# Wind Shear Effects on the Landing of Aircraft

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## Theme

THE problem of wind shear during landing has been analyzed for a variety of wind profiles using a digital stimulation model with fixed aircraft controls.


## Contents

Wind shear is an important consideration in the landing of aircraft and aerospace vehicles. As an aircraft descends its glide slope, a sudden change of horizontal wind will instantaneously effect the velocity of the aircraft relative to the air mass. If the shear is such that the relative velocity of the aircraft increases, the lift force will increase and the aircraft will tend to rise above the glide slope. If the shear causes a sudden decrease in the relative velocity, the aircraft will respond by falling below the glide slope and a potentially hazardous condition may result.

The problem of quantitatively defining the effect of shear of given magnitude on an aircraft during descent has not been completely resolved.[1,2] Consequently a NASA-sponsored study was conducted to investigate the effect of various types of wind shear profiles on aircraft landings and to determine which aircraft are most susceptible to wind shear. A complete discussion of this study is given in Ref. 3.

The wind shear profiles considered represent changes in that component of the horizontal wind along the longitudinal axis of the aircraft as a function of altitude. They describe headwind and tailwind landing conditions. Under this type shear only the three longitudinal degrees of freedom of the aircraft need to be considered in the simulation. The aircraft initially is assumed to be on a 2.7° glide slope at an altitude of 300 ft. The controls (throttle and elevator deflection) are fixed at values such that if the wind does not change, the aircraft will not deviate from the 2.7° glide slope as it descends. No flare maneuver is introduced into the descent. The computer model determines the aircraft's trajectory for various wind profiles. It thus provides the difference in touchdown points between flights involving wind shear and flights in a constant wind field.

The aircraft considered were the Boeing 747, DC-8, C-130, C-135, C-141, and an augmentor-wind STOL. At the beginning of a simulated trajectory (300 ft alt), the aircraft is trimmed by determining the values of angle of attack, throttle setting, and elevator deflection, which will result in unaccelerated flight. The equations of motion are then integrated numerically by a fourth-order Runge-Kutta scheme to determine the aircraft's flight path. For a constant wind and no ground effects, the aircraft flies down the glide slope at a constant velocity until it reaches the ground. However, when a varying horizontal wind field is introduced, the aircraft no longer adheres to the glide slope. The resulting deviation in touchdown point serves as a measure of how severe the particular wind field is to the landing aircraft.

The wind shear model used in the aircraft landing simulation is described in Refs. 4 and 5. The wind profile is defined in terms of the Monin-Obukov atmospheric stability parameter $L$, a surface roughness parameter relative to the surrounding terrain $Z_o$, and the mean wind speed $\bar{u}$ at the specified height of 300 ft. These three parameters define the wind profile as a function of altitude for unstable (Richardson's number $Ri<0$), neutral (Richardson's number $Ri=0$), and stable (Richardson's number $0<Ri<0.2$) atmospheric conditions. In a very stable atmosphere ($Ri>0.2$) no analytic representation of the wind profile is possible since layers of the atmosphere become disconnected due to a lack of mixing. For the very stable atmosphere the wind profiles were described with a discontinuity at the shear level. Above the shear level the wind was considered constant while below the shear level a zero wind was assumed. Both the altitude of the shear level and the magnitude of the wind above the level were varied.

The results for headwind simulated landings of the DC-8 aircraft under stable atmospheric conditions is shown in Fig. 1. Deviations in touchdown in excess of 3000 ft occur in stable conditions for $L$ less than 50. For the stable condition the deviation in touchdown, $\Delta T$, is more sensitive to changes in $L$ ($L$ decreases as stability increases) than to changes in surface roughness, $Z_o$. This is especially true for a highly stable condition such as $L=10$. Thus, the terrain immediately surrounding the airport (characterized by $Z_o$) is not as critical in shaping the wind profiles as is the temperature profile which determines stability. For unstable and neutral atmospheric conditions the deviations in touchdown point are small and probably would not result in critical landing conditions.

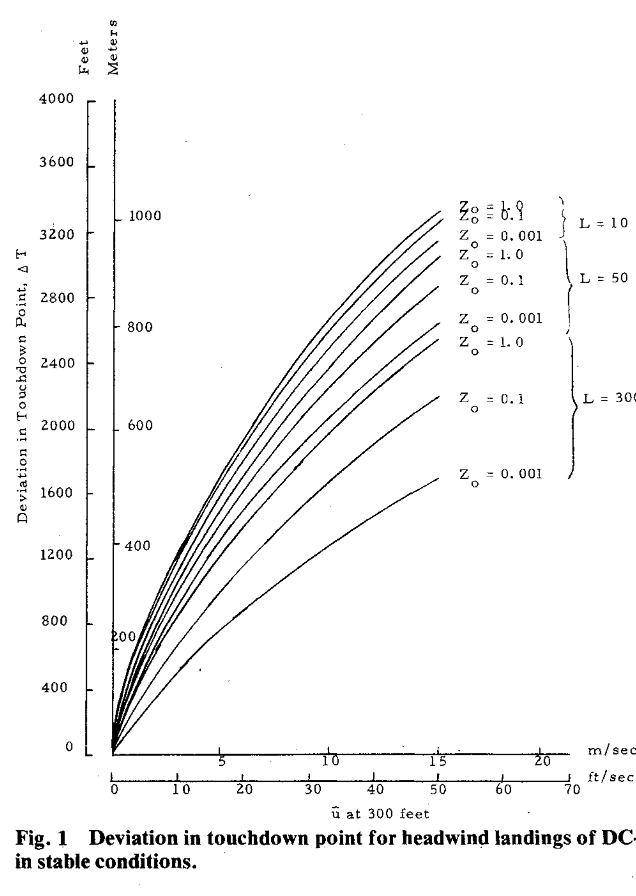


**Fig. 1 Deviation in touchdown point for headwind landings of DC-8 in stable conditions.**

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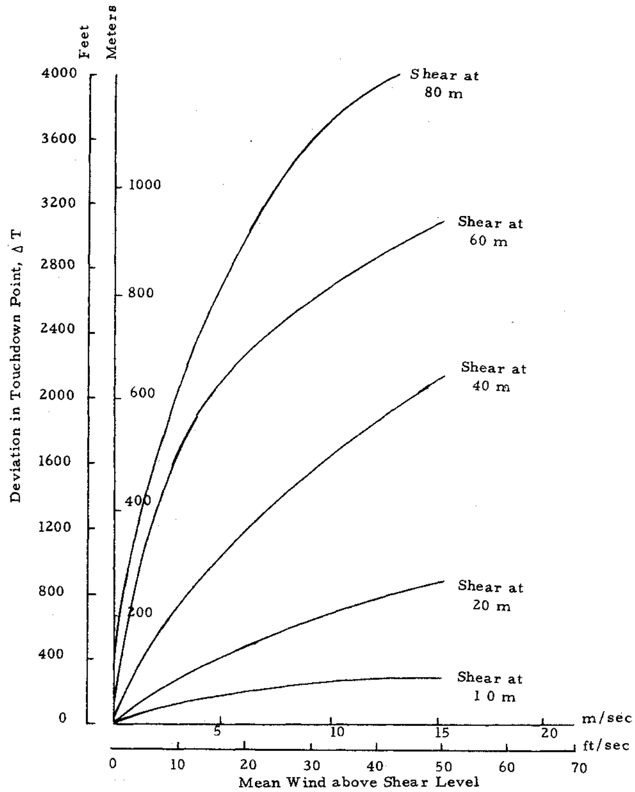


**Fig. 2 Deviation in touchdown point for headwind landings of DC-8 under very stable conditions.**

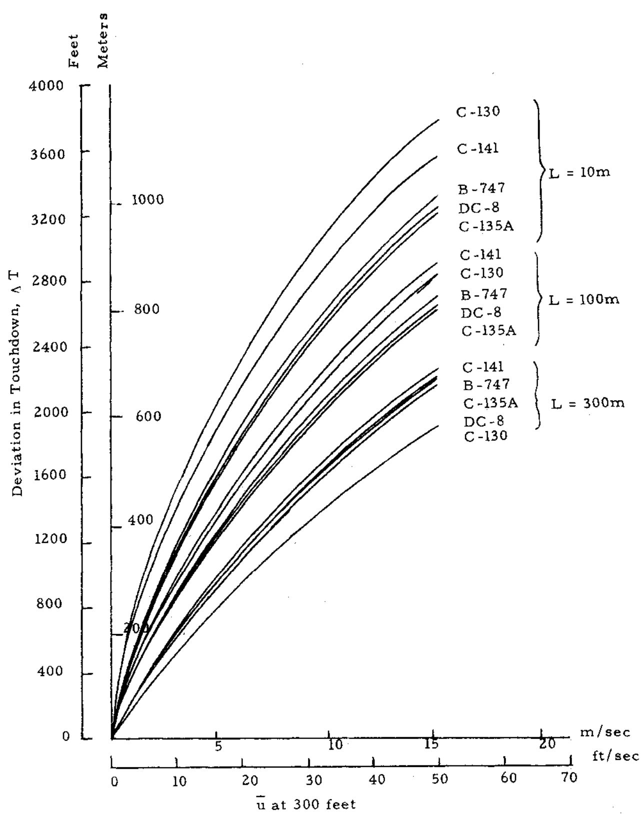


**Fig. 3 Deviations in touchdown for different type aircraft in stable wind profiles: $Z_o = 0.1$ m.**

Results for the very stable condition are shown in Fig. 2. The deviation in touchdown is plotted as a function of the altitude where the shear occurs and the wind mangitude above the shear level. The very stable profiles cause a larger deviation in touchdown point than the other wind profiles, especially when the shear for the very stable profile occurs at a high altitude. In addition, had shears at altitudes higher than 80 m been considered, the very stable condition would show even larger deviations in touchdown. Since however such a shear would allow the pilot additional time to correct his flight path or to abort his landing this case has not been considered.

Figure 3 shows a typical comparison of the results from the DC-8 with that of other aircraft. The other aircraft considered span a large range of size, weight, and landing speeds for transport aircraft. Reference 3 can be consulted for the exact aircraft dimensions and landing speeds used in the simulation. In general, the variation in touchdown point, $\Delta T$, is not largely dependent on the type aircraft. Even the C-130 which is slower and lighter performs very similarly to the other aircraft. It is interesting to observe that the relative sensitivity of different aircraft to a given wind field depends upon the wind field. For example, a stable profile with $Z_o = 0.1$ and $L = 10$ shows the C-130 to produce the largest values of $\Delta T$ and the C-135A the smallest. However, by changing the value of $L$ to $L = 300$, the result is that the C-130 produces the smallest values of $\Delta T$ with the C-135A falling in the middle range.

The variation in $\Delta T$ resulting from the simulated landings of different type aircraft is smaller than the variation in $\Delta T$ due to surface roughness and to stability. For practical considerations, the type of wind profile that is hazardous to one transport type aircraft is hazardous to all transports—at least within the range of aircraft discussed in this paper.

The three-degrees-of-freedom aircraft landing simulation study has determined the types of wind shear profiles that can produce potentially hazardous landing conditions. Deviations in touchdown point in excess of 3000 feet during the final 300 ft of descent have been observed under wind shear conditions that are not unrealistic. Some specific conclusions resulting from this study are:

a) Stable ($0 < Ri < 0.2$) and very stable ($Ri > 0.2$) atmospheric conditions are most likely to produce hazardous landing conditions. Deviations in touchdown of 2000-4000 ft have been observed for transport aircraft assuming fixed controls and no flare. Neutral and unstable wind profiles seldom cause deviations in touchdown point in excess of 2000 ft.

b) For a stable atmosphere the deviation in touchdown point, $\Delta T$, is more dependent upon the stability length $L$ than upon the terrain roughness $Z_o$. For a very stable atmosphere $\Delta T$, is most dependent upon the altitude at which the shear layer occurs.

c) For transport type aircraft, the size, type, and landing speed of the aircraft has some influence on $\Delta T$ but this influence is considerably less than that due to stability length and surface roughness.

## References

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