Modelling of Spacecraft Heat Shield Tile

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# Abstract

This report aims to demonstrate how varying numerical methods may be used to analyse the heat propagation across a space shuttle’s heat shield tiles during the re-entry period of said space craft. 4 methods were used in total. Two implicit methods of Crank-Nicholson and Backwards-Differencing and two explicit methods of Forward-differencing and Dufort-Frankel Method. These methods were then compared using Neuman Boundaries in 1D along the direction of the heat shield tile’s thickness. The four methods were further tested for their stability through both the time step and change in spatial step. This returned that the two aforementioned explicit methods were best equipped to be used for this application. It was found that the Crank-Nicholson Method was the method that was most stable. With analysis in a further dimension (2D), the results provided an understanding as to the interaction of damaged or misplaced/removed tiles with the heating upon re-entry. Most notably that exposed edges and corners experienced significantly higher temperature increases, which could allow for (more) damage of the tile and the inner parts below the tile if tile is removed. With both the 2D and the 1D method using the optimum time step the tile was tested to find the optimal thickness.

# Introduction

Heat shielding is an essential component in the making of a space craft as high-speed travel through an atmosphere creates a significant amount of heat that is felt by the space craft. Heat shielding is often the most important during re-entry of the space craft as the external temperature can reach up to 3000 degrees C on the edge of the space craft’s wings (often the most exposed area). This report is focused on how numerical methods can be used to model the heat transfer and propagation across a heat shield tile upon re-entry. 4 methods were selected, and detailed analysis was undertaken to understand both the best numerical methods to use, and ways in which the best method can be implemented to select optimum thickness and understand relative points of failure for future designs. This was attempted by doing analysis in both one and two dimensions.

# Theory

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# Results and Discussion

For the four numerical methods chosen, preliminary data is required. This data was provided in a jpeg file that contained a graph of temperature against time up to 2000 seconds. Originally a program was coded to use a GUI that allowed for the user to select the data points manually. This was later improved to allow for automatic selection of the data points producing the ‘plottemp\_auto.m’ program. Automation was selected as it reduced unnecessary user input and time required. The program requires only a maximum and minimum of temperature and a maximum of time for the data. This produces a matrix of all the data points organised into temperature and the time at which that point occurs. The program uses a sectioned column method that looks for the red pixels in each column and picks a specific red pixel to extract the time and temperature. This program could further be used for any image in a similar graphical setup with a few minor adjustments.

With the preliminary data collected the program ‘Shuttle\_Final.m’ was coded to allow all four numerical methods to be used individually to calculate the time and temperature variation across the tile along its thickness. This was then improved upon to allow for Newman Boundaries on each method, with the same graphics available.

[FIGURE]

To compare methods a simple function ‘multiple\_method\_plot.m’ was produced that plotted all four methods with Newman Boundaries, giving Figure (FIGURE#)

[FIGURE]

The figure (FIGURE#) demonstrates that each method results in a similar shape/relationship of inner temperature and time. The graphs are nearly identical until between 50 to 60 degrees C where the methods begin to show divergence of the Crank-Nicholson-Newman from the other three methods. This may be attributed to the method’s second order accuracy as it is a second order method in time. This added accuracy does also give larger computational needs. Thusly, depending on the size of data required for computation this method may be limited by available computation capabilities. For this application Crank-Nicholson-Newman would be favourable in terms of accuracy.

Another factor that would affect the method chosen would be its stability within the given application. For this project the stability across both time steps and spatial steps are required. To test this the programs ‘time\_stability’ and ‘spatial\_step\_stabiltiy’ were created. The two program uses the inner point of the tile at varying time steps/spatial steps using the temperature the tile would experience at 4000 seconds upon re-entry, producing Figure (FIGURE#).

[FIGURE]

As seen in Figure (FIGURE #) the stability of the Forward-Newman method was lost after a time step of x=10, this gives a time step of around 40 seconds. Contrastingly, the Dufort-Frankel-Newman methods time step is increasing linearly with the length of the time step. This is unideal; however, Backwards-Newman and Crank-Nicholson-Newman had a very small gradient demonstrating that these two methods are the most stable across varying time steps.

# Conclusion

In conclusion

# References