# LIFTING FORCE ON PEBBLES DUE TO THE WIND

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## Summary

The wind blowing past an obstruction such as a pebble on the ground can create a force which will lift the pebble with a considerable acceleration. This can occur near the centre of a vortex; and during the operation of aircraft thrust reversers. This paper reports wind tunnel tests which reproduce this effect, and these are supported by a simple potential flow analysis.

## Introduction

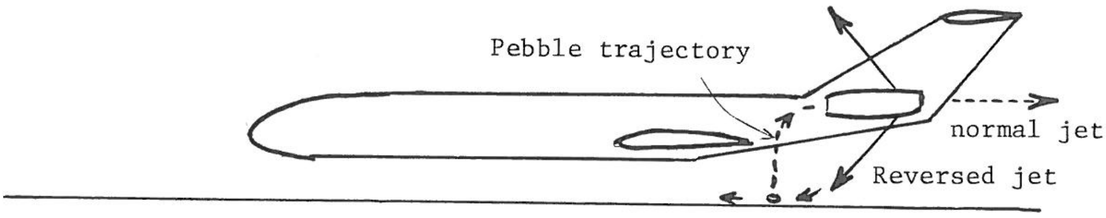

Figure 1

Some of the first designs of thrust reverser fitted to aircraft jet engines were found to raise stones and pebbles from the ground and lift them into the engine intake, causing damage to the engine (see figure 1). This problem was solved by directing the jet from the thrust reverser, so that any stones so disturbed were thrown clear of the aircraft. Suitable directions were determined by properly scaled model tests; but the phenomenon of the generation of lift does not appear to have been investigated.

It was, therefore, the object of the present work to demonstrate this lift force experimentally in a wind tunnel and to try to obtain some confirmation from potential flow theory. It was decided to conduct the tests at approximately 10 times full size (and 10 times the real Reynolds number) to facilitate the pressure measurements. Further, it was decided to use a two-dimensional circular cylinder (stretching from wall to wall of the wind tunnel) to represent the pebble - a simplification which made comparison with potential flow easier.

## Notation

| | |
|---|---|
| $V_o$ | wind velocity |
| $\rho$ | air density |
| $R$ | radius of cylinder (pebble) |
| $p_n$ | static pressure at pressure point n |
| $p_o$ | static pressure in the free stream |
| $C_p$ | pressure coefficient $= \dfrac{p_n - p_o}{\frac{1}{2}\rho V_o^2}$ |
| $C_L$ | lift coefficient $= \dfrac{\text{lift force per unit length}}{\frac{1}{2}\rho V_o^2 2R}$ |

Wind Tunnel Tests

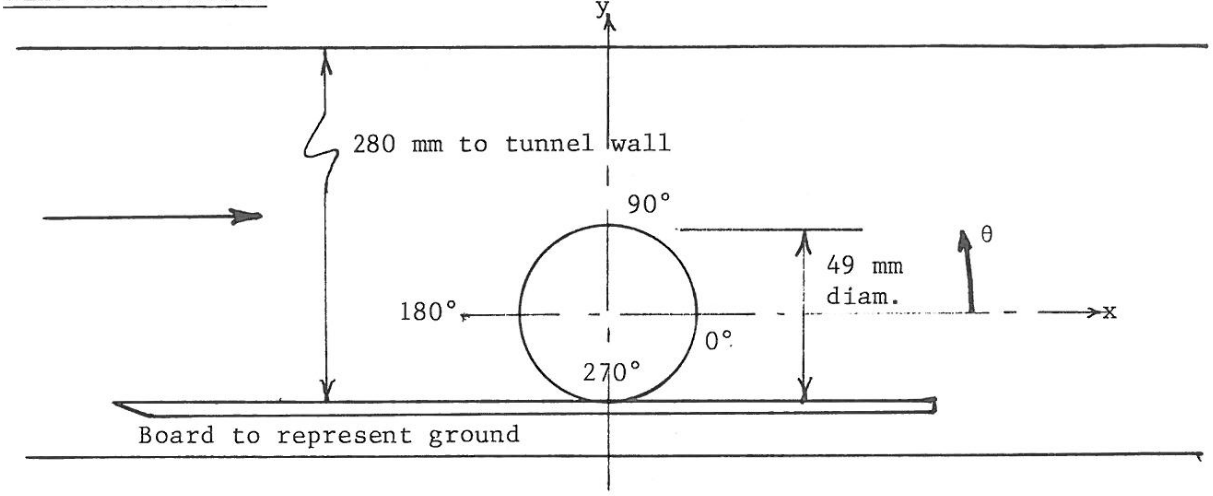

Figure 2

Figure 2 shows a cross-section of the model in the wind tunnel. Pressure tappings were inserted at 15° intervals on the upper surface of the cylinder and at 45° intervals on the lower surface. They were distributed along the length to avoid any interference between them.

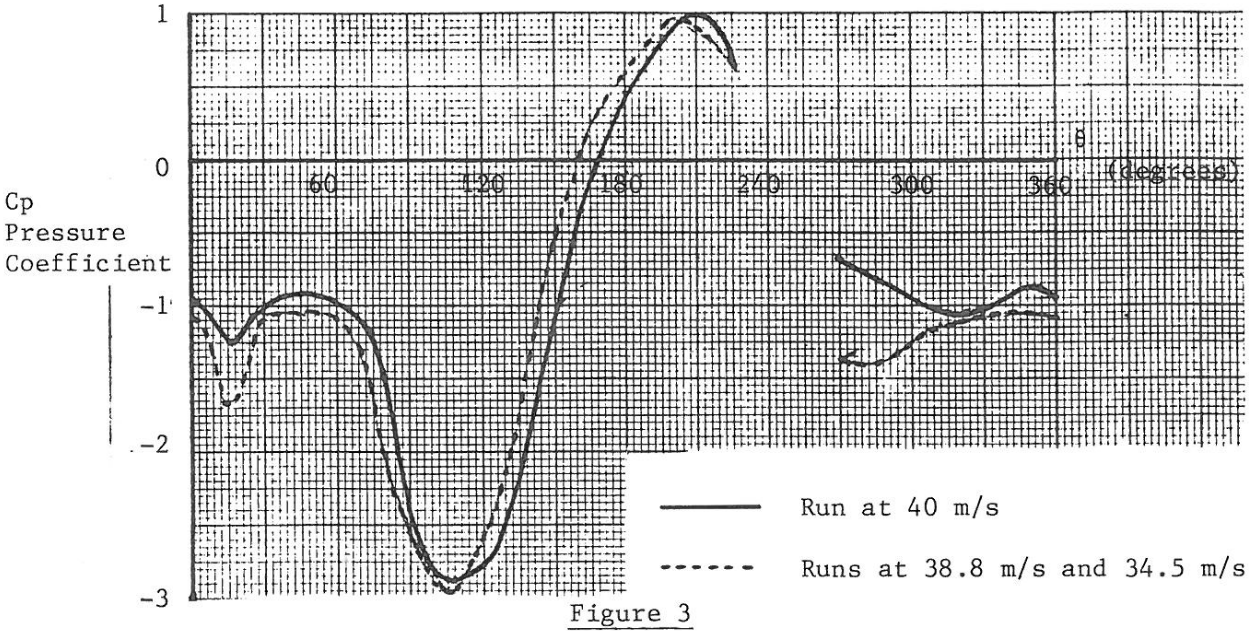

Figure 3

Figure 3 shows the results of pressure plotting for 3 speeds (40 m/s, 38.8 m/s and 34.5 m/s), the pressure coefficient $C_p$ against the angular position $\Theta$. The highest pressure occurred at about 210°, 30° below the foremost point of the cylinder. More significantly, the pressures over the upper surface were low over a large area, below those on the lower surface, giving rise to a lift coefficient of 1.29, 1.09 and 1.06 in the three runs. Pressures in the region of contact with the ground (270°) are affected by the nature of the contact, whether there is a small leakage path for the air. In these tests, no attempt was made to seal this.

## Potential Flow Analysis

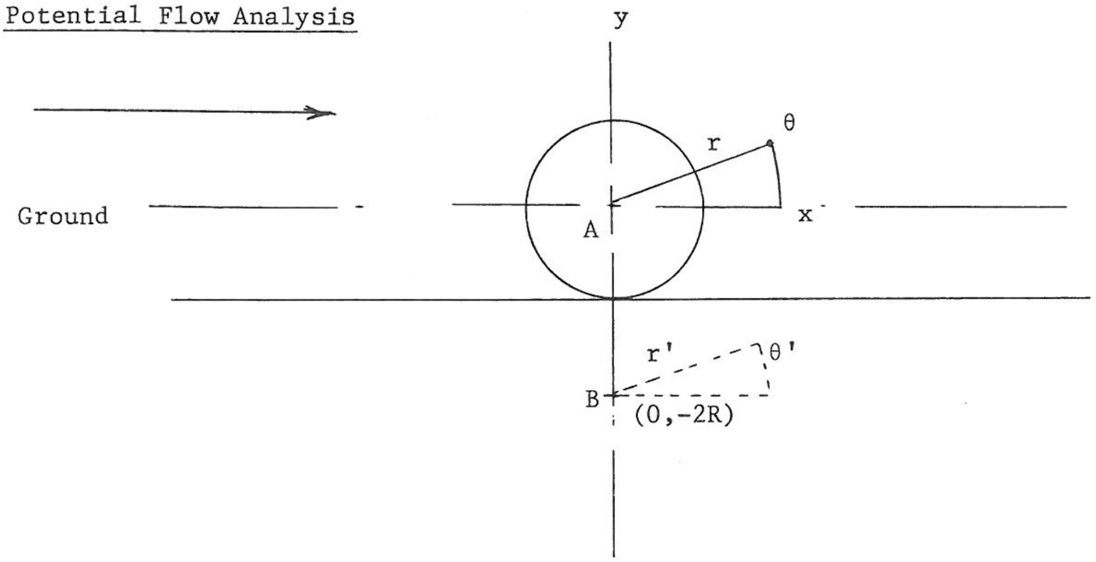

Figure 4

Figure 4 shows the elements chosen to represent the flow. Doublet at A $(\psi = \frac{\mu}{2\pi r}\sin\theta)$ and $B(\psi = -\frac{\mu}{2\pi r'}\sin\theta')$ give a plane of symmetry representing the ground.

This gave a reasonable representation of the flow, except in the region of the point of contact.

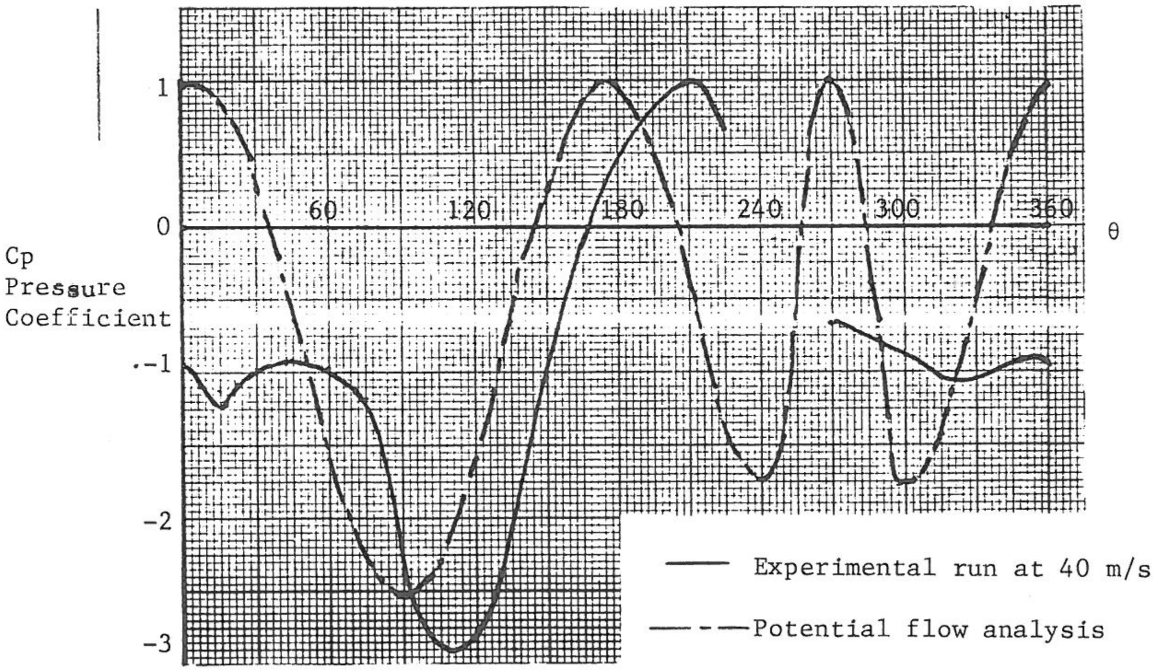

Figure 5

Figure 5 shows the pressure coefficients calculated from the stream function, which gave a lift coefficient $C_L$ of 0.8. The experimental results are shown for comparison. Inevitably, the agreement is not good around the back of the cylinder (0-90°, 270°-360°). Separation of the boundary layer causes lower pressures to occur here in practice. Further, agreement in the region of the point of contact (270°) is poor.

## Discussion

The experimental results confirm that a considerable lift force is generated on a cylindrical pebble, giving a lift coefficient of about 1, sufficient to give a 10 mm diameter pebble in a 40 m/s wind an acceleration of 50 m/s$^2$. This is due to the high velocity and low pressure which occurs round the top of the cylinder; the bottom is shielded by the ground which inhibits high velocities in this region. The potential flow analysis confirms the low pressures over the top.

This phenomenon is likely to occur when a sudden increase in wind velocity occurs, as in the case mentioned above, when an aircraft using a thrust reverser moves along a runway. Another case where it has been known to occur is in the vortex generated by flow into an intake of a fan or compressor near the ground. Such a vortex has high velocities near the centre and its centre line moves around is a random way, and this can raise stones and other debris from the ground which is ingested into the intake.

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