Rocket Design and Nose Cones

DISCUSSION:

When we design a rocket, one of the first questions we ask is what do we want the rocket to do? In other words, what mission will the rocket perform? Identifying what mission a rocket will perform helps us understand what characteristics a rocket must have (these are called "mission requirements"). For example, if a rocket's mission is to carry humans into space, then it will require cabin space for the astronauts, pressurization equipment, and multiple redundancies to ensure safety. Identifying these mission requirements helps us understands the multiple design tradeoffs we need to consider to get to a final design. To get to a final design, a rocket designer must tradeoff three things – size, weight, and power. Going back to our example, the astronaut cabin, pressurization system, and redundant components will add weight to the rocket and will require more power to keep running. More weight and power means we need a larger structure, and probably have to design a rocket with bigger engines that produce more thrust. Let's explore these different design tradeoffs and considerations.

Let's first start with the rocket's payload. For any type of payload, be it a satellite or astronauts, we must also include additional supporting equipment that acts like an umbilical cord attaching the payload to the main rocket. This includes equipment such as certain instruments, gadgets, or recorders that generate and store data to monitor the health and status of the payload throughout the rocket's flight. All this equipment requires some amount of power, thus establishing the need for an electrical power supply to provide power to the payload. If this is a rocket used for war, we may want to have a warhead of high explosives but let us assume, for the time being, that the payload is for peaceful purposes.

Once the payload is selected, the designer then has to think about the structure that must hold the payload, including the weight of the structure, the size and weight of the rocket engine, and the need for aerodynamic or engine control systems (to control the flight path of the rocket). The designer also has to consider designing a cooling system to prevent the payload from heating and to ensure the power supply doesn't overheat the rest of the rocket components. Think of your home computer – a fan turns on inside the central processing unit (CPU) to prevent the circuit boards from overheating. A cooling system also adds weight and must be considered in the overall rocket design. Making estimates for the weight and sizes of these sub-systems is an important first step because they then give you an idea about how long, wide and tall the rocket system will be.

We now have a design problem that needs to be solved in an iterative fashion. In other words, let's say we take our first stab at a design. We aim for designing a lightweight structure with lighter and

smaller engines. Because our structure is lightweight, it cannot support the weight of the payload and the smaller engine won't generate the needed thrust to reach our desired altitude or velocity. When this happens, we'll need to go back to each of the subsystems. We may want to decrease the payload's weight, or increase the weight of the structure and increase the size of the engine to provide increased structural support and more thrust, respectively.

V-2 rocket being prepared for a May 10, 1946 flight. Note the rocket fins.

Courtesy of NASA Goddard Spaceflight Center (http://gsfc.nasa.gov)

During the design process, we must consider rocket aerodynamics. Aerodynamics involves the effects of the air flow on the rocket body. The biggest forces acting against the rocket body are gravity and drag. Powerful rocket engines generate the thrust needed to overcome both gravity and drag. But, control surfaces are needed to provide stability, guide the rocket on the right trajectory, and minimize drag by keeping it orientated in the right direction. Active control surfaces include fins and tilting nozzles that direct the thrust exiting the rocket engines. Without active control, such as fins, a rocket would tumble out of control much like an inflated balloon that is let go. Let's look at the different design aspects of rocket aerodynamics.

First, we need to design a nose cone for our rocket. If the nose section is flat, the rocket will experience a considerable amount of drag. To experience what drag feels like, stick your hand out the window the next time you're in a moving car. If your palm is facing down to the ground you don't feel a lot of resistance against your hand. If you rotate your hand so that you palm is facing forward, you feel a lot of resistance from the air flow hitting you hand. This is drag. To compensate for increased drag, we'll need more thrust and a bigger rocket engine. But remembering the interdependencies of size and weight, a bigger engine drives up the rocket's weight and we may now have a rocket system that exceeds what we want. What can we do?

The drag felt by a rocket is proportional to the square of the rocket's velocity ($DRAG=f(VELOCITY)^2$). Knowing that these rockets travel at very high velocities, it is imperative that we try to reduce drag. To do this we can go to a wind tunnel and try several different nose shapes. If the first shape is a simple cone, my wind tunnel tests will reveal that the drag drops considerably, by as much as 60% when I use a cone. Moreover, the drag drops more if the length of the cone increases. However, we can increase the length of the cone to the point that the length can become impractical. To lessen the length of the rocket, we could move things up into the cone such as the guidance sensors.

As a rocket travels faster, other considerations need to be taken into account. For example, at higher speeds, the aerodynamic heating may melt the rockett structure. This is due to the increased friction experienced by the rocket at high speeds. Aerodynamic heating on the nose cone is a particularly intense problem during re-entry. To keep from melting the structure during re-entry, early spacecraft such as the Apollo command module were very flat surfaces made with ablative material. Ablative material is intended to melt away, or ablate, with increasing temperature, thus dissipating the heat and keeping it away from the module itself. The space shuttle uses a certain type of heating tile to absorb

the heat of re-entry and keep the shuttle itself away from the intense heat. During these periods of aerodynamic heating, the nose cone is a particular concern, and designers have to ensure that the nose cone does not fail. Recall that we said a nose cone in the shape of a simple cone was good for reducing drag; unfortunately, the sharper the nose cone, the more susceptible it is to aerodynamic heating; as with the Apollo command module, the ideal shape for absorbing the heat of re-entry is a very flat surface. Thus there is a design trade-off between the demand to reduce drag and the demand to survive the heating of re-entry.

Another important design consideration is the "pitching moment" of the rocket body. The best way to visual the pitching moment is to take your pencil and try to balance it on a single finger. The point at which the pencil is stable is the center of gravity. Similarly in a rocket body, we want to have the center of gravity placed in such as way as to make the rocket to be stable. If the rocket gets too long or if the weight of the rocket components are unevenly distributed, the rocket would fall over on its side!

We've talked mostly about the aerodynamics of a rocket in this lesson plan. Let's put our knowledge of nose cones, fins, and rocket stability to work as we test the drag of different rocket designs.

ACTIVITY:

Test drag on a rocket. This activity involves building a wind tunnel tester. Mission Team members can test model rockets, different shaped objects (blocks and bottles), paper or balsa wood airplanes. A form below allows Mission Team members to test operation of a paper (or Styrofoam airplane – see Federation of Galaxy Explorers Aerodynamics Lesson Plan) in a wind tunnel.

OBJECTIVES:

- To demonstrate the effects flight control surfaces have upon the rocket (or plane) and its flight characteristics.
- To demonstrate on a small scale how scientists test those characteristics on larger planes and rockets.
- To realize some of the benefits which may occur from scientific "modeling".

MATERIALS:

- A piece of furnace pipe or carpet roll about 1.3 meters long.
- A piece of transparency film for the tunnel window.
- Separation foam from a crate of egg cartons (available at the grocery, some bakeries, a restaurant, or you may build a similar one from strips of light cardboard).
- Heavy cardboard or a box the same size as the egg carton divider.
- Book tape or duct tape.
- An electric fan.
- 2 small hooks (cup hanger hooks).
- Metal shears or saber saw depending on the material used to construct your tunnel.

MISSION TEAM LEADERS NOTES: The tunnel-like chambers through which air is passed at different velocities are used to study airflow over an object like a plane or rocket. The automobile

industry also uses wind tunnels in their research to produce more fuel-efficient cars. Some of the wind tunnels in the United States are large enough to hold full size planes or rockets. One such tunnel is located at the Langley, NASA Research facility in Virginia. A supersonic tunnel can be found at the NASA Lewis Research Center in Cleveland, Ohio. A model of the shuttle was tested in this tunnel.

There are a number of small wind tunnels that you or Mission Team members can construct. The one suggested here is a relatively simple one requiring minimum materials.

1. Open the carton separators and strengthen the corners with tape.
2. Open a box at both ends and place the separator grid into the box. It should be a snug fit.
3. Cut a window near one end of the roll or pipe and cover it with the clear film or acetate.
4. Tape the film down using the bookbinder or duct tape.
5. Fasten the hooks on opposite sides of the tube so that a plane hanging from the top hook will be positioned in front of the window.
6. Set the egg carton separators flush against the pipe or tube and place a fan in the box holding the separators. The separators will straighten the swirling air from the fan.
7. Prepare a suspension system for the models to be tested.
    a. Use a strong rubber band, the type you find on model airplanes. Cut the band in one place.
    b. String two notebook paper reinforcement rings on the rubber band and glue together.
    c. Tie the cut ends of the rubber band back together again
    d. Attach the model to be tested by placing a pin through the model and the ring near the model's center of gravity.
    e. Attach a similar rubber band to the lower hook

Have the Mission Team members begin by building paper airplane models and testing the effects of manipulation of the control surfaces of the model. They should discover that to climb, the elevators are up; to dive the elevators are down; to turn right, the rudder is right, the right aileron is up, the left aileron is down; to turn left, the rudder is left, the left aileron is up and the right aileron is down. Additional diagrams are available in the Federation of Galaxy Explorers Aerodynamics Lesson Plan.

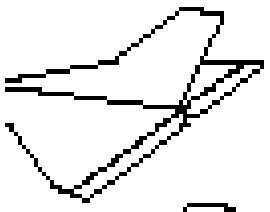
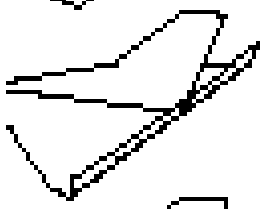
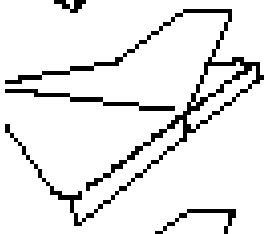
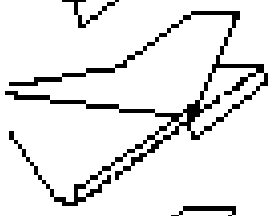
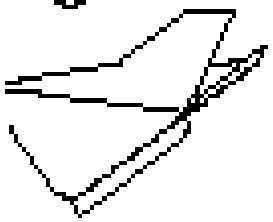
Have the Mission Team members investigate the effects of changing the center of gravity on the stability of the rocket or plane.

EXTENSIONS: Have the Mission Team members prepare and test model rockets in the tunnel before actual flight. Compare the actual flight results with the data collected from the wind tunnel tests. Have Mission Team members research wind tunnel testing on automobiles and investigate the spin offs from the science of aerodynamics to the auto industry

Test Question: Does changing the position of the elevons on a delta wing glider change its flight path?

Directions: Bend the elevons into the positions listed below. Be sure to predict the flight path before flying the glider. Test fly the glider and record the results (up, down, left, right).

Student Test Pilot Record Sheet (What I Observed)

Position of elevons		Predicted Flight Path	*Path of Test Flight*
Right and left straight		– – – – – – –	———
Right and left up		———	———
Right and left down		– – – – – – –	———
Right down, left up		———	———
Right up, left down		———	———

Does moving the elevons change the way the glider flies?

What happens when both elevons are in the up position?

What happens when both elevons are in the down position?

Does changing the position of elevons on a delta wing glider change its flight path?