Working on new gas turbine cycle for heat pump drive

By Irwin Stambler, Field Editor

Small recuperated gas turbine engine, design rated at 13 hp and 27% efficiency, is sized for a 10-ton heat pump system — will be scaled to power a commercial product line ranging from 7.5 to 25 tons capacity.

AiResearch is working on the design development of a low pressure gas turbine — one which operates in a semi-closed loop mode at less than atmospheric pressures in part of the cycle— as a heat pump drive for commercial installations.

Company is testing prototype gas turbine hardware sized for a 10-ton system. Expects to come out with a full product line in the mid-1980's that will range from 7.5 to 25 tons in capacity.

Although the program is aimed at the development of a heat pump drive, AiResearch says the gas turbine design concept is applicable to generator sets or high-speed fluid pumps and air compressor drives. Claim performance is competitive with that of a diesel engine.

Right now, though, company is concentrating 100% on the heat pump application. More specifically on the production design development of a commercial 10-ton system. Breadboard tests have been run on a prototype system and project engineers have started the next phase of hardware design:

☐ **Breadboard Tests.** Second generation gas turbine design been tested at full design conditions of 1500°F turbine inlet temperatures and 80,000 rpm output shaft speed. Combined with a breadboard recuperator and combustor to drive a 10-ton refrigerant compressor and heat pump assembly.

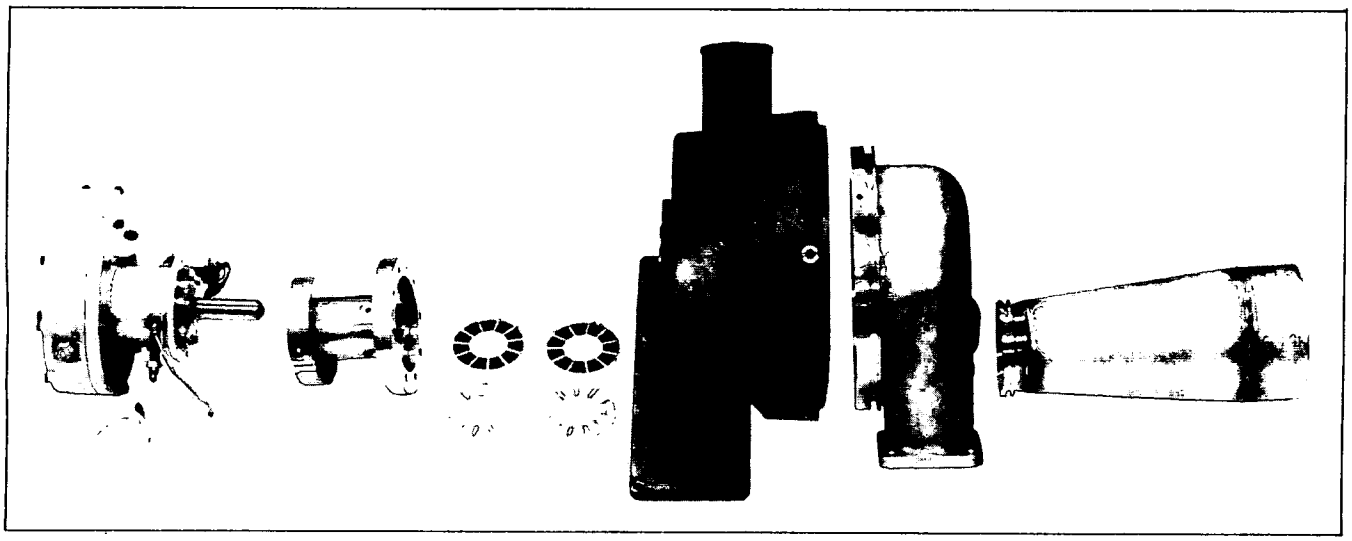
☐ **Commercial Prototype.** Now into a 3-year program to develop production prototype of complete system including controls, heat pump, and recuperator hardware. Schedule calls for building two commercial prototype systems for operational test and evaluation.

☐ **In-Service Evaluation.** Follow test phase with production of 10 units for in-service test and evaluation out in the field (around 1982-83 time period). At the same time start pilot production building up to full scale production in the mid-1980's.

AiResearch's advanced development program is being supported in part by the Gas Research Institute (in Chicago) and, more recently, the U.S. Dept of Energy as an alternative to electric driven heat pump systems. One that will be more efficient than current designs.

Basic system consists of a natural gas fueled gas turbine (Brayton cycle) driving a vapor (Rankine) cycle heat pump centrifugal compressor through a magnetic coupling. As described by AiResearch's program manager, David Friedman, the pacing item in the system is the design of the rotating assembly for the gas turbine — which is now completed.

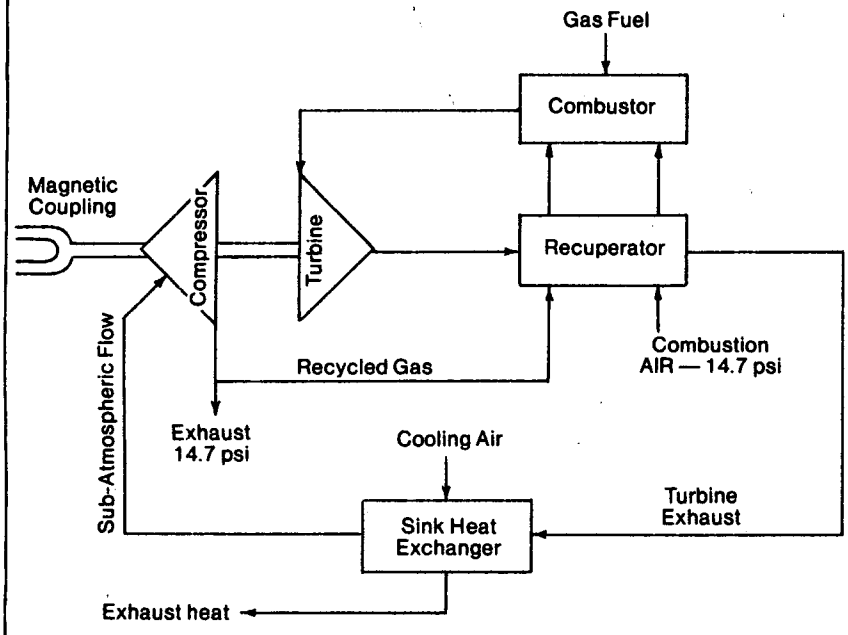
A second generation gas turbine has been tested for close to 100 hours with good results. "Design is rated for



Brayton cycle rotating group disassembled shows refrigerant compressor (at left) and turbine-compressor housing (at right). Rotating group is supported by foil air bearings which use loop air as both coolant and lubricant.

Sub-Atmospheric Gas Turbine Cycle

Instead of relying on pressurized compressor discharge for combustion the "sub-atmospheric" gas turbine cycle mixes outside air with the fuel for combustion at atmospheric pressure. Compressor is used to restore atmospheric pressure to the cycle.



Basic system consists of a centrifugal compressor, radial inflow turbine, recuperator, sink heat exchanger, and in-line combustor. During operation the fuel is mixed with the air, burned, and hot combustion gases expanded through the turbine to power the compressor and output shaft which drives the load (not shown) through a non-slip magnetic coupling.

The expansion process is accompanied by a pressure drop so that the gas flow leaves the turbine at less than atmospheric pressure. This low-pressure exhaust is then passed through the recuperator (to preheat combustion air) and heat exchanger (for cooling) for delivery to the compressor.

The compressor pumps the gas back up to atmospheric pressure for recycling through the loop. A small portion of the flow is dumped. But most of it is recycled through the recuperator into the combustor as a secondary flow to dilute the combustion flow and help control turbine inlet temperatures.

Main function of the heat exchanger is to cool off the low pressure gas so as to reduce the load (and power requirements) on the compressor. Also serves as supplemental heat source where the heat extracted can be used for space heating.

Assembled Brayton/Rankine rotating group is only about 18 inches long (including the attached compressor) and 12 inches in diameter at its widest point.

1500°F into the turbine at 80,000 rpm," says Friedman, "but we've actually run the turbine up to an inlet temperature of 1610°F at shaft speeds of over 81,000 rpm. Under those conditions, we've combined the unit's operation with a breadboard recuperator and combustor and manual controls to drive a 10-ton heat pump."

The system is designed around the optimum working fluid for each cycle. Air is used in the heat engine — where high turbine inlet temperatures permit high thermal efficiencies — while Freon 12 was selected for the heat pump in which the conventional reciprocating compressor has been replaced with a high speed centrifugal one.

The Rankine cycle pump unit is hermetically sealed from the Brayton cycle natural gas fired turbine by means of a magnetic coupling. "The gas turbine drive system puts out about 13 hp," Friedman says, to provide direct drive of the Freon compressor through the magnetic coupling.

A unique feature of the system is the use of a semi-open subatmospheric gas turbine cycle consisting of a centrifugal compressor, radial inflow turbine, recuperator, sink heat exchanger and in-line combustor. "Reason for this," says Friedman, "is that we can use natural gas at line pressure — a couple of inches of water — whereas normally we would have to pump the gas up to a couple of atmospheres. It allows us to maintain ambient pressure in the combustor so we can use a low cost in-line design."

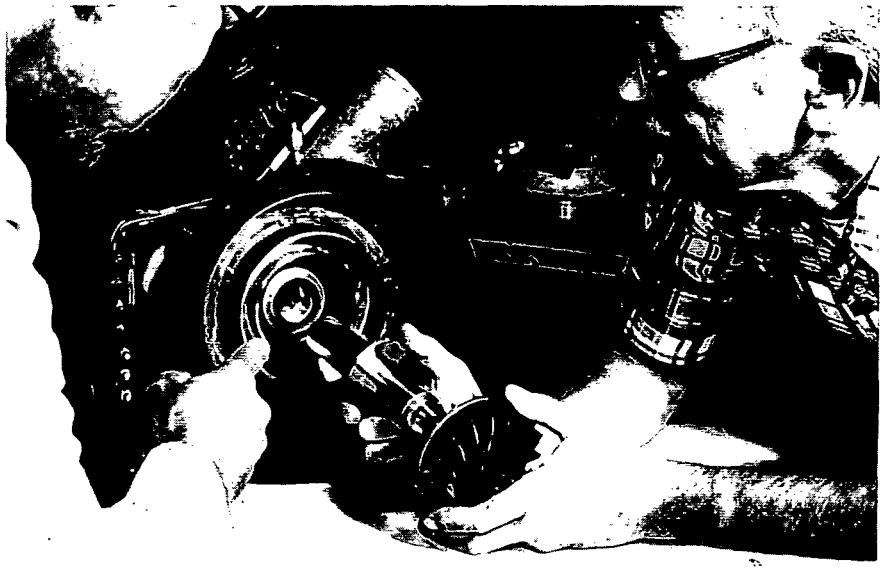
Flow from the combustor is expanded through the turbine power cycle to subatmospheric pressure, providing energy to drive both the turbine and Freon compressors. The turbine discharge is processed through the recuperator where it preheats incoming combustor inlet air.

The sink heat exchanger is used to lower gas temperature still further to reduce compressor power consumption. This heat sink feature, it's stressed, is one of the advantages an on-site system offers over electric heat pump installations.

"In the heating mode particularly," Friedman points out, "the waste heat recovery feature helps make a gas driven system much more efficient than an electric design since it works as a heat source to help heat the building. An estimated 71% of the energy required for an electric system never reaches the building because it is lost at the power plant and during transmission.

"Our system uses about half the energy of an equivalent electric heat pump which means the overall Coef-

Foil air bearings which support turbine-compressor shaft are demonstrated by Jim Wenban, development engineer. Round discs in foreground are thrust bearings; rectangular pieces are journal bearings.



Technician Paul Philbrick (on the right) shown inserting turbine-compressor shaft and wheels into Brayton assembly.

ficient of Performance (COP) is about twice that of an electric system. We're talking COPs for our system of 1.4 to 1.5 in heating. In the cooling mode, we lose the advantage of the heat sink because the waste heat is discharged but other properties of the gas turbine approach still make it more efficient than electricity. And, compared to a gas furnace, the turbine-heat pump combination is twice as efficient."

According to Friedman, the two most unique design features of this system are the subatmospheric cycle and the non-slip magnetic coupling. "We use a samarium-cobalt magnet system. Those materials are being used in permanent magnet motors but I believe this is the first time they've been applied to a high speed coaxial magnetic coupling. As far as I know it's also the only subatmospheric gas turbine ever run in the world."

The gas turbine shaft is supported by foil air bearings cooled and lubricated by outside ambient air. No liquid cooling loop is required. "Besides eliminating the need for lube and oil pumps and associated components, air bearings have a much longer life than ball bearings, on the order of 60,000 hr versus 20,000 hr or less for ball bearings." He notes the MTBF for air bearings used in DC-10 cooling turbines is over 60,000 hr and that such bearings have been chosen for systems to be used on Boeing's new 767.

The recuperator design is based on the industrial gas turbine regenerator technology developed by AiResearch in recent years. The system is a pure counterflow device with 1300°F gas coming into it and with a claimed effectiveness of 0.9. The device is made from nitride dispersion strengthened stainless steel using a formed tube sheet design. This construction, it's claimed, both reduces stress and increases the recuperator cycle life.

The turbine wheel is a high temperature alloy casting about four inches in diameter. Friedman points out that "at this stage of the game you usually don't go to a cast turbine section. Typically you start with a forging and cast later on. In our case, we had problems in machining a forging to meet our needs and we had to go to a casting which has worked out pretty well."

The gas turbine compressor, though, is a simple forged wheel. The engine compressor and turbine wheels are bolted back to back, which is unusual. The compressor-turbine rotor section rides on two oil journal bearings. Design originally had five foils, but in the current Mk 2 configuration has gone to seven foils.

The Freon compressor has a 1.75-inch aluminum impeller mounted on

one end of the shaft, and the driven magnet cartridge at the other end, with the shaft supported on two standard precision ball bearings. A stationary cover seal encloses the driven magnet and forms a part of the refrigerant unit assembly. The compressor in this system delivers 10 tons of cooling but is about a quarter the size of standard compressors because of its high speed characteristics.

The in-line combustor, made possible by the subatmospheric pressure approach, is a very efficient component capable of providing 95 to 100% combustion efficiency. In operation, Friedman explains, sufficient air near stoichometric is introduced to support combustion. Dilutant and quenching gas are added as recirculated combustion products to maintain a reasonably low combustion chamber temperature. The combustor is a straight tube six inches in diameter and 12 to 18 inches long. "That's the beauty of it — it's so simple."

Program objectives are to deliver a gas-fired commercial heat pump system that will be attractive to business and industry. The major milestone up to this point has been proving out the rotating assembly. As reported by Friedman, the prototype rotating assembly tested as part of a breadboard system "met performance goals and design mechanical goals. Results of close to 100 hours of testing encouraged us to move into the next phase."

The new phase is a three-year accelerated program with all members working towards development of a full prototype commercial system. Emphasis will be on system packaging and designing controls, heat pump hardware and recuperator hardware.

Schedule calls for building two commercial prototypes. If all goes as expected, the next step after completion of the three-year program will be to put 10 units out in the field for a year's demonstration (around the 1982-3 time period) while at the same time starting pilot production hopefully leading to a full scale production line in the mid '80s.

"In production," Friedman says, "our estimates suggest we're looking at an installed cost in the area of 15 to 20% higher than existing systems — but with a payback of less than two years in energy cost savings." Taking a 10 year lifespan, the calculations indicate projected savings to the user over that period of over $10,000.

This should appeal to many commercial customers, though not necessarily to the residential field. "We looked at the residential market but it appears at this point that the initial cost would be prohibitive though this might change as the cost of energy rises. At any rate, for the commercial market, we see a potential volume in the mid '80s of 10,000 units a year."

AiResearch program manager, Dave Friedman, is shooting to complete design development of a full prototype commercial system by the end of 1981.

Though the program is concentrating on a 10-ton heat pump capability for now, other sizes are seen necessary for the future. "We chose 10 tons because that size has sufficient sales volume to bring down the cost of manufacturing to reasonable levels. But anybody who goes into the heat pump marketplace has to offer more than one size. A commercial program might start with 10 tons, then be extended to include units covering a range from 7.5 to 25 tons."

Though the initial thrust for the new system is expected to be in space conditioning, Friedman sees other potential applications on the horizon. "The drive concept is applicable for generator sets. In that size range, the natural gas fired Brayton cycle engine is competitive in performance with a diesel. It might be used to drive high speed fluid pumps or air compressors."

It should be noted that the Gas Research Institute program includes gas fired heat pump concepts besides the gas turbine. Other approaches being studied elsewhere include a Sterling cycle driven system, a gas absorption technique, and a steam turbine drive. Friedman, though, believes the gas turbine has a lot going for it — and that includes probably being nearest to commercial implementation.

With good market acceptance, AiResearch studies indicate demand for a Brayton/Rankine heat pump design could lead to rapid expansion of the use of such equipment in the late 1980s. It's seen possible that the annual volume could increase in the late '80s until some 200,000 units were in operation in 1990. "That," says Friedman, "could bring savings in natural gas use from 1982 through 1990 of over 250 billion cubic feet."