Journal of Physics Special Topics

P2_7 Mobile Suit Gundam: Falling From Space

R. Hall, A. West, M. McHugh, J. Blake,

Department of Physics and Astronomy, University of Leicester, Leicester, LE1 7RH.

November 30, 2011

Abstract

This paper explores the upper limits of the active cooling system on board a Mobile Suit from the Gundam series as it goes through atmospheric re-entry. A Mobile Suit falling through the Earth's atmosphere experiences drag forces of nearly 10,000 kN. The increase in temperature due to the resistive drag forces felt upon re-entry would require an active cooling system with an output of 112MW which is over 37 times greater than known power outputs on board Mobile Suits.

Introduction

The Gundam metaseries is a popular work of science-fiction in Japan. It features large machines known as Mobile Suits that are used in terrestrial and interplanetary combat. There are many suits within each series, all with different specifications, weaponry and modifications. In the animated series Mobile Suit Gundam SEED, phase 13 features a scene in which 3 mobile suits are forced to undergo atmospheric re-entry and land on Earth after straying too far from their docking ship and being unable to escape the Earth's gravitational field [1].

This paper will look at the velocities they undergo during re-entry, putting limits on the requirements of the active cooling thermal protection systems on board.

Specifications

Figure 1 A photograph of the life sized Gundam built in Tokyo [2]

Though different Mobile Suits have different specifications, all suits are roughly 18m tall [2]. One of the suits in question, the GAT-X102 Duel, has a mass of 100 metric tonnes when equipped for combat [3]. The Suits are also equipped with propellant fuel with some suits having almost 10 tonnes of extra mass from the propellant [4]. The on-board thermonuclear reactor has a power output of 2980 kW [4]. The outer shield of the Mobile Suit is assumed to be made of grade 5 Titanium alloy, which is often used in aerospace applications, with a thickness of 30cm. The Suits are cooled on re-entry using active cooling systems [5].

Stars Falling In Space

Before falling back to Earth, two suits stay at a constant altitude giving them an initial velocity of 0ms^{-1}. It is assumed that the majority of the propellant fuel has been expended therefore neglecting any extra mass added by the propellant tanks. Assuming that after the fight both suits allow gravity to pull their mobile suits back to Earth, the heat generated by re-entry can be calculated.

The local value of gravity was calculated in 5km steps for the different layers of the atmosphere. Using these values the changing velocity of the suit during its descent was calculated. The mesosphere was taken to have a density of 1x10^{-5}kgm^{-3} and extends from 100km to 50km from the Earth's surface, the stratosphere from 50 to 20km with a density of 1x10^{-3}kgm^{-3} and the troposphere from 20km to the Earth's surface with a density of 1kgm^{-3}[6], [7]. The air density was modelled to vary linearly in each layer of the atmosphere. Using the drag equation,

$$F_D = \frac{1}{2}\rho v^2 C_D A \quad (1),$$

where ρ is the density of the fluid, v is the velocity calculated for each 5km, C_D is the drag coefficient and A is the frontal area of the Mobile Suit, the force due to the drag F_D was calculated for every 5km. Assuming a simplified model in which the Suit is modelled as a cuboid C_D was taken as 0.82, and A as $50m^2$. Using the values of drag the resultant velocities were iterated along the trajectory.

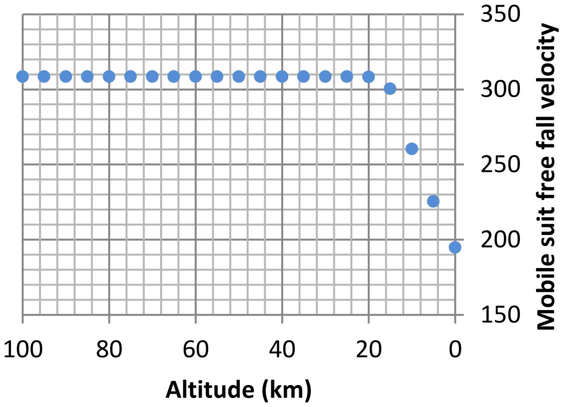

Figure 2 A graph showing the velocity of the Suit in free fall against altitude

As shown in figure 2 the velocity of the Suit was not dramatically changed and remained relatively constant until it entered the lower layer of the atmosphere where there is a significant change in air density and therefore an increase in the force exerted by drag.

The change in kinetic energy (*ΔE*) across each 5km interval was then calculated. Using these values, the mass of the Mobile Suit (*m*) and the specific heat capacity (*C*) of grade 5 Titanium Alloy (565 $Jkg^{-1}K^{-1}$[8]) the change in temperature across each interval was found by substituting the values into the equation

$$\Delta T = \frac{\Delta E}{mC} \text{ (2).}$$

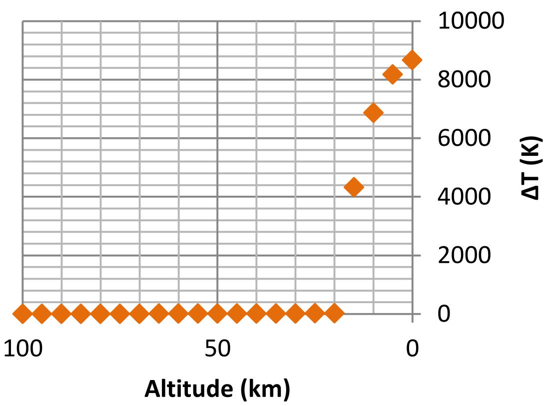

Figure 3 A graph plotting the change in temperature at different altitudes during free fall

These temperature changes give an upper limit on the required output of the cooling system and are shown in figure 3. The largest change in temperature is over the last 5km where there is an increase in temperature of 8657K. Using the thermal conductivity of the alloy (k=6.6$Wm^{-1}K^{-1}$[9]), assuming a surface area of $640m^3$ and a thickness of 0.3m, it was calculated that the suit would require a cooling system with an output of 112MW.

Conclusions

As the suit falls through the atmosphere, the terminal velocity changes with altitude. This change is more pronounced in the lower layers of the atmosphere where the density is greater. The modelling on the changes in density is not perfectly accurate, but rather an estimation to achieve maximum limits. For the purposes of this paper estimating a linear variation across 5km is reasonable.

The output required of the cooling system is much greater than the power output of the reactor. Since the Mobile Suits in question are from a later generation with increased power and capabilities, it may be the case that there is enough energy to power the cooling systems.

Further work could be done to find a lower limit on the outer cooling systems and the temperatures that the pilot would then be subjected to in the cock pit.

References

Equation(1)http://www.grc.nasa.gov/WWW/K-12/airplane/drageq.html

[1] Mobile Suit Gundam Seed, Episode 13, 'Stars Falling in Space', BANDAI, first aired 28th December 2002.

[2]http://www.wired.com/gadgetlab/2009/07/gundam/#more-20571 (last visited 28/11/11)

[3]http://www.mahq.net/mecha/gundam/seed/gat-x102.htm (last visited 28/11/11)

[4]http://www.mahq.net/mecha/gundam/cca/rx-93.htm (last visited 07/11/11)

[5]http://www.gundamofficial.com/worlds/uc/background/glossary_technology.html#helium3 (last visited 07/11/11)

[6]http://library.thinkquest.org/21418/spacee/Mesos.htm (last visited 07/11/11)

[7]http://www.srh.noaa.gov/srh/jetstream/atmos/layers.htm (last visited 07/11/11)

[8]http://www.substech.com/dokuwiki/doku.php?id=titanium_alpha-beta_alloy_grade_5_ti-6al-4v (last visited 07/11/11)