation test of one of the configurations simulated in this analysis of fuselage ventilation under wind conditions. Such a test requires careful adherence to the conditions of the analysis, including a leak-free vessel. Finally, this approach could be applied to noncircular and prismatic cross sections and to specific three-dimensional objects for the extension of the results to general aircraft-component shapes, to other modes of transportation, and to buildings.

SECTION IV

CONCLUSIONS

The result of this analysis is an elementary formula that pro-
vides a general estimate of the ventilation rate through any two
circumferentially located openings in a postcrash aircraft fuselage
as caused by the ambient wind. The necessary polar distribution of
pressure coefficients is simulated approximately by available data for
the two-dimensional flow about a circular cylinder displaced from a
plane with its boundary layer. The ventilation rate caused by a common
10-mph wind perpendicular to the fuselage is about an order of magnitude
greater than the in-flight air-conditioning rate. In comparison with
a free-ventilation test under somewhat inconsistent conditions relative
to the analysis, the measured ventilation rate is scaled coarsely to
25 percent less than the analytical estimates. It is possible for the
ventilation flow to be in the reverse direction by simply a change
in the local wind-flow pattern.

This analysis would benefit from a full-scale validation test
having consistent conditions. Any general application to fire prevention,
aircraft design, and evacuation operations would also benefit from a
complete and broad investigation of the effects and interactions of
all the parameters.

Finally, since this analysis conservatively predicts ventilation
volumetric rates of 12,000 cfm in a common 10-mph normal component
of wind with a common fuselage opening configuration, any relevant
test program resorting to forced ventilation should use equipment with
this capability.

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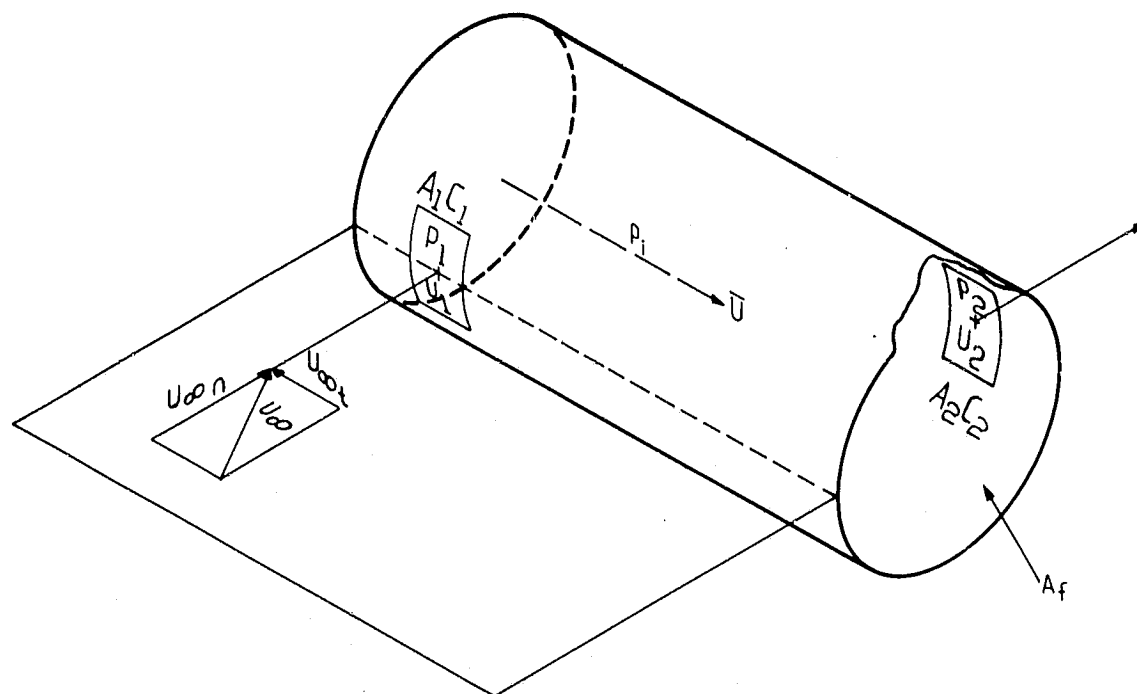
Figure 1. Wind Fuselage Ventilation
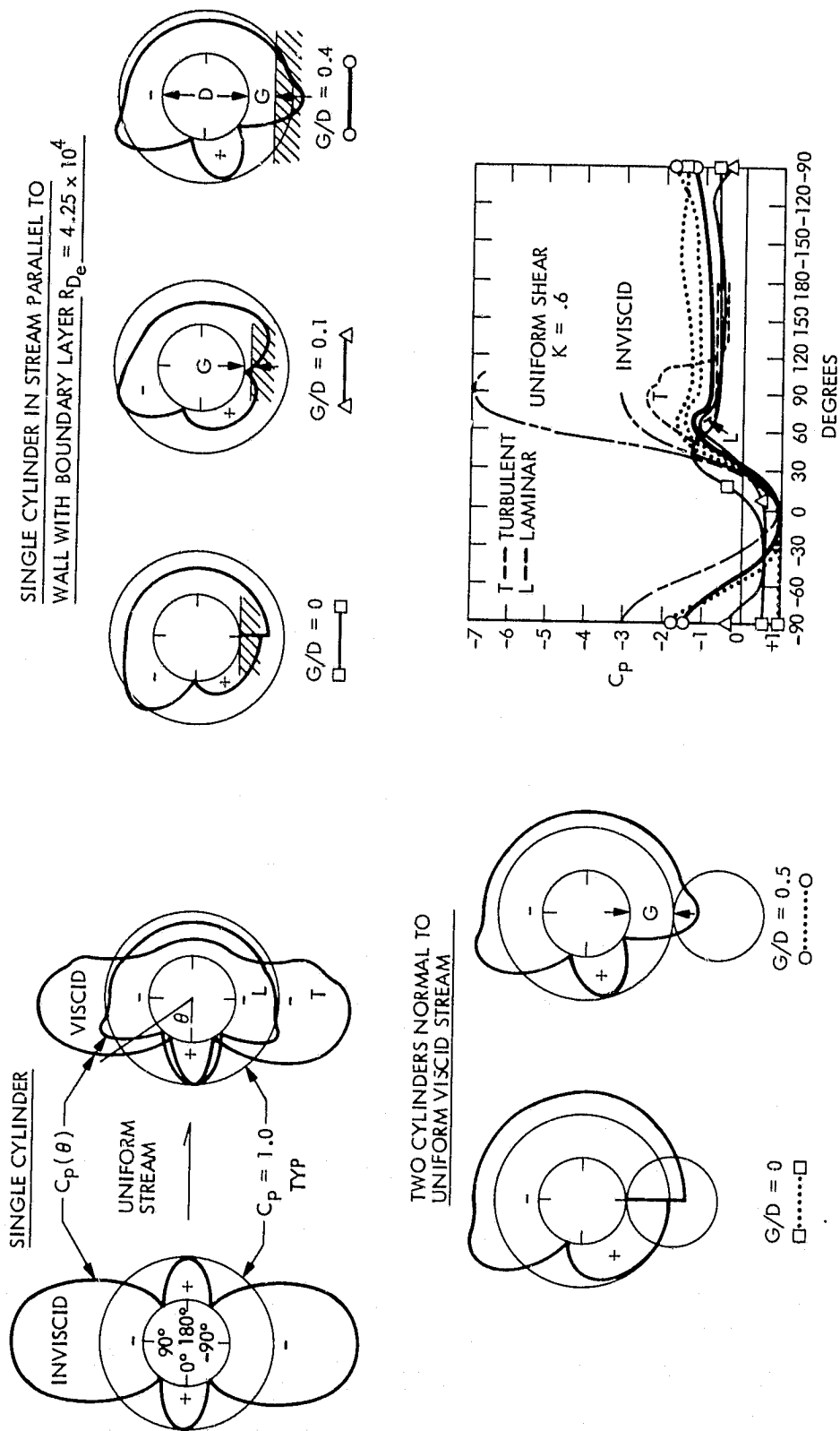
Figure 2. Pressure-Coefficient Distributions for Flows Around Infinite Circular Cylinders
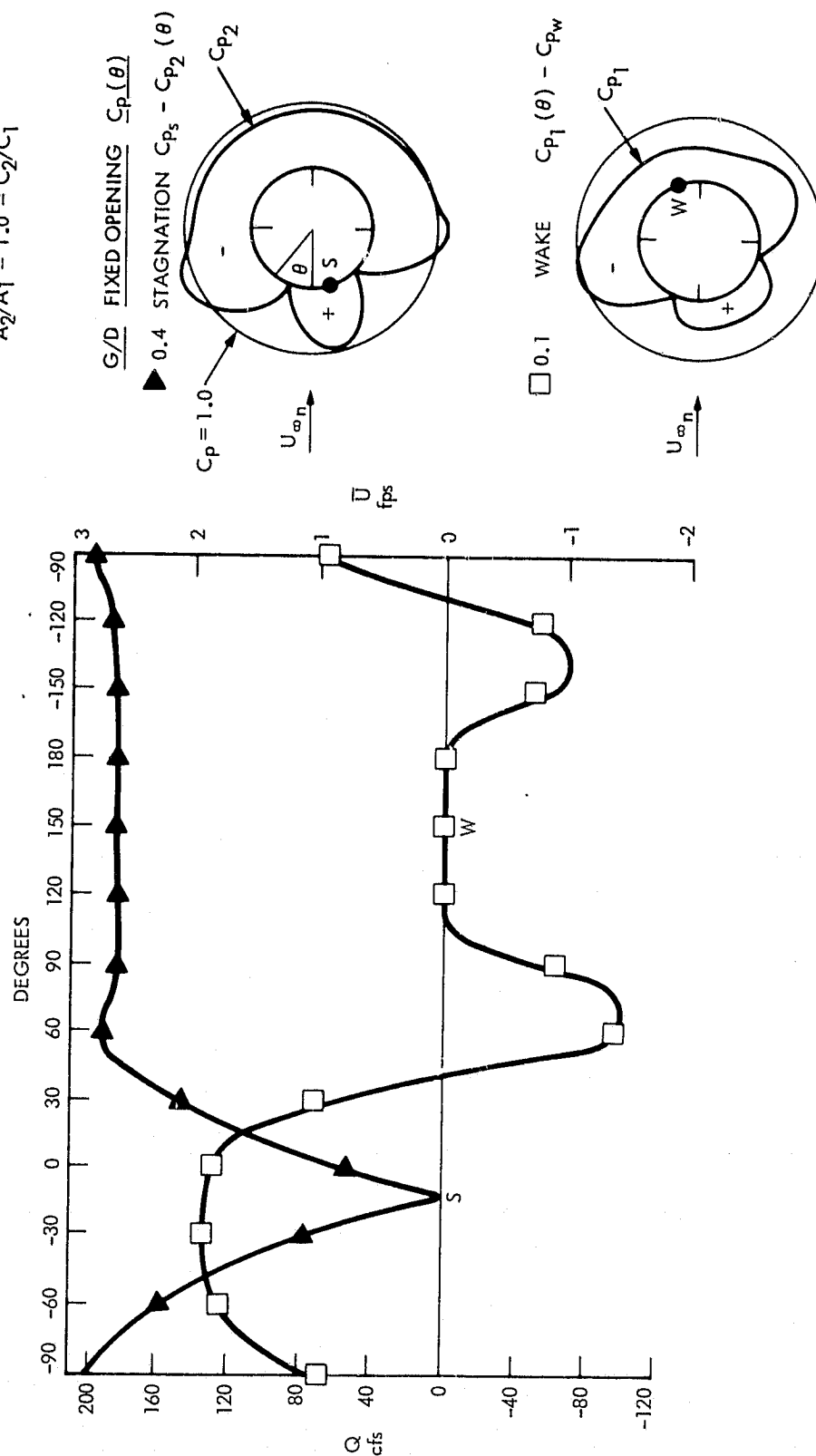
Figure 3. Variation of Volumetric Rate With Circumferential Location of Second Opening
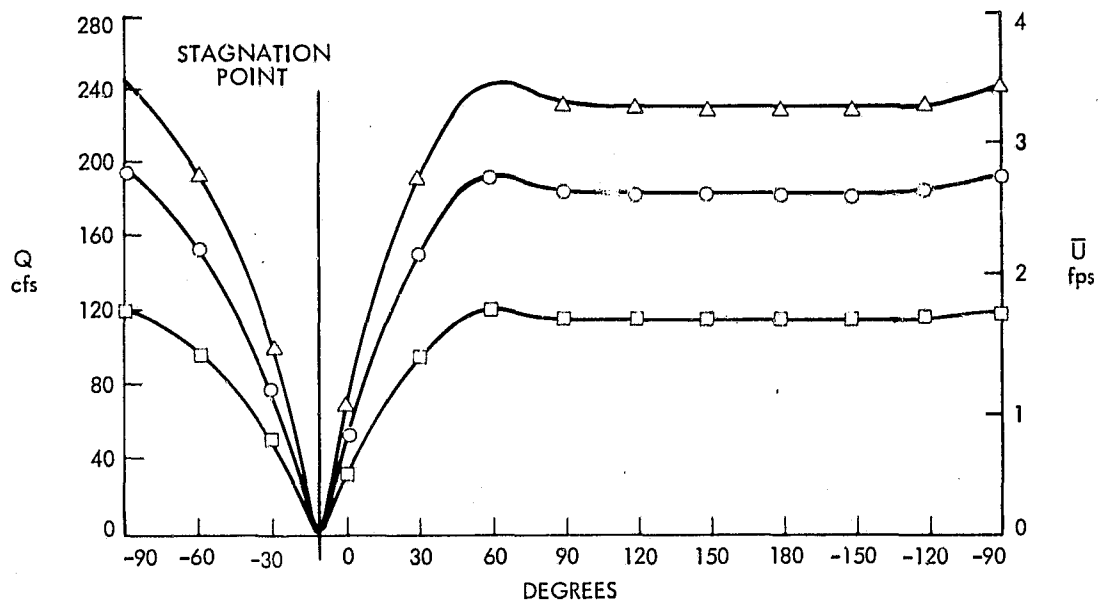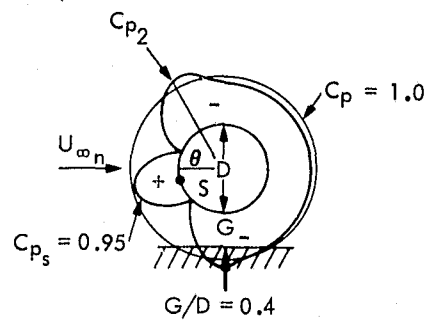
Figure 4. Effect of Opening Area Ratio on Ventilation Performance
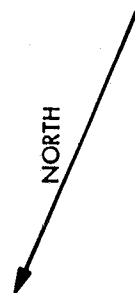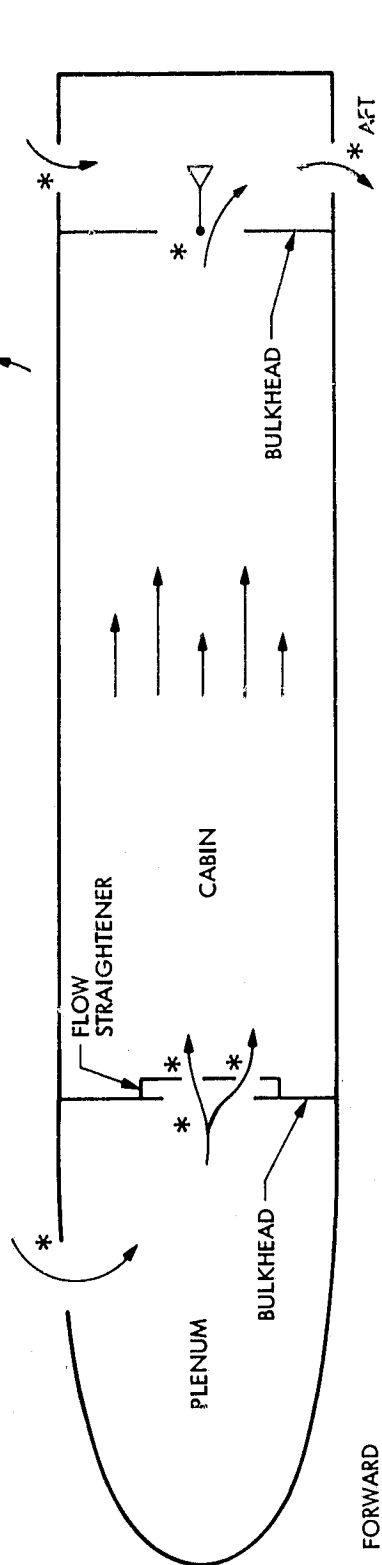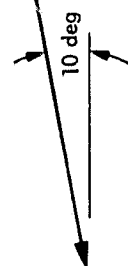
Figure 5. NASA/JSC Wind and Ventilation Sample Test Environment