TWENTIETH QUARTERLY PROGRESS REPORT
BASELINE GAS TURBINE DEVELOPMENT PROGRAM

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ABSTRACT

Progress is reported for a program whose goals are to demonstrate an experimental Upgraded gas turbine powered automobile which meets the 1978 Federal Emissions Standards, has significantly improved fuel economy, and is competitive in performance, reliability, and potential manufacturing cost with the conventional piston engine powered, compact-size American automobile.

Activity during this twentieth program quarter has continued to emphasize development towards correcting a power deficiency in the Upgraded Engine. Though no absolute improvements have been realized in this quarter, significant progress has been made in identifying causes, appropriately adjusting original design constraints, and proceeding with corrective designs. Specifically, to reduce endwall and secondary flow losses, a new low velocity compressor turbine inlet duct, and blading both with an increased height and lighter loading is being designed. A large increase in the power turbine annulus is being used to significantly lower blade Mach number and leaving loss. Progress is also being made in uniforming regenerator flow for better heat recovery, and in the development of control system components. A Public Interest Car has been built and has proved effective in communicating overall program benefits and goals. In the area of advanced engine development, work is now underway towards processing sintered alpha silicon carbide into high temperature turbine stage components.

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INTRODUCTION

This Baseline Gas Turbine Development Program is being sponsored by the Heat Engine Systems Branch, Division of Transportation Energy Conservation (TEC) of the Department of Energy (DOE). One of the major components of the Department of Energy, when formed October 1, 1977, was the former Energy Research and Development Administration (ERDA). ERDA in turn had been established in January, 1975, as a result of the 1974 Energy Reorganization. Prior to this reorganization, TEC had been the Advanced Automotive Power Systems Division (AAPSD) of the Environmental Protection Agency (EPA).

The overall mission of AAPSD, which resulted in the generation of this particular program, had been to evaluate, develop and demonstrate automotive powerplant concepts potentially superior, in the area of emissions control and fuel economy, to the standard spark ignition reciprocating engine. A principal area of activity has been the automotive gas turbine. Programs were first initiated in this area early in 1971 when several contracts were let for the development of low emissions combustion, and for studies related to cycle optimization, engine arrangement, and cost to manufacture. Additionally, EPA enlisted NASA for technical support to these programs through an inter-agency agreement.

This Baseline Engine program was implemented on November 22, 1972, with the signing of a contract between EPA and Chrysler Corporation. Specific goals of this program were to demonstrate in 1976 an experimental gas turbine powered automobile which would meet the 1978 Federal Emissions Standards, have significantly improved fuel economy and be competitive in performance, reliability and potential manufacturing cost with the conventional piston engine powered, standard-size American automobile.

Structurally, this program was made up of three parts: (1) documentation of the existing automotive gas turbine state-of-the-art, (2) conduction of an extensive component improvement program, and (3) utilization of the improvements in the design, and building of an Upgraded engine capable of demonstrating program goals.

Chrysler Corporation's Sixth Generation Gas Turbine Engine, having been selected as representative of the state-of-the-art at the beginning of this program, was used as the Baseline Engine. This was a 4:1 pressure ratio regenerative engine with variable power turbine nozzles which meets the .41 HC, 3.4 CO, 3.0 NOx grams/mile original 1975 emissions standards. The Baseline vehicles were intermediate-size, 4-door sedans modified to accept the turbine engines.

As is shown in the detailed Program Plan (Appendix B), Baseline documentation (Tasks 1 and 2) was accomplished early in the program. Also as shown, the Baseline Engine improvement work (Tasks 5 and 6) has been completed except for a small Task 5.7 effort for verifying an MTI hydromechanical CV transmission concept. Efforts still to be completed include building and testing Upgraded Engines and vehicles, Tasks 7 and 8, and a recently implemented improved automotive gas turbine study, Task 10.

With respect to Tasks 7 and 8, initial running of the Upgraded Engine took place on July 13, 1976. This engine, though mechanically sound, started out about 43% deficient in power. The principal problem has been low efficiencies of the aerodynamic subsystems resulting from compromises made to satisfy packaging/interface and other design constraints. Changes in the compressor and compressor turbine along with some reductions in leakage and pressure drop have to date reduced the power deficiency to about 25%. To fully eliminate these deficiencies, major turbomachinery redesigns, made possible by reconsideration and relaxation of stress and overspeed constraints, are currently well underway. DOE is continuing to support corrective development of this engine to provide a sound base for their advanced engine programs.

Chrysler Corporation efforts on this program are being managed and coordinated by the Research section of the Engineering Office. Those who have contributed directly in writing this report include C. Belleau, A. Billington, B. Chapman, J. Corwin, F. Dosenberger, C. Elliott, J. Engel, T. Golec, J. Gross, F. Hagen, E. Kohl, J. Lewakowski, C. Mader, D. Musgrave, R. Pampreen, L. Pritchard, N. Sparks, R. Swiatek, and E. Trieskey.

PROGRESS SUMMARY

- Baseline Car 667, the replacement for Car 671 in Washington, D.C., was transported to Alabama where it was used for multi-fuel demonstrations (including peanut oil) in conjunction with the National Peanut Festival.
- The new, special bodied Public Interest Car became operational and was displayed at the October Contractors' Coordination Meeting.
- Analysis of the pump-motor module data of the MTI hydro-mechanical transmission is nearly complete. Writing of the final evaluation report will conclude this Task 5.7 effort.
- Upgraded Engines 1, 3, and 7 are undergoing various corrective development tests on the dynamometer, and additional corrective designs are in progress. Specifically, to reduce endwall and secondary flow losses, a new low velocity compressor turbine inlet duct, and blading both with an increased height and lighter loading is being designed. A large increase in the power turbine annulus is being used to significantly lower blade Mach number and leaving loss.
- Regenerator flow distribution has been improved.
- A subcontract for developing processing of sintered alpha silicon carbide for high temperature components fabrication is underway.

DETAILED PROGRESS STATEMENT BY TASK

TASK 3a SUPPORT TO D.O.E.

Baseline Car 671

The vehicle, placed in service in Washington, D.C. during July, 1977, experienced problems in late August. The engine surged and stopped running; restart attempts were not successful. Troubleshooting by a local service facility did not disclose any unusual problems. The engine was reinstalled and another start was attempted and manually aborted due to an overtemperature condition. Chrysler personnel made a service call, reported severe engine damage, and had the vehicle returned to Detroit. Close inspection showed the following:

- The left regenerator hub had broken completely and as a result the core moved up and forward hitting the regenerator cover. The resultant debris lodged into the mesh resulting in ring gear tooth damage. The hot side of the core is locally burned.
- Right core; inner surface burned.
- First stage hardware; nozzle and wheel damaged, almost all blades disintegrated.
- Impeller inducer rubbed due to unbalance.
- Power Turbine Nozzle Assembly; blades locally distorted and disintegrated.

Some molten metal was sprayed on the shrouds. It appears that the left core hub failure caused the original complaint of engine failure. Core shifting and debris in the gear mesh would cause leakage, overfueling and stopping of the engine. Subsequent start attempts resulted in the present engine conditions. The engine has been reconditioned and is waiting for replacement regenerators. Regenerators are currently being machined. Assembly and installation will follow.

Baseline Car 667

Following reconditioning and reinstallation of the engine and correction of the oil system problems discussed in the previous

quarterly report, the vehicle was delivered to D.O.E. in Washington, D.C. on September 13, 1977, as a replacement for Car 671. Overall vehicle response and driveability are good, but gas generator rotor noise is somewhat higher than desirable.

The vehicle was transported to Alabama to demonstrate its multifuel capability at Huntsville and Dothan during the week of October 17, 1977. The demonstration in Dothan was in conjunction with the National Peanut Festival. Peanut oil was one of the fuels used. The test apparatus was the same as used in Washington, D.C. in May, 1976, and reported on Page 5 and shown in Figure 5 of the Fourteenth Quarterly Progress Report.

Limited burner rig testing was conducted to determine if a Baseline engine diffusion flame combustor system could run on peanut oil. The rig ran successfully with 100% peanut oil for steady state speeds between 50 and 80% speeds. However, HC and CO emissions were unacceptably high. In addition, the exhaust odor was very distinct.

A 50/50 mix of peanut oil and 3900 A lead-free gasoline was selected as a compromise and emissions recorded - the odor was still present but reduced.

Figure 1 shows the relative emission difference for 3900 A and the 50/50 mix. Figure 2 shows the reduction in emissions with increasing dilution of the peanut oil at 50% Ngg.

Contractors' Coordination Meeting

Program status was presented on October 5, 1977, at the meeting in Dearborn, Michigan. Display efforts included the Public Interest Car discussed below, Baseline Car 618, and Expanded Upgraded Engine, and a number of program descriptive panels.

TASK 3c PUBLIC INTEREST CAR

This modified Chrysler LeBaron, Car 649, powered by an Upgraded Engine was first run on September 19, 1977, 14 weeks after initiation of vehicle refiltering. Figures 3 through 6 show the distinctively styled front and rear engine compartment packaging. It was first displayed at the October 4-6 Contractors' Coordination

Meeting where its styling, engine packaging and quiet operation were well received. A 2-position VIGV system is used for idle and off-idle running, and for maximum starting reliability a "Baseline" style droplet diffusion flame combustor is being used.

The vehicle is built principally for static demonstration, and as such, minimum effort has and will continue to be expended towards making it safely roadable. Accordingly, it is currently fitted with manually adjustable power turbine nozzles and non-protective fiber-glass front and rear. Estimates are being prepared for incorporating a soft energy absorbing front and rear, but it is unlikely that follow through action will be taken. Upgraded Engine driveability demonstrations would rely on use of the standard 4-door Dodge Aspen installations, Cars 385 and 386. The curb weight of Car 649 is 3884 pounds with fuel tank half full.

TASK 5.7 HYDROMECHANICAL TRANSMISSION

Following Chrysler Research testing of the CVT pump-motor module shown in Figure 7, the unit was returned to Mechanical Technology, Incorporated for disassembly and inspection of parts. They report all parts to be in excellent condition and have found negligible wear on such critical components as pistons, cylinders, swash plates, and swash plate bearing surfaces.

A reevaluation of the potential performance capability of the MTI hydromechanical CVT has now been made by the Chrysler Performance Analysis Engineering group using Research Lab data instead of MTI's original pump-motor module efficiency data. As Research test equipment permitted module operation at low speeds and moderate to high torques, and, as transmission efficiencies in this region proved to be higher than expected, it was found desirable to shift engine-transmission match points to effect an improvement in overall economy. An indication of their performance and economy improvements which might be expected by substituting the MTI CVT for a conventional 3-speed automatic transmission with lock-up torque converter is shown in the accompanying table:

Transmission	% IMPROVEMENT		
	50 to 70 mph Acceleration	EPA Cycle Economy	
		Urban	Composite
3-Speed Automatic T/C with Lockup	--	--	--
MTI CVT (MTI Data)	3.8	4.0	2.0
MTI CVT (MTI and Chrysler Data)	11.0	7.5	5.0

Some additional economy improvement could be expected from reducing the CVT parasitic losses. The current analysis includes the losses resulting from the use of a conventional transmission lube pump, but an additional evaluation is in progress using a lower capacity pump which MTI believes adequate for the make-up and lubricating oil requirements of the CVT.

TASK 7.2 TO 7.3 UPGRADED ENGINE PROCUREMENT AND ASSEMBLY

Procurement

Procurement of 12 engine housing castings was completed with delivery of 4 useable castings. Two of this latest delivery were machined to fulfill program engine, fixture, and display needs (10 housings). The remaining 2 castings were ordered as spares.

Five inertia welded power turbine pinion and sleeve assemblies are currently being processed. Two are needed for remaining engine builds, and 3 will serve as spares.

Three aluminous keatite regenerators were received. Bench tests showed matrix porosity to be lower than the standard LAS cores. Exact measurements will require installation of a lower capacity flowmeter in the leakage test fixture.

Cores of this material have undergone over 5000 hours of testing under another D.O.E. contract (Ceramic Regenerator Reliability Development, Ford Motor Company) where they have been shown to be virtually immune to sulfur or sodium attack.

Assembly

The last 2 program engines are being assembled. One is for Car 385; and the other, which is for general development, is being instrumented for measuring bulkhead and crossarm metal temperatures to aid in reducing bulkhead cooling parasitic heat loss.

Figure 8 tabulation summarizes the status of all power plant assemblies and Figure 9 tabulation summarizes the status of all active regenerators.

TASK 7.4 UPGRADED ENGINE TEST

Summary Test Log

For the purposes of reference documentation, following is a log of the various tests run during this reporting period:

Engine 1 (Power Plant 3-9)

This engine, previously ran 160 hours as Power Plant 3-1, has been re-built with extensive compressor and power turbine instrumentation. For this initial checkout, the cascade diffuser was fitted with 26 static taps and 4 total probes. The cell was also outfitted with a 24-channel Scanivalve unit to facilitate data recording. Interstage and power turbine instrumentation included:

3 P _{t6} Total Probes	6 P ₇ Static Ports
3 T _{t6} Total Probes	3 P _{t7} Total Probes
3 P _{6.3} Static Ports	8 P _{7.5} Static Ports
3 P _{t6.3} Total Probes	8 T _{7.5} Grid

Testing began October 10, 1977, with 19.7 hours logged as of October 18. Test highlights are as follows:

Build A, Runs 1-15

Initial testing of the cascade diffuser was disappointing, with compressor performance slightly poorer than that of the original release 14-channel diffuser. Power was 24.7 hp at 80%. Full

sets of data were run for 50 to 90% speeds at $T_{7.5}$ temperatures of match, -100° , and $+100^{\circ}$, to provide initial compressor map data. The engine performed well mechanically, and with no evidence of burner flash-back; but a minor fuel control problem prevented running above 90%. The Scanivalve unit functioned flawlessly, and effectively reduced data acquisition time. The $T_{7.5}$ grid measured circumferential exhaust diffuser exit temperature distribution at eight points. Maximum recorded spread was 61°F at 90% Ngg. The average grid $T_{7.5}$ matched the three standard $T_{7.5}$ thermocouple average (eight, nine, and ten o'clock locations) very closely, with the grid reading a maximum of 20° lower at 90%. To check air bearing and compressor turbine rotor seal environment, two skin thermocouples were installed on the bearing carrier and one on the seal case front face. Results of these tests are discussed under Task 7.5, Gas Bearing Development.

Build B, Runs 16-21

Following regenerator and burner inspection, the engine was fitted for injection of shop air into the P_3 cavity and surge margin was checked at 80 and 90%. Surge margin was good, at 12.3% and 9.0%, respectively. Because of the highly opened power turbine nozzle angle required to run 95% (45°), no attempt was made to run 100%. At the completion of testing, India ink was injected through an impeller discharge static tap. The gas generator has been disassembled, and analysis of the ink traces is in process.

For the next build, the engine will be assembled with a $+1^{\circ}$ first cascade vane stage in place of the 0° part initially tested. The following build will test an 18-18 splitter impeller and the cast Mod 1 compressor turbine wheel, using the best corrective development gas generator from Room 4S. This gas generator (S/N4) includes the 28-channel $+1^{\circ}$ diffuser with tandem deswirl, the Mod 2 compressor turbine nozzle, and a variable capacitance sensor for reading the speed of the all-aluminum 18-18 impeller. Future tests planned for this engine include:

- Original release 14-channel diffuser/deswirl with instrumentation comparable to the cascade diffuser now under test.
- Improved flow distribution regenerator cover.
- Additional cascade diffuser modifications.

Engine 3 (Power Plant 2-3)

During this quarter, Engine 3 continued on a program of aerodynamic component development testing, until Engine 1, rebuilt with more extensive instrumentation, became operational. Engine 3 was then diverted principally to control work in support of vehicle system development.

Minor program delays resulted first from a compressor rub due to a piece of loose gasketing and later from an air bearing seizure; nevertheless, 60.1 test hours were still logged, and 95 sets of data recorded. Total engine time is now 221.9 hours. Test highlights are as follows:

Build AJ, Runs 352-376

This assembly was built up to evaluate the performance of the Mod 1 scaled Baseline wheel with the originally released nozzle. Except for this nozzle, the assembly was the same as build AH (see Nineteenth Quarterly Report) where the Mod 1 nozzle was used. No significant difference in performance was measured.

Next, using the dynamometer in the motoring mode, a series of 50% speed steady state engine braking tests were run at various temperatures, nozzle angles, and propshaft speeds. These are summarized on Figures 10, 11 and 12.

Builds AK Through AR, Runs 377-416

This series of assemblies was run with the Mod 1 compressor turbine nozzle (10% flow oversize) and the scaled baseline Mod 1 wheel in combination with a variety of 28-channel diffuser arrangements to investigate surge margin sensitivity. Within data scatter (normal leakage variation) the +1° diffuser showed no better surge margin at 90% speed than the nominal diffuser angle setting. Both combinations were also tested with cut back deswirl vanes, again showing no significant difference. Overall, surge margin remained at 5 to 6% at 90% speed. During build AQ, on reaching 90% speed, the compressor rotor experienced a sudden stoppage, and on teardown, the air bearing was found seized (see Task 7.5 Gas Bearing Development). Aside from damaged middle and rear seals, and light inducer and turbine tip rubs, there was no secondary damage from the failure.

Builds AS, AT, AU, Runs 417-439

Surge margin investigations were continued with a Mod 2 nozzle (1.05 flow size) replacing the Mod 1 nozzle (1.10 flow size). Surge

margin with the nominal 28-channel diffuser was about 1% at 90% speed. In contrast to tests with the larger nozzle, the margin increased to about 3% with the +1' diffuser vane settings. The cut-back deswirl vane again showed no effect on performance or range.

Builds AV and AW, Runs 440-447

The engine was readied for vehicle support testing by installing a one-piece all-aluminum impeller in place of the standard steel front, aluminum rear two-piece assembly, and by replacing the limited service Mod 1 machined scaled Baseline wheel with an originally released cast part. With no change to the compressor diffuser or compressor turbine nozzle and about the same leakage, surge range increased to 5%, while power decreased about 8%. Burner liner temperature with a standard premixed combustor did not exceed 1900°F and no flashback occurred. Steady state emissions are shown on Figure 13 in comparison with the Baseline type diffusion flame combustor of power plant 8-10 being used for initial vehicle check out.

A redesigned nozzle actuator was installed; and after some control programming development, the unit showed good response and accuracy in closed loop temperature control.

Engine 7 (Power Plant 8-10)

This engine was built for installation in Public Interest Car 649. Therefore, testing was limited to assurance of mechanical integrity and proper functioning of the burner and control system. A total of 15.3 hours of testing were logged prior to transferring the engine to the vehicle on September 9, 1977.

Build A and B, Runs 1-5

The initial build was a standard engine with no corrective development hardware; and as such, 80% power was only 26 horsepower. Upon initially approaching 90% speed (2200 propshaft rpm), the oil pressure safety shut the engine down. The oil pump was found to have a seized bearing, which had caused the over-running clutch to slip. Dimensional check showed the bearing clearance to be a blueprint minimum, with local irregularities in the bearing bore (a machined hole in the cast iron pump housing) indicating drill wander. After reaming the bore to size, polishing the journal, and installing a new overrunning clutch, testing was resumed to higher speeds without incident.

Build C, D, E and F, Runs 6-25

The engine was rebuilt with a baseline-type diffusion flame burner for vehicle demonstration reliability, and the best available corrective development diffuser/deswirl hardware (28-channel +1° diffuser with 4° tapers and tandem deswirl). Minor adjustments were made to the burner premixer and dilution areas until satisfactory emissions were obtained (Figure 13), and power increased to about 29 HP at 80% speed. Because a variable nozzle actuator was not available for the vehicle, after recording full match data through 80%, the power turbine nozzle vanes were fixed at the 80% match point (nominally 29°) and data at lower speeds again recorded. Aside from the expected changes in cycle temperature (T_g 60° hot at idle and 60° cold at 60 and 70% Ngg), the engine performed well with fixed power turbine nozzle vanes. The engine was next fitted with a two-position VIGV actuator, to permit operation with a throttled inlet (+41° vane angle) at idle and an open inlet (0° vane angle) at all other speeds. The actuator operated satisfactorily in reducing idle output shaft speed, needed to minimize vehicle creep.

TASK 7.5 CORRECTIVE DEVELOPMENT

No improvement in engine power has been realized in this quarter. Potential improvement items evaluated included a cascade compressor diffuser (loss of performance) and a Mod 2 compressor turbine nozzle (no improvement over Mod 1). A scheduled test on an 18 full blade, 18 splitter blade impeller was delayed by procurement.

The current program to bring the engine up to design power includes:

1. Continued Chrysler-NASA-Consultant development of the compressor to improve efficiency from 78 to 80.5% and obtain a consistent 5% surge margin. In addition to the 18-18 splitter impeller, conical pipe and three-dimensionally divergent channel diffusers are being studied.
2. Design of an all new compressor turbine section with an enlarged vortex, convergent shroud nozzle, and increased reaction wheel with a 15% increase in blade height. There is general agreement between Chrysler,

NASA, and outside consultants that this design approach should achieve the 84% goal efficiency. The design release is scheduled for December 1, 1977, and initial test parts are scheduled for March 1, 1978.

3. Design of an all new power turbine section with 40% increase in annulus area, higher wheel reaction, and lower leaving loss. The required design and fabrication of this section was subcontracted to Noel Penny Turbine Limited, so as to secure parts in parallel with the new compressor turbine section.

Details of the overall development effort, i.e., turbomachinery, regenerator, control system, gas bearing are discussed in the following sections.

Compressor

The cascade-type diffuser (Reference Figure 18 of the Nineteenth Quarterly Report) was built during the past reporting period and testing began with the nominal vane setting angle on all three rows. Initial test results showed that the second row failed to achieve the intended diffusion. Consequently, the overall efficiency was below target. Because of this, the intended reduction of the impact of the collector on diffuser recovery cannot yet be evaluated.

Compressor Turbine

The performance deficiency of the originally designed stage, by general consensus of Chrysler, NASA, and consultants, is primarily ascribable to poor inlet conditions into the first stage nozzle. Surveys at this location have shown very high positive incidence angles at the hub and shroud. These, together with the small blade heights to which the design was constrained, probably result in the propagation of large end-wall and secondary flow losses throughout the nozzle and wheel blading.

The problem is being corrected by enlarging the vortex to significantly reduce the nozzle inlet Mach number and by eliminating the narrow flow path leading from the vortex chamber to the nozzle leading edge, the latter a likely strong boundary layer generator. In addition, by a moderate relaxation in the blade root stress constraint, blade height is being increased 15% to

further minimize endwall and clearance effects. The flow coefficient of the original design based on the average axial velocity across the rotor and the mean wheel speed is 0.901. At a work coefficient of 2.0, Reference 1 shows an increase of 1.5 points in efficiency if this flow coefficient is reduced 15%. Shroud contouring of the nozzle is being utilized to make the transition between a 30% increase in area at the nozzle inlet and the 15% enlarged wheel.

Two types of cross-section were examined in the process of arriving at a final configuration of an enlarged vortex chamber. The first shape was of approximately circular cross-section at the inlet and, gradually changed to semi-circular arcs separated by straight lines, as in the original configuration. A check with a styrofoam mock-up showed interference with the insulation in the engine housing at the largest lobe as shown in Figure 14. To avoid this interference, the inlet cross-section was changed to an ellipse which is rotated 52° from the vertical as also shown in Figure 14. The shape of the ellipse and the angle of orientation diminish with circumferential distance until, at 65°, the cross-section is circular. From this point on, the cross-section consists of the semi-circular arcs separated by straight lines. Finally, local revisions were made to mate with the nozzle inlet flow path.

The resultant design has an inlet vorticity of 72 ft²/sec, compared to 104 ft²/sec for the original design. The inlet Mach numbers are 0.07 and 0.12 for the revised and original designs, respectively. The inlet vorticity for the Baseline Engine vortex chamber was 138 ft²/sec and the Mach number was 0.15.

An initial cut at the redesigned turbomachinery flowpath is shown in Figure 15. The design curves of Reference 2 were used to guide nozzle shroud contouring and in specifying the leading edge tip radius of 2.4 inches.

Figure 16 shows the variation of nozzle exit absolute air angle and Mach number. Figures 17 and 18 show rotor exit work, air angle and reaction plots.

Reference 1: Craig; H.R.M. and Cox, H.J.A.: Performance Estimation of Axial Flow Turbines. Proc. Instn. Mechn. Engrs., Volume 185 32/71, Pages 407-424.

Reference 2: Deich, M.E., and Zaryankin, A.E.: Method of Increasing the Efficiency of Turbine Stages with Short Blades. Translation N. 2816, Associated Electrical Industries (Manchester) Limited, 29 April 1960.

Rotor work (Figure 17) was distributed to give maximum work at mid-span, 10% less than maximum at the root and 15% less at the tip. Consultation with Pratt and Whitney Canada in this area gave suggested variations between 10% and 20%. The higher work reduction at the tip was an attempt to minimize tip reaction; and hence, make the blade less sensitive to clearance loss. An example of this is shown in Reference 3.

Figure 18 shows a relative air angle comparison between blocked and mixed-out calculations. The blocked calculations refer to computed results at the rotor trailing edge which include the blockage of the blade thickness. The mixed-out calculations refer to computed results at a calculation station 1.6 true-chord lengths downstream from the trailing edge. Also included are the values of $\arccos(\text{throat/pitch})$, with correction for curvature downstream of the throat computed by the methods of Reference 4.

Figures 19 to 21 show blade channels at root, mean, and tip. Included on the plots are the values of unguided turn after the throat. The values of aerodynamic loading coefficient would allow a reduction in blade number from 61 to 56. However, this would result in a mean-radius unguided turn of 12.4 degrees. Consequently, the blade number was not reduced to 56 blades.

Power Turbine Rig Testing

The regenerative power turbine test rig became operational during this period. Three power turbine tests have been completed and a fourth test is underway. Tests No. 1 and No. 2 were conducted at room temperature with the difference being that in test No. 2, wax was added to the seal ring annulus at the interstage diffuser inlet to insure zero leakage. Accordingly, test No. 2 has been classified as the baseline "zero leakage" cold test. Test No. 3 was conducted at cycle inlet temperature and overall stage total-to-static pressure ratios with an operating ceramic regenerator.

Reference 3: Dorman, T.E., Welna, H. and Lindlauf, R.W.: The Application of Controlled-Vortex Aerodynamics to Advanced Axial Flow Turbines. ASME Paper No. 68-GT-4, March, 1968.

Reference 4: Ainley, D.G. and Mathieson, G.C.R.: An Examination of the Flow and Pressure Losses in Blade Rows of Axial-Flow Turbines. Aeronautical Research Council, R.&M. No. 2891, March, 1951.

The rig installation is shown in Figure 22. Metered shop air, supplied through the vertical inlet, is routed first through the high pressure side of the regenerator, then through the axially extending burner, and then through the power turbine before discharging through the low pressure side of the regenerator.

Figures 23 and 24 are schematics of the test rig instrumentation. Testing to date has utilized only fixed Kiel-type pressure probes and shielded thermocouples. Some of this instrumentation can be seen in Figure 25 which is the interstage nozzle assembly. A full map of turbine performance was obtained without adjustment of the probes, a procedure which was satisfactory except for the power turbine exit (Station 7.0) where at some operating conditions the incidence is beyond the probes' $\pm 25^\circ$ yaw insensitivity range. However, these conditions occur only at rotative speeds away from the maximum efficiency point.

Tests were conducted by setting stage total-to-static pressure ratio, inlet temperature, and variable nozzle angle and then recording data at a range of rotative speeds. This procedure was repeated until a full range of engine conditions was covered.

In the initial cold test, leak paths were sealed by incorporating a stationary dummy regenerator (no matrix) sealed with gaskets, and by the use of wax in other areas. Under these conditions, the static and total pressure instrumentation at Station 6.0 (interstage inlet) were calibrated for use as a turbine stage flowmeter. This was needed for hot testing where regenerator and other seal leakages would exist. The calibration obtained is shown in Figure 26.

Stage flow characteristics for both the hot and cold tests at 80 and 100% speed design pressure ratio settings are shown on Figures 27 and 28, respectively. At design nozzle settings, these show the flow to be about 20% too high at 80% speed and 13% too high at 100%. To match engine flow conditions, therefore, the stage would have to operate 5 to 7° closed from design intent, which generally agrees with engine test experience.

Overall total-to-static ($6 T_{8s}$) efficiency maps for the room temperature tests are shown on Figure 29. Also superimposed are hot test data points for the 80% speed 32° condition. Hot 100% speed test points were in the range of the cold data, but because of a high scatter are not shown.

Interstage duct and exhaust diffuser performance is illustrated in Figures 30 and 31 for the cold and hot tests, respectively. Exhaust diffuser performance is somewhat in doubt, since high swirl can be generated at the power turbine discharge, and may be beyond the yaw insensitive range of the fixed exit Kiel probes. The increased performance of the interstage duct as the power turbine nozzles are closed down may be due to a decrease in duct Mach number (.62 versus .45 at 41° and 29° nozzle angle, respectively. Calculated regenerator and seal leakage bypassing the turbine stage varied from about 3 to 6 percent as shown on Figure 32.

Regenerator Flow Distribution

Initial tests on the High Pressure Side Flow Rig (Figure 31, Nineteenth Quarterly Report) indicated a distribution, as shown in Figure 33a, with appreciably lower flow in the peripheral area of the regenerator than at the center. In an effort to uniform the flow, several attempts at tapering the cover inner wall to restrict flow from the core center were tried with little success. However, installation of a circular wall 8 in. radius x 3/4 in. wide extending to within 5/8 in. of the regenerator surface was effective. A photograph of the wall as clayed in for these flow tests is shown in Figure 34. The measured flow distribution is shown on Figure 33b.

Steps are currently being taken to mold such a wall to a regenerator cover of Sylgard 186 elastomer (material used for attaching the ring gear to ceramic regenerator) for testing both on the NASA-Lewis Regenerator Test Rig, and program engines.

Gas Bearing Development

Reports on simulator testing with a front oil damper bearing indicated the quad-section elastomer rings on this bearing gave as good stability and performance as the cut away o-rings. MTI recently noted, however, that January, 1977, data showed satisfactory oil bearing damper motion could not be obtained with the quad rings. The difference in the results is attributed to the rotor unbalance level, which was 0.003 oz. in. at each plane in January, but was recently changed to 0.005 oz. in. This may be sufficient to affect the motion of the damper as a result of changes in dynamic motion and force at the oil bearing.

A new front oil bearing/damper assembly was installed following the seizure reported previously. The same gas bearing was used and the unbalance set at 0.006 oz. in. Initial runs up to 45,000 rpm showed very low oil damper motion ($< 50 \mu$ -in.) and some subsynchronous motion decreased; however, the gas bearing failed at design speed.

Investigation of the test tape recordings showed the rotor orbit to be 0.001 in. at each end and no abnormal rotor motion or mode was noted prior to the seizure. Some welds holding bearing components to the cartridge had separated; however, it was not clear if this was a cause or result of the failure. This gas bearing had about 100 hours running time with 200 start-stop cycles.

Further study of the test data will continue, but funds for simulator testing under this task are exhausted and no further runs are planned.

Carbon ring seals have been ordered under MTI's Task 2. These will accommodate instrumentation if it is found necessary to investigate the influence of the seals as rotor/bearing exciters. It should be pointed out that significant wear of the rear seal has been noted during power plant operation. The vendor for the seal is investigating the possibility of a seal discrepancy.

Chrysler is processing journals with low porosity chrome carbide and tungsten carbide/cobalt coatings. These will be sent to MTI for evaluation in their start/stop test fixture under Task 3.

Three air bearing sets have been rebuilt by MTI and received by Chrysler.

A gas bearing failure was encountered in Power Plant 2-3 AQ during 90% speed general performance testing. The bearing, with 106.9 hours of operation, has been returned to MTI for investigation. The bearing and sleeve are not repairable; however, secondary damage was limited to the midshaft and rear seals and light compressor and turbine tip rubs.

The proposed increase in vortex chamber size and the change in the gas flow passage just forward of the first stage nozzle will reduce the insulation thickness on the rear bearing carrier of the gas generator. Therefore, bearing carrier temperatures were measured to determine if excessive temperatures might be expected from the reduced insulation. The results are shown in Figure 35 along with the temperatures calculated during thermal studies. Note that the measured temperature (640°F) at the rear of the carrier checks well with the calculated temperature (645°F) despite the lower measured gas temperatures. However, the measured temperature (600°F) near the front of the carrier on the outer surface appears high when compared with

the calculated temperatures of 400 and 345°F which were inboard of the thermocouple location. Oil cooling in the cavity should produce a radial gradient, but a difference of 255°F would not be expected. No evidence of varnish has been observed in the inner surface of the bearing support, indicating the temperature to be below 450°F. Additional thermocouples will be installed to verify temperature levels in this area.

Control System

A position loop nozzle actuator control program was developed for the electronic control unit (ECU). The new nozzle actuator incorporates a position sensing linear solenoid to achieve stable closed loop control of engine temperature. Following successful bench check of the system, the actuator was installed on Power Plant 2-3. Initial steady state T₈ tracking performance was good (see Figure 36). However, the position loop tracking was found to be sensitive to both changes in assembly and indexing of the servo valve linear solenoid valve. This necessitated tailoring of the ECU program whenever such mechanical adjustments were made.

Preliminary transient power and braking mode testing showed satisfactory actuator performance (see Figure 37). However, alternate control program routines must be applied for tighter T₈ tracking following a rotor accel. ECU program additions are also still needed for braking mode temperature modulation.

Of the five originally procured variable inlet guide vanes (VIGV), four actuators were found to have porous castings in the spool valve area. Oil leaks rendered these units unacceptable for use. Commercially, available anaerobic sealant was applied at a commercial source without improvement. Repetition of the process in the laboratory using a vacuum pump to draw the sealant into the porous metal eliminated leakages in three units. Porosity in the fourth unit is causing leakages past the spool valve which can be eliminated only by repairing still porous spool valve porting.

Present status of actuators:

- # 1 Porous valve seat
- # 2 To be assembled for test.
- # 3 Converted to 2 position actuator; car 649.
- # 4 Converted to 2 position actuator; car 386.
- # 5 Assembled for test.

TASK 8.2 BUILD UPGRADED VEHICLES

Car 385

The mock-up engine has been reinstalled and reassembly of the vehicle has been initiated.

Car 386

During this period, a number of corrections and improvements were made to the overall vehicle system. A reduced sensitivity brake pedal linkage was installed similar to that operating acceptably on Public Interest Car 685. Reduction gear noise was reduced by locating and stoning a chipped tooth. Corrections were made to insure proper alignment of the regenerator drive shaft oil seal. A VIGV system, together with a two-position actuator for low speed control, was installed. The engine was equipped with an air pump and Baseline type diffusion flame combustor for optimum system reliability during check-out and development of the overall control system. Also, a pancake motor-fan assembly mounted to the oil cooler is performing satisfactorily providing an additional 20°F ΔT .

TASK 8.3 UPGRADED VEHICLE EVALUATION

Testing currently being scheduled for Car 386 includes:

- Transient fuel and power turbine nozzle control
- Preliminary FDC emissions
- Power turbine/reduction gear sound evaluation
- Under hood temperature surveys
- Heater - A/C system evaluation

Correction

On page 28 of the Eighteenth Quarterly Report, under Task 8.3, the emission data for Upgraded Car 386 was incorrectly labeled. The HC parts per million should have been CO and vice-versa.

TASK 10.1 IMPROVED AUTOMOTIVE GAS TURBINE (IAGT) DESIGN STUDY

TASK 10.1.1 Establish Near Term Material Technology

- Superalloy-Base Materials

Conventional superalloys, directionally solidified eutectics, oxide dispersion strengthened alloys and tungsten fiber-reinforced superalloys were reviewed and compared on the basis of "turbine blade temperature capability". Today's best conventional cast superalloys are limited to an uncooled blade temperature of about 1000°C (1800°F). Wrought superalloys prepared by the usual forging or powder metallurgy techniques do not generally attain the strength of cast alloys in this temperature range. Recently, however, wrought alloys produced from powder prepared by a new rapid solidification rate process appear to have the potential of increasing the maximum temperature capability of superalloys by 50 to 100°C (90 to 180°F).

Significant increases in high temperature properties have been attained by applying the directionality concept to eutectic systems and tungsten fiber superalloy composites. Directionally solidified eutectics offer the possibility of blade temperatures 60 to 110°C (110 to 200°F) above those used for conventional cast superalloys. Although tungsten fiber reinforced superalloys afford potentially the highest use temperature capability of any of the superalloy-base systems studied for turbine blades, i.e. 1200°C (2200°F) plus, their application, because of cost and fabrication problems, is most remote. Advanced oxide dispersion strengthened alloys appear to have a potential-use temperature of about 1040°C (1900°F) for blades and up to 1230°C (2250°F) for lower stressed stator vanes.

Before most of the advanced superalloy-base materials studied in this report could be considered for a practical small automotive-size turbine wheel, many serious cost, design and fabrication problems would have to be solved. A near net shape integral wheel would avoid the intolerably high fabrication and assembly costs associated with the individual blade-type construction commonly used for larger aircraft-type turbine wheels. Two processes, investment casting and isothermal superplastic forging, have the potential to produce relatively low cost integrally bladed turbine wheels.

Politically generated uncertainties in the supply of key alloying elements, particularly chromium, and rapidly rising prices cloud the future for any large scale usage of superalloys in automotive gas turbines.

- Refractory Alloys

Five refractory metals; chromium, columbium (niobium), molybdenum, tantalum and tungsten, and their alloys have been critically evaluated to determine the most suitable for use as a turbine wheel material for the IAGT. A state-of-the-art review of high temperature properties, fabricability, and oxidation protection as well as current cost, availability and strategic importance has shown molybdenum alloys to be the most likely candidate. A composite TZM wheel, cast blade ring welded to a wrought disc, suitably coated for oxidation resistance, is thought to fill the design requirements for the high temperature engine. Coating development work would be required to insure adequate service life.

- Ceramic Material Candidates - Property Characterization

Material property characterization for high, medium and low-stressed turbine parts has been completed. Those materials emerging as having highest potential are hot isostatically pressed silicon nitride for medium and possibly highly stressed parts. For ceramic regenerators, most promising candidates are LAS/MAS and AS compositions. Subjects remaining to be evaluated include joining methods for ceramics, machining methods for ceramics, and raw materials and processing economics.

TASK 10.3 DEVELOPMENT OF SINTERABLE SILICON CARBIDE TECHNOLOGY (CARBORUNDUM SUBCONTRACT)

- Configuration Definition

Designs were established for a simulated axial rotor wheel, and the radial rotor wheel (Figures 38 and 39). Both designs incorporate a center, axial hole to facilitate binder bake out. The injection molding dies will have inserts which are radially pulled for molding of the simulated blade portion of each rotor. The radial wheel will have provision for two hub thicknesses and for two vane shapes, one of which will extend past the outer radius of the hub.

It was decided to utilize the Baseline Engine power turbine inner shroud (PN 2803136) as an initial simple slip cast vortex shape.

The full size metal vortex design is being used for development of a more closely simulated vortex shape.

- Tooling Fabrication

Injection molding tooling for the small test bar (2.5 x 5 x 50 mm) has been received ahead of schedule. Tooling for the large test bar (35 x 7 x 70 mm) is expected by October 30.

Designs for the simple axial and radial wheels have been sent out for quotes on die manufacture. Delivery of tooling is expected by mid-December.

A power turbine inner shroud part was supplied by Chrysler to provide the model for fabrication of molds for the simple vortex shape.

- Fabrication Technology

Cold Pressing

Material preparation has continued for cold pressed test specimens.

Injection Molding

An initial study utilizing a spiral flow die with standard material examined: (1) hot mixing only, Batch 1, versus hot mixing and extruding/pelletizing, Batch 2, (2) molding nozzle temperatures, and (3) molding pressures. The maximum flow conditions of 290°F and 5000 psi (Gauge 1000 psi) will serve as a guide for other dies. Additional extruding/pelletizing did improve the flow characteristics but not the visual appearance of the samples. Further work utilizing strength and subsequent failure analysis will be conducted.

Additional mixing and molding studies were performed utilizing a four cavity test bar die (2.5 x 2.5 x 25.4 mm sintered size). This die was used to determine uniformity of flow into the four cavities under various temperatures and pressures. The most consistent and highest "molded" densities were obtained at a minimum of 290°F and 5500 psi (Gauge 1100 psi).

Casting

The cast test bars will be cut from drain cast, flat sided crucibles. Attempts will be made to cast ridges into the plaster

mold to provide the test bar edge chamfers. The mold side of the bar will be the tensile surface during the flexural strength test.

Simple rectangular molds were prepared along with casting slips with two different degrees of deflocculations end points (650 and 1250 cps) at 65% solids content. A series of blends will be cast to quantify release from mold walls and degree of brittleness in the dried material.

Molds for the power turbine inner shroud shape were begun.

TASK 10.4 EVALUATE HIGH TEMPERATURE CERAMICS

Test bar quotations from GTE Sylvania (sinterable silicon, nitride), Kawecki Berylco (reaction sintered silicon nitride), General Electric (Si/SiC composite) and Norton Company (hot pressed silicon nitride and reaction bonded silicon nitride) have been received; a quotation from AiResearch Division of Garrett is expected soon. Ordering of test bars, based on these quotations has begun.

FUTURE ACTIVITIES

In the next quarter, it is anticipated that:

- The NASA testing of the Upgraded Engine and the regenerator rig will be underway.
- Fabrication of the corrective development test rigs will be nearing completion.
- Corrective development of the Upgraded Engine will be continuing. Aerodynamic component designs will have been completed and procurement will be in process.
- The last of the Upgraded vehicles will be built and under development.

APPENDIX A

DOE CONTRACT NO. EY-76-C-02-2749.A006

TWENTIETH QUARTERLY REPORT

FIGURES

LIST OF FIGURES

FIGURE

- 1 Exhaust Emissions for Peanut Oil
- 2 Exhaust Emissions for Peanut Oil
- 3 Public Interest Car
- 4 Public Interest Car
- 5 Public Interest Car
- 6 Public Interest Car
- 7 MTI Test Assembly
- 8 Engine Status
- 9 A-926 Ceramic Regenerator Status as of October 18, 1977
- 10 Upgraded Engine, Braking Mode - 50% Ngg
- 11 Upgraded Engine, Braking Mode - 50% Ngg
- 12 Upgraded Engine, Braking Mode - 50% Ngg
- 13 Emission Performance, Droplet vs. Prevaporized Concept
- 14 Upgraded Engine, Vortex Chamber Configurations
- 15 Upgraded Engine, Compressor-Turbine
- 16 Upgraded Engine, Mod 3 Compressor-Turbine Nozzle
- 17 Upgraded Engine, Mod 3 Compressor-Turbine
- 18 Upgraded Engine, Mod 3 Compressor-Turbine
- 19 Revised Upgraded Engine, C.T. Rotor Blade Section at Hub
- 20 Revised Upgraded Engine, C.T. Rotor Blade Section at Mean
- 21 Revised Upgraded Engine, C.T. Rotor Blade Section at Tip
- 22 Regenerative Power Turbine Test Rig
- 23 Regenerative Power Turbine Test Rig - Instrumentation
- 24 Regenerative Power Turbine Test Rig - Exhaust Plenum Instrumentation
- 25 Interstage Nozzle Instrumentation
- 26 Flow Calibration Curve
- 27 A-926 Power Turbine Performance 80% Ngg Equivalent
- 28 A-926 Power Turbine Performance 100% Ngg Equivalent

LIST OF FIGURES (CONT.)

FIGURE

29	A-926 Power Turbine Performance
30	A-926 Power Turbine Performance
31	A-926 Power Turbine Performance
32	Power Turbine Test Rig Estimated Leakage
33	High Pressure Side, Regenerator Flow Distribution
34	Regenerator Cover With Flow Distribution Baffle
35	Upgraded Engine, Gas Generator Rear Bearing Carrier
36	Steady State T_8 Tracking
37	Rotor Acceleration T_8 Tracking
38	Ceramic Simulated Axial Rotor Wheel
39	Ceramic Simulated Radial Rotor Wheel

Figure 2

T-153

FIGURE 3
PUBLIC INTEREST CAR

FIGURE 4
PUBLIC INTEREST CAR

FIGURE 5
PUBLIC INTEREST CAR

FIGURE 6
PUBLIC INTEREST CAR

MTI TEST ASSEMBLY

PUMP-MOTOR UNIT OF
HYDROMECHANICAL TRANSMISSION

Figure 7

ENGINE STATUS

11/01/77

ENGINE	1	2	3	4	5	6	7	8E	9F	10F
P.P. No.:	3-9	4-2	2-3	5-4	6-8	7-6	8-10	1-7	9-11	10-12
Location/Usage	12S/Perf.	Car 386	4S/Cont.	NASA/Perf.	7S/PT Test Rig	NASA/Reg. Rig	Car 649	Lab/ Display	Car 385	Lab/ Perf.
Engine Housing No.:	3	4	2B	5	6	7	8	1	9	10
P.T. Nozzle	6	2	3	4	7	-	1	-	-	-
Gas Generator No.:	9	1	4	5	None	None	3	None		
CTW	112	111	123	117	-	-	110	-		
CTN	117	101	122	103	-	-	100	-		
Impeller	2	5	13	1	-	-	4	-		
VIGV	7D	3A	1D	4	-	-	5A	9		
Reduction Gear Assembly	2	1	3	4	7	None	8	6		
PTW	207	210	200	212	209	-	213	206		
Oil/Air Pump	1	51C	3	4	-	-	50C	6		
Regenerator	12	9	5	14	2	7	15			

NOTES:

- A - Functional Assembly
- B - "L" Seal System
- C - Working Air Pump
- D - Three Strut
- E - Partially Disassembled
- F - In Process

A-926 CERAMIC REGENERATOR STATUS AS OF OCTOBER 18, 1977

Serial #	Test Hours	ΔP "H ₂ O ^①	Mount Type ^②	Thickness	Location	Remarks
1	0	24	U	3.27	LAB	
2	21.0	25	E	3.27	PP 6-8 Room 7S	Repaired
3	5.1	25	E	3.27	LAB	Repaired
4	18.7	21	U	3.19	Creare	Resurfaced. At Creare for flow studies
5	241.1	21	E	3.27	PP 2-3 Room 4S	
6	< 0.1	18	E	2.87	Show Eng.	Resurfaced after glazing
7	0	22	E	3.27	PP 7-6 NASA	
8	< 0.1	19	U	3.07		Resurfaced after glazing
9	54.3	22	E	3.27	PP 4-2 Car 386	
10	< 0.1	20	U	3.00	LAB	Resurfaced after glazing
11	18.4	20	E	3.27	LAB	Room 6 Flow Fixture. Rough Surface.
12	111.4	21	E	3.27	PP 3-9 Room 12S	
13	0	21	E	3.27	LAB	
14	34.2 ^③	20	E	3.27	PP 5-4 NASA	
15	24.9	22	E	3.27	PP 8-10 Car 649	
16	0	22	U	3.27	LAB	Aluminous Keatite Material
17	0	-	U	3.27	LAB	Aluminous Keatite Material
18	0	-	U	3.27	LAB	Aluminous Keatite Material

- NOTES: 1. Characterization ΔP 27" H₂O.
 2. E=Elastomer; U=Unmounted.
 3. Logged at Chrysler prior to shipment to NASA.

Figure 10

ET E-1129

Figure 11

ST E-1190

UPGRADED ENGINE
BRAKING MODE - 50% Ng8

room 4 S 07-19-77

PP 2-3 AJ runs 352-371

BRAKING TORQUE, LB-FT

T8= 1400 DEG. F. (85° DAY)
1300
1200

OUTPUT SHAFT SPEED, RPM

AT E-1191

Figure 12

EMISSION PERFORMANCE (OBSERVED)
DROPLET VERSUS PREVAPORIZED CONCEPT

△ DIFFUSION FLAME COMBUSTOR PP 8-10 F

X PRE-MIXED, PREVAPORIZED COMBUSTOR PP 2-3 AP

Figure 13

UPGRADED ENGINE

VORTEX CHAMBER
CONFIGURATIONS

Figure 15

UPGRADED ENGINE
MOD 3 COMPRESSOR-TURBINE NOZZLE
DESIGN-POINT ESTIMATES

Figure 16

UPGRADED ENGINE

MOD 3 COMPRESSOR-TURBINE

ROTOR EXIT
DESIGN-POINT ESTIMATES

Figure 17

UPGRADED ENGINE

MOD 3 COMPRESSOR-TURBINE

ROTOR EXIT RELATIVE AIR ANGLE & DEVIATION ANGLE ESTIMATES

Figure 18

REVISED UPGRADED ENGINE

C.T. ROTOR BLADE SECTION AT HUB

Figure 19

REVISED UPGRADED ENGINE

C.T. ROTOR BLADE SECTION AT MEAN

Figure 20

REVISED UPGRADED ENGINE

C.T. ROTOR BLADE SECTION AT TIP

Figure 21

FIGURE 22

REGENERATIVE POWER TURBINE TEST RIG

REGENERATIVE POWER TURBINE TEST RIG INSTRUMENTATION

Figure 23

REGENERATIVE POWER TURBINE TEST RIG EXHAUST PLENUM INSTRUMENTATION

STATIC TAPS

THERMOCOUPLES

VIEW LOOKING TOWARDS REAR

FIGURE 25
INTERSTAGE NOZZLE INSTRUMENTATION

STATION 6.0 PLANE

VIEW SHOWING SWIRL VANE ASSEMBLY

3/4 VIEW

KIEL TYPE PRESSURE PROBE AND
SHIELDED THERMOCOUPLE AT STATION 6.0

FLOW CALIBRATION CURVE

- TEST 2 ASSEMBLY PP 6-8 B
- room 7 S 09-17-77
- POWER TURBINE WHEEL 3813807 S/N 208
- POWER TURBINE BUILD TIP CLEARANCE .0173 in.
- POWER TURBINE BUILD RIM CLEARANCE .088 in.
- POWER TURBINE BUILD BEARING CLEARANCES .0024 and .0023 in.
- WAX USED ON STATION 6.0 RINGS TO INSURE SEALING
- DUMMY REGENERATOR (NO MATRIX)
- MECH. AND AERO WINDAGE LOSSES FROM ROOM 4 S TEST USED

Figure 26

A920 POWER TURBINE PERFORMANCE

80% NCG EQUIVALENT

- TEST 2 ASSEMBLY PP 6-8 B
- room 7 S 09-17-77
- POWER TURBINE WHEEL 3813807 S/N 203
- POWER TURBINE BUILD TIP CLEARANCE .0173 in.
- POWER TURBINE BUILD RIM CLEARANCE .088 in.
- POWER TURBINE BUILD BEARING CLEARANCES .0024 and .0023 in.
- WAX USED ON STATION 6.0 RINGS TO INSURE SEALING
- DUMMY REGENERATOR (NO MATRIX)
- MECH. AND AERO WINDAGE LOSSES FROM ROOM 4 S TEST USED

EX 4-39

1926 POWER TURBINE PERFORMANCE

100% KEG EQUIVALENT

- TEST 2 ASSEMBLY PP 6-8 B
- room 7 S 09-17-77
- POWER TURBINE WHEEL 3813807 S/N 208
- POWER TURBINE BUILD TIP CLEARANCE .0173 in.
- POWER TURBINE BUILD RIM CLEARANCE .088 in.
- POWER TURBINE BUILD BEARING CLEARANCES .0024 and .0023 in.
- WAX USED ON STATION 6.0 RINGS TO INSURE SEALING
- DUMMY REGENERATOR (NO MATRIX)
- MECH. AND AERO WINDAGE LOSSES FROM ROOM 4 S TEST USED

Figure 28

A926 POWER TURBINE PERFORMANCE

- TEST 2 ASSEMBLY PP 6-8 B
- room 7 S 09-17-77
- POWER TURBINE WHEEL 3813807 S/N 208
- POWER TURBINE BUILD TIP CLEARANCE .0173 in.
- POWER TURBINE BUILD RIM CLEARANCE .088 in.
- POWER TURBINE BUILD BEARING CLEARANCES .0024 and .0023 in.
- WAX USED ON STATION 6.0 RINGS TO INSURE SEALING
- DUMMY REGENERATOR (NO MATRIX)
- MECH. AND AERO WINDAGE LOSSES FROM ROOM 4 S TEST USED

CHAS H-34

TEST 2 ASSEMBLY PP 6-8 B
 ROOM 7 S 09-17-77
 POWER TURBINE WHEEL 3813807 S/N 208
 POWER TURBINE BUILD TIP CLEARANCE .0173 in.
 POWER TURBINE BUILD RIM CLEARANCE .088 in.
 POWER TURBINE BUILD BEARING CLEARANCES .0024 and .0023 in.
 WAX USED ON STATION 6.0 RINGS TO INSURE SEALING
 DUMMY REGENERATOR (NO MATRIX)
 MECH. AND AERO WINDAGE LOSSES FROM ROOM 4 S TEST USED

ET H-48

Figure 30

A926 POWER TURBINE PERFORMANCE

STATIC PRESSURE RECOVERY AND LOSS CHARACTERISTICS

- TEST 3 ASSEMBLY PP 6-8 C
- room 7 S 09-27-77
- POWER TURBINE WHEEL 3813807 S/N 208
- POWER TURBINE BUILD TIP CLEARANCE .0173 in.
- POWER TURBINE BUILD RIM CLEARANCE .088 in.
- POWER TURBINE BUILD BEARING CLEARANCES .002 and .0023 in.
- CYCLE STATION 6.0 INLET CONDITIONS SET
- CERAMIC REGENERATOR S/N Z
- MECH. AND AERO WINDAGE LOSSES FROM ROOM 4 S TEST USED

C_p - EXHAUST DIFFUSER

$$C_p = \frac{P_{s8} - P_{s7}}{P_{t7} - P_{s7}}$$

C_p - INTERSTAGE DUCT

$$C_p = \frac{P_{s6.3} - P_{s6}}{P_{t6} - P_{s6}}$$

ω INTERSTAGE DUCT

$$\omega = \frac{P_{t6} - P_{t6.3}}{P_{t6} - P_{s6}}$$

- ◇ 50% NEG 32° PTN ANGLE
- 80% 32°
- ▽ 80% 34°
- × 80% 36.5°
- ⊙ 100% 32°
- 100% 34°
- ▽ 100% 36.5°

POWER TURBINE SPEED, RPM $\times 10^{-3}$

ET H-44

POWER TURBINE TEST RIG ESTIMATED LEAKAGE

- TEST 3 ASSEMBLY PP 6-8 C
- room 7 S 09-27-77
- POWER TURBINE WHEEL 3813807 S/N 208
- POWER TURBINE BUILD TIP CLEARANCE .0173 in.
- POWER TURBINE BUILD RIM CLEARANCE .088 in.
- POWER TURBINE BUILD BEARING CLEARANCES .002 and .0023 in.
- CYCLE STATION 6.0 INLET CONDITIONS SET
- CERAMIC REGENERATOR S/N Z
- MECH. AND AERO WINDAGE LOSSES FROM ROOM 4 S TEST USED

87 H-41

Figure 32

HIGH PRESSURE SIDE

REGENERATOR FLOW DISTRIBUTION

A. STANDARD COVER

B. MODIFIED COVER

Figure 33

FIGURE 34

REGENERATOR COVER WITH FLOW DISTRIBUTION BAFFLE

Figure 35

STEADY STATE T_8 TRACKING

PTN angle vs Ngg
A-926 Optional PTN Actuator 951-2063

Room 43 10-10-77
Steady state: T_8 tracking
Dither: yes
 T_8 = 1350 OF
 T_1 = 80 OF

Figure 36

ROTOR ACCELERATION T_8 TRACKING

Figure 37

Figure 38

Figure 39

APPENDIX B

DOE CONTRACT NO. EY-76-C-02-2749.A006

TWENTIETH QUARTERLY REPORT

OCTOBER 31, 1977

PROGRAM PLAN PROGRESS CHARTS

TASK/DESCRIPTION	1977												1978												NOTE	%
	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J											
Task 7.5 -- Upgraded Engine Corrective Development																										
A. Provide Test Rigs																										
Task 7.5.1 Non-Regenerative Rig																										
Task 7.5.2 Regenerative Power Turbine Rig																										
Task 7.5.3 Vortex/Nozzle Flow Rig																										
B. Design and Analyze Improvements																										
Task 7.5.4 Compressor																										
Task 7.5.5 Compressor Turbine Stage																										
• Vortex																										
• Nozzle																										
• Wheel																										
Task 7.5.6 Power Turbine Stage (N.P.T.)																										
• Initial Assessment																										
• Preliminary Design																										
• Detail Design																										
• Fabrication																										
Task 7.5.7 Regenerator																										
• Flow Distribution																										
• "L" Seals																										
Task 7.5.8 Burner																										
Task 7.5.9 Control System																										
Task 7.5.10 Mechanical Components																										
C. Development Testing																										
Task 7.5.11.1 Engine Tests																										
• Compressor Impeller/Diffuser																										
• Fuel Economy																										
• Plastic VIGV and Actuator																										
• Rotor Bearings																										
• Power Turbine Stage (N.P.T.)																										
Task 7.5.11.2 Turbomachinery Rig Tests																										
• Non-Regenerative Rig																										
• Regenerative Power Turbine Rig																										
• Vortex/Nozzle Flow Rig																										
Task 7.5.11.3 Regenerator Rig Tests																										
• Flow Distribution																										
• "L" Seals																										
Task 7.5.11.4 Bench Tests																										
Task 7.5.11.5 Ordering, Documents, Build-up																										

#1 D=Design; P=Procure and Assemble

[illegible]