Internet2 Event – BIG BLUE on I2

February 27, 2008

Flying on Mars and Testing on Earth

Overview

This series of questions and activities will help you understand and appreciate some of the challenges of designing and testing an airplane to fly exploration missions on Mars or other planets and moons.

Background

Exploration of Mars via a “Mars Airplane” has long been a goal of researchers. Mars has an atmosphere sufficient to support flight. An aircraft can fly long distances to observe much larger areas than a lander/rover and from much closer than an orbiting satellite. Much like is done on Earth, an aircraft could also collect atmospheric samples to provide understanding of the planetary atmosphere that may not be possible to achieve from observations on the ground or in orbit.

Question #1 - If you were going to design an aircraft to fly exploration missions on Mars (or other planets), how would you start?

You might begin by looking at important properties of the planetary atmosphere and how they relate to flight. Planetary atmospheres, including that on Earth, are made up of various gasses. On Earth, the main constituents are Nitrogen and Oxygen; on Mars it is Carbon Dioxide. The study of the motions of gasses and liquids is called fluid dynamics. Whether you are considering the wind and its part in weather or the flow over a wing, fluid motion is an important subject.

In the study of fluids and forces, two important dimensionless quantities that are used to describe flight and aircraft are the Reynolds Number and Mach Number.

The Reynolds Number, Re, is the ratio of inertial forces to viscous forces

$$Re = \frac{\rho v L}{\mu}$$

where ρ is the fluid mass density, *v* is the fluid velocity, *L* is a characteristic length such as wing width (chord), and μ is the fluid viscosity.

The Reynolds Number is used to predict the occurrence of different flow characteristics such as laminar, transitional, or turbulent flow, as well as to define experiments with dynamic similarity so that smaller scale models can be tested in wind tunnels or water tunnels during the design process instead of building and testing more expensive full-scale models.

The Mach Number, M, is the ratio of the speed of an object in a fluid to the speed of sound in that fluid.

$$M = \frac{v}{v_s}$$

where *v* is the speed of the object and v_s is the speed of sound in the fluid. High-speed flight is categorized using the Mach Number.

Question #2 – Make a list of all of the variable quantities that appear in the dimensionless Reynolds and Mach Numbers. Define each quantity. List appropriate units for each quantity in both English and Metric units. Show that the Reynolds Number and Mach Number are dimensionless. Write down two sets of quantities (density, velocity, length, and viscosity) with air as the fluid that result in the same Reynolds Number. What if one set included properties of a gas (air, for example) and the other included properties of a liquid (water). Can you write down two sets (density, velocity, length and viscosity) so that the Reynolds Number is the same?

Question #3 – Flow characteristics can be predicted by considering the Reynolds Number. Laminar flow is smooth, with the fluid particles following parallel paths as they move. For example, if a faucet is lightly turned on, the water is clear and forms a column with straight sides. Turbulent flow is not smooth, with the fluid particles following very different paths as they mix with each other. If the faucet is turned on more strongly, the water changes its appearance. Tubing on a stream flowing smoothly is a very different experience than white-water rafting. Laminar flow over an airfoil (the cross section shape of a wing) is also very different than turbulent flow. Transitional flow, like the name implies, is somewhere in between. For airfoils (note: pipe flow and other flows will be different), find Reynolds Number ranges for laminar, transitional and turbulent flow. Note that these will vary for different situations and applications, so different sources may give different ranges.

Question #4 – The Mach Number is used to categorize different flight regimes (for example, hypersonic). Find and list Mach Number definitions for different flight regimes.

From these important dimensionless quantities, we can start a list of important atmospheric fluid properties including mass density, viscosity and the speed of sound in the fluid. Other important properties include temperature, pressure, and the chemical composition of the fluid.

Question #5 – Think about everything that you know that flies, from creatures to toys to man-made aircraft and spacecraft. Make a list of all of the atmospheric fluid properties and characteristics that you can think of that might be important for flight. What about sunshine (radiation from the sun)? Should this be on your list? Why or why not?

Pre-Event Activity

Your first pre-event activity includes an assignment to find out information about the atmosphere of Mars (and/or other planets) that is important for flight. In particular, we'd like to know Mars density and viscosity, but other information such as temperature and wind speeds would be useful. Thinking about the wind speed of the air on Earth, you might realize immediately that it varies with altitude and with location. Density and other atmospheric properties also vary with altitude and location. Density varies in a known way with pressure and temperature according to the Ideal Gas Law.

Challenge #1 – This is not as easy or as straightforward as it might seem. The first problem is where to get the information for this challenge. The resources list below includes technical references and web sites you might find useful, providing equations and/or data. You may also find data from other sources.

For the Earth AND for Mars, plot the following:

- the variation of temperature versus altitude
- the variation of pressure versus altitude
- the variation of density versus altitude
- the variation of wind speed versus altitude

In addition to knowing characteristics of the Martian atmosphere, to build and test a Mars Airplane on Earth, we also need to know the same characteristics of Earth's atmosphere. At what altitude on Earth is the density the same as that at low altitudes on Mars?

Challenge #2 – At what altitude on Earth would you propose to conduct a flight test to approximate the conditions for low altitude on Mars? On Mars, consider the flight altitude range of interest to be from 0 to 10,000 m. What was the primary reason that you selected this Earth altitude? What conditions (atmospheric properties) will be similar to those on Mars? What conditions will be different?

Here are some resources to try:

NASA Glenn Research Center created a web resource called the Beginner's Guide to Aeronautics (http://www.grc.nasa.gov/WWW/K-12/airplane/short.html). One element of this resource is an interactive atmospheric model simulator that includes the Earth and Mars.

http://www.grc.nasa.gov/WWW/K-12/airplane/atmosi.html

From the NASA archives, see NASA SP-8010, "Models of Mars' Atmosphere (1974); NASA Space Vehicle Design Criteria (Environment)" from December 1974.

http://trs.nis.nasa.gov/archive/00000154/01/sp8010.pdf

The Kentucky Cluster Fluid Dynamics (CFD) research group is lead by Dr. Raymond P. Lebeau, who received his PhD in Planetary Science from the Massachusetts Institute of Technology, focusing on Computational Fluid Dynamics (CFD) models of planetary atmospheres. His research laboratory website has a simulation of planetary flight, including information on planetary atmospheres (except Mars).

http://www.engr.uky.edu/~cfd/Planet_Flight.html

Mars Scout missions are selected every four years with current missions launched in 2007 and planned for 2011. The NASA Langley ARES "Mars Airplane" team has been developing and testing an aircraft for Mars exploration. Their web site has lots of good information on their approach to this challenge, along with animations of concept designs and videos of high-altitude testing. The ARES project has developed technologies of interest for other applications on Earth, including the recently announced DARPA Rapid Eye program. The Rapid Eye Industry Day presentation on ARES includes information of interest.

http://marsairplane.larc.nasa.gov/index.html

http://www.engr.uky.edu/~bigblue/I2Event/NASA_ARES_REBrief.pdf

Other NASA paper and reports on flight projects for planetary exploration include the following:

Murry, J.E. and P.V. Tartabini, "Development of a Mars Airplane Entry, Descent, and Flight Trajectory," NASA/TM – 2001-209035, January 2001. http://www.engr.uky.edu/~bigblue/I2Event/NASATM-2001-209035_MarsEntry.pdf

Greer, D., P. Hamory, K.Krake and M. Drela, "Design and Predictions for a High-Altitude (Low-Reynolds-Number) Aerodynamic Flight Experiment," NASA/TM-1999-206579, July 1999. http://www.engr.uky.edu/~bigblue/I2Event/NASATM-1999-206579_LowReFlight.pdf

Guynn, M.D., et. al., "Evolution of a Mars Airplane Concept for the ARES Mars Scout Mission," AIAA-2003-6578, AIAA" Unmanned Unlimited" Systems, Technologies and Operations Conference, San Diego, CA, September 2003. http://www.engr.uky.edu/~bigblue/I2Event/AIAA-2003-6578_ARES.pdf

Landis, G.A., A. Colozza and C.M. LaMarre, "Atmospheric Flight on Venus," NASA/TM-2002-211467, June 2002. http://www.engr.uky.edu/~bigblue/I2Event/NASATM-2002-211467_VenusFlight.pdf

The UK BIG BLUE experiments have collected data while ascending from ground level in Denver, Colorado to altitudes from 60,000 ft to 97,000 ft. A collection of some of that data is available as a powerpoint presentation.

http:/www.engr.uky.edu/~bigblue/I2Event/flightdata.pdf (not currently available)

The NASA Dryden Environmental Research Aircraft and Sensor Technology (ERAST) program included a Pathfinder aircraft that provided data on windspeed and altitude currently used for an educational activity available on the web. For information on the Pathfinder aircraft and the ERAST program, and the windspeed data, use the following links.

http://www.nasa.gov/centers/dryden/history/pastprojects/Erast/pathfinder.html

http://www.ed.arizona.edu/ward/Pathfinder/Wind/wind-speed.GIF

Annenberg Media offers a free-for-download video course for high-school and college students and teachers called, "The Habitable Planet: A Systems Approach to Environmental Science." The second program of the course is on the Earth's atmosphere, including recent research themes and how researchers gather data on this dynamic fluid environment.

http://www.learner.org/resources/series209.html?pop=yes&vodid=835518&pid=2270#