Journal of Physics Special Topics

An undergraduate physics journal

P4 8 Spider-Man or Gecko-man?

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December 10, 2025

Abstract

In several cinematic portrayals, the character *Spider-Man* adheres to moving surfaces at extreme speeds. This paper estimates the coefficient of friction and adhesive forces required for a human of mass 75 kg to remain attached to the exterior of an aircraft travelling at 150 ms^{-1}. Using aerodynamic drag models, published estimates of gecko-inspired adhesive stress, and reasonable assumptions about body orientation and exposed area, we compute forces generated by biological-style adhesion and the resulting frictional demands. Results indicate that, depending on adhesive stress and contact area, the required friction coefficient ranges from 0.10–1.72, with realistic adhesion parameters bringing the requirement within the performance range of high-performance synthetic adhesives.

Introduction

The *Marvel Cinematic Spider-Man Homecoming*, includes a scene where *Spider-Man* is crawling along the exterior of an aeroplane. We use the adhesive stresses, equations for the drag and lift coefficients, and the average palm contact areas of the average male to calculate the coefficient of friction required for *Spider-Man* to remain attached to the plane.

Parameters & Method

In the film scene, the plane is flying at a low altitude, so we can use the sea-level density of air, $\rho = 1.225$ kgm^{-3} [1].

The dynamic pressure, q of the air acting on the aircraft is [2]:

$$q = \frac{1}{2}\rho V^2 \tag{1}$$

The aircraft is assumed to be a low-speed aeroplane/private jet, which can fly at around 125 – 180 ms^{-1} [3]. Therefore, we can approximate it to be flying at $V = 150$ ms^{-1}.

The drag F_D, and lift L, forces acting on *Spider-Man* in a crawling position are [4] [5]:

$$F_D = qC_D A_{\text{proj}} \tag{2}$$

$$L = qC_L A_{\text{proj}} \tag{3}$$

Where the drag coefficient of a crawling human is approximated as $C_D = 1.0$. Literature values for crouched cycling positions range $C_D = 0.70$–1.0 [6]. Due to irregular positions, our choice was conservative.

A value of $C_L = 0.2$ was chosen for the lift coefficient to reflect small aerodynamic lift generated by non-symmetric body posture. Human body lift coefficients in skydiving range 0.1–0.4 depending on angle of attack [7].

Typical human frontal area ranges from 0.30–0.70 m^2 for an upright stance [6]. This significantly reduces for a streamlined crawling posture, so we can assume an aerodynamic frontal area of $A_{\text{proj}} = 0.25\ \text{m}^2$.

A 75 kg [8] mass is assumed for a lean adult male. Therefore, the weight of *Spider-man* is:

$$W = mg = 75 \times 9.81 = 735.75\ \text{N} \quad (4)$$

If $L < W$, no adhesive traction is required to resist lift. Otherwise, adhesion must supply the uplift. Normal force, N from adhesion is [9]:

$$N = PA \quad (5)$$

Where P is adhesive stress. Realistic adhesive stresses were taken from:

- 100 kPa: lower bound of gecko spatula adhesion [10].
- 300 kPa: typical synthetic gecko-inspired polymer adhesives [11].
- 600 kPa: high-performance carbon nanotube adhesives. [12]

The human palm area is $\approx 0.015\ \text{m}^2$ [13]; frictional or adhesive clinging would require recruitment of multiple limbs. To represent this, the values for contact area $A = 0.02, 0.04, 0.06\ \text{m}^2$ correspond to one hand, two hands, and the two hands plus forearm contact, respectively.

By definition, the required coefficient of friction is:

$$\mu_{\text{req}} = \frac{F_D}{N} \quad (6)$$

Results & Discussion

At $V = 150\ \text{ms}^{-1}$,

$$q = 13{,}781\ \text{Pa} \quad (7)$$

Thus,

$$F_D = 3445\ \text{N} \qquad L = 689\ \text{N} \quad (8)$$

Because $L < W$, uplift does not exceed body weight, and the limiting requirement is frictional.

P (kPa)	A (m^2)	N (N)	μ_{req}
100	0.02	2000	1.7227
100	0.04	4000	0.8613
100	0.06	6000	0.5742
300	0.02	6000	0.5742
300	0.04	12000	0.2861
300	0.06	18000	0.1907
600	0.02	12000	0.2871
600	0.04	24000	0.1430
600	0.06	36000	0.0957

Table 1: Required friction coefficients for Spider-Man clinging at $150\ \text{ms}^{-1}$.

The required friction coefficient spans across a wide range depending on adhesive performance. For low-end biological pressures of 100 kPa and minimal contact area of $0.02\ \text{m}^2$, the friction requirement exceeds $\mu_{req} = 1.7$. However, for synthetic fibrillar adhesives with stresses near 600 kPa this reduces below $\mu_{req} = 0.3$ for moderate contact areas, which falls within achievable limits. Increasing the contact area is highly effective, as frictional capacity scales linearly with N. In addition to this, reducing the aerodynamic frontal area by tucking in the limbs of *Spider-Man* would proportionally reduce the required value of μ_{req}.

Conclusion

Using reasonable aerodynamic and biological assumptions, we conclude that a *Spider-Man*-like human would require adhesive stresses between 300–600 kPa over a minimum contact area of $0.04\ \text{m}^2$ to remain attached while crawling along an active aeroplane. This pressure range leads to the large range for the coefficient of friction of 0.10-1.72 being reduced significantly to approximately 0.10-0.57, which seems to be a more appropriate range of values. We see that both an increased contact area and a decreased frontal area would significantly reduce μ_{req}. If these factors are applied, then *Spider-Man* would have a much calmer experience during this scene.

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