**Space Grant 2024 Summer Fellowship**
**Final Report**
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The goal of the research conducted this summer was to investigate design flaws and improvements for the Thermospheric Winds Imager (TWI) through theory, simulation, and experimentation. The device has been flown on sounding rocket missions in the past with enigmatic results. This summer the TWI's feasibility and design were analyzed in preparation for construction and flight of the instrument in November 2025.

To analyze the TWI's feasibility as a winds instrument, I began by investigating the fundamental physics behind the instrument's functionality. The instrument collects winds data by measuring a temperature change caused by impinging gas on the microbolometer array. Using a pinhole aperture at the front of the device, the wind direction can be determined from where on the sensor a detection is seen, yielding a cross trac winds component. The magnitude of the detection determines the wind speed of the incident gas. The question does the impinging gas transfer enough energy to the microbolometer array for a detection to be noticed? To determine this, I investigated the specifications of the camera and found that it has a thermal sensitivity of 30mk. This means that the impinging gas must have enough energy to create a temperature change greater then 30mk on a microbolometer in the array to be detected. Using the equation for blackbody radiation at the desired $\Delta T$ of 30mk I determined that an incident heat flux of 0.049 $W/m^2$ would need to be supplied by incident gas to be registered on the device. Knowing that the energy transferred by the impinging gas will be some percent of its kinetic energy, $E_{transfer} = \alpha \cdot \frac{1}{2} m\bar{v}^2$, and that the flux of incident particles will be $\Phi = nv$, where n is the number density of the impinging gas, the heat flux can be written as $q = \frac{1}{2}\rho v^3$, which has units of $W/m^2$. The heat flux of impinging gas depends on the velocity of the gas and the density of the gas. The instruments feasibility was assessed by using atmospheric air density data from the MSIS database to calculate heat flux values at different altitudes and rocket velocities. These values could then be compared to the theoretical value of 0.049 $W/m^2$. Theoretically the instrument was well within functional limits for a multitude of altitudes and velocities, most within mission constraints. To further analyze the effectiveness of these theoretical calculations the next step was to use the trajectory data from the Auroral Jets sounding rocket mission, as can be seen in figure 1. Figure 1 shows the altitude and velocity of the Auroral Jets sounding rocket with respect to time. Additionally, is shows a plot of q values, calculated using the MSIS air density data interpolated to the rocket's altitude and the rockets total velocity. The goal is to see how well this theoretical functional range compares to the apparent functional range seen from the TWI flight data. The results from the TWI on the Auroral Jets mission indicated the device was in an operational state till around 270 km. Although very noisy, the device was operating as expected until that point, past which point noise makes any useful signal indiscernible, and the signal never recovers for the rest of the flight. We can see from figure one that the theoretical functional range is 252 km which closely correlates to the instruments functional range from the Auroral Jets flight. Taking this a step further $\Delta T$ was calculated using $\Delta T = \frac{\alpha \cdot A_{pixel} \cdot \rho \cdot \bar{v}^3 \cdot t}{2 \cdot m_{plate} \cdot c_{VOx}}$ , where $C_{VOx}$ is the specific heat capacitance of the absorber in the microbolometer array, for the flight and directly compared to the desired $\Delta T$ of 30mk as can be seen on the bottom plot of figure 1. It's worth noting that the $\Delta T$ plot indicates that the device is much less functional, with a 30mk change mot occurring past 207.56km. This could be due to some improper assumptions about the mass of a pixel and the specific heat capacitance of the material used in the camera. In conclusion the theoretical feasibility predictions align well with the observed operational range of the instrument from the Auroral Jets mission with the instrument functioning to a higher altitude then predicted.

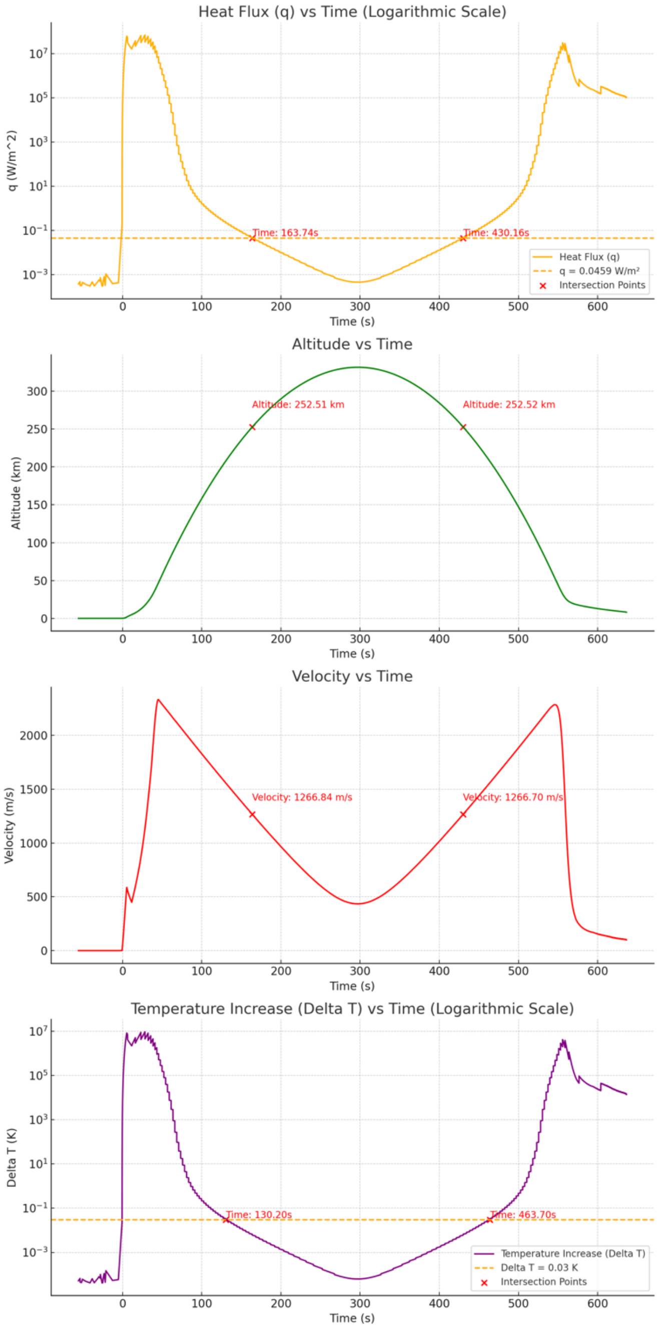

*Figure 1: Using Auroral Jets Trajectory flight data with theoretical equations to determine TWI feasibility. ΔT intersects the 30mk line at 207.56 km.*

These calculations and correlation to flight data indicates the instrument functions on a fundamental basis as intended, therefore design improvements had to be investigated. The instrument functions as a very sensitive thermal device and detects incident gas particles. How the gas enters and vents from the device is of great importance for determining design improvements. Additionally, where heat is building up and mitigating itself through the device is another major factor and device functionality. Creating useful simulations to model heat transfer and gas flow through the device were of great importance for determining design improvements. Fluid simulations were done in Open Foam using DSMC to model rarefied gas flow through the instrument. Additionally thermal simulations are underway but are not complex enough to yield useful comparison to instrument parameters.

These simulations can be compared to experimental results generated from tests conducted in the low atmosphere environment vacuum chamber using a nitrogen beam to serve as impingent gas.

From these comparisons design improvements can be made on the material and structure of the device to limit thermal noise with the sensor and mitigate gas buildup in the device due to improper venting.  Following design improvements, the TWI will be constructed and calibrated for flight in November 2025.