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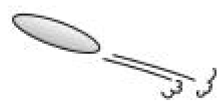
LAUNCH A FRISBEE INTO ORBIT!



When Pete Rossoni was a kid he loved to throw Frisbees. Most kids do—it's pure fun. But in Pete's case it was serious business. He didn't know it, but he was practicing for his future career . . . in space exploration.

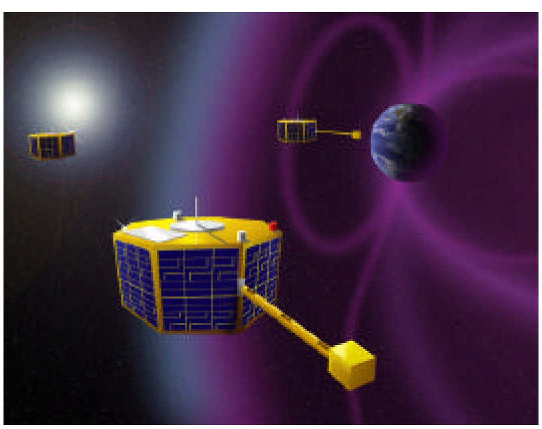
Grown-up Pete Rossoni is now an engineer at NASA's Goddard Space Flight Center. His main project there is figuring out how to hurl spacecraft into orbit Frisbee-style.

The spacecraft are small—about the size of birthday cakes. "This wouldn't work with big satellites or heavy space ships like the shuttle," notes Pete. But a cake-sized "nanosatellite" is just right.

Nanosatellites—nanosats for short—are an exciting new idea in space exploration. Ordinary satellites tend to be heavy and expensive to launch. The cost alone is a deterrent to space research. Nanosats, on the other hand, can travel on a budget. For example, a Delta 4 rocket delivering a communications satellite to orbit could also carry a few nanosats piggyback-style with little extra effort or expense.

"Once the nanosats reach space, however, they have to separate from their ride," says Pete. And that's where Frisbee tossing comes in.

Pete and his team have designed a device that can fling a nanosat off the back of its host rocket. "It's a lot like throwing a Frisbee," he explains. "The basic mechanics are the same. You need to impart the spin and release it cleanly—all in about a fifth of a second." (The spinning motion is important because it allows sunlight to shine on all the nanosat's solar panels.)



The Space Technology 5 nanosats will test nanotechnologies in space while studying Earth's magnetic field.

"We haven't done anything like this before," says Pete. Soon, however, the concept will be tested. NASA hopes to launch a trio of nanosats in 2004 that will ride on the back of a rocket yet to be determined. The name of the mission, which is part of NASA's New Millennium Program, is Space Technology 5 (ST5).

The ST5 nanosats are designed to study Earth's magnetosphere—a magnetic bubble that surrounds our planet and protects us from the solar wind. But their primary goal, notes Pete, is to test the technology of miniature satellites.

HOW TO FRISBEE-TOSS A NANOSAT INTO SPACE

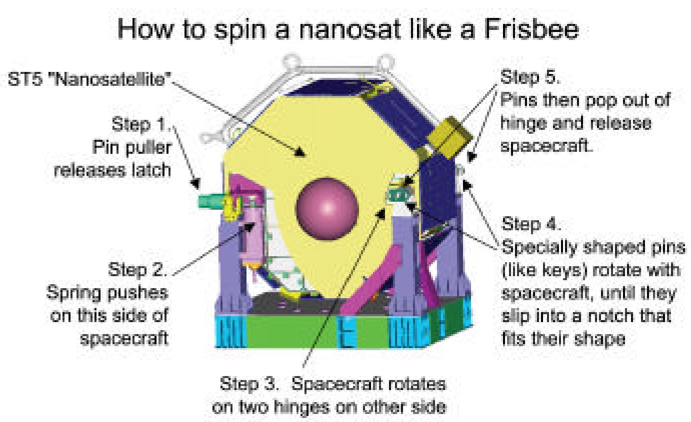
To allow the scientific instruments and experiments aboard the nanosat to operate correctly, the nanosat must spin at 20 revolutions per minute. For the nanosat launcher, producing that rate of spin is a primary objective. Calculating the exact force required to produce this rate of spin involves a bit more math than we will explain in detail here, but we want to give you an idea of Pete and his team's thought process in analyzing the problem.

To precisely measure rate of spin, designers use the term *angular velocity*, which can be expressed in revolutions per minute (RPM). If your parents (or grandparents) have an old record player (phonograph) that plays vinyl records, you may have seen the records turn at 33 RPM. The nanosats will be spinning quite a bit slower. Angular velocity can be described in other ways, too. If we divide a circle into 360 parts (called degrees), we can describe angular velocity in terms of degrees of rotation per a certain time interval. So 20 RPM could be 7,200 degrees/minute (20 revolutions of 360 degrees each minute), or 1/3 revolution per second or 120 degrees per second.

Unlike the record player, the nanosats will get only one powered twist to set them spinning at the proper angular velocity. But how much force needs to be behind this one-chance-only twist? That depends on how quickly it is driven to full speed (called its *angular acceleration*) and how much the nanosat resists being twisted (called *rotational inertia*). Inertia is the tendency of objects at rest to remain at rest and objects in motion to remain in motion. (More about rotational inertia later.) The twisting force needed to produce the spin is called *torque*. To get torque, we multiply angular acceleration times rotational inertia.

But how quickly should the nanosat reach its required 20 RPM spin? *Angular acceleration* is exactly how much the angular velocity (spin) increases over a unit of time. For example, if the angular velocity is given in revolutions per minute, angular acceleration is expressed in revolutions per minute, per minute. In other words, how many revolutions per minute will the speed increase (or decrease) each minute?

The angular acceleration rate in this case must depend on how much time is available to reach the desired angular velocity. For the ST5 nanosat launcher, a pusher-tipped, coiled spring will be used produce the torque, setting the nanosat spinning. The pusher will push on one hard point at the edge of the nanosat, with the opposite side's hard point hinged to act like a pivot. As the spring moves in a straight line, the hard point begins to rotate out of the pusher's path.

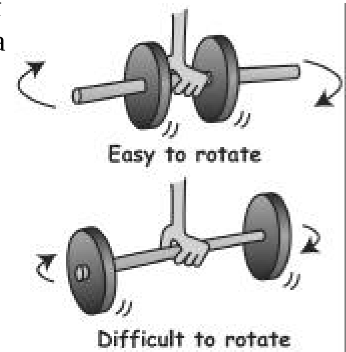


There will be contact between the pusher and hard point during only the first 12 degrees of rotation. This means that the full angular velocity of 120 degrees each second must be delivered in just 12 degrees of rotation—or $1/5^{th}$ of a second! An angular acceleration rate of 600 degrees/second/second is needed to reach full angular velocity of 20 RPM within $1/5^{th}$ of a second.

How hard will the satellite resist being twisted? The mass of the nanosat is 19.5 kilograms (43 pounds). If we push it in a straight line to get it moving, the resistance that 19.5 kilogram mass puts up to being moved is called inertia. So the nanosat has an inertia of 19.5 kilograms.

However, when twisted, that 19.5 kilograms presents much greater resistance. When turning, more power is needed to keep at the same speed than when going straight ahead. We notice this when steering a car or bicycle around a corner.

But there's more. The nanosat's 19.5 kilogram mass is distributed in a circle around its center, between the center and outer perimeter. The distance between that circle of mass and the center acts like a lever, adding to the resistance of the mass to getting in motion.

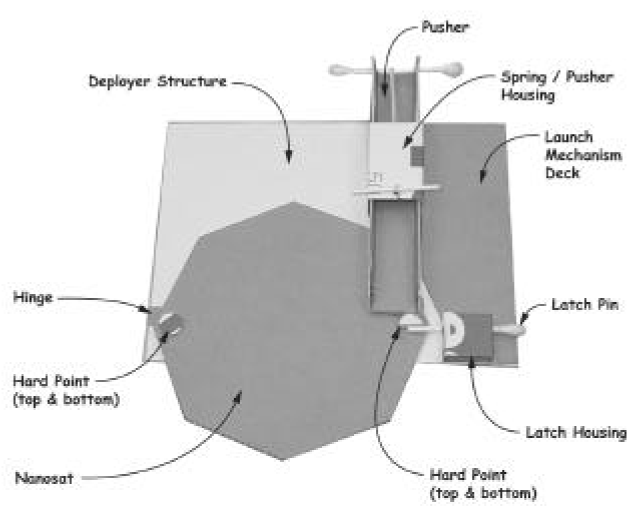


So, the total resistance to turning, or *rotational inertia*, depends upon the mass and its distribution.

Another factor the designers of the ST5 launcher have to consider is the effect of the magnetometer boom on the spin rate. This segmented boom holds the instrument that measures Earth's magnetic fields. It unfolds with its instrument attached after the satellite is set spinning. Just as spinning ice skaters spin faster when they draw in their arms and slower when they hold them outstretched, the satellite will spin slower when the magnetometer boom is deployed. So the satellite's initial spin rate when it leaves the launcher must take this slowing into consideration.

So, from its *rotational inertia*, the designers can calculate just how much *torque* must be provided by the spring to give the correct *angular acceleration* that will give the nanosat the correct final *angular velocity.*

BUILD YOUR OWN TOY NANOSAT LAUNCHER



This toy launcher works on the same principles as the real ST5 nanosat launcher. The "nanosat" is positioned on the launcher so that it is pushed on one side, while pivoting around a hinge on the other side. When the pivot "pin" reaches a notch in the hinge, the nanosat is released to go spinning like a Frisbee off into "space." (The toy nanosat has air and gravity to contend with, so it won't go very far.)

Materials

- 1/16" poster board, or narrow-flute corrugated board—3 sheets, 8-1/2" x 11", or enough to cut out all the pattern pieces. (Various products such as small electronics come boxes made of narrow-flute corrugated board.)
- Restickable (temporary) adhesive glue stick to mount pattern pieces to board for cutting.
- Permanent adhesive like contact cement, super glue, or wood (Elmer's) glue
- Rubber band, "average" size (for spring)
- 1 plastic coffee stirrer tube (for Latch Pin sleeve) about 3 millimeters (1/8 inch) diameter.
- 3 Q-tips or other sturdy cotton swabs (for Latch Pin and for front and rear Spring Connection).

Tools

- Copy machine
- Matte knife, X-acto knife, or box knife
- Metal straight edge
- Nail to punch hole centers
- Old (dry) ballpoint pen to enlarge holes and score fold lines. (On corrugated board use wooden tongue depressor, ice cream stick, or a very blunt point to score fold lines).
- Straightened paper clip

Preparing the Components

- Photocopy the three pages of patterns on the last three pages of this article. Mount the patterns to the cardboard panels with temporary adhesive. If you use corrugated board, be sure to align the direction of the dotted fold lines (except for those on Panel 1) with the direction of corrugated fluting.
- So that the folds are sharp and accurate, score all the dotted fold lines. If you are using poster board, score with an old (dry) ballpoint pen. If you are using corrugated board, use a wooden tongue depressor, ice cream stick, or soft, blunt tool to score fold lines.
- With a nail, punch through the centers of the holes in Panels 8 and 10 on the Launch Mechanism Deck (B) and through the end-of-slot centers on Panels 14 and 15 of the Pusher (C). Gently press and twist the tapered part of an old ball pen body to enlarge those holes to the sizes shown. Make small nail holes only in the Nanosat and in Hard Points G, H, and I.
- Cut out all pieces. Cut curves carefully with an X-acto, matte or box knife. With a knife and metal straight edge, cut carefully along the remaining straight lines.

Build Launch Mechanism Deck—B

- Remove (unstick) the pattern from Part B.

Pusher Housing

- Fold Panel 1 upward at the two fold lines shown, then glue it firmly (using permanent glue) to the Deck (2).

Note: Use the permanent glue for all the steps to follow.

- Fold over Panels 3, 4, 5, and 6 in upward sequence, then glue the bottom of Panel 3 firmly to top of Panel 1.

Latch Housing

- Fold Panels 7, 8, 9, and 10 upward, in sequence, then glue the bottom of Panel 7 firmly to the Deck (11).
- Slide a coffee stirrer (for the Latch Bushing) through the two holes, glue in place and cut off the excess length of the stirrer.
- Cut one end off a Q-tip (for the Latch Pin). Holding the cotton end, slide the cut end through the coffee stirrer from the Deck side toward the open side.

Build Pusher—C

- Remove (unstick) the pattern on Part C.
- Fold Panel 12 downward at the two fold lines shown, then glue it firmly to the underside of Panel 13.
- Fold Panels 14 and 15 upward.

Assemble Pusher Housing and Pusher

- Holding the Pusher by the Panel 12 end, with Panel 12 at bottom, insert it into the open end of the Pusher Housing, opposite the Deck side.
- Slip an end loop of the rubber band into the slot at the top of the Pusher Housing. Pass a Q-tip (you can cut off the cotton ends) through the end of the rubber band to keep it from slipping through the slot.

- Pass a Q-tip through the other end of the rubber band. Position the Q-tip into the Pusher's rear notches to connect power for launching.

Build Nanosat—J

- Remove pattern paper from Hard Point F. Fold Panel 16 upward at the two fold lines shown, then glue it firmly to Panel 17.
- Note the position of Hard Point F on the Nanosat pattern, then remove the paper and firmly glue Hard Point F into position (F) on the Nanosat.
- Align Hard Point G with the Nanosat hole (G) by inserting a straightened paper clip through the holes in each. Glue Hard Point G firmly in place.
- Turn the Nanosat over. With holes and paper clip, align and firmly glue Hard Points H and I into their respective positions.

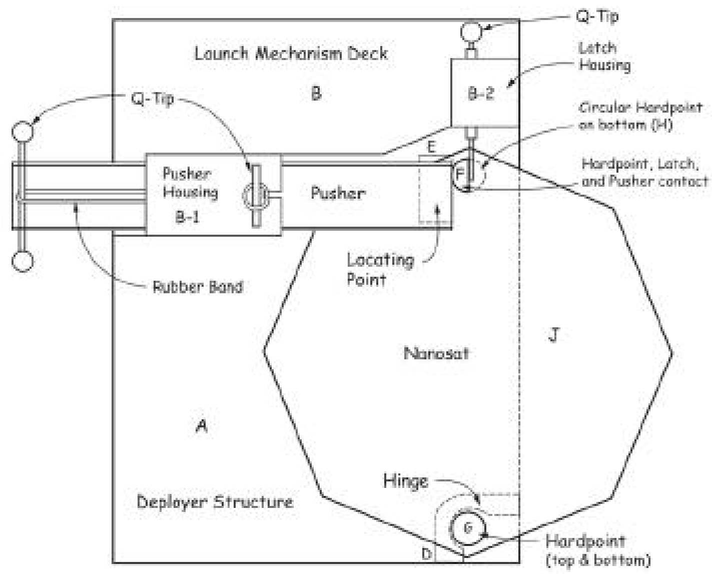
Assemble All Onto Deployer Structure—A

- Score the outlines of components B, D, and E onto the board material with an old (dry) ballpoint pen before removing pattern paper.
- Disconnect the rubber band Spring from the Pusher's rear connection while assembling the Deployer Structure.
- Glue the Launch Mechanism Deck, B, firmly to area (B); the Hinge, D, to area (D); and the Locating Point, E, to area (E).

Now, Let 'er Fly!

- Disconnect the rubber band Spring from the Pusher's rear connection.
- Place Nanosat, with Hard Point F on top and Hard Point G at the hinge side, into the Hinge.
- Move Hard Point F toward the pusher until the lower Hard Point, H, contacts the Locating Point, E. Extend the Latch Pin to contact the flat side of Hard Point F.
- Power the launcher by carefully placing the Q-tip that holds the rubber band into the Pusher's rear connection.
- Grasp the cotton end of the Latch Pin Q-tip; pull it back until the Nanosat deploys.

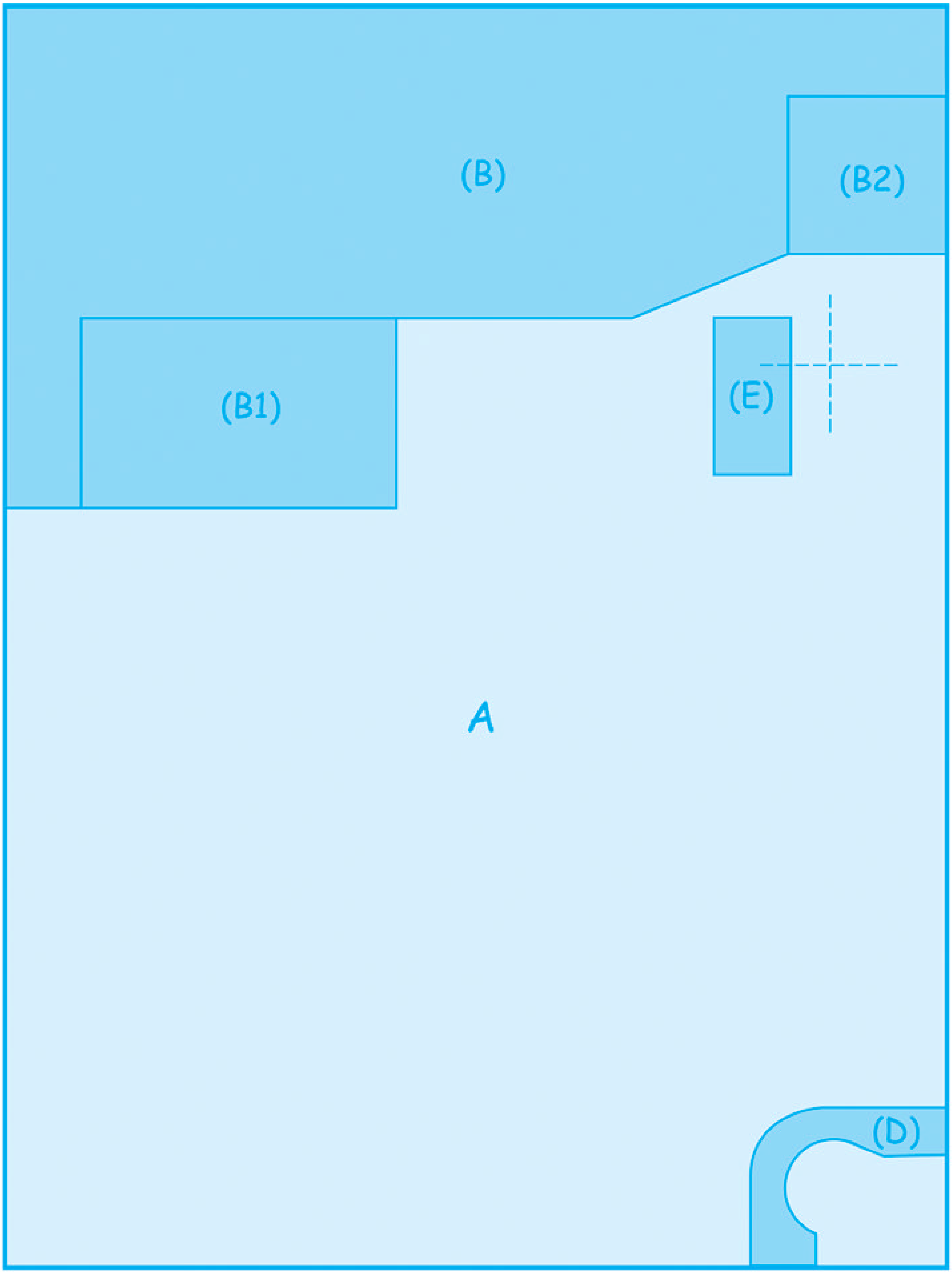
Discussion Questions

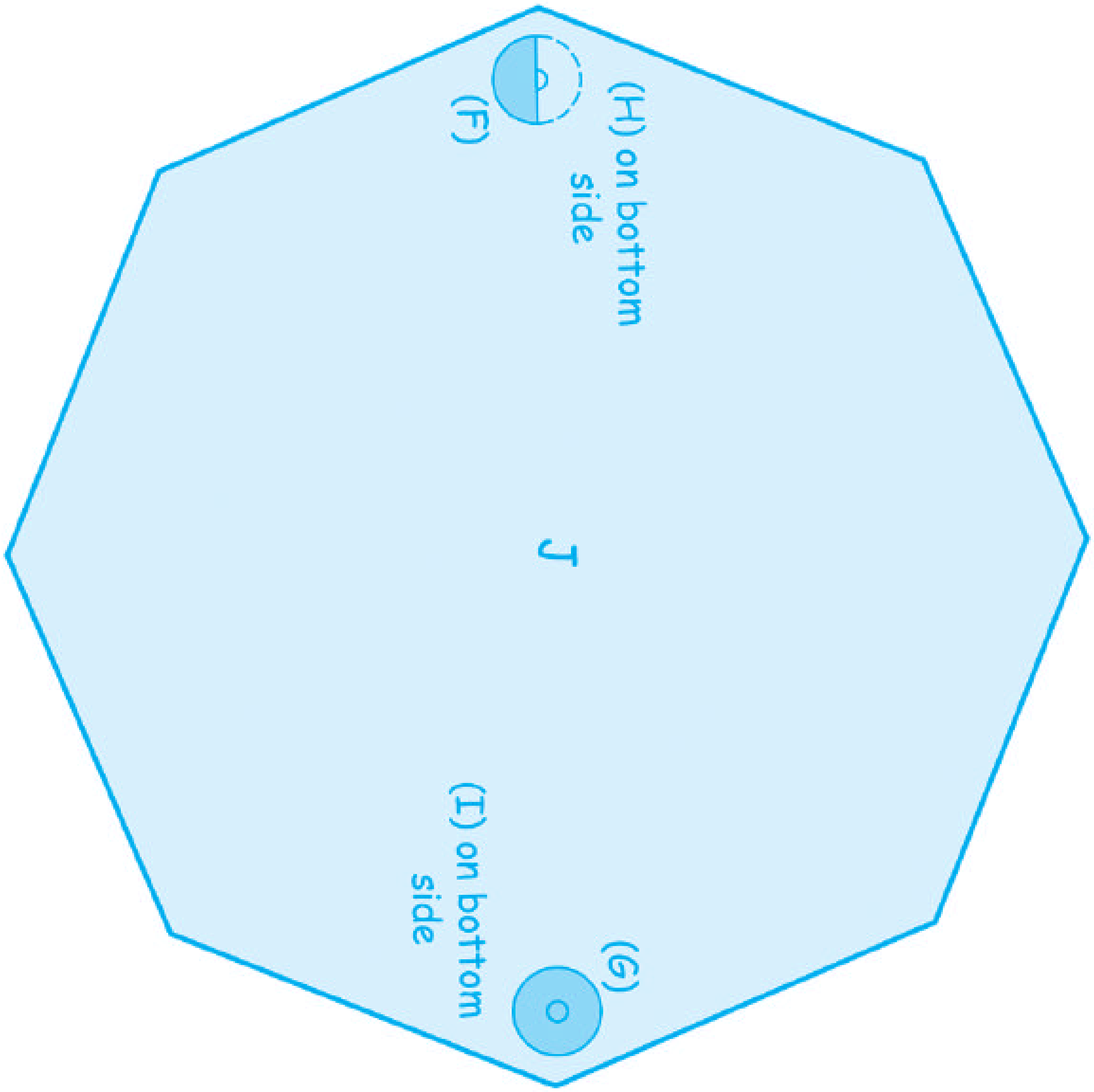


- If you increase the force exerted by the Spring (by shortening the rubber band with a knot at one end, for example), what happens to the toy nanosat's angular velocity?
- What happens to the toy nanosat's angular acceleration if it's made of lighter material like styrofoam? Heavier cardboard?
- Can you give both materials the same angular acceleration by adjusting torque? How?

Now that you are an expert, go to The Space Place web site at **http://spaceplace.nasa.gov/st5/flingman.htm** and play a fun, interactive word game about the ST5 nanosat launcher.

This article was written by Diane Fisher, Tony Phillips, and Gene Schugart. Alex Novati illustrated it. Ms. Fisher is writer and designer of The Space Place website at ***spaceplace.nasa.gov****. Dr. Phillips is an astronomer and editor of the Science@NASA Web site (science.nasa.gov). Mr. Schugart is a consultant in educational product development. Thanks also to Pete Rossoni, chief engineer of the ST5 nanosat launcher, for technical help. The article was provided through the courtesy of the Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California, under a contract with the National Aeronautics and Space Administration.*


(B)
(B2)
(B1)
(E)
A
(D)


(H) on bottom side
(F)
J
(I) on bottom side
(G)

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