Low Density Atmospheric Turbulence Measurement using Pitot-Static Tubes

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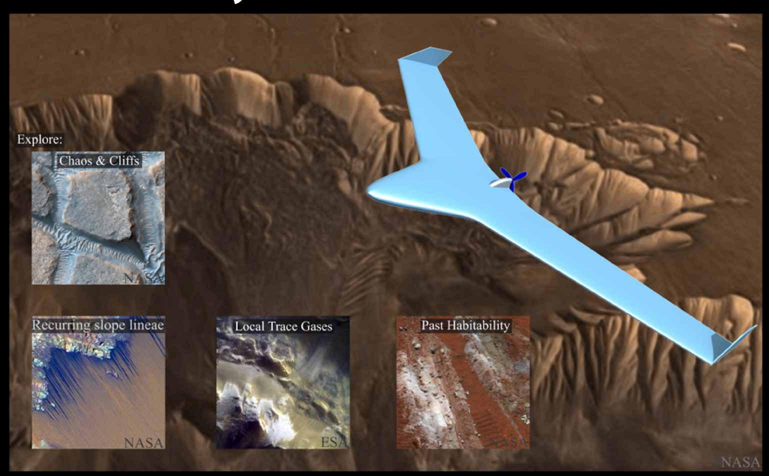
Motivation

With the increase in UAV popularity for atmospheric flight and testing, atmospheric instruments for small UAVs are in higher demand. However, atmospheric instruments for small UAVs are limited and expensive. Measuring accurate atmospheric data in the form of relative wind is necessary for autopilot systems and modeling atmospheric behavior around a UAV. Multi-directional measurements of wind speeds in the low-density, turbulent atmosphere of Mars is needed for UAV applications in Martian environments. Current systems contain multiple, separate sensors that are both large and expensive, making available solutions inviable for small UAVs. The proposed solution is a set of pitot probe sensors. Arranging these readily available UAV sensors enables complete determination of relative wind and any associated turbulence.



UAV design for Martian Surface Exploration by Adrien Bouskela & Dr. Shkarayev.

Objectives

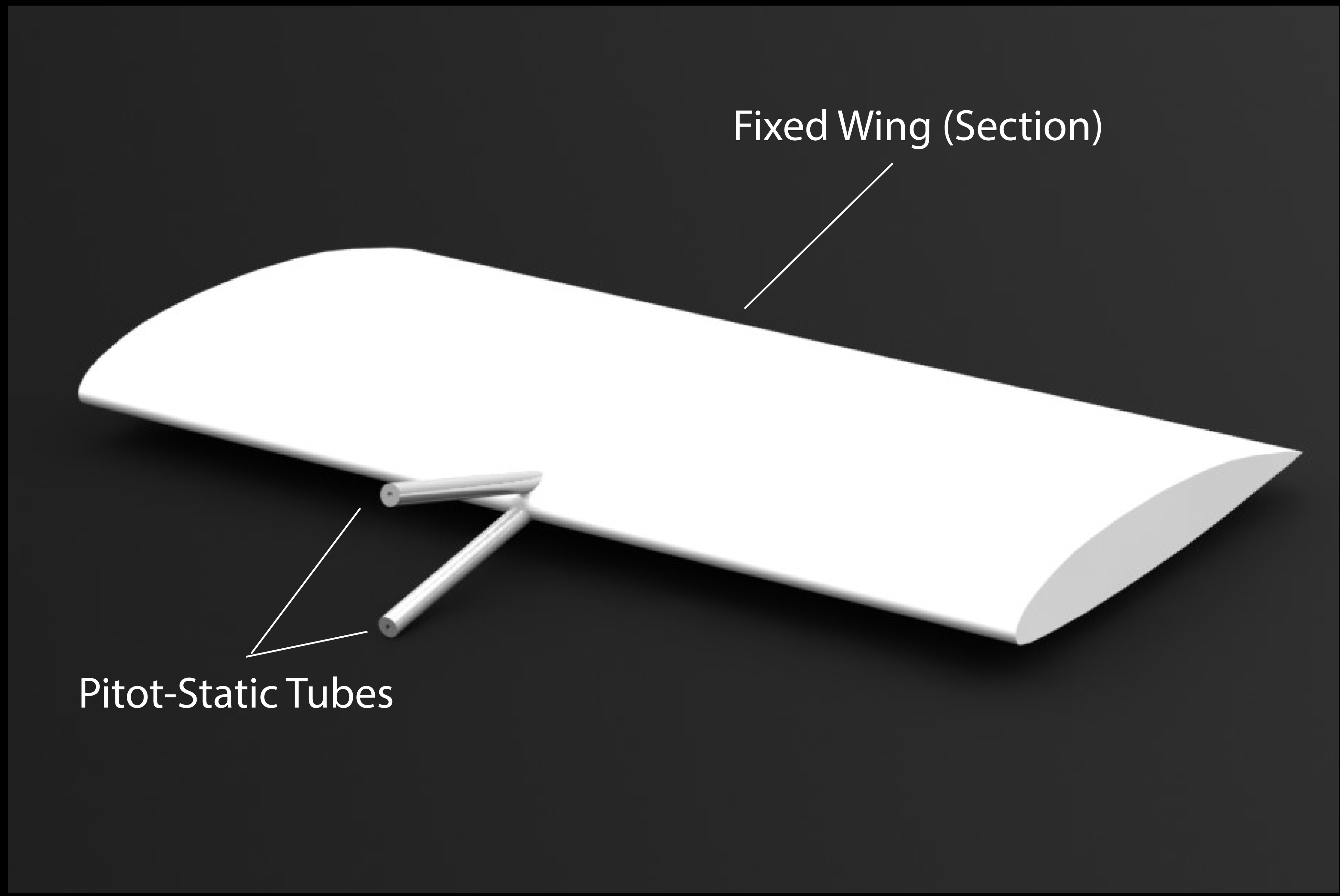
Identify the usability of this system for different atmospheric applications such as UAVs, Martian landers, or weather balloons.

1. Accurately measure UAV airspeed and angle of attack from the pitot-static tube readings.
2. Measure turbulence of the local atmosphere with high frequency measurement of pitot-static tube readings.
3. Determine relative wind vector while airborne, either on a fixed wing UAV or HAB (high-altitude balloon).

Use Cases

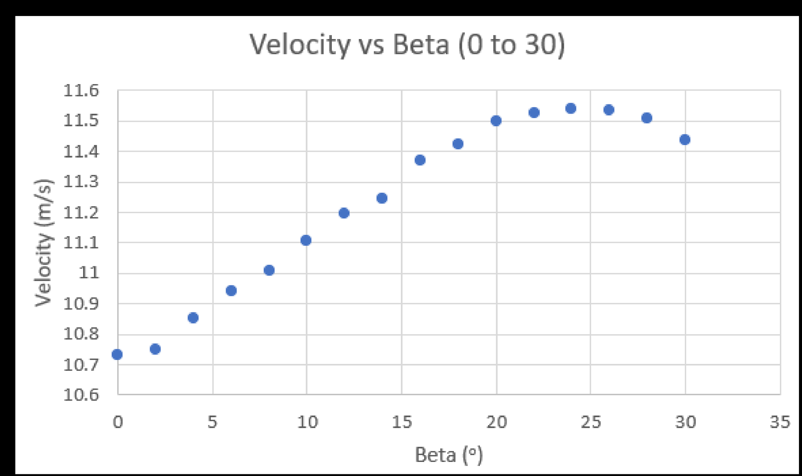
1. Usable as a flight sensor to measure angle of attack and airspeed on fixed wing UAVs for autopilot systems. This is favorable for small UAVs which are typically designed on much smaller mass budgets than large space exploration vehicles.
2. For in-flight turbulence measurements, the system can detect local turbulence the UAV experiences, which is useful to the autopilot for flight corrections and determining which parts of the atmosphere produce advantageous unsteadiness.
3. Capable of measuring relative wind to the ground. It can be placed in an area of interest to measure the atmospheric behavior and track the direction of the wind vector.

Dual Pitot-Static Tube System

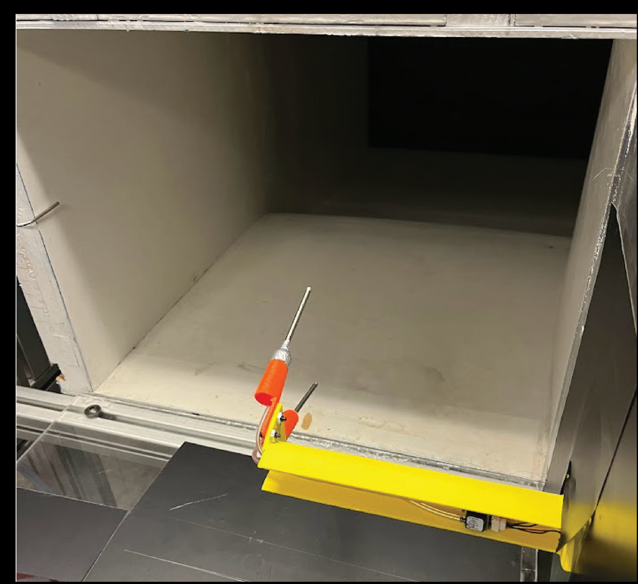


Dual pitot-static tube system mounted on a fixed-wing. Rendering is zoomed into a small section of the wing.

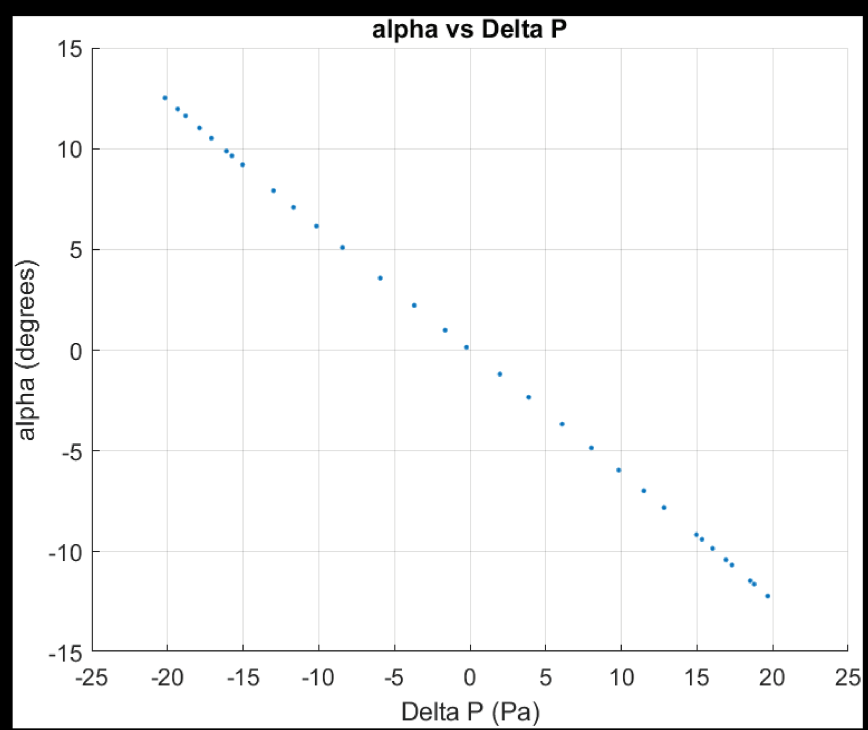
Single pitot-static tube test.



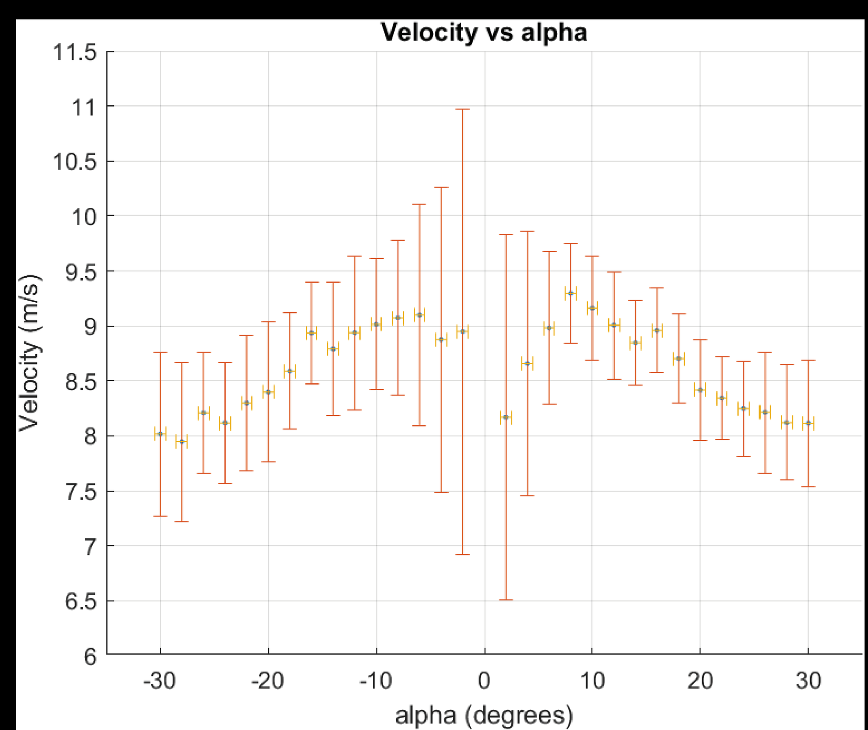
Single pitot-static tube test data with airspeed fixed at 10 ms.



Dual pitot-static tube test with only stagnation ports connected.



Dual pitot-static tube test angle of attack measurements with airspeed fixed at 10 m/s.



Dual pitot-static tube test airspeed measurements with uncertainty in velocity represented as vertical error bars.

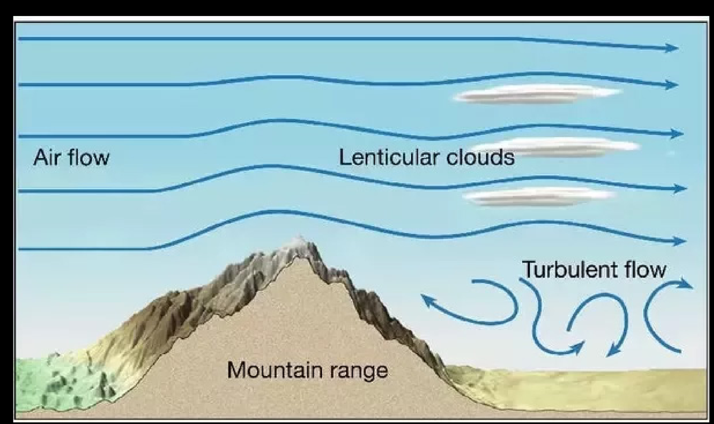


Diagram of Turbulence effects over a mountain.

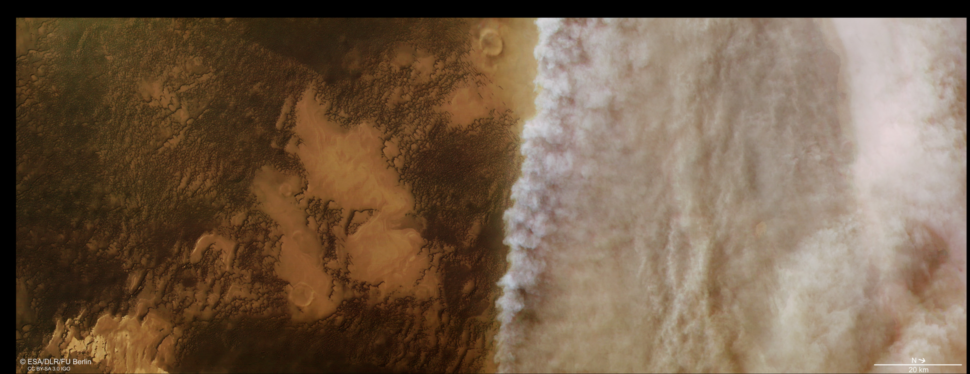


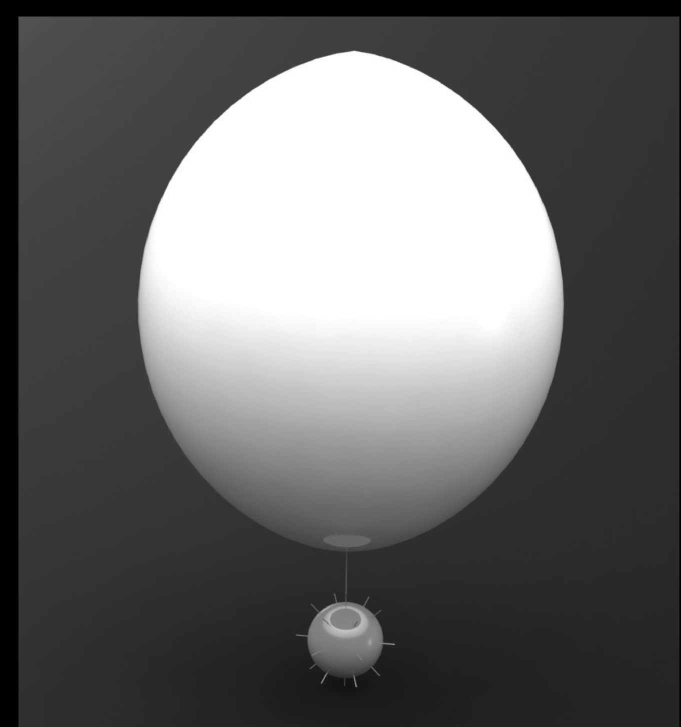
Photo of a dust storm on the surface of Mars.

Current Status

The dual pitot-static tube design has progressed from individual pitot-static tube studies to dual pitot-static tube design testing. After studying the behavior of a single pitot-static tube we concluded the static ports of pitot-static tubes inaccurately measured static pressure at angle of attacks greater than 5 degrees. Looking at the dual pitot-static tube design, we concluded if just the stagnation ports of the pitot-static tubes were connected to a single differential pressure sensor, we can calculate angle of attack and airspeed if one is already known, which eliminates the static ports altogether. To solve the issue of two unknowns, a third pitot-static tube will have to be used in conjunction with the dual pitot-static tube design.

After concluding a third pitot-static tube will be used, testing of the dual pitot-static tubes was conducted. Results for measuring the angle of attack were promising with a few areas of error. The behavior was very linear, but groupings appeared at the ends of the measurement range, making only a certain area of measurement usable. However, velocity measurement were too inaccurate an imprecise to be used alone.

Moving forward, turbulence testing will be conducted to determine the dual pitot-static tube design's ability to measure turbulence. This will be conducted with a cylinder moving in front of the pitot-static tubes at a roughly consistent frequency to see if the turbulence frequency will appear in a power spectral density graph (PSD).



Pitot tube network on HAB for high frequency measurements of turbulence.