Predicting in-flight air density for more accurate landing

April 2 2020

Credit: CC0 Public Domain

In the final few minutes of a spacecraft landing it is moving at hypersonic speeds through many layers of atmosphere. Knowing the air density outside of the vehicle can have a substantial effect on its angle of descent and ability to hit a specific landing spot. But air density sensors that can withstand the harsh hypersonic conditions are uncommon. A student from The Netherlands, working with an aerospace engineer at the University of Illinois at Urbana-Champaign, developed an algorithm that can run onboard a vehicle, providing important real-time data to aid in steering the craft, particularly during the crucial entry, descent, and landing stage.

"The algorithm we created can run in-flight, onboard the vehicle and estimate what the atmosphere outside is like," said Hamza El-Kebir, an undergraduate at Delft University of Technology. "So this is a complete game changer, because now you can use prior knowledge about the vehicle's motion to estimate the air density, inform your decisions in flight, and make minor alterations in your course. This can provide more certainty that you're going to hit that spot, instead of dealing with really conservative guidance."

El-Kebir conducted the research with Melkior Ornik, assistant professor in the Dept. of Aerospace Engineering at U of I, during a semester abroad program and will begin graduate school at Illinois in the fall. He said his work is new because it uses data from sensors that weren't intended to provide air density data. "It extracts that density information from it by using really nifty algorithms that don't require any real knowledge of the aerodynamics or the atmosphere."

Ornik explained how the algorithm learns the air density. "The algorithm starts from almost nothing. It doesn't know anything about the air density. It gathers data from accelerometers and gyroscopes available on any vehicle to gather data, and combines it with prior knowledge about maximal rate of acceleration to obtain a time-varying estimate of air density. And it gets, in a sense, smarter over time. It changes its estimations onboard, based on the input data it receives."

El-Kebir and Ornik used data acquired from the entry, descent, and landing of the Phoenix lander—a Mars science probe—representing the last 220 seconds, the ballistic phase, until parachute deployment.

"There's no steering at the later portion of that stage, so it's really important to immediately know the air density in the rarified flow regime—from about 80 kilometers and up. When it enters that later portion, its flight path angle gets fixed and the vehicle just descends, and is barely affected by the direction of the wind," El-Kebir said.

What if the Phoenix had the algorithm?

"If you know the air density, you can estimate your angle of attack with respect to the wind. You could also predict what the density will be like in the future, so you can make decisions. There was no control on Phoenix during the ballistic stage. If it had the knowledge of air density, it would have had an edge. They could have leveraged the data and landed more accurately."

Ornik said there is often an assumption that there exists a fixed model that we know in advance and we figure out control methods that lead the vehicle to land. "That is often a strong assumption. It's often wrong because it's not just about air density. Due to the speed and the impact with air, hypersonic vehicles change shape slightly during the flight and that changes their dynamics during flight."

"So we don't have a unified model that describes the whole flight because the dynamics change gradually over time. We know the maximal rate of change, so with this algorithm, we can exploit that knowledge to create an estimate," Ornik said.

El-Kebir said there are other fields this knowledge can be applied to, even outside of aerospace and even vehicles. He is looking at ways to use it in electrosurgery to predict the temperature field during a surgical operation so that the surgeon can know how deep the cut is.

More information: In-flight air density estimation and prediction for hypersonic flight vehicles. 23rd AIAA International Space Planes and Hypersonic Systems and Technologies Conference, 2020. mornik.web.illinois.edu/wp-con … ent/uploads/EO20.pdf

Provided by University of Illinois at Urbana-Champaign