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HISPANIC HERITAGE MONTH

Franklin Chang Díaz

Specific Impulse, Thrust, and the Physics of Getting to Mars

The Propellant Problem

Franklin Chang Díaz was born in San José, Costa Rica, in 1950, of Costa Rican and Chinese ancestry. He emigrated to the United States as a teenager with minimal English and limited funds, repeated a year of secondary school, and completed a doctorate in **applied plasma physics** at MIT in 1977. NASA selected him for the astronaut corps in 1980, and between 1986 and 2002 he flew seven Space Shuttle missions — tying the record for the most spaceflights by any individual.

Chemical rockets are constrained by the **Tsiolkovsky rocket equation**, $\Delta v = v_e \cdot \ln(m_0/m_f)$, which relates the achievable change in velocity to exhaust velocity and to the ratio of initial to final mass. Because the mass ratio enters logarithmically, increasing Δv by carrying more propellant produces sharply diminishing returns. The leverage is in **exhaust velocity** (v_e), equivalently **specific impulse**, which appears as a linear multiplier. Chemical combustion caps exhaust velocity near 4.5 km/s, a hard limit set by the chemistry itself.

Chang Díaz's **VASIMR** — Variable Specific Impulse Magnetoplasma Rocket — sidesteps that ceiling. Propellant such as argon is ionized and then heated by radio-frequency waves to plasma temperatures far beyond what any material nozzle could survive; a **magnetic nozzle** confines and directs the exhaust, so no physical surface contacts the plasma. Exhaust velocities on the order of 50 km/s are achievable, roughly an order of magnitude above chemical propulsion. The engine's name reflects a further capability: the ratio of thrust to specific impulse can be tuned in flight, trading high thrust for high efficiency as a mission phase requires.

The cost is thrust density. Electric propulsion produces forces measured in newtons rather than meganewtons, making it useless for surface launch and dependent on a substantial electrical power source — a serious constraint, since a high-power VASIMR would require nuclear or very large solar power. Chang Díaz founded Ad Astra Rocket Company, with operations in Texas and Costa Rica, to develop the technology toward in-space cargo transport and eventual crewed interplanetary missions.

Part 1 · Comprehension & Analysis

1. Explain, using the structure of the rocket equation, why raising exhaust velocity is more effective than carrying more propellant.

2. Why does VASIMR require a magnetic nozzle rather than a conventional physical one?

3. What does "variable specific impulse" mean operationally, and why would a mission designer want it?

4. Identify the principal engineering obstacle to a high-power VASIMR and explain why it is fundamental rather than incidental.

Part 2 · Quantitative Challenge

Applying the Rocket Equation

Use $\Delta v = v_e \cdot \ln(m_0/m_f)$. Take chemical exhaust velocity as 4.5 km/s and VASIMR as 50 km/s. Show all work and state units.

1. A spacecraft with a dry mass of 10,000 kg must achieve $\Delta v = 9$ km/s. Calculate the required propellant mass using chemical propulsion.

2. Repeat the calculation for VASIMR at 50 km/s exhaust velocity.

3. Express the propellant saving as a percentage, and state what that mass could be used for instead.

4. VASIMR delivers about 5 N of thrust in this scenario. Calculate the acceleration of the 11,970 kg vehicle, then the time required to accumulate 9 km/s, ignoring gravity losses. Comment on the result.

Part 3 · Discussion & Extension

The VASIMR concept has been in development for decades and has still not flown an operational interplanetary mission, while chemical rockets — a fundamentally limited technology — continue to fly everything. Evaluate how a space agency should divide finite funding between improving a mature technology near its physical ceiling and developing an unproven one with a higher ceiling. Use specifics from the passage to support your position.