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P5_4 Where's Wall-E?

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Abstract
We have calculated that a fire extinguisher under incompressible flow has a change in velocity, Δv, of 4.10 ms^{-1} and a Δv of 8.40 ms^{-1} under adiabatic flow. If Wall-E were to use fire extinguishers as a method of propulsion in space rather than NASA's MMU (with $\Delta v = 25$ ms^{-1}) he would require 10 fire extinguishers for incompressible flow and 4 for adiabatic flow. However due to the asymptotic nature of Δv, as the number of fire extinguishers tends to infinity, $\Delta v \rightarrow 64.1$ ms^{-1}, and 134 ms^{-1} for incompressible and adiabatic flows, respectively.

Introduction

A scene in the 2008 Walt Disney and Pixar animated film *Wall-E* [1] depicts the main protagonist, Wall-E the robot, using a fire extinguisher to accelerate through space. In this article we explore the possibility of using fire extinguishers as a method of propulsion in the vacuum of space; we compare the propulsive strength of a single extinguisher to the grouped strength of multiple extinguishers. We find Δv for fire extinguishers with incompressible, and adiabatic flows, and then compare this to the NASA Manned Manoeuvre Unit's (MMU) Δv value. From this we can find the number of fire extinguishers Wall-E would require to have the same Δv value as the MMU.

Theory

The fire extinguisher used in this article is the CHUBB-EC50C CO_2 extinguisher. It has a wet mass (the mass including propellant) of $M_w = 11$ kg and a dry mass (the mass excluding propellant) of $M_d = 6$ kg. A typical canister holds 5 Litres, which gives a propellant density $\rho = 1000$ kgm^{-3}. It operates at a pressure of 56 Bar which is equivalent to $P_0 = 5.6 \times 10^6$ Pa, and at full thrust lasts for approximately $t = 15$ s. [2]

To understand the effectiveness of a fire extinguisher in space, and further to find the Δv of the system (the impulse required to perform a specific manoeuvre), we must first calculate the exhaust velocity of the propellant gas exiting the extinguisher, carbon dioxide (CO_2). To do this we utilise fluid dynamics for subsonic flows, specifically Bernoulli's Theorem. Assuming that the flow is incompressible, as may be done for the largely gas composition of the extinguisher, the Bernoulli equation [3] is

$$B = \frac{P}{\rho} + \frac{v^2}{2} + gz = constant, \qquad (1)$$

where ρ is constant, P is the presure, v is the velocity, g is the acceleration due to gravity and z is the distance in the azimuthal direction. In space, as $g = 0$, we can say:

$$\frac{P_0}{\rho} + \frac{v_0^2}{2} = \frac{P_{Space}}{\rho} + \frac{v_{exhaust}^2}{2} \approx \frac{P_0}{\rho} = \frac{v_{exhaust}^2}{2}, \qquad (2)$$

where v_0 and P_{Space} are negligible and can be ignored, due to the gas at high altitude being so sparse and inactive. Rearranging, we find $v_{exhaust} = 106$ ms^{-1}.

If we assume that the flow is adiabatic, i.e. that no heat exchange occurs, then the Bernoulli equation [3] may be given as

$$B = \frac{\gamma}{\gamma - 1}\frac{P}{\rho} + \frac{v^2}{2} + gz = constant, \qquad (3)$$

where γ is the adiabatic constant.

With $g = 0$, as mentioned previously, we can say

$$\frac{\gamma}{\gamma - 1}\frac{P_0}{\rho} + \frac{v_0^2}{2} = \frac{\gamma}{\gamma - 1}\frac{P_{Space}}{\rho} + \frac{v_{exhaust}^2}{2} \approx \frac{\gamma}{\gamma - 1}\frac{P_0}{\rho} = \frac{v_{exhaust}^2}{2}, \quad (4)$$

where, again, v_0 and P_{space} are negligible and can be ignored following similar reasoning to before. For CO_2 $\gamma = 1.30$ [4], therefore rearranging Equation (4) we find that $v_{exhaust} = 220$ ms^{-1}.

To find Δv, we can then substitute the exhaust velocity into the Tsiolkovsky rocket equation [5]

$$\Delta v = v_{exhaust} \ln\left(\frac{M_0}{M_f}\right), \quad (5)$$

where M_0 is the mass of Wall-E, $M = 122$ kg [6], plus the wet mass of the fire extinguisher m_w, and M_f is the mass of Wall-E plus the dry mass of the fire extinguisher m_d.

For an astronaut of mass 148 kg (including propellent), the MMU has $\Delta v = 25$ ms^{-1} [7].

Results

For one fire extinguisher attached to Wall-E, $\Delta v = 4.10$ ms^{-1} when assumed to be incompressible flow, and $\Delta v = 8.40$ ms^{-1} when assumed to be adiabatic flow.

In the case of multiple fire extinguishers, where n is the number of fire extinguishers, M_0 and M_f change to become $M_0 = M + nM_w$ and $M_f = M + nM_d$ respectively, in the Δv equation. The Δv against the number of fire extinguishers for incompressible and adiabatic flow are plotted below in Figure 1.

To achieve a Δv of 25 ms^{-1}, Wall-E would need at least 10 extinguishers for incompressible flow, or 4 extinguishers with an adiabatic flow.

Due to the asymptotic nature of the graphs, there is a point where adding more fire extinguishers will not have a significant effect on the Δv of the system. Therefore, as $n \to \infty$, $\Delta v \to 64.1$ ms^{-1}, and 134 ms^{-1} for incompressible, and adiabatic flows, respectively.

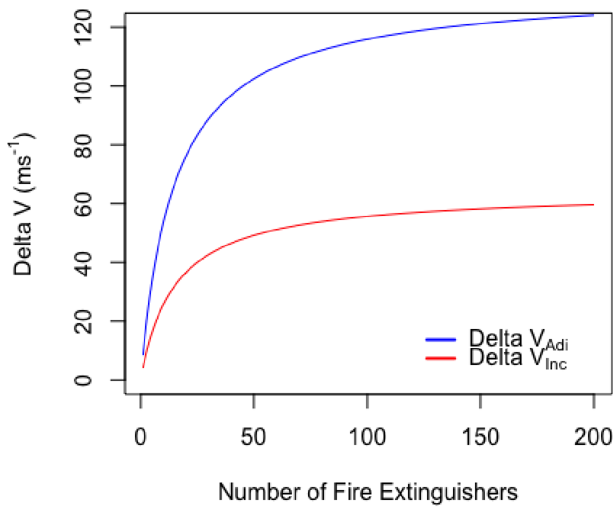

Figure 1: This graph shows how Δv changes with the number of fire extinguishers. Where adiabatic flow is shown in blue and incompressible flow is shown in red.

Conclusion

In conclusion we can expect a fire extinguisher to produce a Δv of 4.10 ms^{-1} for incompressible, and 8.40 ms^{-1} for adiabatic flows. In comparison to the MMU; Wall-E would need at least 10 fire extinguishers for incompressible flow or at least 4 fire extinguishers for adiabatic flow, to reach at least 25 ms^{-1}. However because of the asymptotic nature of Δv, as $n \to \infty$, $\Delta v \to 64.1$ ms^{-1}, and 134 ms^{-1} for incompressible, and adiabatic flows, respectively. Although not a negligible source of thrust, the fire extinguishers would likely run out of propellant faster than a NASA MMU. As such, the authors recommend future astronauts continue to follow standard procedure, and use MMUs for untethered space walks, and leave extinguishers for accidental fires.

References

[1] `https://goo.gl/JxL6g8` [Accessed 03/11/16]

[2] `https://goo.gl/mfCp0e` [Accessed 03/11/16]

[3] `https://goo.gl/fLkpo0` [Accessed 03/11/16]

[4] `https://goo.gl/Y4bEXp` [Accessed 03/11/16]

[5] `https://goo.gl/XJTHWI` [Accessed 03/11/16]

[6] `https://goo.gl/pZw7db` [Accessed 03/11/16]

[7] `https://goo.gl/a32tDs` [Accessed 03/11/16]