Journal of the Minnesota Academy of Science

Volume 39 | Number 1 Article 8

1973

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Recommended Citation

Dombeck, T. (1973). A Study on Conical Rocket Stabilization. *Journal of the Minnesota Academy of Science, Vol. 39 No.1*, 15-17.
Retrieved from https://digitalcommons.morris.umn.edu/jmas/vol39/iss1/8

A study on conical rocket stabilization

THOMAS DOMBECK*

ABSTRACT – The objective was to develop a finless model rocket. The idea evolved after seeing the Army's Sprint anti-ballistic missile, which is conical in shape and does not have fins for primary aerodynamic stabilization. In designing the model rocket, a scale drawing was made, and center of gravity (CG) and center of pressure (CP) computations transferred to it. The initial design proved unstable because the CG and CP were too close together. Another drawing was made with the addition of a payload section to carry necessary weight to allow moving the CG forward. This second design was mathematically stable.

For stability testing, a string was attached to the rocket's CG and spun in a circular path. Stability was achieved when all counterclockwise torques equaled all clockwise torques (not measured). An engine was selected by weight-carrying ability. The rocket was flown using conventional techniques, and flight characteristics were collected. Movies were made for further reference, and the rocket proved stable.

Most model rocket vehicles are stabilized by the use of fins. Fins move a rocket's center of pressure behind the center of gravity by increasing the area on the vehicle's aft section. When a rocket is stabilized, rotating forces from air currents, drag, offset thrust, etc. are counteracted.

The purpose of this research is to create and study a finless body stabilized by its own shape. The Sprint, an Army anti-ballistic missle, conical in shape and without fins, inspired this experiment with a conical model rocket vehicle. The Sprint of course, uses a guidance system for stabilization.

The procedure in this research consists of three phases: design, construction and stability, and aerodynamic flight. XSV is used to identify this experimental stabilization vehicle.

Phase I – Design

Feasibility studies show that a conical body which increases in area triangularly uniform from the apex towards the base can be flightworthy under certain conditions. The piercing conical shape is suitable for aerodynamic flight. The vehicle would also be more durable for re-entry because its base is much larger than the rest of the vehicle.

To begin, a scale drawing of the vehicle's dimensions was made. After the scale drawing was made, the center of gravity and the center of pressure had to be determined. To calculate the center of gravity, the following formula and format was employed.

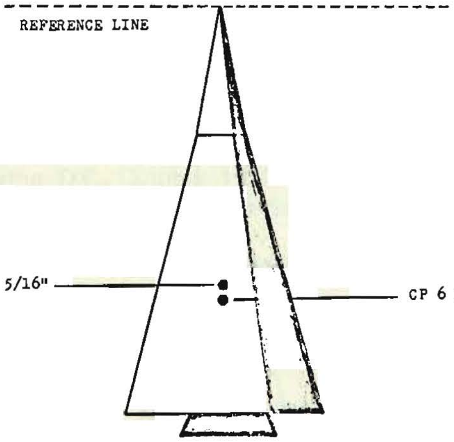
CG = Center of gravity (inches from reference line)
W = Weight of vehicular parts (ounces)
D = Distance of CG of vehicular parts from reference line (inches)

The final center of gravity, 6 5/16 inches, was then transfered to the scale drawing. This designated center of gravity is the point at which the rocket will rotate if acted apon by an external force, such as an air current. The center of gravity is an integral part of any vehicle design and has to be calculated first-hand so the stable center of pressure can be found. The stable center of pressure is the point on the vehicle where equal torque will be applied in flight, or where the forces acting on both ends of the vehicle are in equilibrium. Torque is the product of a force and its torque arm. It is the twisting of a body about a point.

Equilibrium occurs when all clockwise torques equals all counter-clockwise torques: $T_1=T_2$ so (AB) (F_S)=(BC)(F_D) where T_1, T_2=Torques, AB, BC=Torque arms, F_S=Stabilizing Force, and F_D=Defecting Force.
Fins move center of pressure back so greater force is exerted on aft section of vehicle:
(Large force) (small distance)=(small force)(large distance).

On most rocket vehicles, equilibrium can be achieved after a stabilizing device is installed. Since the conical body *is*

XSV-IA



UNSTABLE
CG AHEAD CP 1/16"

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*THOMAS DOMBECK, a member of the Minnesota Junior Academy of Science from Virginia, Minn., reported his rocket stabilization study at the Junior Scientist National Symposium at West Point Military Academy. He is a member of Explorer Aerospace Post 73 of the Boy Scouts of America, which is sponsored by United States Steel Corporation in the Iron Range area. He is presently attending the University of Minnesota Institute of Technology.

its own stabilizing device, the computed center of pressure will be the stable center of pressure.

To calculate the center of pressure, or more explicitly, the *stable* center of pressure, the following formula and format was used:

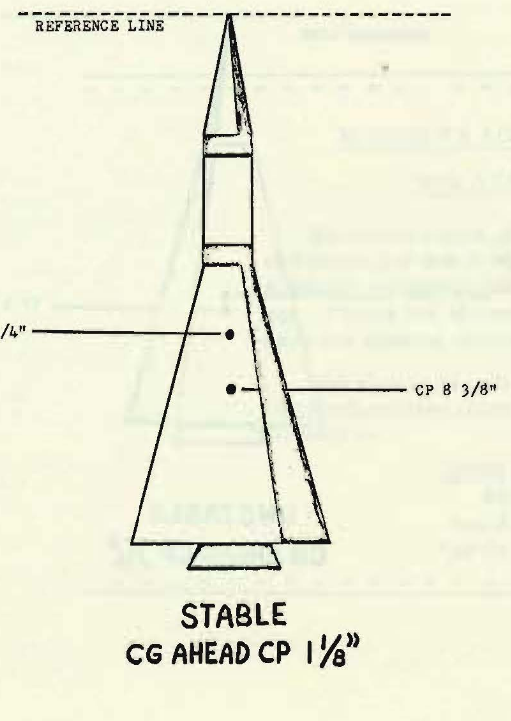
CP = Center of pressure (inches from reference line)
A = Area of vehicular parts exposed to free stream (inches squared)
D = Distance of CP of vehicular parts exposed to free stream (inches) from reference line)

The computed center of pressure, 6 3/8 inches, was then transferred to the scale drawing. Again, the stable center of pressure is the point of equal torque on both ends of the rocket in flight. In flight, there may be other forces acting on the vehicle, causing it to be unstable in some cases, so fins are usually added to most rocket vehicles. But in this XSV the conical body serves as a stability device. If the rocket is unstable due to air currents in flight, the conical shape causes the greatest force to be exerted towards the aft section, and stability would then be achieved.

The center of gravity in the first XSV design was ahead of the center of pressure 1/16 of an inch. The two points were too close together and the rocket unstable. To make the rocket stable, the center of pressure had to be moved further from the center of gravity. The weight was increased in the forward section of the vehicle to move the center of gravity towards the front the further from the center of pressure. Nose cone weights were tried, but there wasn't enough room in the vehicle for sufficient weights. The design was then changed. The nose cone was replaced by a payload section to accommodate the necessary weight. This required a new scale drawing, new center of gravity computations, and new center of pressure computations.

Two versions of the vehicle, identified as XSV-1A (the original model) and the XSV-1B were constructed. The center of gravity of the XSV-1B is 7 1/4 inches, the center of pressure is 8 3/8 inches. The center of gravity follows the center of pressure by 1 1/8 inches. The rocket should be stable, according to the calculations for the XSV-1B model.

XSV-1 B



STABLE
CG AHEAD CP 1 1/8"

Phase II – Construction and Stability

The rocket vehicle consists of three cardboard shrouds centered about a cardboard body tube which houses the engine and fits onto the pavload section of plastic. The nose cone was of balsa. The engine restrainst is the only metal part. The vehicle was assembled and painted, and the parachute contructed to complete the rocket assembly for stability testing.

If a conventional model rocket starts to rotate in flight, it will rotate about its center of gravity. When it turns, air rushing past will hit the rocket at an angle. If the center of pressure is behind the center of gravity on the model, the air pressure will exert the greatest force against the fins. This will counteract the rotating forces and the model will continue in a stable trajectory. If, on the other hand, the center of pressure is ahead of the center of gravity, the air currents will exert a greater force against the nose end of the vehicle, causing it to rotate even further into an unstable mode and an unpredictable trajectory. In the XSV, the conical shape stabilizes the rocket and no more area (fins) are needed.

Since there was no wind tunnel available to test the XSV, a tether was attached to the vehicle at its center of gravity and then swung around in the air. This method is crude, but the results are adequate. If there were any pitching about the horizontal axis in near rotations, the vehicle would prove to be unstable. It was found stable after some trial and error testing. For stability, the payload section had to be filled with approximately 1/2 ounce of modeling clay. The rocket was tested several times with an engine installed and swung on the tether.

Phase III – Aerodynamic Flight

An engine selected for its weight-carrying ability, the Estes B4-2, was chosen for the first flight. Its operational parameters are as follows:

Total Impulse: 1.12 lb sec 5.00 newton sec
Time Delay: 2 sec (Time of delay from exhaustion of fuel to time of ejection charge to blow out parachute.)
Maximum Lift-off Weight: 4.0 oz (includes engine)
Maximum Thrust: 48 oz
Thrust Duration: 1.20 sec
Initial Weight: 0.70 oz 19.8 gm
Propellant Weight: 0.294 oz 8.33 gm

Operational parameters of the XSV-1B are as follows:

Loaded Weight: 2.25 oz (vehicle weight) + 0.70 oz (engine weight) = 2.95 oz
Length: 12.375 in
Diameter of Base: 4.0 in
Diameter of Payload Section Tube: 0.736 in

A time-thrust curve of the B4-2 engine illustrates the burn of the B4-2.

Before flight testing, wadding to protect the parachute was put inside the vehicle's body tube next to the engine. Finally, the rocket was positioned on the launch pad. The engine was. ignited electrically by a special nichrome wire coated with a flash-type substance. The rocket was launched with a "failsafe" type ignition system and a 36-inch rod for initial guidance.

Achieving Stability

By recording the development and observing the flight characteristics of the XSV, it was found that a conical shaped rocket vehicle is able to fly. From this information and related calculations pertaining to the flight, it may be concluded that:

1. – Stability would be achieved when the nose was sufficiently weighted to move the center of gravity further from the center of pressure. The right weight-carrying engine would have to be used to ensure stability.

2. – Another possible means of stabilizing the vehicle would be to make a shroud which has an area that would move the center of pressure rearward, further from the center of gravity. The effect of this is to increase the cone's base area, in essence adding "conical fins." The right weight-carrying engine would have to be used to ensure stability.

3. – It might appear that the conical shape reduces drag on the vehicle because there are no fins, but drag is increased because the cone creates a more highly turbulent wake.

4. – The day of the XSV test flight was perfect, so all characteristics could be observed. Aerodynamic flight was highly stable – the trajectory was nominal for a vertical flight, very little pitch. Several zero drag parameters were computed to be compared with positive drag calculations and actual altitude figures from future research. Among those computed were mass ratio, burnout velocity, burnout altitude, coast altitude, and total altitude. Formulas and format follow:

MASS RATIO

M_O = Vehicle loaded weight
M_F = Vehicle empty weight
R_M = Mass ratio

BURNOUT VELOCITY

I_T = Total impulse
G = Acceleration due to gravity (32.2 ft/sec^2)
W_B = Burnout weight
V_B = Burnout velocity

BURNOUT ALTITUDE

V_{av} = Average velocity
T_B = Burn time
S_B = Burnout altitude

COAST ALTITUDE

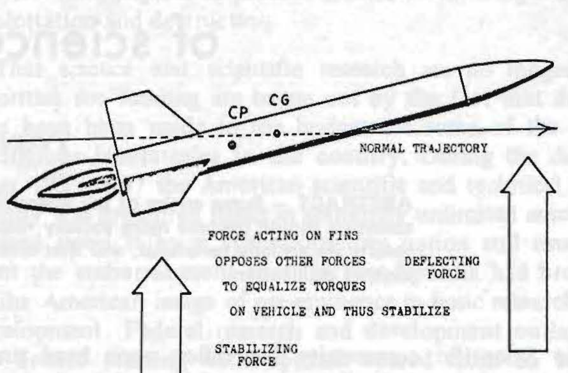
$V_{max}{}^2$ = Maximum velocity squared
G = Acceleration due to gravity
S_C = Coast altitude

TOTAL ALTITUDE

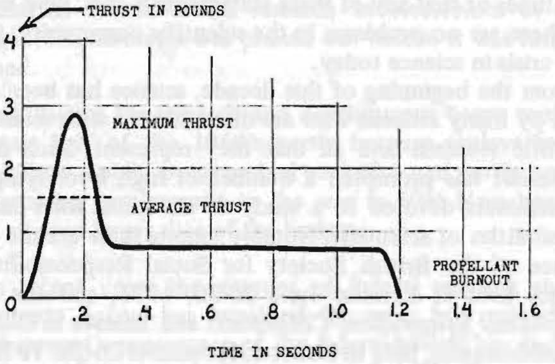
S_B = Burnout altitude
S_C = Coast altitude
S_{max} = Maximum or total altitude

The XSV performed well in the experiment and flew in a way superior to conventional model rockets, but there doesn't seem to be clear place for it as a workhorse in model rocket research. Because of its shape and the drag characteristics, however, the XSV may be a useful first step toward development of a model rocket lifting body for re-entry experimentation.

ROCKET STABILITY



TIME-THRUST CURVE OF B4-2 ENGINE



Acknowledgements

I would like to thank William Somero, my physics teacher and sponsor, for his assistance in time and patience; John Everett of Army Ordnance who provided the Sprint missile photo, and Maj. James P. Remenicky of Army Air Defense for data on Army rocket vehicles.

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