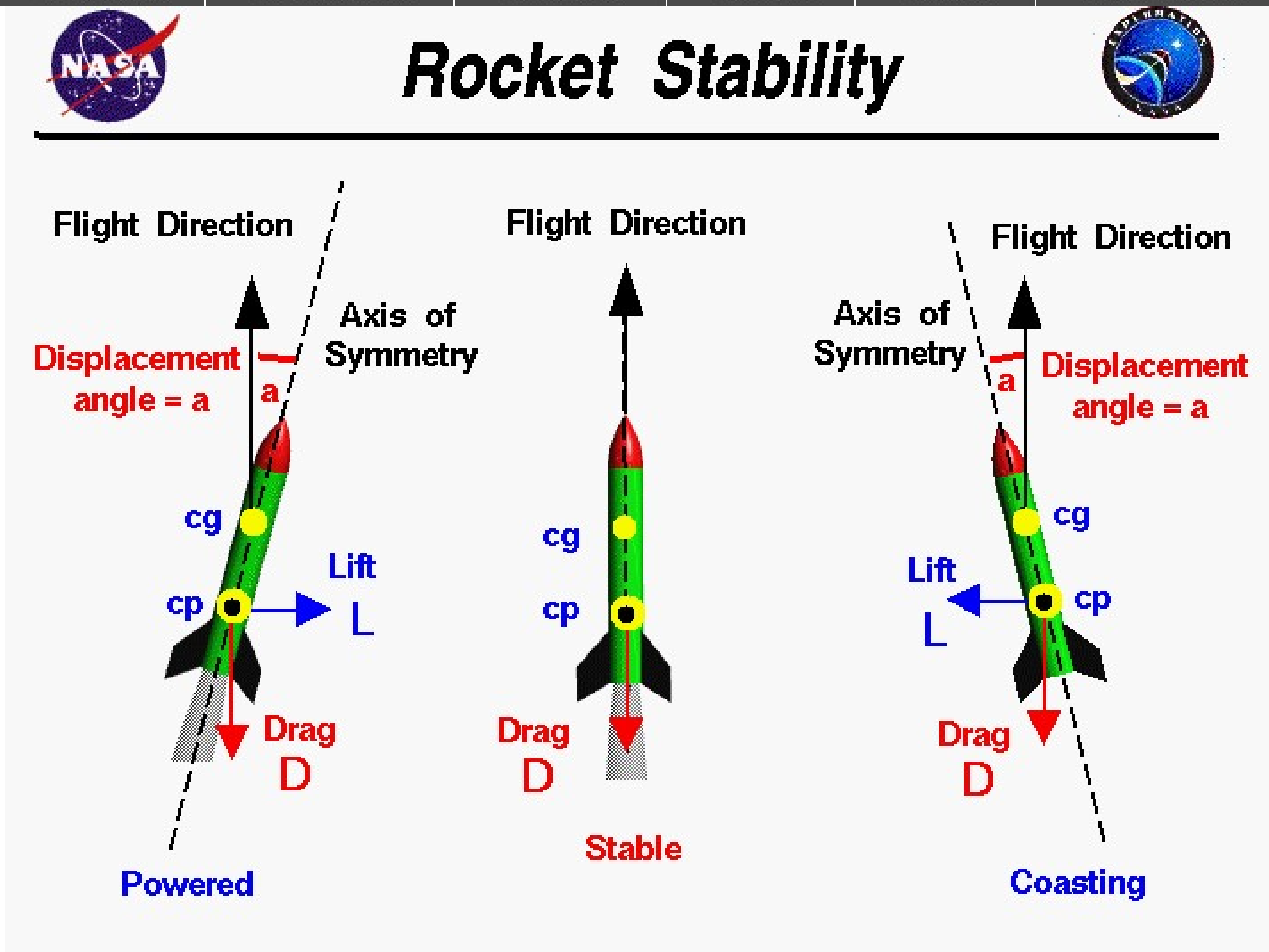

During the flight of a model rocket small gusts of wind, or thrust instabilities can cause the rocket to "wobble", or change its attitude in flight. Like any object in flight, a model rocket rotates about its center of gravity **cg**, shown as a yellow dot on the figure. The rotation causes the axis of the rocket to be inclined at some angle **a** to the flight path. Whenever the rocket is inclined to the flight path, a lift force is generated by the rocket body and fins, while the aerodynamic drag remains fairly constant for small inclinations. Lift and drag both act through the center of pressure **cp** of the rocket, which is shown as the black and yellow dot in the figure.

On this slide we show three cases for which the flight direction is exactly vertical. In the center of the figure, the rocket is undisturbed and the axis is aligned with the flight direction. The drag of the rocket is along the axis and there is no lift generated. On the left of the figure, a powered rocket has had the nose of the rocket perturbed to the right. On the right of the figure, a coasting rocket has had the nose of the rocket perturbed to the left. We denote the angle in both cases by the symbol **a**. Considering the powered rocket case, we see that a lift force is generated and directed towards the right or downwind side of the rocket. On the coasting rocket case, the lift is directed towards the left, also the downwind side of the rocket. For the powered case, both the lift and the drag produce counter-clockwise torques, or twists, about the center of gravity; the tail of the rocket will swing to the right under the action of both forces and the nose will move to left. For the coasting case, both lift and drag produce clockwise torques about the center of gravity; the tail of the rocket will swing to the left under the action of both forces and the nose will move to the right. In both cases, the **lift and the drag forces move the nose back towards the flight direction**. Engineers call this a **restoring force** because the forces "restore" the vehicle to its initial condition and the rocket is determined to be **stable**.

A restoring force exists for this model rocket because the center of pressure is below the center of gravity. If the center of pressure is above the center of gravity, the lift and drag forces maintain their directions but the direction of the torque generated by the forces is reversed. This is called a **de-stabilizing force**. Any small displacement of the nose generates forces that cause the displacement to increase. The conditions for a stable rocket are that the center of pressure must be located below the center of gravity.

There is a relatively simple test that you can use on a model rocket to determine the stability. Tie a string around the body tube at the location of the center of gravity. Be sure to have the parachute and the engine installed. Then swing the rocket in a circle around you while holding the other end of the string. After a few revolutions, if the nose points in the direction of the rotation, the rocket is stable and the center of pressure is below the center of gravity. If the rocket wobbles, or the tail points in the direction of rotation, the rocket is unstable. You can increase the stability by lowering the center of pressure, increasing the fin area, for example, or by raising the center of gravity, adding weight to the nose.

NOTE: *Modern full scale rockets do not usually rely on aerodynamics for stability. Full scale rockets pivot their exhaust nozzles to provide stability and control. That's why you don't see fins on a Delta, Titan, or Atlas booster.*

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