

drive a turbine/generator unit at a time of high power demand.

Multiple submerged turbine/pump units could be positioned across a channel to extract more power than could be extracted by a single unit. In that case, the pressurized flows in their output pipes would be combined, via check valves, into a wider pipe that would deliver the combined flow to a

power-generating or pumped-storage facility.

*This work was done by Jack Jones and Yi Chao of Caltech for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1).v*

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## Nitrous Oxide/Paraffin Hybrid Rocket Engines

**Thrusts can exceed those of engines that burn HTPB fuels.**

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Nitrous oxide/paraffin (N<sub>2</sub>OP) hybrid rocket engines have been invented as alternatives to other rocket engines — especially those that burn granular, rubbery solid fuels consisting largely of hydroxyl-terminated polybutadiene (HTPB). Originally intended for use in launching spacecraft, these engines would also be suitable for terrestrial use in rocket-assisted takeoff of small airplanes. The main novel features of these engines are (1) the use of reinforced paraffin as the fuel and (2) the use of nitrous oxide as the oxidizer.

Hybrid (solid-fuel/fluid-oxidizer) rocket engines offer advantages of safety and simplicity over fluid-bipropellant (fluid-fuel/fluid-oxidizer) rocket engines, but the thrusts of HTPB-based hybrid rocket engines are limited by the low regression rates of the fuel grains. Paraffin used as a solid fuel has a regression rate about 4 times that of HTPB, but pure paraffin fuel grains soften when heated; hence, paraffin fuel grains can, potentially, slump during firing. In a hybrid engine of the present type, the paraffin is molded into a 3-volume-percent graphite sponge or similar carbon matrix, which supports the paraffin against slumping during firing. In addition, because the carbon matrix material burns along with the paraffin, engine

performance is not appreciably degraded by use of the matrix.

The use of nitrous oxide as the oxidizer offers the following advantages:

- Because nitrous oxide is non-toxic, the extra precautions for handling of toxic oxidizers are unnecessary.
- Unlike liquid oxygen, nitrous oxide can safely be stored for indefinitely long times under non-cryogenic conditions: for example, it can be stored at 0.7 the density of water at a pressure of 700 psi ( $\approx 4.8$  MPa) at a temperature of 20 °C.
- Because it can be stored non-cryogenically, nitrous oxide can be stored in a rocket prior to launch, making it possible to launch in less time than would be required if it were necessary to transfer the oxidizer fluid from cryogenic storage.
- Nitrous oxide can serve as its own auto-genous pressurant gas, eliminating the need for the high-pressure helium tanks that are necessary for pressurizing propellant fluids in fluid-bipropellant and hybrid rocket engines of prior design. The elimination of the helium tanks and associated plumbing increases reliability while reducing mass and cost.
- Subcooled liquid nitrous oxide could be used as a propellant in upper rocket stages to reduce upper-stage engine

masses and thereby enable increases in payloads. Alternatively, subcooled nitrous oxide could be used with oxygen pressurant to increase the specific impulses achievable at given tank weights.

Another advantage is the potential to use nitrous oxide as a monopropellant, in place of hydrazine. Although the specific impulse achievable by use of nitrous oxide is somewhat lower than that achievable by use of hydrazine, cost would be reduced and safety enhanced by elimination of the toxic hazard posed by hydrazine.

Yet another alternative would be to utilize catalytic decomposition of nitrous oxide in a monopropellant reactor to effect a hybrid ignition system. The exhaust of a nitrous oxide from a monopropellant reactor is a 2:1 N<sub>2</sub>/O<sub>2</sub> mixture at a temperature of 1,200 °C. This exhaust can be used to ignite a hybrid propellant as many times as desired, making it possible to restart a stopped hybrid rocket engine.

*This work was done by Robert Zubrin and Gary Snyder of Pioneer Astronautics for Marshall Space Flight Center.*

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