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TECHNICAL NOTE

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AN INVESTIGATION OF THE EFFECT OF DOWNWASH FROM A VTOL AIRCRAFT AND A HELICOPTER IN THE GROUND ENVIRONMENT

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SUMMARY

Dynamic-pressure measurement, in ground effect, have been obtained about a single-rotor helicopter and a dual-propeller VTOL aircraft. The results indicate that the slipstream dynamic pressure along the ground, some distance from the center of rotation, is not a function of disk loading but merely a function of the gross weight or thrust of the aircraft. Furthermore, for a given gross weight the thickness of this outward flowing sheet of air is less for a small-diameter propeller (higher disk loading propeller).

The variation of the dynamic-pressure flow field for single and dual propellers or rotors is significantly different in the plane of symmetry between the two rotors than in a direction normal to this plane. The interaction of the two flows produces a region of upflow in this plane where the fuselage is located, and the decay of the maximum dynamic pressure with distance ahead of the fuselage is slower.

INTRODUCTION

Airflow directed downward by the action of flaps, rotors, or by the exhaust of turbine engines to produce lift for vertical take-off and landing may present problems which range from visibility obscurement to possible damage from foreign objects. Commercial operations take place primarily from prepared areas and, as a result, the problem may be only of nuisance value, except for the handling qualities involved in flying near the ground in a disturbed flow field. (See ref. 1.) Military operations which must be performed over unprepared surfaces may, however, be influenced by all these problems.

The action of the downwash from VTOL aircraft is similar to the effect on the ground of the slipstream from conventional aircraft. The downwash from a VTOL aircraft magnifies the problem by turning the slipstream from near horizontal to vertical with an attendant increase in the affected area near the airplane.

This report discusses downwash from considerations of the dynamic-pressure flow field and the tendency to slide or overturn box-type objects on the ground. To implement this the measured dynamic-pressure decay with distance from the rotor for a single rotor and a dual propeller is presented along with characteristic variations of the dynamic pressure with height above the ground.

SYMBOLS

A	area of propeller or rotor, sq ft
D	diameter of propeller or rotor, ft
h	height of pitot tube from the ground, ft
M	overturning moment, ft-lb
q	dynamic pressure of outward flowing sheet of air, lb/sq ft
q_{max}	maximum dynamic pressure of outward flowing sheet of air, lb/sq ft
T	propeller or rotor thrust, lb
x	distance forward in plane of symmetry measured from intersection of plane of symmetry and plane through axis of rotation of VTOL aircraft, ft
y	lateral outward distance from center of rotation of propeller or rotor, ft
z	height of plane of rotation of propeller or rotor from ground, ft

Subscripts:

36	36-foot-diameter rotor
72	72-foot-diameter rotor

APPARATUS AND PROCEDURE

The aircraft used in the investigation were a tilting propeller type of VTOL aircraft and an H-13 helicopter. The VTOL aircraft had two 10-foot-diameter propellers (located 1.0 diameter above the ground) and the maximum disk loading obtained during the test was 25 pounds per square foot. The helicopter had a single 35-foot-diameter rotor (located 0.3 rotor diameters above the ground) which produced a maximum disk loading of 3.0 pounds per square foot. Photographs of the VTOL aircraft and the helicopter are presented as figure 1.

The dynamic-pressure environment was measured with both aircraft restrained on the ground in the take-off or landing attitude. The propellers of the VTOL and the rotor on the helicopter were parallel to the ground and the fuselage of the VTOL was leveled by using the temporary tail-wheel structure shown in figure 1.

For the tests with the helicopter the dynamic pressures were measured with a Kollsman pitot static tube connected to a strain-gage pressure cell with a maximum range of 3 pounds per square foot. The output of the pressure cell was indicated on a milliammeter with a system response flat to about 1 cycle per second. Dynamic pressures were measured at various heights above the ground in a lateral plane about the helicopter by utilizing the portable tower shown in figure 2. The pitot static tube was mounted parallel to the ground and manually translated through a vertical plane. The pitot static tube was moved in discrete intervals of height and the height intervals were marked on the tower. The pitot static tube was insensitive to angularity of the flow up to angles of $\pm 15^\circ$. Measurements were not taken when it was determined by tuft studies that the angularity of the flow was greater than 15°.

The measurements about the VTOL aircraft utilized a 25-pound-per-square-foot strain-gage pressure cell. The survey was made in a lateral plane off the wing tip and in a plane on the aircraft center line ahead of the nose. The output of the pressure cell was recorded on an oscillograph and the system response was flat to 5 cycles per second. The pitot static tube was continuously translated to the extent of the tower height (approximately 8 feet) and the height of the pitot was recorded on the oscillograph from the output of a rotary control position transmitter.

The total thrust of the helicopter was estimated from the rotor characteristics whereas the thrust of the VTOL aircraft was obtained from a thrust calibration supplied by the aircraft manufacturer.

RESULTS AND DISCUSSION

A schematic illustration of the flow field from a single rotor is shown in figure 3. The presence of the ground turns the flow from a vertical to a horizontal direction and it is this flow of air parallel to the ground which is of concern.

Measurements of the dynamic pressure of the outward flow of air from the helicopter rotor and the VTOL propellers obtained with the vertically traversing pitot static tube were made along the survey lines shown in figure 4. The long-period large-scale instability of the flow discussed in reference 2 and shown in the film supplement to reference 2 was quite apparent under the conditions of this test. It was manifested by an oscillation in the dynamic pressure at about 1 cycle per second and could be detected physically by observers operating in the flow-field environment. Since this oscillation was time dependent with respect to the pressure probe, it was faired in the resulting records. The dynamic pressure divided by the disk loading $\frac{q}{T/A}$ is shown in figure 5 as a function of height above the ground measured in propeller or rotor diameters h/D at several lateral distances measured in propeller or rotor diameters y/D from the center of rotation. Both propellers on the VTOL aircraft were operating; however, their influence on each other along the lateral survey line is considered negligible. The results therefore were assumed to represent the flow of a single rotor. The data for both configurations indicate a general geometric similarity of the profiles with a decrease in maximum dynamic pressure as the lateral distance from the center of rotation is increased and the profiles for either configuration indicate that the average height of the sheet of air is relatively constant.

The decay of the measured maximum dynamic pressure divided by the disk loading with increase in distance from the rotor and the propeller along the survey lines previously discussed is shown in figure 6.

The decay for several configurations both model and full scale is compared in figure 6. The data for dual propellers are those measured in a lateral plane outboard from the center of rotation of one of the propellers, which is assumed to be representative of a single rotor or propeller. The data for the VZ-2 aircraft were taken from unpublished NASA model and full-scale tests. The decay of the maximum dynamic pressure for all the different configurations compares favorably with the relationship $\frac{q_{max}}{T/A} = \frac{1}{(y/D)^2}$ as shown in figure 6. The differences in configurations, sizes, and height above the ground result in a rather broad spread in the data. Any one of the curves should be adequate to study qualitatively the effect of the slipstream on the ground environment. The data of figure 6 for the 10-foot propeller are scaled up in the subsequent analysis to study the effect of downwash for two single-rotor machines producing equal thrust of 40,000 pounds and disk loadings of 10 and 40 pounds per square foot.

The results have so far been presented nondimensionally; in the cases considered comparison of the actual dynamic pressure at a given distance from an aircraft for different disk loadings is desired. To facilitate a comparison, the propeller data have been scaled to represent two large-size single-rotor configurations. In figure 7 the decay of the maximum dynamic pressure of the air flowing along the ground for two 40,000-pound-gross-weight configurations, one with a disk loading of 10 pounds per square foot, and the other at half the diameter with a disk loading of 40 pounds per square foot is compared. The main feature to be noted here is that at a distance of about one of the large rotor diameters or more from the center the maximum dynamic pressure is of similar magnitude for the two rotors. The maximum dynamic pressure at these distances is a function of gross weight or thrust and is not a function of disk loading.

The distribution of dynamic pressure with height above the ground, for the two rotors at a distance of one large rotor diameter from the center of rotation is shown in figure 8. The greater depth of the flow for the large rotor indicates that, in the regions where dynamic pressure is approximately equal for the two rotors, the tendency to slide or overturn objects on the ground will actually be greater for the low disk loading machine.

The movement and overturning characteristics produced by the slipstream of the two 40,000-pound aircraft are compared in figure 9 for objects located 72 feet from the center of either rotor. The forces and moments that would be produced in a vertical plane per unit foot of width were obtained from integration of the profiles of figure 8. The data indicate the greater forces and moments produced by the 72-foot-diameter rotor in comparison with the 36-foot-diameter higher disk loading rotor. The forces and moments required to move or slide solid boxes of material of unit width and depth in feet for various heights are also shown in figure 9 for material densities of 23 and 35 pounds per cubic foot. On the assumption that the coefficient of friction at the ground is 0.5, the force and the moment curves are identical for a given density. The large rotor would not slide or upset material with a density of 35 pounds per cubic foot or greater while the small rotor would not slide or upset material denser than 23 pounds per cubic foot. Either of these densities is lower than packages of fuel, food stuff, and a wide range of building materials. In the event that the force and moments required to slide or overturn stacked boxes at varying heights and density is desired, they may be obtained by integrating the profiles of figure 8 over the proper height range.

The flow field on the plane of symmetry when two slipstreams meet is shown diagrammatically (from ref. 1) in figure 10. The first feature of the flow is the vertical flow of air under the fuselage that turns to horizontal by about one or two rotor diameters ahead of the center of rotation on the plane of symmetry. The other feature of the flow on the plane of symmetry is that for appreciable distances ahead of and behind the aircraft the meeting of the two slipstreams reinforce each other. This condition results in an appreciably slower decay in this plane than in a plane to the side off the wing tip and is illustrated in figure 11 along with a comparison of the decay of the maximum dynamic pressure along these two survey planes. A comparison of typical dynamic-pressure profiles obtained from vertical surveys at several locations along the x- and y-planes is presented in figure 12. The plot of the profiles measured at locations on a line off the wing tip is the same as presented in figure 5. The shaded area at $x/D = 2.0$ is indicative of the variation in dynamic pressure caused by large low-frequency disturbances which exist because of the mixing and eddying of the two flows. This oscillation was considerably reduced at $x/D = 4.0$.

CONCLUDING REMARKS

Measurements of the slipstream dynamic pressure about a single-rotor helicopter and a dual-propeller VTOL in ground effect have been made to study the dynamic-pressure flow field and its effect on the movement of box-type objects.

The value of slipstream dynamic pressure along the ground some distance out from the center of rotation of a propeller or rotor is not a function of disk loading but merely a function of the gross weight or thrust of the aircraft. Furthermore, the greater depth of the flow for the large rotor indicates that in the regions where dynamic pressure is approximately equal for the two rotors, the tendency to slide or overturn objects on the ground will actually be greater for the low disk loading machine.

The variation of the dynamic-pressure flow field for single and dual propellers or rotors is significantly different in the plane of symmetry between the dual rotors than in a direction normal to this plane. The interaction of the two flows produces a region of upflow in this plane where the fuselage is located and the decay of the dynamic pressure with distance ahead of the fuselage is slower.

Langley Research Center,
National Aeronautics and Space Administration,
Langley Air Force Base, Va., August 29, 1961.

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1. Schade, Robert O.: Ground Interference Effects. NASA TN D-727, 1961.

2. Heyson, Harry H.: An Evaluation of Linearized Vortex Theory As Applied to Single and Multiple Rotors Hovering In and Out of Ground Effect. NASA TN D-43, 1959.

(a) H-13 helicopter. L-96946

(b) Dual-propeller VTOL aircraft. L-60-7902

Figure 1.- General view of test vehicles.

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Figure 2.- General view of portable tower and associated instrumentation.

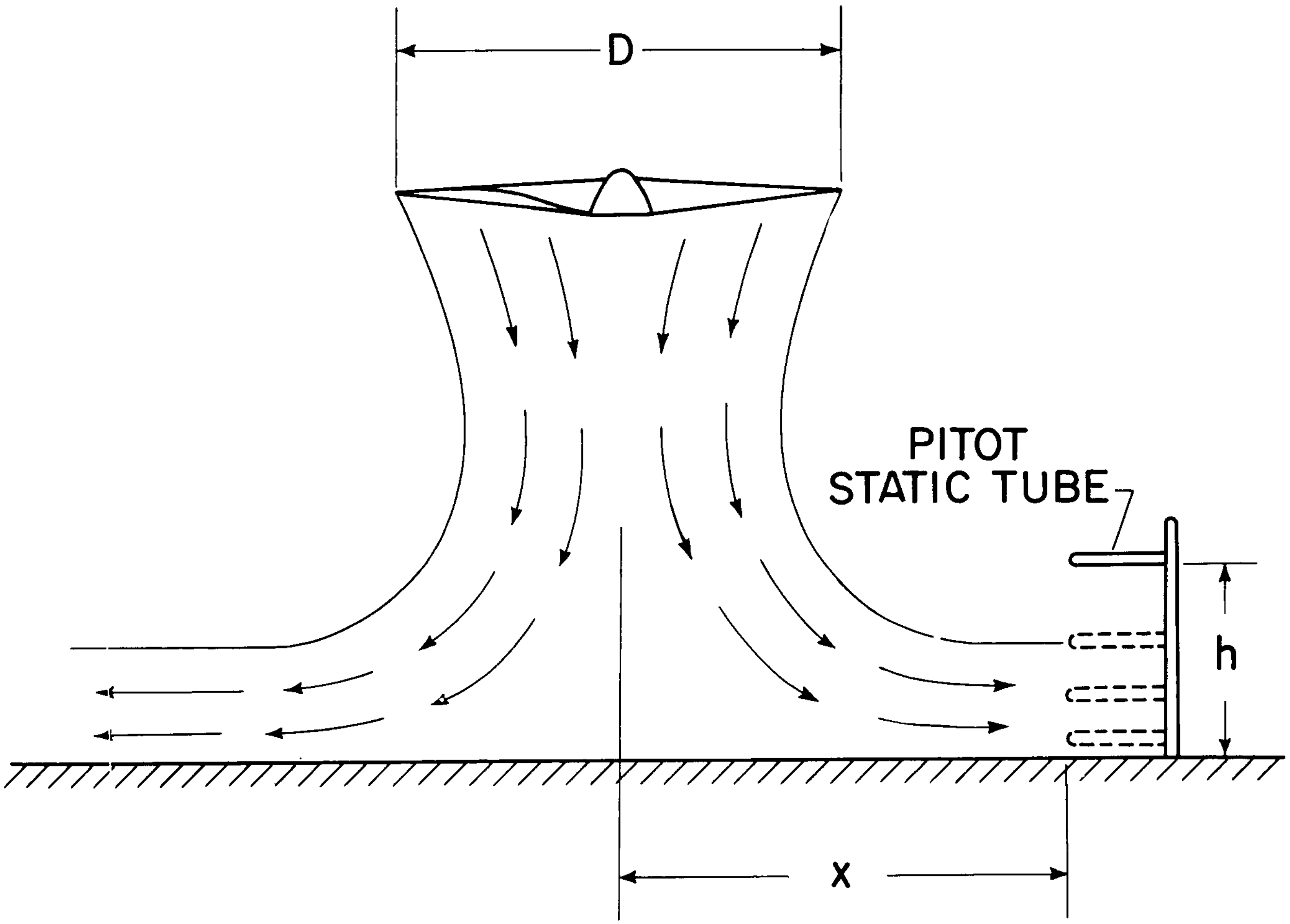


Figure 3.- Schematic illustration of downwash from an isolated rotor.

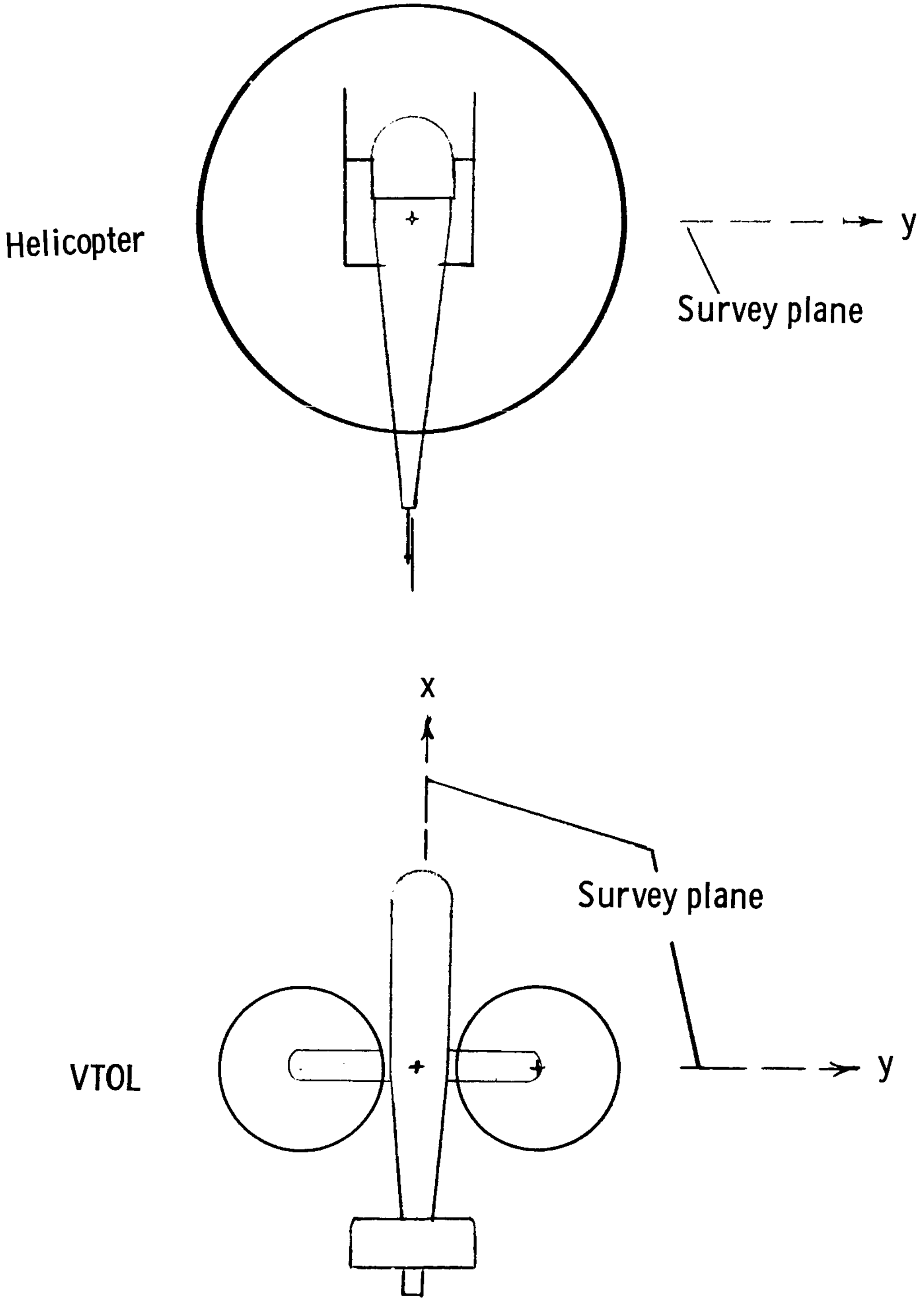
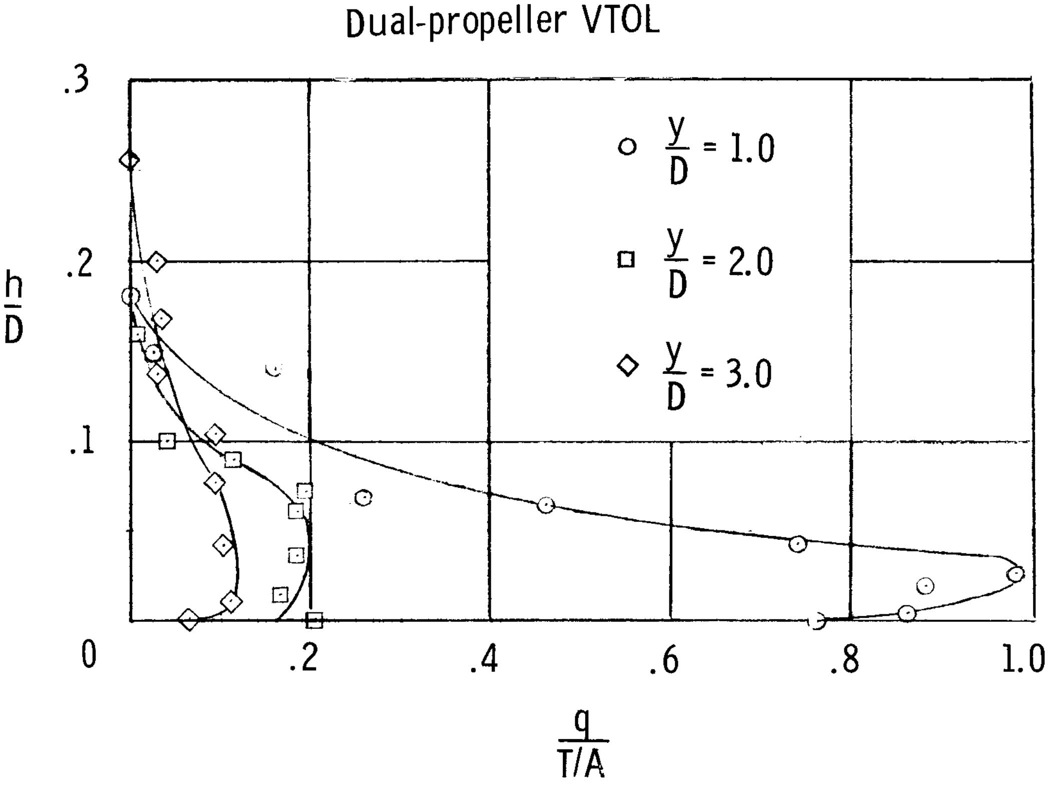


Figure 4.- Location of survey lines along which dynamic-pressure measurements were obtained.



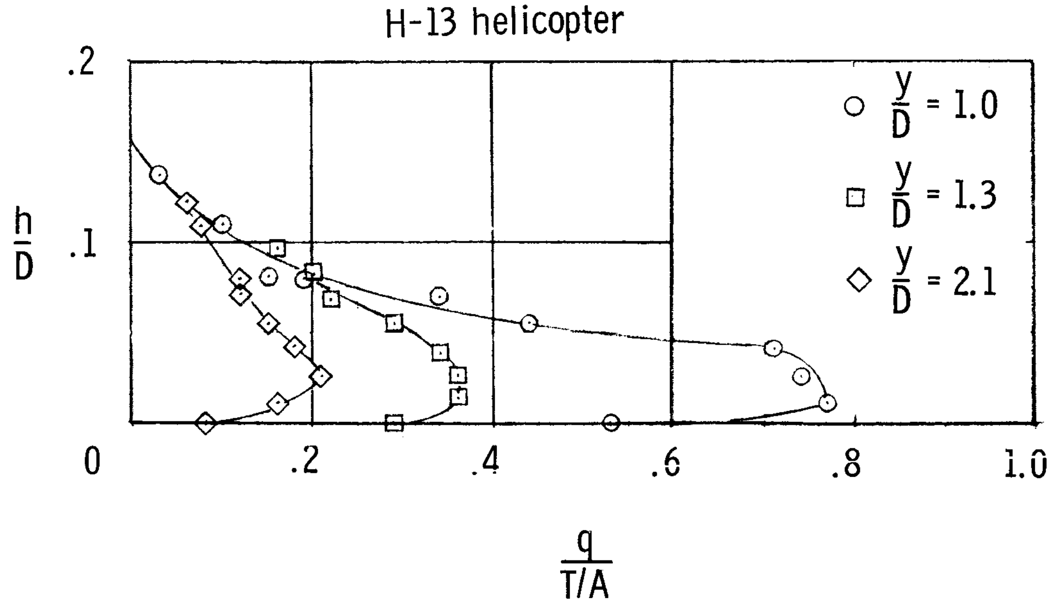


Figure 5.- Variation of dynamic pressure with height above the ground at several locations for a helicopter and a dual-propeller VTOL.

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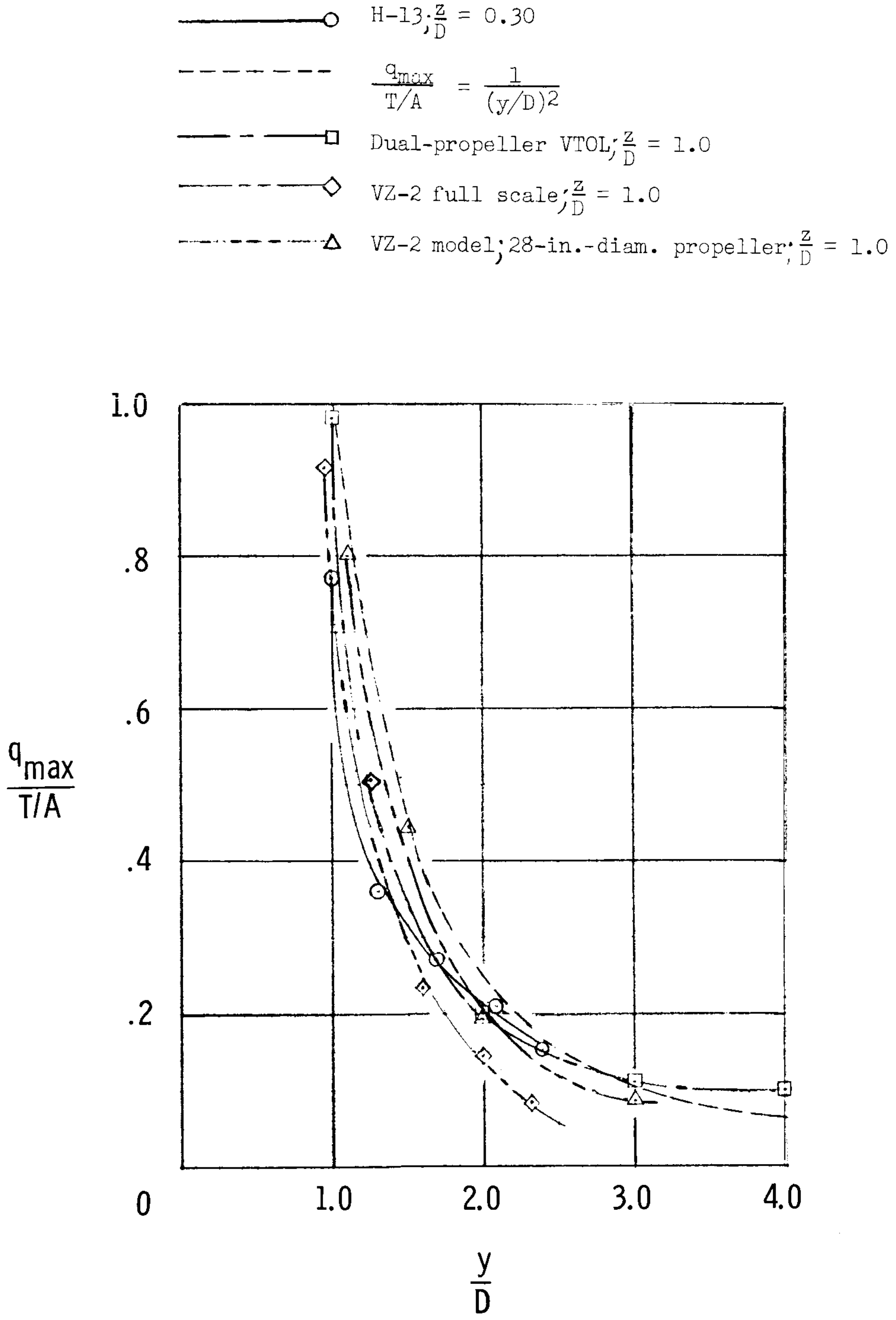

Figure 6.- Variation of maximum dynamic pressure for rotors and propellers with distance from the center of rotation.

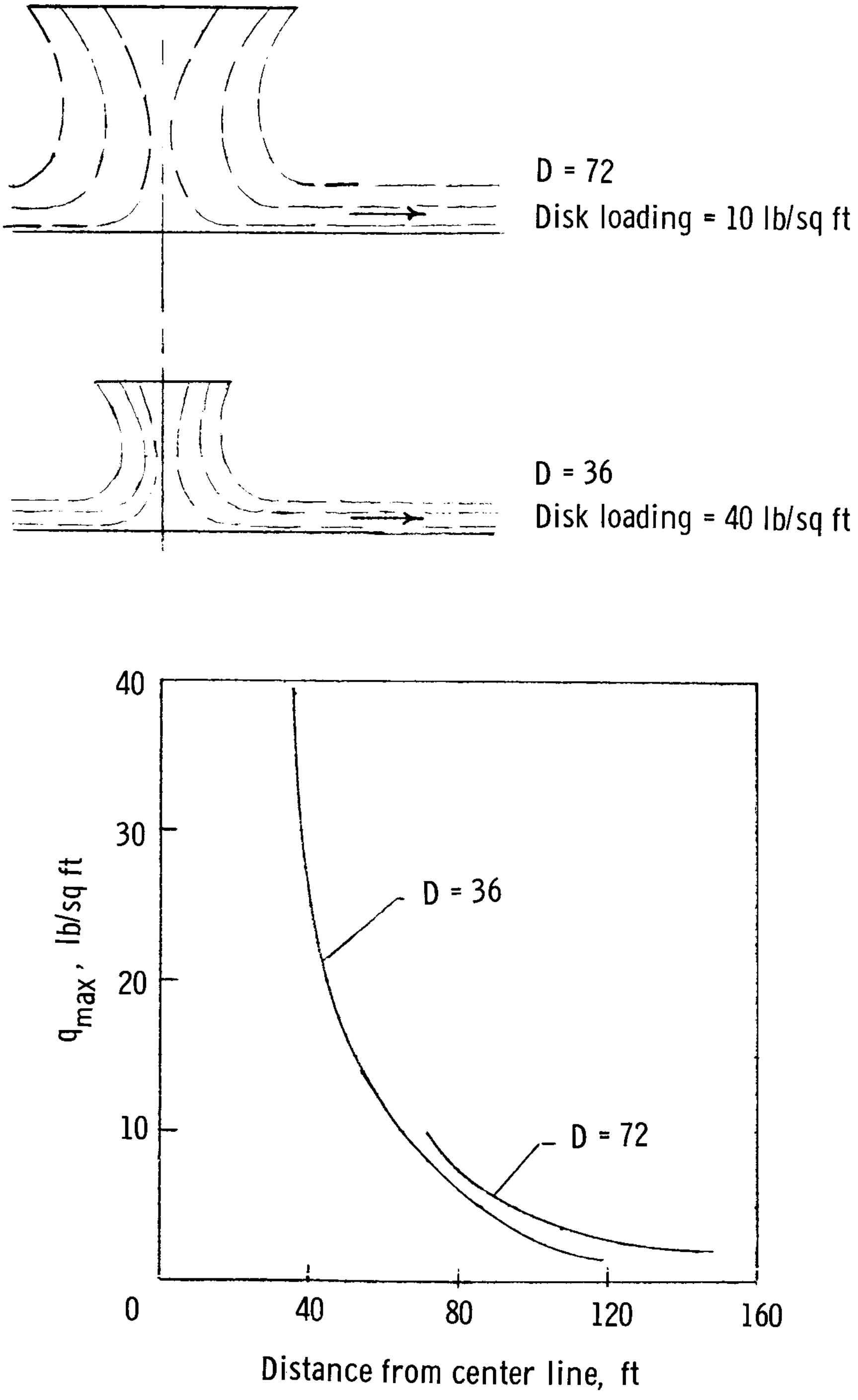

Figure 7.- Comparison of maximum dynamic pressure with distance from center line for two single-rotor VTOL aircraft with equal gross weight of 40,000 pounds for two different disk loadings. $\frac{z}{D} = 1.0$.

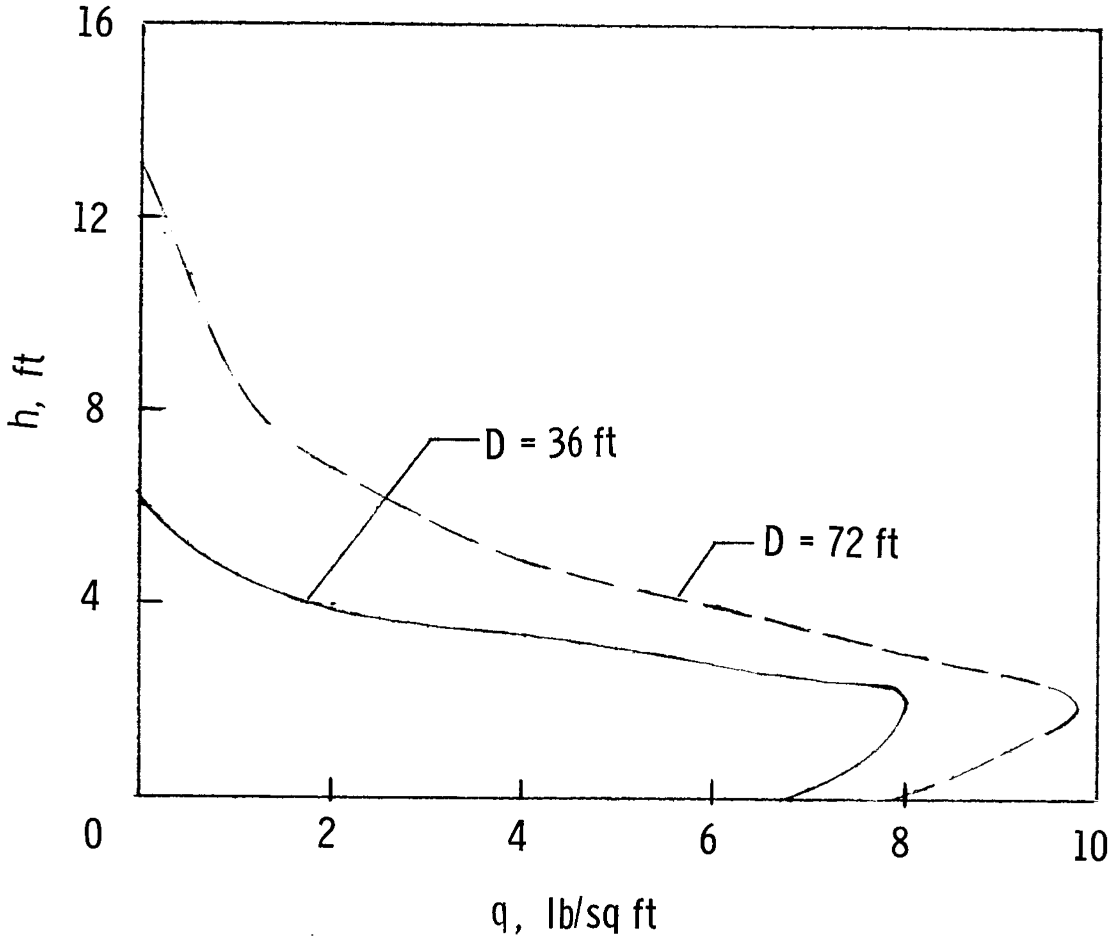

Figure 8.- Variation of dynamic pressure with distance above the ground at 72 feet from the center line for two single-rotor VTOL aircraft with equal gross weight of 40,000 pounds for two different disk loadings. $\frac{z}{D} = 1.0$.

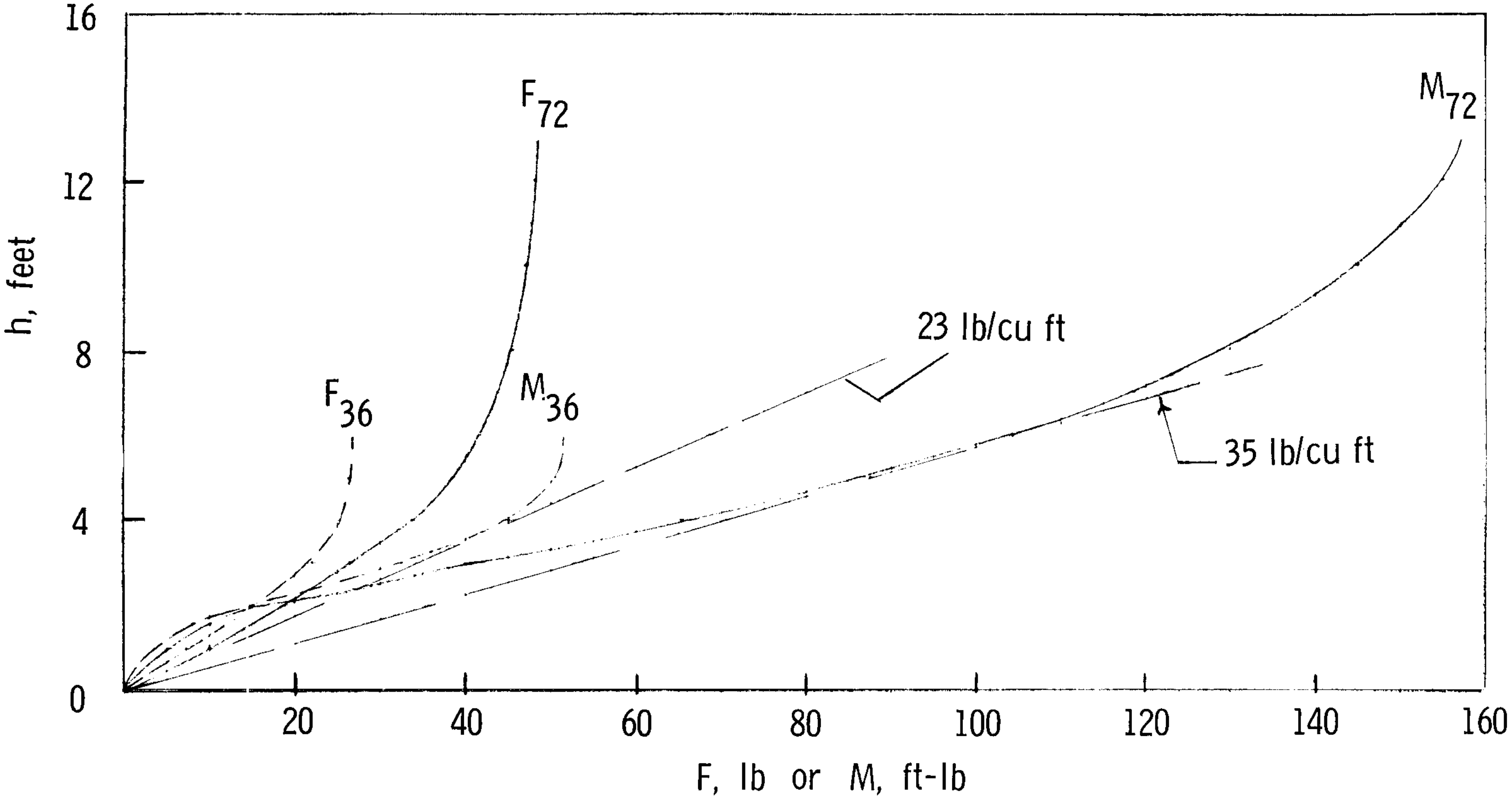

Figure 9.- Force and moments per 1-foot width produced by the downwash from two single-rotor aircraft with equal gross weight of 40,000 pounds for two different disk loadings at 72 feet from the center line.

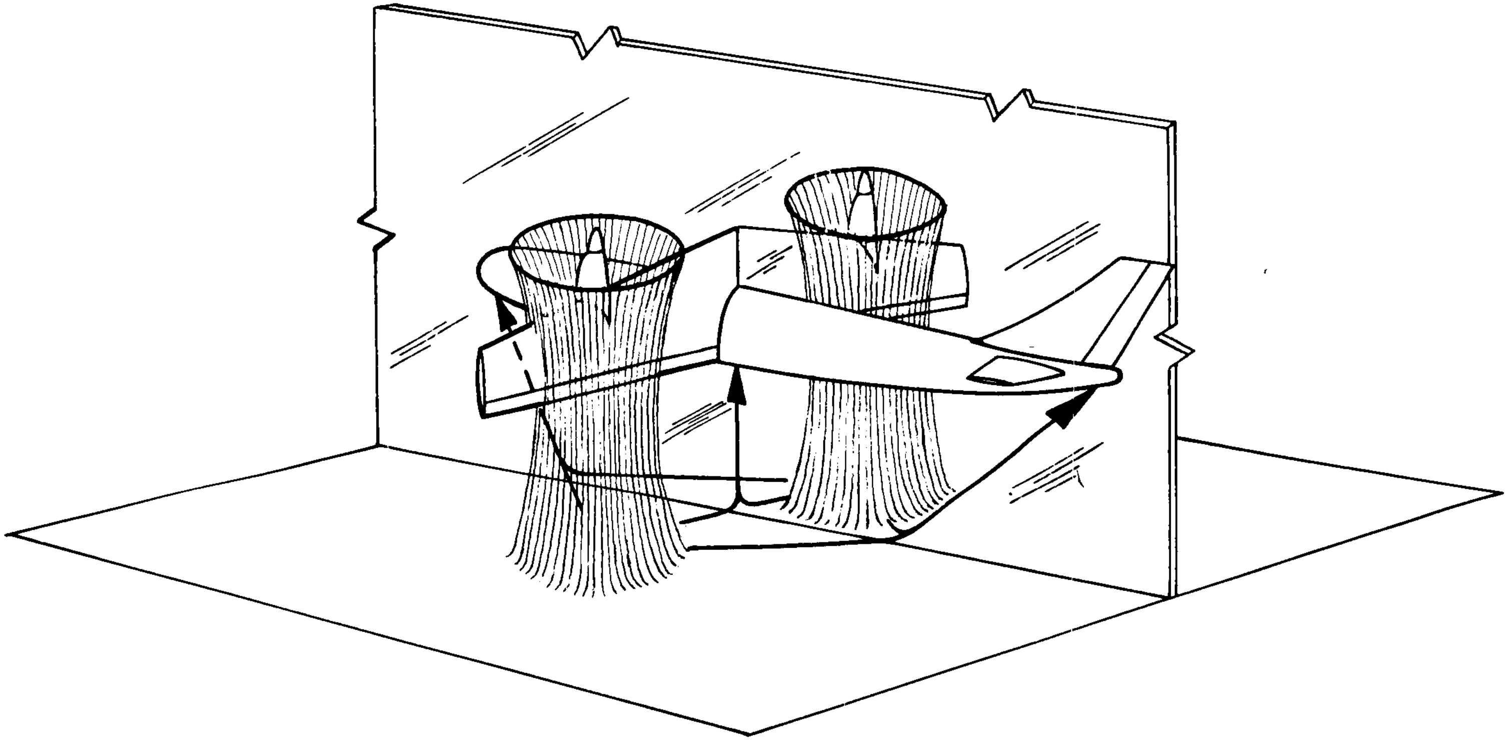

Figure 10.- Schematic illustration of downwash flow field for dual-propeller VTOL.

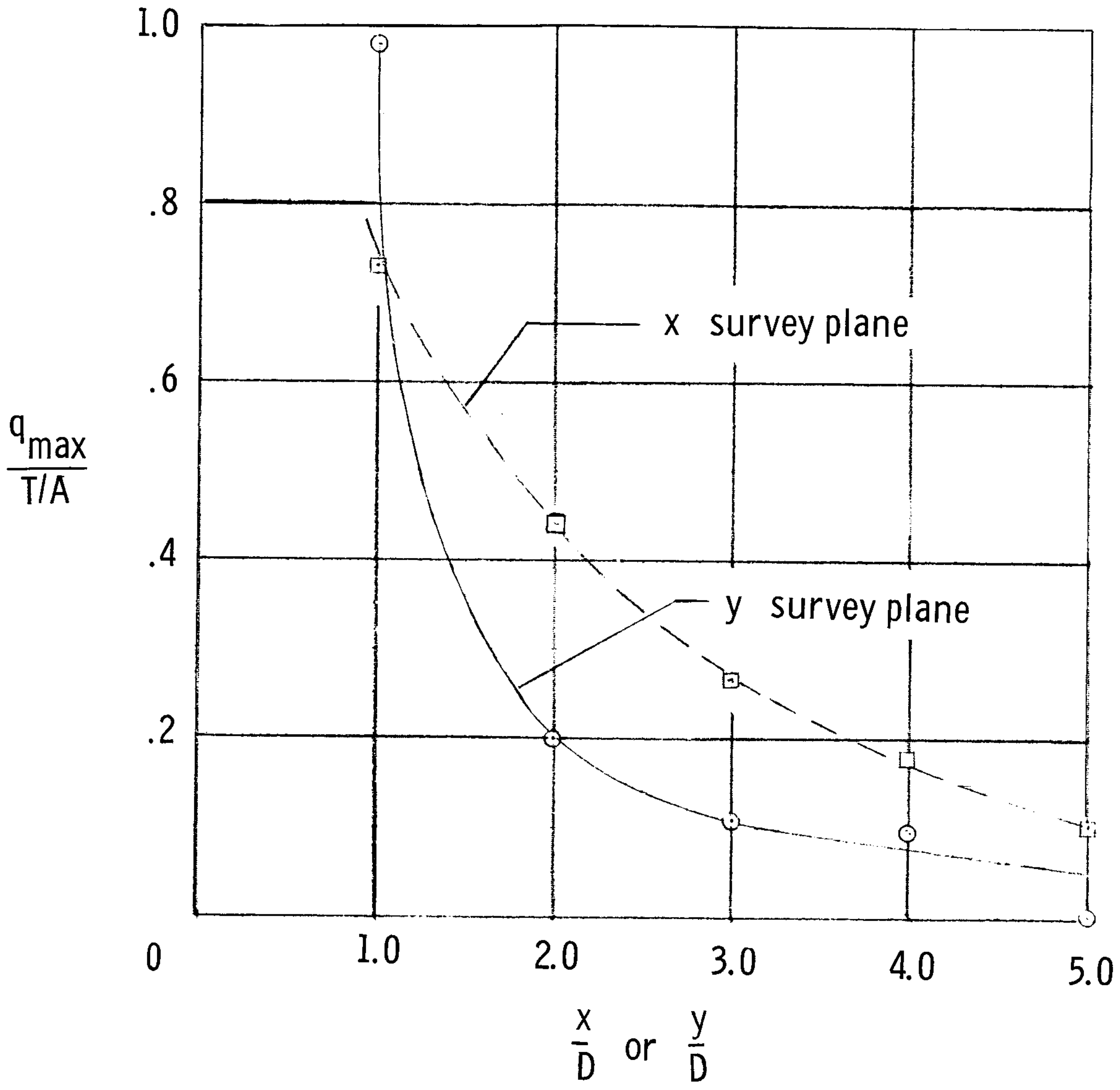

Figure 11.- Variation of maximum dynamic pressure for the dual-propeller VTOL measured on the plane of symmetry and on a line normal to the fuselage through the center of rotation.

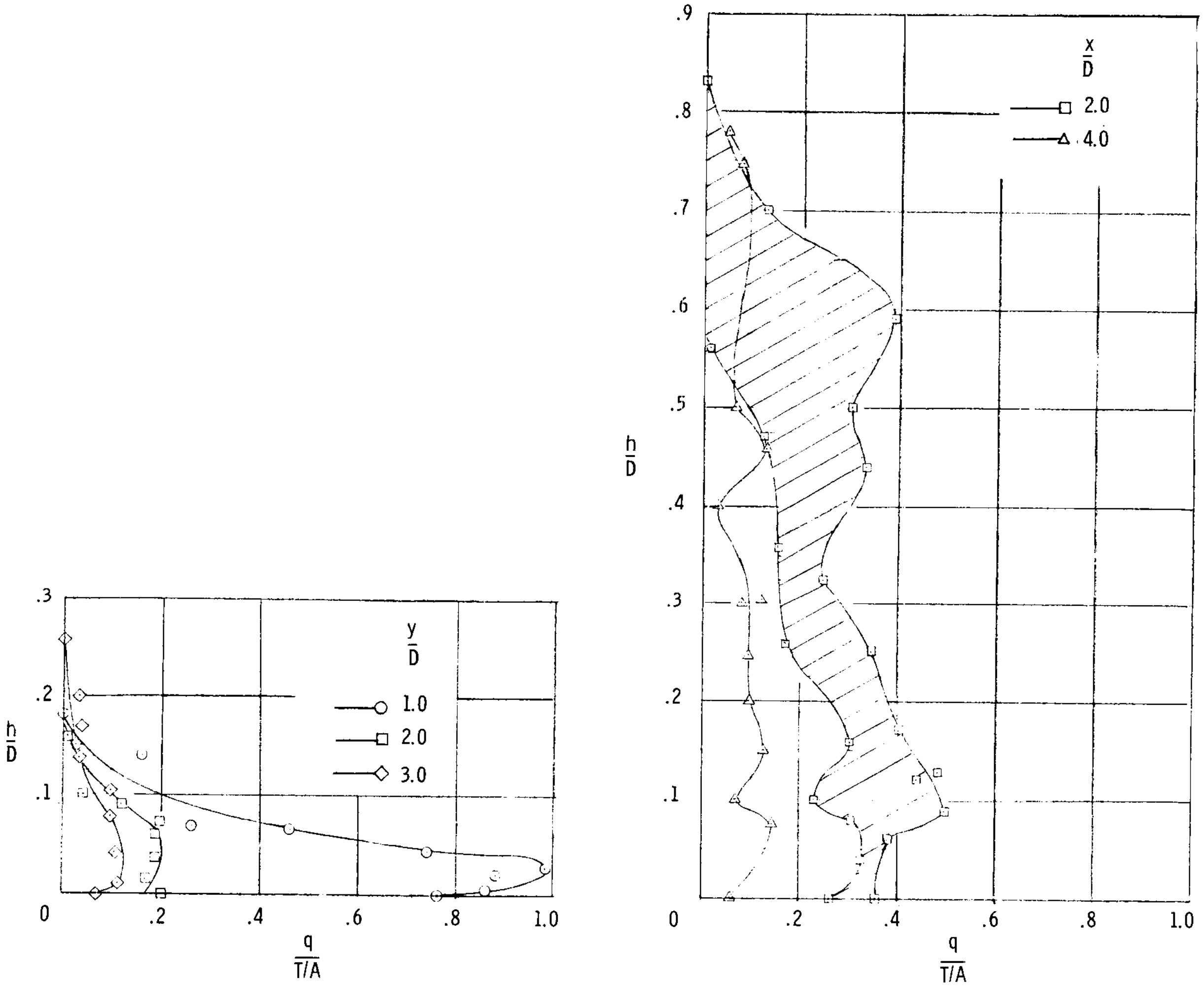

Figure 12.- Variation of dynamic pressure for a dual-propeller VTOL, with height above the ground, at several locations on the plane of symmetry and on a line normal to the fuselage through the center of rotation of the propellers.

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