

SIMPLEX TURBOPUMP DESIGN

Matt Marsh, Penny Cowan
Propulsion Laboratory
National Aeronautics and Space Administration / MSFC
Marshall Space Flight Center, AL 35812

SUMMARY

Turbomachinery used in liquid rocket engines typically are composed of complex geometries made from high strength-to-weight super alloys and have long design and fabrication cycle times (3 to 5 years). A simple, low-cost turbopump is being designed in-house to demonstrate the ability to reduce the overall cost to \$ 500K and compress life cycle time to 18 months. The Simplex turbopump was designed to provide a discharge pressure of 1500 psia of liquid oxygen at 90 lbm/s. The turbine will be powered by gaseous oxygen. This eliminates the need for an inter-propellant seal typically required to separate the fuel-rich turbine gases from the liquid oxygen pump components. Materials used in the turbine flow paths will utilize existing characterized metals at 800° R that are compatible with a warm oxygen environment. This turbopump design would be suitable for integration with a 40 K pound thrust hybrid motor that provides warm oxygen from a tapped-off location to power the turbine. The preliminary and detailed analysis was completed in a year by a multiple discipline, concurrent engineering team. Manpower, schedule, and cost data were tracked during the process for a comparison to the initial goal. The Simplex hardware is in the procurement cycle with the expectation of the first test to occur approximately 1.5 months behind the original schedule goal.

DISCUSSION**I. Technology Advancements****Integrated Engineering Environment**

The Simplex turbopump project demonstrated various technology advancements in parallel to the design and analysis cycle. The turbopump design process prototyped an Integrated Engineering Environment. The conceptual layouts, 2-D or 3-D geometry models, manufacturing drawings, and requirements were shared with the multiple-discipline team via an electronic bulletin board. This type of environment shortened the design release cycle from 2 years to 1 year.

Rapid Prototyping

The first parts prototyped used the Stereo-Lithography process which builds parts layer by layer out of a photo-sensitive resin cured by a laser. Design changes were implemented as a result of visually inspecting the 3-D models. The next parts prototyped utilized a Fused Deposition Modeling process which builds parts layer by layer by extruding a thin heated filament of investment casting wax. The Simplex impeller and inducer geometries were used as sample cases to produce prototype castings as a demonstration of the technology maturity level.

Oxidizer Rich Turbine Technology

Limited experience exists in U.S. technology base on the use of an oxygen rich turbine. A small scale turbopump demonstrator was built by Aerojet, Buckman et al [1] to explore oxygen rich turbine technology as well as material selections for oxygen driven turbopumps by Schoenmann [2]. This pump was designed for a Dual Expander cycle.

Extensive use of an oxygen rich turbine drive has been demonstrated in Russian engine designs, such as the RD-170, referenced by Sutton [3]. These turbines use a subsonic blade design which has lower gas velocities than a supersonic design. The Simplex turbine requires a warm, oxygen rich, supersonic impulse blade design and therefore, an oxygen rich, high gas velocity, compatible material. Extensive research of oxygen rich material testing has been conducted at White Sands, by Stoltzfus and Benz [4] and for MSFC by Beveridge [5]. From these databases K-Monel 500 was selected to meet the turbine gas path environment to minimize development cost and maximize gox compatibility.

II. Design Description

The Simplex turbopump functional performance requirements were chosen based on the maximum pressure and flow rates needed to support a 40 K pound thrust hybrid testing with the capability to power the turbine with gasses tapped off from the motor. The schematic of a hybrid tap-off cycle is shown in Figure 1. The pump discharge pressure was chosen to accommodate the system test configuration due to facility piping and the injector. The modest turbine temperature was chosen to accommodate the use of existing well characterized material in an oxygen rich environment. The functional performance requirement for the pump and turbine are shown in Table 1. A cross-section of the Simplex turbopump is shown in Figure 2. A video of the 3-D solid model geometry will be shown to explain the design and assembly of the hardware.

III. Analysis

Analysis of the Simplex design was accomplished by integrating the following disciplines: Computational Fluid Dynamics, Stress, Structural Dynamics, Thermal, Rotordynamic, Axial

Thrust Balance and Secondary Flows, Metallurgy Research, and Lubrication and Surface Physics. Preliminary analysis lead to cost effective design changes and the detailed analysis verified that all the design requirements were met with sufficient margin. A thorough description of the Simplex design analysis was presented by Marsh, Cowan, et al [6] earlier this year.

IV. Project Status

The Simplex Turbopump program includes all aspects of development from conceptual design through final turbopump testing. In the area of program management, the project focused on three specific areas - cost, schedule, and manpower. Each of these categories has been carefully tracked to generate a more current program experience database.

Total program costs include turbopump hardware, assembly / disassembly tooling, instrumentation, propellants, and facility modifications necessary to test the turbopump on MSFC's Test Stand 500. The most recent program cost projection is \$ 338 K -- well below the original \$ 500 K estimate. Upon program completion, comparisons between estimated and actual program costs can be made.

One of the original goals for the Simplex turbopump program was to design, fabricate, and assemble a turbopump in 18 months. This schedule allowed approximately 9 months for preliminary and detailed design and then 9 months for fabrication and assembly of the hardware. The current program schedule is shown in Figure 3. To date, the Simplex program is approximately 1.5 months behind the original 18 month goal.

The final category monitored was total manpower support. Beginning in May of 1993, the Simplex team was tasked to begin tracking the manpower expended to perform all design, analysis, and program management tasks. Thus far the average monthly labor has been equivalent to 11 full-time personnel.

Upon successful completion of the Simplex turbopump program all cost, schedule, and manpower data will be compiled as part of a growing experience database. This database can then be used to evaluate more accurately proposals for future turbomachinery applications.

V. Future Applications

Once the Simplex turbopump has been tested, future applications could be demonstrated by modifying the hardware. Possible material options are alternate metals or ceramic coatings in the turbine flow path capable of withstanding higher temperatures. An alternate turbine disk could be retrofitted to demonstrate a full ceramic disk with an innovative shaft attachment design. Other modifications could be made to the rotor support system to demonstrate the use of hydrostatic or hydrodynamic bearing technology. Low cost castings technology utilizing rapid prototyped

patterns for investment casting molds could be demonstrated as an alternative fabrication method. The initial cost of tooling for cast parts would be substantially reduced for prototype hardware.

REFERENCES

1. Buckmann, P.S., Shimp, M.R., Viteri, F. and Proctor, M., "Design and Test of an Oxygen Turbopump for a Dual Expander Cycle Rocket Engine," AIAA-89-2305, AIAA / ASME / SAE / ASEE 25th Joint Propulsion Conference, Monterey, CA, July 10-12, 1989.
2. Schoenman, L., "Selection of Burn- Resistant Materials for Oxygen - Driven Turbopumps." Journal of Propulsion and Power, Vol. 3, No. 1, Jan.- Feb. 1987.
3. Sutton, G.P., Rocket Propulsion Elements, An Introduction to the Engineering of Rockets, Sixth Edition, John Wiley & Sons, Inc., 1992, pp 213, 232-235.
4. Stoltzfus, J.M., and Benz, F.J., "Development of Methods and Procedures for Determining the Ignitability of Metals in Oxygen", TR-281-001-int-1, NASA, White Sands Test Facility, Las Cruces, New Mexico, November 1984.
5. Beveridge, J.H., Ducey, F.D., and Evleth, R.V., "Materials Compatibility with Oxidizer-Rich Gasses at Elevated Temperatures and Pressures", Final Report, NASA Contract # NAS8-36713, Acurex Corporation, Cryopro Group, March 1987.
6. Marsh, M., Cowan, P., Van Hooser, K., Forbes, J., "Simplex Turbopump Design", 1994 Conference on Advanced Earth-to-Orbit Propulsion Technology, May 17-19, 1994, MSFC.

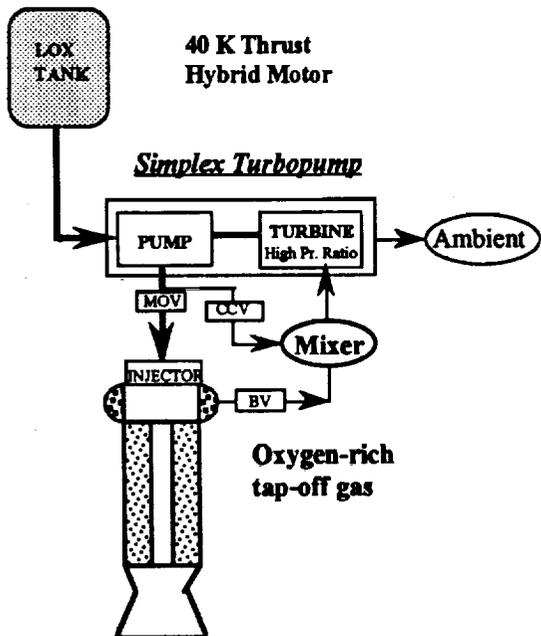


Figure 1. Hybrid Tap-off Cycle

Table 1. Turbopump Requirements

PUMP		
Pump inlet pressure	45	psia
Pump discharge pressure	1545	psia
Mass Flow rate	90	lbm/s
Rotational speed	25,000	rpm
Pump Efficiency	71.5	%
Shaft Horsepower	700	hp
TURBINE		
Turbine inlet Temperature	800	° R
Pressure Ratio	15	-
Velocity ratio	0.38	-
Nozzle Arc of Admission	45	%
Turbine inlet Pressure	800	psia
Mass flow rate	9.24	lbm/s
Efficiency	55	%

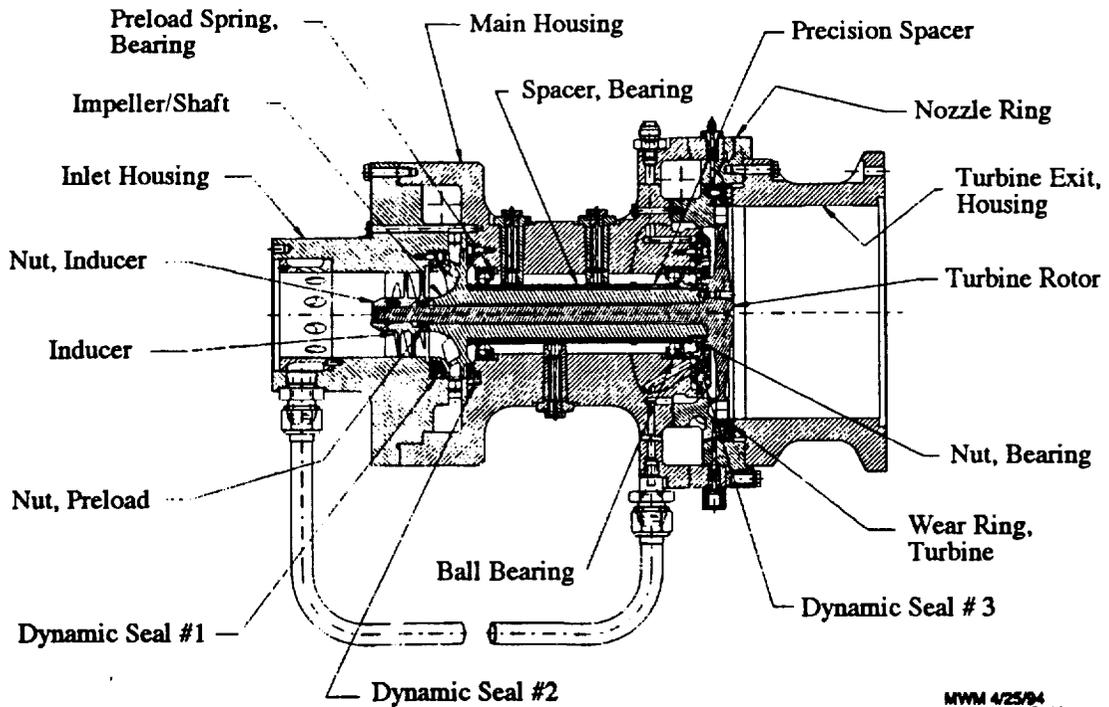
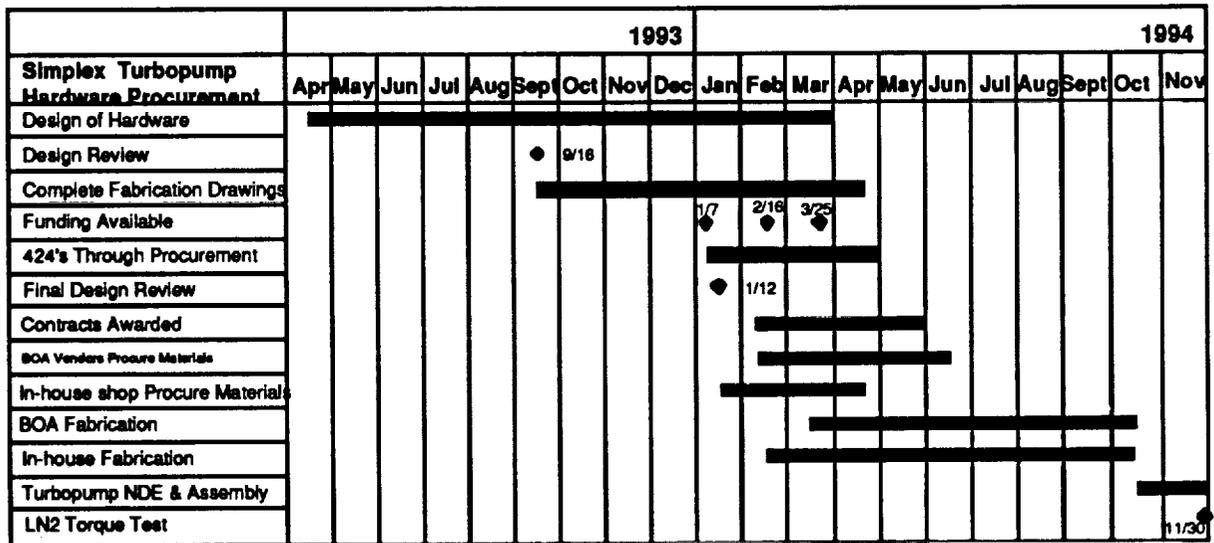


Figure 2. Drawing of Simplex Turbopump Cross Section



* BOA - Basic Ordering Agreement

Figure 3. Simplex Turbopump Program Schedule