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Apogee Components, Inc.
Your Source For Rocket Supplies That Will Take You To The "Peak-of-Flight"
3355 Fillmore Ridge Heights Colorado Springs, Colorado 80907-9024 USA
www.ApogeeRockets.com e-mail: orders@apogeerockets.com Phone: 719-535-9335 Fax: 719-534-9050

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Is Air Breathing Rocketry In Your Future?

By Rene Nardi

What goes up like a rocket, but is propelled by a turbojet engine? It is the turbo-rocket: a rocket that uses a turbojet engine as the main propulsion element, for a brand-new category of air-breathing rockets that may help to solve the difficulties faced by hobbyists in the design, manufacturing, and operation of liquid propellant rockets. The turbo-rocket can foster the development of a new hobby, capable of bringing together the expertise of amateur high-power rocketeers and model jet aircraft builders.

What is a Turbo-Rocket all about?

On a beautiful Sunday morning, a small crowd watches a group of brave men flying their amazing jet model airplanes. Upon deciding that they have had enough for the day, one of the jet flyers started to disassemble his aircraft in preparation to get back home. While packing the wing, he left the fuselage lying down on the workbench for a while. What I saw was a slender airframe with tail fins, resembling a rocket. “What about removing the wings, landing gear and all the equipment that makes a beautiful jet aircraft and keep just the essential to transform it into a rocket?” I thought. The turbo-rocket is like a transformer, a jet aircraft that became a rocket, and now flies in the vertical, going up to where it belongs.

Using a turbojet engine instead of a typical bi-propellant liquid rocket engine would make sense under the assumption that rockets for the amateur purpose should fly high enough to justify the efforts, but may not have to go so high in the skies to the point of leaving the atmosphere. Under a similar rationale, one may consider that high speed is desirable, but the rocket does not necessarily need to go supersonic. In fact, maintaining subsonic speed would be an interesting feature considering the possible development of a vectoring thrust based automatic flight control system. Another aspect of air-breathing is the tremendous simplification in the rocket operational procedures by eliminating the infrastructure needed for handling liquid oxygen, associated with the cost reduction made possible with the removal of the cryogenic system, including the pressurized tanks and all its auxiliary equipment (valves, tubes, and connections). Finally, the turbo-rocket makes a nice, reusable machine.

A Configuration to Start With

The requirements for the turbo-rocket stipulated is that it should reach an altitude of 5 kilometers above sea level carrying a 1 kg payload. The initial studies resulted in a 2.5 m (100 in) long vehicle that incorporates a 0.15 m diameter carbon fiber tube dubbed as the fuselage, with a 300 N thrust turbojet mounted on the lower end. **Figure 1** shows a turbo-rocket next to a person, for the sake of size comparison.

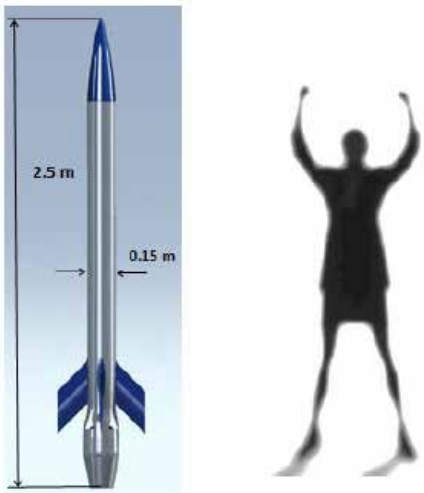

Figure 1: A turbo rocket size comparison.

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Newsletter Staff
Writer: Rene Nardi
Layout/Cover Artist: Chris Duran
Proofreader: Will Franks

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Figure 2 gives further information on the rocket configuration. The airframe is made of four main components: the nose cone, the fuselage, the fins, and the engine cowling. The ejectable, elliptical nose cone with drag characteristics suitable to subsonic speeds contains the ballast used for the center of gravity calibration and acts as a compartment to partially store a two-stage parachute. The fuselage structure consists of a low weight carbon fiber cylinder, with the payload and the flight control computer compartment at the upper end. Plenty of space is available in the central part of the fuselage for installation of some extra equipment for future versions or to implement adjustment on the CG location. Strategically placed close to the rocket CG is the one-liter fuel tank. Located just under the fuel tank are the electronic engine control unit, the fuel pump, and the batteries. The turbo-rocket has four, swept back aerodynamically shaped carbon fiber fins, used for stabilization during the vertical ascension into the atmosphere. At the very bottom of the vehicle is the engine cowling, which holds the engine in place and incorporates the air inlets. It attaches to the fuselage just behind the fins. In the case of swapping the current engine for another model, the engine cowling can be replaced, with no need to introduce major modifications on the cylindrical fuselage.

Figure 2: Turbo-rocket Exploded View

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The Turbojet Engine

There are several commercially available turbojet engines but only a few with the required thrust, so, for the initial design phase the selection went to the JetCat 300 model, shown in **Figure 3**.

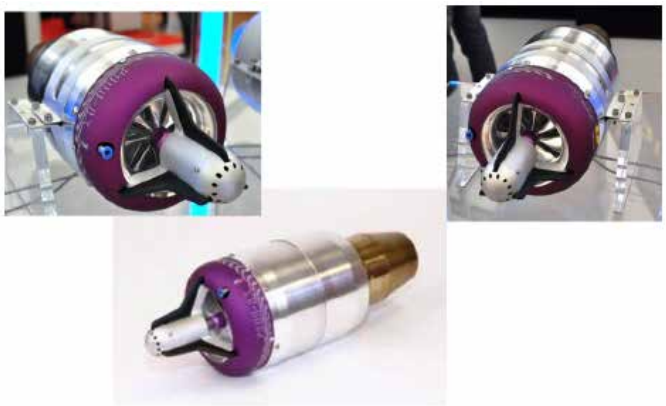

Figure 3: The Turbojet Engine

With a total weight of 2.6 kg, the JetCat engine can deliver a maximum thrust of 300 N, resulting in an interesting thrust to weight ratio of 11:1. However, it may not be much when compared to a liquid rocket engine of the same thrust that can easily reach values above 30:1. Burning kerosene mixed with 5% full synthetic turbine oil at a rate of 13 g/sec, it offers a specific fuel consumption of 45 g/kN.s (1.6 lb/lbf.s), not a wonder machine regarding fuel consumption efficiency, but significantly better than a liquid rocket engine at 300 g/kN.s (10 lb/lbf.s). **Table 1** contains more details about the engine specification.

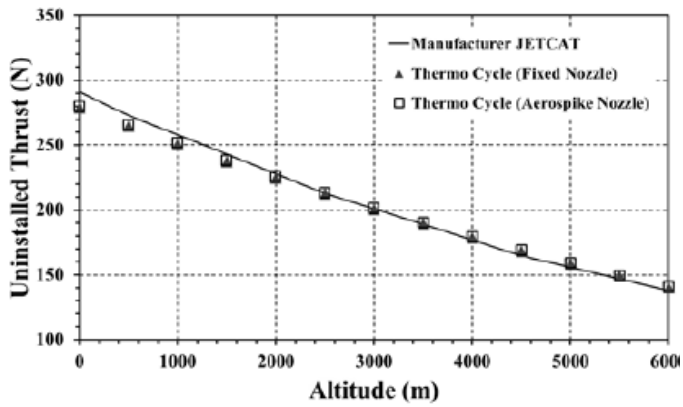

Figure 4: Engine Thrust Curve

Unlike a regular rocket engine, which delivers a somewhat constant thrust across a wide range of altitude, the jet engine presents a noticeable reduction in thrust as a function of the altitude. By the time the vehicle is flying at 4,000 m above sea level, the engine thrust would be approximately 60% of the sea level value, according to the thrust curve diagram in **Figure 4**.

Thrust, Max	300 N	**Pressure Ratio**	3.55
Weight	2.6 kg	**Mass flow**	0.50 kg/s
Diameter	134 mm	**RPM, Max**	106,000 RPM.
Overall length	381 mm	**Fuel**	Kerosene, with 5% oil
Fuel Consumption	980 ml/min @ Max RPM	**Specific Fuel Consumption**	45 g/kNs (1.6) @ Max RPM
Exhaust Gas Temperature	1,000 K	**Exhaust Gas Velocity**	600 m/s

Table 1: JetCat-300 Specifications

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Comparing the Turbo-Rocket

Using a turbojet engine to propel a rocket brings some interesting technical particularities, setting this class of flying machine halfway between jet airplanes and liquid rockets. The turbo-rocket does not behave as a model jet aircraft: flying long periods mostly at the horizontal position at almost the same altitude with a reduced power setting. The turbo-rocket blasts off from the launch pad in a near-vertical position and keeps flying on the vertical, constantly changing flight altitude and speed, with the jet engine power lever set at full throttle all the way along a short-powered flight. The turbo-rocket is not a pure rocket because a rocket is supposed to carry its working fluid in the form of fuel and oxidizer, its speed is independent of the flight speed and, most importantly, it can operate in or out of the atmosphere. The turbo-rocket carries its fuel but relies on the surrounding air as the source of oxygen, which limits its operation within the confines of the lower atmosphere.

Results from application of flight simulation software show that a 300 N thrust turbojet engine operating at full power could launch a 10 kg maximum take-off weight vehicle to the desired altitude of 5,000 m. From analyzing the chart in **Figure 5**, it is possible to conclude that twenty seconds after takeoff, at an altitude of 1,500 m, the vehicle reaches its maximum speed of 600 km/h. From that point on, due to the expected reduction on the engine thrust as a function of the altitude, the flight speed stabilizes for a while and then begins to decrease. After a 30-second powered flight to an altitude of 4,000 m, the engine is turned off. The coasting distance accounts for the remaining 1,000 m needed to reach the 5,000 m maximum altitude, reached 10 seconds after the engine shut down. Unlike solid rockets, the turbo-rocket spends 80 % of the flight trajectory into the propulsion phase.

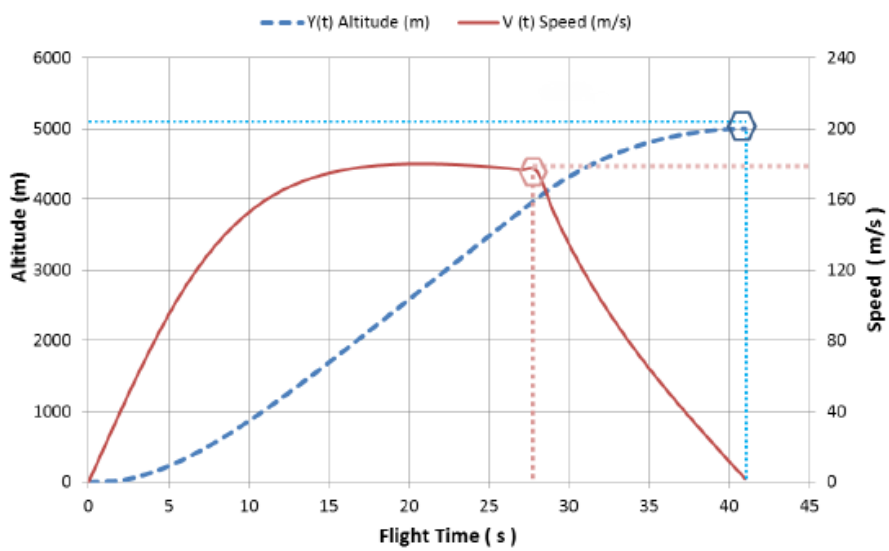

Figure 5: Altitude and Speed Simulations

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Until thrust vectoring becomes available, controlling the turbo-rocket during flight would be exercised by the aerodynamic reaction against the four fins. The initial performance simulations show that reaching the minimum control speed of 100 km/h at the end of a 6 m long launching platform would require the help of a pair of solid propellant boosters with 180 N of thrust each.

As with any flying machine, maximum weight is always a concern to be addressed during all phases of design and fabrication. The target for this project is to keep the takeoff thrust to weight ratio near three, which requires the maximum take-off weight to be limited to no more than 10 kg.

Construction Techniques

Jet engine powered, radio controlled model airplanes are part of an exciting form of hobby that demands skilled modelers to master complex systems required for flight. The turbo-rocket draws heavily from jet model construction techniques and pushes the technology one step further by targeting a much higher flight altitude and speed. Figure 6 shows clearly that some solutions typical of the model airplane environment were preserved into the construction of the turbo-rocket. The fuel mass flow rate and fuel inlet pressure levels demanded by the jet engine justify using an electric motor driven fuel pump as well as the plastic fuel tank and fuel lines. Carbon fiber, with its unmatched strength to weight ratio is the best option for the clear majority of the turbo-rocket airframe. Whenever metallic parts are needed, aviation grade aluminum is the option of choice. The availability of low-cost, relatively powerful computers and high-speed communication devices condensed in low volume package contributes to placing the flight control computers and the electronic engine control unit within the target weight.

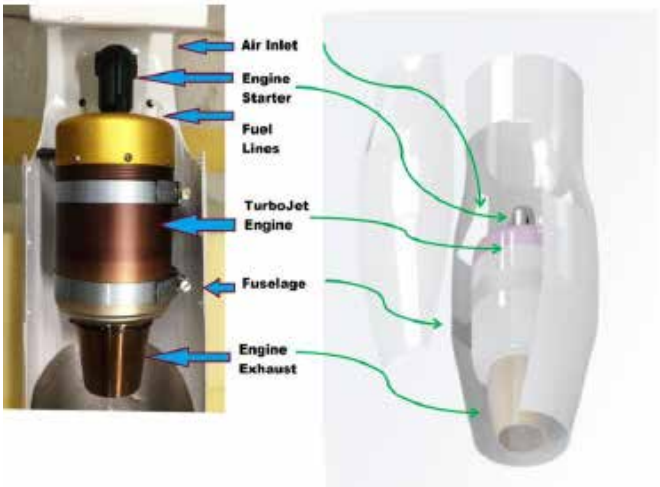

Figure 6: Turbo-rocket Construction Details

Conclusion

Replacing rocket engines with turbojets may be an attractive option for a new kind of hobby that combines the skills of jet modelers and high power rocketry enthusiasts. The turbo-rocket opens avenues for hobbyists looking for new technological challenges and opportunities for entrepreneurs who are bold enough to move the concept into the commercial arena. There are many technological challenges to be overcome before making the turbo rocket a fully operational machine. For example, because jet engine's power can be adjusted in flight and thrust vectoring is feasible, an automatic flight control system is an almost mandatory item for realistic takeoff and maybe for a vertical landing.

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