



Scan to try this lesson
in the TBoard app



PUSHING AGAINST NOTHING

THE EDITORIAL AND THE ROCKET

In January 1920 an unsigned New York Times editorial mocked Robert GODDARD, a PHYSICIST who had proposed sending a rocket to the Moon. In the VACUUM of space, a region emptied of air, there would be nothing to push against, the paper argued, so the machine could not move. Goddard kept building. On a Massachusetts farm in 1926 he flew the first liquid-fueled rocket, a hop of about two and a half seconds that rose roughly 41 feet. The Times printed a RETRACTION in 1969, as Apollo 11 flew toward the Moon.

SPELL Spell: RETRACTION

RETRACTION

SPELL Spell: PHYSICIST

PHYSICIST

KNOWN What is the last name of the scientist who proposed sending a rocket to the Moon and later flew the first liquid-fueled rocket?

GODDARD

KNOWN What is the airless region of space called, where a rocket has nothing to push against?

VACUUM

OPEN The newspaper mocked Goddard in print and took forty-nine years to say it was wrong. How long would you wait for someone to admit a mistake?

Open response - use practitioner judgment

MATH The New York Times mocked Goddard's Moon rocket in 1920 and printed its retraction in 1969. How many years passed between them?

49

PUSHING AGAINST EXHAUST

The editorial had the physics backward. An engine does not shove against the air; it shoves against its own exhaust. Burning PROPELLANT - fuel plus an OXIDIZER, the chemical that supplies oxygen where none exists - produces gas that the engine hurls out the back at enormous speed. Newton's third law says the gas pushes back just as hard on the engine, and that forward push is THRUST. MOMENTUM, the product of mass and velocity, is conserved: mass going backward means the vehicle goes forward. Common fuels are KEROSENE, HYDROGEN, and METHANE, usually burned with liquid oxygen.

SPELL Spell: OXIDIZER

OXIDIZER

SPELL Spell: PROPELLANT

PROPELLANT

KNOWN The escaping gas pushes back on the engine just as hard as the engine hurls it out. What is the term for that forward push?

THRUST

KNOWN What is the term for the product of an object's mass and its velocity, the quantity that is conserved when a rocket sends mass backward and moves forward?

MOMENTUM

SEMI_OPEN Name two of the fuels rocket engines burn.

NEEDS 2 OF KEROSENE / HYDROGEN / METHANE

OPEN The engine pushes against its own exhaust, not the air. What is something else that moves by throwing part of itself the other way?

Open response - use practitioner judgment

THROAT AND BELL

The shape of the engine turns heat into speed. Gas passes through four parts in turn: the INJECTOR, which sprays and mixes the propellants; the CHAMBER, where they burn at thousands of degrees; the THROAT, the narrow waist that pinches the flow; and the BELL, the flared cone downstream. Squeezing the flow at the throat drives it to the speed of sound, and the WIDENING bell lets the gas expand and go SUPERSONIC, faster than sound. How far the bell flares compared with the throat is called the expansion RATIO.

SPELL Spell: **RATIO**

RATIO

SPELL Spell: **WIDENING**

WIDENING

KNOWN What is the word for moving faster than the speed of sound?

SUPERSONIC

SEMI_OPEN Name two of the four parts the gas passes through on its way out of the engine.

NEEDS 2 OF **INJECTOR / CHAMBER / THROAT / BELL**

OPEN What do you predict would happen to the gas if the bell never flared out at all?

Open response - use practitioner judgment

MATH An engine's expansion ratio is the exit area of the bell divided by the area of the throat. Suppose the throat measures 8 square centimeters and the bell's exit measures 640 square centimeters. What is the expansion ratio?

80

TWO LEVERS

Having nothing to push against also means having nothing to draw on. A jet scoops in free air as it flies; a rocket must carry every gram it throws, which is why the overwhelming majority of a launch vehicle's **LIFTOFF** mass is propellant. Two levers help. Specific **IMPULSE** measures how much thrust each unit of propellant buys per second, the engine's version of fuel economy, and hydrogen scores high because its exhaust is light and fast. **STAGING** is the other lever: the vehicle sheds empty tanks and engines so it stops accelerating dead weight.

SPELL Spell: **LIFTOFF**

LIFTOFF

SPELL Spell: **IMPULSE**

IMPULSE

KNOWN What is the term for a vehicle shedding its empty tanks and engines partway up, so it stops accelerating dead weight?

STAGING

OPEN A rocket sheds its empty tanks partway up so it stops carrying dead weight. What would you drop first if you had to climb faster?

Open response - use practitioner judgment

MATH A hydrogen-burning rocket engine reaches a specific impulse of about 450 seconds in vacuum, while a kerosene-burning engine reaches about 350 seconds. How many seconds higher is the hydrogen engine?

100

THE BACKWARD KICK

You have felt this. Step from a CANOE onto a dock and the canoe slides backward under you; the water is not pushing it, your own shove is. Throw a heavy ball while standing on slick ice and you glide the other way, a RECOIL, the backward kick a THROWER takes from whatever it throws. Your center of mass, the average position of your mass, does not budge in either case; you and the thing you threw simply move apart. Goddard's rocket was doing the same trick with hot gas.

SPELL Spell: THROWER

THROWER

SPELL Spell: CANOE

CANOE

KNOWN What do you call the backward kick a thrower takes from whatever it throws?

RECOIL

OPEN Step from a canoe onto a dock and the canoe slides away under you. When have you felt something push back like that?

Open response - use practitioner judgment

MATH Suppose you are on slick ice and you throw a 3 kilogram ball away from you at 8 meters per second. How many kilogram-meters per second of momentum does the ball carry away?

24