20

CONSIDERATIONS OF THE EFFECT OF VTOL DOWNWASH ON THE GROUND ENVIRONMENT

By Thomas C. O'Bryan

Langley Research Center

L 1 4 2 9

This paper will consider VTOL downwash from the standpoint of ground erosion and movement of objects to determine the present status of the downwash problem.

The first problem which will be considered is the erosion effect of the downwash. Figure 1 indicates the dynamic pressure required to start erosion for a number of ground surfaces. This information is a summary of small-scale erosion tests reported in reference 1 except for the example of loose crushed rock at 19 lb/sq ft. This example was obtained from an incident with the Vertol VZ-2 operating over an area covered with loose rock which resulted in damage to the airplane. All data shown in figure 1 were obtained with the use of cold jets. Since sod withstands erosion at dynamic pressures up to 1,000 lb/sq ft, operation of jet VTOL aircraft over this surface would appear feasible. Landings of the Bell X-14 and Short S.C.1 on sod have, in fact, verified this feasibility. Experience indicates, however, that hot jets operating over sod would eventually burn off the grass and dry out the soil with resulting erosion.

The most serious effect of erosion arises when the dynamic pressure is sufficient to dig a crater in the ground, a condition which is usually imminent once erosion starts. The crater not only represents a source of material to be recirculated, but in addition, the sides of the crater provide a path for the eroded material to be projected vertically into the rotor.

In addition to the crater problem, eroded material moving radially may encounter large enough objects on the surface of the ground to project them vertically into the rotor or onto the airframe.

The flow field around a hovering aircraft determines the extent of the area to which these considerations apply. A schematic illustration of the flow field is shown in figure 2. 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 were made with a vertically traversing pitot head at several radial distances from the center of the rotor. The height of the rotor above the ground varied from about

Preceding page blank

1/3 diameter to 1 diameter, so the effect of rotor height on the flow field is not considered significant.

Typical results of these surveys for a 35-foot rotor are shown in figure 3. Shown in this figure is the variation of the ratio of dynamic pressure to disk loading $\frac{q}{T/A}$ with height above the ground measured in diameters h/D. The data indicate a general geometric similarity of the profiles and a decrease in maximum dynamic pressure as distance from the rotor is increased. Inasmuch as these profiles indicate that the height of this sheet of air is nearly constant, momentum considerations would indicate that this decrease in dynamic pressure with increase in distance from the rotor would be expected because as the radial distance (the distance in all directions from the center of the rotor) increases, the circumference of the sheet of air increases linearly with distance. Therefore the flow area increases and continuity requires that the velocity must decrease. From these considerations it would be expected that the dynamic pressure would decrease inversely as the square of the radial distance.

L1429

A typical decay of the maximum dynamic pressure with increase in distance from a rotor x/D is shown in figure 4. Here the ratio of the maximum dynamic pressure divided by the disk loading is plotted as a function of the radial distance for a full-scale 9.5-foot rotor and for a 28-inch-diameter model and is compared with the calculations based on the previous considerations. The actual decay is somewhat more rapid than this simple estimate as a result of the mixing of the flow with the still air above it and the friction with the ground beneath as the flow moves away from the source.

These results have been presented nondimensionally; in the practical case it is of interest to compare the actual q at a given distance from the aircraft for different disk loadings. To facilitate this comparison model data have been scaled to full-scale disk loadings. In figure 5 the decay of maximum dynamic pressure of the air flowing along the ground is compared for two 40,000-pound-gross-weight configurations, one with a disk loading of 10 lb/sq ft and the other at half the diameter with a disk loading of 40 lb/sq ft. The main feature to be noted here is that at a reasonable distance from the center the maximum dynamic pressure is equal for the two rotors. Except in the near vicinity of the aircraft dynamic pressure is a function of gross weight or thrust and not a function of disk loading. Moreover as indicated by the sketch at the top of figure 5, the sheet of air flowing along the ground is thinner for the smaller rotor. Figure 6 shows the distribution of dynamic pressure with height above the ground for the two rotors at a distance of 72 feet from the center. The greater depth of the flow for the large rotor indicates that in these regions where dynamic pressure is equal for the two rotors the large-diameter low-disk-loading machines would produce larger overturning moments to objects under its influence than would the smaller diameter high-disk-loading rotor. However, in the area in the immediate vicinity of the aircraft the erosion problems that may be encountered are a function of disk loading.

The discussion so far has dealt with single-rotor configurations. When multiple rotors are used, interactions can exist which bring in other considerations. Figure 7 is shown in order to discuss the effect of the flow at the plane of symmetry that exists when the flow from two rotors meet. The first point to be made is that the resulting vertical flow of air under the fuselage provides a path for the products of erosion to be recirculated. An example of this is the Vertol VZ-2 incident mentioned previously. In this case the loose rock was projected by the flow into the open fuselage, as well as into the propellers with considerable resulting damage to the machine. It is expected that the situation would have been less severe in the case of a closed fuselage.

Another feature of the flow in the plane of symmetry is that for short distances ahead of and behind the airplane the meeting of the two slipstreams results in an increase in the dynamic pressure of the airflow parallel to the ground. Figure 8 illustrates this effect using model data scaled to full-scale disk loadings. Here is shown the contour line for a constant dynamic pressure of 8 lb/sq ft around a two-propeller configuration. This increase in dynamic pressure shows up as the peak in the contour line ahead of the nose. Also shown is the contour line for a constant dynamic pressure of 8 lb/sq ft that would be obtained with a single rotor of the same disk loading. It can be seen that for practical purposes there is little difference between these contours. Thus the effects of the interaction of these two flows are confined to the immediate vicinity of the airplane.

CONCLUSIONS

In conclusion, ground erosion becomes a serious problem as disk loading is increased, and operating experience is needed to define the tolerable limits.

The problems associated with increased disk loading are confined to the immediate vicinity of the aircraft. Except for this area in the vicinity of the aircraft the dynamic pressure of the outward flowing sheet of air is dependent only on the gross weight of the aircraft. Furthermore, the thickness of this outward flowing sheet of air decreases directly with decreases in the diameter of the slipstream.

REFERENCE

1. Kuhn, Richard E.: An Investigation To Determine Conditions Under Which Downwash From VTOL Aircraft Will Start Surface Erosion From Various Types of Terrain. NASA TN D-56, 1959.

L
1
4
2
9

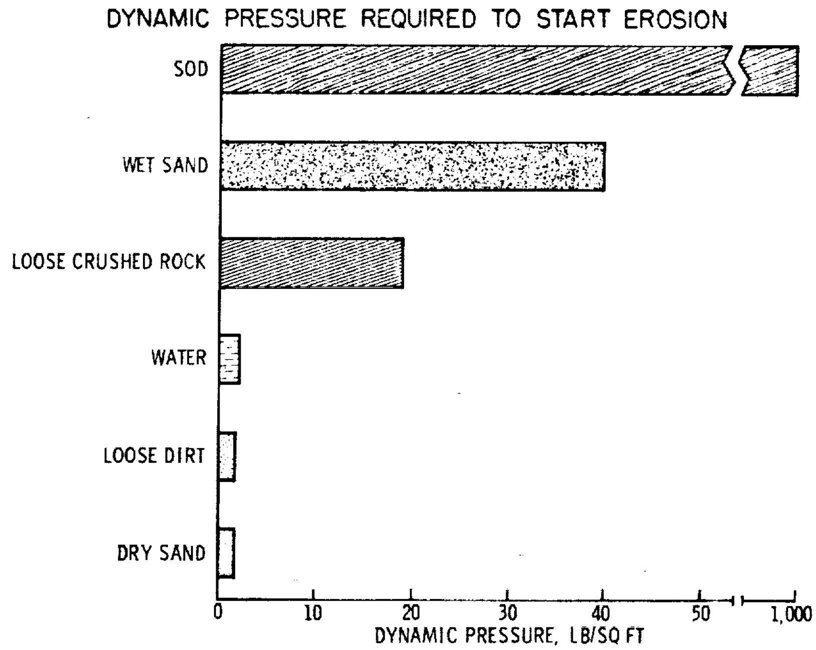

Figure 1

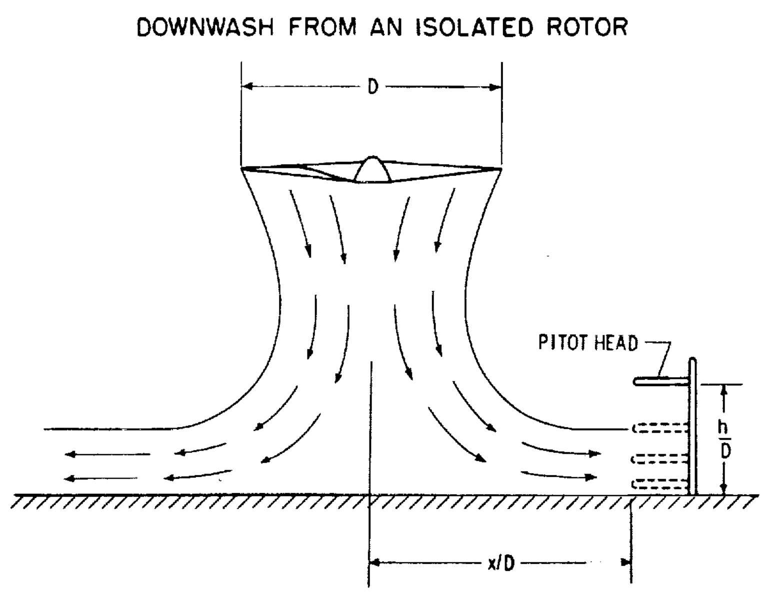

Figure 2

DYNAMIC-PRESSURE PROFILE FOR ISOLATED ROTOR MEASURED ON RADIAL LINE FROM CENTER OF ROTATION

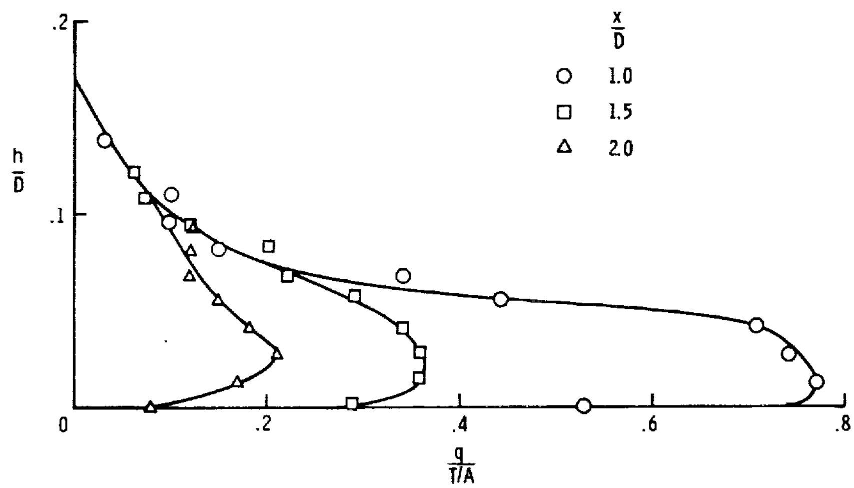

Figure 3

COMPARISON OF ESTIMATED AND MEASURED DYNAMIC-PRESSURE DECAY

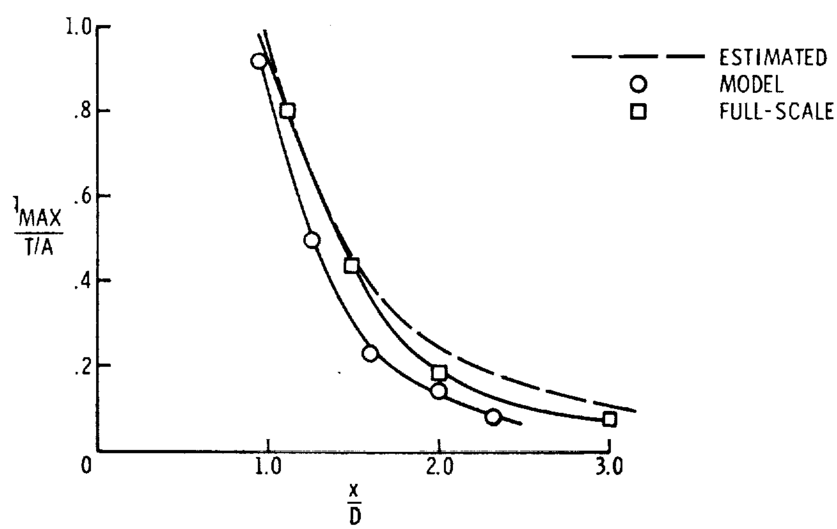

Figure 4

COMPARISON OF THE DECAY FOR TWO DISK LOADINGS

W = 40,000 LB

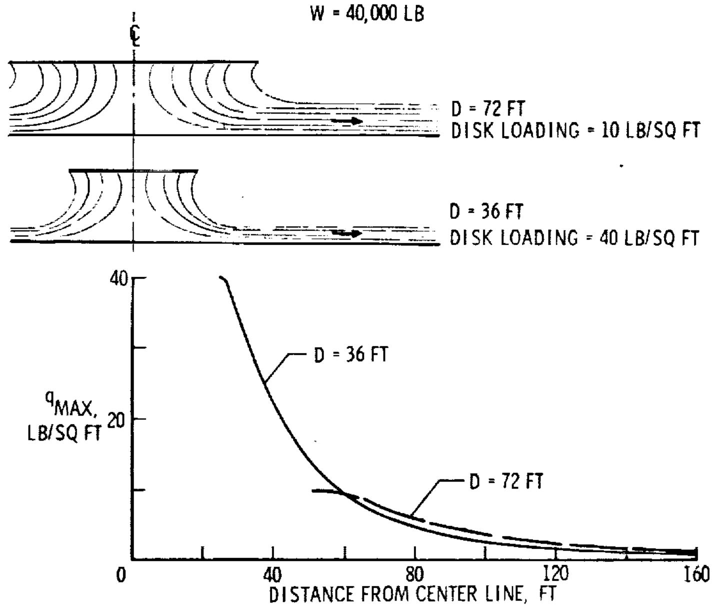

Figure 5

THICKNESS OF DYNAMIC PRESSURE PROFILES

W = 40,000 LB; x = 72 FT

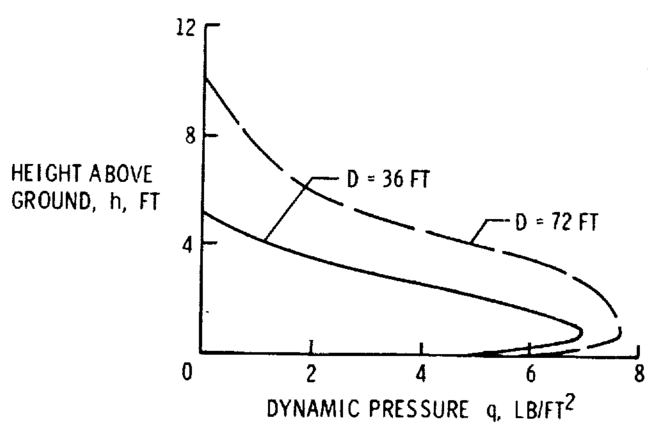

Figure 6

THREE-DIMENSIONAL SLIPSTREAM PATTERN

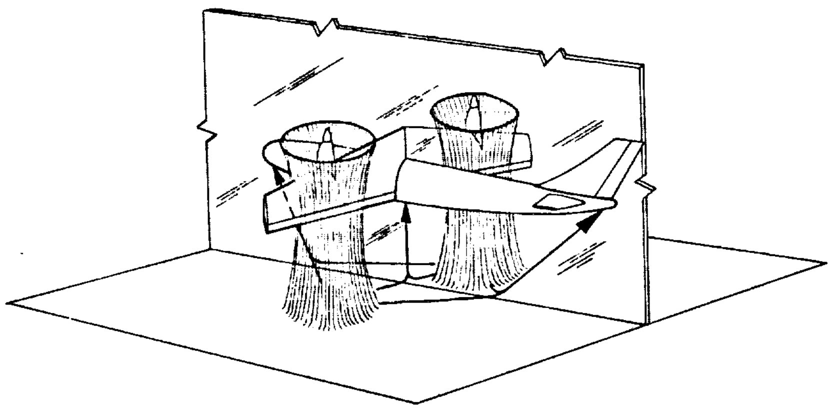

Figure 7

GROUND DYNAMIC PRESSURE CONTOUR
FOR HOVERING VTOL

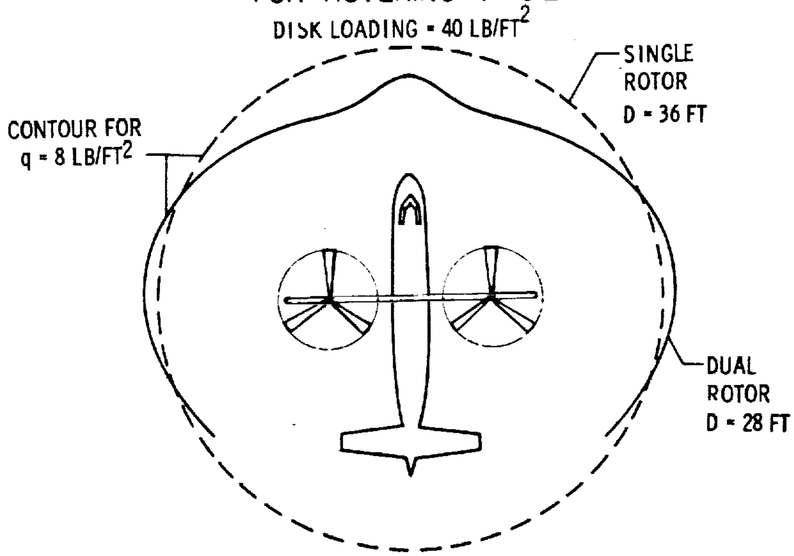

Figure 8