Design Laboratory Assignment: Atmospheric Satellites

ASEN 2002: Thermodynamics and Aerodynamics

Assigned: 12 September 2018

Due: 3 October, Prelab report on balloon scale model results

Due: 16 October, All Presentations due 11:59 pm to Canvas

Red Bull Stratos Launch Vehicle and Limb of the Earth's Atmosphere Viewed by Felix Baumgartner from an Altitude of 37 km (~120,000 feet)

1.0 Background

1.1 Lighter than air Vehicles

There are only two practical methods of producing a buoyant aircraft. If the air inside a suitably large and lightweight envelope is heated to a high temperature, the gas expands and a sufficient amount of fluid (air can be considered a fluid) may be forced out of the interior so that its weight decreases and the total weight of the craft becomes less than the amount of fluid (or air) displaced. Hot air balloons were flown by the brothers Joseph and Etienne Montgolfier as early as the spring of 1783. While the materials and technology are very different, the principles used by the earliest eighteenth-century experimenters continue to carry modern sport balloons aloft.

The other means of achieving buoyant flight is to fill the envelope with a gas that is sufficiently lighter than air. The first hydrogen-filled balloon was designed and constructed by Jacques A.C. Charles and launched from the Champs de Mars in Paris on August 27, 1783. Jean Pierre Blanchard, a French aeronaut, made the first free flight with a gas balloon in the United States from Philadelphia in January 1793.

Today, research balloons capable of reaching high-altitudes (>30 km) for extended periods of time (weeks to months) are being deployed by NASA. These balloons carry research payloads that enable scientific measurements that are otherwise hindered on the ground by atmospheric effects. These balloons also serve to test spacecraft instrumentation prior to satellite deployment while mitigating the significant forces incurred during launch. Scientists use scientific data collected during balloon flights to help answer important questions about the universe, atmosphere, the Sun and the space environment. Questions such as "How did the universe, galaxies, stars, and planets form and evolve?" and "Are there Earth-like planets beyond our solar system?" are being answered by NASA with the help of experiments flown on scientific ballons.

In October 2012, the Red Bull Stratos project set new records by carrying Austrian skydiver Felix Baumgartner to an altitude of 37,640 m (123,491 ft) where he leapt into the record books, http://www.redbullstratos.com/ . A less publicized feat by Google Exec, Alan Eustace, broke the record of highest free-fall again in October, 2014 setting the record at 135,890 feet, http://www.rt.com/news/199136-eustace-stratosphere-jump-record/ .

Renewed interest in inflatable systems is occurring with the push towards space commercialization. NASA contests such as the 2017 eXploration Habitat (X-Hab) Academic Innovation Challenge, http://www.nasa.gov/exploration/technology/deep_space_habitat/xhab/ - .Ui3qsj_3Prg, and Bigelow Aerospace's space habitats,such as the BEAM deployed on the International Space Station, http://www.bigelowaerospace.com/beam/ , are current examples of recent developments in inflatable space systems.

New endeavors involving commercial companies, such as Google, are exploring lighter-than-air vehicles for aerial wireless network connectivity in rural and remote areas. Google's Project Loon involves developing high-altitude balloons placed in the stratosphere at an altitude of about 20 mi (32 km) to carry the companies' electronics aloft, http://www.google.com/loon/ .

Google's Project Loon research balloon

1.2 Balloon Design: An Application of the Ideal Gas Law and First Law

There are two types of research balloons: zero-pressure balloons (Red Bull Stratos) and super-pressure balloons (Google's Project Loon). A more appropriate name would be zero-pressure gradient balloons and super-pressure gradient balloons but the word "gradient" is commonly dropped or implied. Research these balloon types and understand their differences as you will be reporting on those differences in your presentation.

The most basic design question about high-altitude balloons is how to **achieve** and **maintain** a desired altitude for a given instrument payload. This needs to take into account the following issues:

- The density, pressure and temperature conditions of the atmosphere.
- The Ideal Gas Law and Archimede's Principle.
- Material properties and their design limits
- The mass budget of the balloon system and final volume.

1.3 Scale Model Balloon System

Prior to developing a design for a high-altitude balloon system, your task is to build a scale model of a zero-pressure balloon and develop a mechanical and thermal assessment of the system.

1.3.1 Construct a helium balloon with payload. Gather all balloon material and determine their mass. With the assistance of a lab technician, fill the balloon with helium gas. Attach a payload and acheive neutral buoyancy in the lab. **Draw a free-body diagram of the system and perform a force analysis identifying all forces involved.** Record local temperature and pressure from ITLL reading or NCAR website (http://www.eol.ucar.edu/cgi-bin/weather.cgi?site=fl).

1.3.2 Make your balloon "slightly" negatively buoyant. Add additional payload to your balloon to make it fall. Place the balloon system in front of a heater and hold it to allow sufficient time for energy to be transferred to the balloon. Release the balloon and record your observations. **Define your thermal system and describe thermodynamically the processes taking place during your observations that includes processes and energy conversions.**

1.3.3 Re-establish neutral buoyancy with your balloon. Record the mass of your payload (string, washers, etc…). Remove payload and estimate the balloon volume by making careful measurements of the balloon dimensions. Use a water tank to provide another means of estimating balloon volume. Determine the volume of the balloon by recording the volume of water displaced in a graduated tank after fully submerging the balloon in the water tank. **Contrast your tank results with your dimensional estimate for volume.**

1.3.4 Determine the mass of the gas. Using the neutrally buoyant force balance analysis, estimate the required mass of the gas. Contrast this estimate with estimating the mass of the gas using the measured volume and the Ideal Gas Equation. **Evaluate errors and discrepancy between the two estimates. What is the total mass budget and the fractional percent of each balloon system component to the total system mass?**

1.3.5 If you wanted to lift more payload, what design modifications would you make and what would be the impact? If you were to make your originally designed balloon neutrally buoyant in water, what would be the required mass of the payload?

Prepare a brief group report addressing all these questions and submit this report in lab on October 3.

1.4 Design a High-Altitude Balloon

In your groups, perform a design analysis of a high-altitude balloon for carrying a research payload.

Your design requirements are as follows:

1.4.1 Payload. A 500 kg research instrument.

1.4.2 Altitude. The balloon should be able to reach an altitude of 35 km

1.4.3 Duration. The balloon should be able to stay in residence for at least one day.

Assumptions:

1.4.4 Shape. Assume the shape of the balloon at target altitude is a sphere

1.4.5 Transients. Ignore transient effects during ascent

1.4.6 Stresses. Ignore stresses on balloon material associated with attaching the payload or wind loading

1.5 Zero-Pressure Gradient Balloons – Design Expectations

Your primary analysis will involve designing a zero-pressure balloon to satisfy the clients design requirements

You should determine the following design aspects for the balloons:

- Select and support use of your internal gas – know its properties and characteristics given the expected environment
- Determine the **volume** of the balloon at the target altitude
- Research and describe balloon material properties
- Evaluate your full-scale ballon system's mass budget and relate to the scale-model mass budget determined in pre-lab by its fractional percent

1.5.1 Provide a free-body diagram and perform a force analysis of the balloon applying Archimedes Principle. Determine the lifting gas and its properties, balloon material and thickness, the final volume of the balloon, the necessary mass of your lifting gas. Provide material stress analysis to indicate possible balloon failure – i.e., plot factor of safety values of your material versus balloon volume.

1.5.2 Research super pressure balloons and describe how to design such a system to carry the same payload.

2.0 Learning Goals

In this Design Lab, you have the opportunity to achieve the following learning goals:

1. Learn about the requirements and design assumptions for developing lighter-than-air vehicles and the approach using intensive / extensive properties.

2. Integrate your knowledge of the first law of thermodynamics in a practical design analysis. Include factors of safety, for example on material stresses, imposed by the characteristics of the design and the environment.

3. Learn about the utility of scale models and the insight provided in developing the final system design

4. Use MATLAB for engineering calculations and plotting.

5. Learn trade studies and sensitivity analysis

6. Learn research skills, both in the Library and on the Web.

7. Further develop your team and presentation skills.

8. Develop engineering reasoning skills

3.0 Required Deliverables

3.1 Group Pre-Lab Report: Due Wednesday, October 3

Your group will prepare a brief written lab report that summarizes your findings and answers questions posed for the scale model experiment performed on September 19 and described in section 1.3. The report does not need to include abstract, introduction or conclusion sections but simply a summary of the results with succinct discussion of the results by answering the questions. Follow the provided grading rubric.

3.2 Group Presentations: Due Wednesday, October 16 at 11:59 pm in Canvas

Your group will prepare a 15-minute presentation reporting the results of your design investigation. Include in your presentation how the scale model results were used in developing your high-altitude balloon design. This report must present how each requirement is met by your design *in a quantitative manner supported by analysis and research* - follow **section 1.5** to support your design. The presentation must also provide some rationale for your decisions. Each person in your group must speak during the presentation. All presentations will be due by 8am this day regardless if you are scheduled for the following week.

4.0 Suggested Study Questions/Issues

The following statements are offered to help you clarify the issues involved in this assignment.

1. The lab experiment to build a scale model of a zero-pressure balloon and develop mechanical and thermal analysis to evaluate balloon characteristics should provide some insight into the actual balloon system design. Consider the mass budget of the scale model and what implications it has on the full system.

2. Research zero-pressure balloons. Formulate a "homework problem" that computes the volume of the research balloon at the required altitude – do this for a zero-pressure balloon. Discuss margins of safety before the balloon fails.

3. Write a MATLAB routine that calls the function that computes the pressure, density and temperature from the 1976 Standard Atmosphere Model. A description of this atmospheric model is given in Chapter 3 of Anderson, Introduction to Flight and code can be found on the Mathworks website.

4. Develop your analysis code to enable flexibility in your design parameters. That way, you can study how changes in design parameters affect the output design specifications.

5.0 Suggested Activities

You are free to organize your groups as you wish. However, we offer the following set of weekly objectives to help guide your development. Every group will probably adapt their own variation of these suggestions. You are expected to attend each laboratory session. Your group will be expected to present weekly update briefings to the faculty and staff of the class.

5.1.1 <u>Week 1 – Sept 19</u>. Read over the lab description and requirements. Establish a schedule for required assignments. Begin to research zero-pressure gradient balloon systems.. Organize your groups. Brainstorm ideas. Draw pictures of the problem, to make sure you understand the parameters of the assignment. Build scale model and develop analysis. Try to distill the problem into a few equations.

5.1.2 <u>Week 2 – Sept 26</u>. Review lab documents and prepare pre-lab report for submission next week and develop a presentation outline. Formulate a "homework problem" for the design to compute final volume. Research needed information and write the MATLAB code.

5.1.3 <u>Week 3 – Oct 3</u>. Submit your pre-lab report. Begin to finalize your presentation. Identify missing pieces that require further work. Presentation is due next week.

5.1.4 <u>Week 4 – Oct 10</u>. Presentation preparation time during Lab sessions on Oct 10. All Presentations must be submitted by October 16th 11:59 pm to the Canvas.

5.1.5 <u>Week 6 – Oct 17</u>. Presentations during Lab sessions.