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THIRD QUARTERLY PROGRESS REPORT

BASELINE GAS TURBINE DEVELOPMENT PROGRAM

CONTRACT NO. 68-01-0459

JULY 31, 1973

PREPARED FOR

ENVIRONMENTAL PROTECTION AGENCY

DIV. OF ADVANCED AUTOMOTIVE POWER SYSTEMS DEVELOPMENT

CHRYSLER CORPORATION

Engineering and Research Office
Detroit, Michigan 48231

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PREFACE

The Division of Advanced Automotive Power Systems Development (AAPSD) of the Environmental Protection Agency (EPA) has a program for developing and demonstrating automotive powerplants which might be considered as an alternative to the Otto cycle. Correspondingly, one of the areas of intensive AAPSD activity has been the Brayton Cycle or more specifically the automotive gas turbine. In support of this activity, EPA, beginning in early 1971, has let several contracts for technological improvements in the area of combustion and for determining optimum cycles and high volume engine cost potential. Additionally, NASA Lewis has been contributing to the Program through an inter-agency agreement.

On November 22, 1972, Chrysler Corporation contracted to support this activity by carrying out a Baseline Engine program. The goal of this program is to demonstrate by 1976 an experimental gas turbine powered automobile which meets the 1976 Federal Emission Standards, has significantly improved fuel economy and is competitive in performance, reliability and potential manufacturing cost with the conventional piston engine powered, standard-size American automobile.

Specifically, component improvements resulting from the technology contracts, NASA programs, and Chrysler's efforts are being evaluated and developed in automotive gas turbine engines and vehicles.

Chrysler Corporation's sixth generation automotive gas turbine engine is the Baseline Engine. This is a 4:1 pressure ratio regenerative engine with variable power turbine nozzles which meets the 1975 emissions standards. Baseline Vehicles are intermediate-size, 4-door sedans modified to accept the turbine engines.

The program, which is scheduled to run for 3-1/2 years, also calls for an Upgraded Engine design. This will incorporate a selection of improvements best able to achieve overall program goals. Building and vehicle demonstration of the Upgraded Engine is to conclude the program.

Chrysler Corporation efforts are being managed and coordinated by the Research Section of the Engineering and Research Office.

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INTRODUCTION

This is the third quarterly report of the Baseline Engine Program, EPA Contract No. 68-01-0459. It covers work done during the period May through July, 1973.

The Program Plan has been revised to reflect the change in the nature of the regenerator development (Task 5.2) from a two-part effort involving metal and ceramic regenerators to a ceramic-only program as described in the previous quarterly report. Additionally, the control system effort (Task 5.3) was delayed and restructured so as to be compatible with anticipated Modification 3 fuel economy improvements; the combustion system effort (Task 5.1) was made consistent with the Solar schedule; and the design of a solid disc wheel was added to the turbine wheel evaluation effort (Task 5.4). The program for improving fuel economy will be included when the contract modification details are completed. This will detail efforts towards higher temperature operation, use of variable inlet guide vanes and water injection, and support to NASA aerodynamic component upgrading.

Tasks 1 and 2 continue to be paced by the availability of hardware. Procurement difficulties have been receiving a great deal of vigorous attention during the period, but a continued high level of effort in this area will be necessary to maintain the present schedules.

The first new engine built under the contract was delivered during the period; and major milestones were passed in the completion of the design of the vehicle installation, the completion of the conversion and qualification of the final test cell, and the completion of the vehicle chassis and structural modifications.

Program progress utilizing loaner engines has continued. Endurance testing of improvements by Chrysler to the basic program engine, development efforts toward a variable geometry combustor control, and extensive efforts in test and evaluation of the free gas generator rotor concept have taken place.

Support was continued to NASA and EPA in such areas as personnel training and familiarization, consultation on and discussion of development concepts and hardware requirements, and program presentations.

PROGRESS SUMMARY

- Procurement delays have caused an additional one-month slippage in engine deliveries.
- All test cell conversion and preparation tasks are complete.
- Assembly, qualification and delivery to NASA of Engine 3 were accomplished.
- Vehicle installation design tasks were completed.
- Vehicle structural modifications were completed.
- Initial operation of the first vehicle has slipped two weeks due to engine delivery schedule changes.
- The planned training activity for the NASA technician took place.
- Endurance activity has included continued testing of molded insulation and the start of testing of new coarse pitch regenerator drive gears.
- Testing of a variable geometry combustor for control schedule optimization started.
- The all-ceramic regenerator core program has been formulated and work started on design and fabrication or procurement of core, drive and seal hardware required specifically for these cores.
- The integrated control system sub-contract is delayed pending resolution of the adjustments to the scope of work for requirements associated with contract Modification 3.
- An elasto-plastic stress analysis program is being written in support of design efforts associated with the low cost turbine wheel manufacturing process development.
- The torque converter lock-up program has been defined and hardware procurement started.
- The original test request for free versus geared gas generator rotor evaluation was completed. Preliminary analysis of the test results has taken place.
- Copies of Program Plan charts with heavied-in bars indicating progress and expenditures to date are shown in Appendix B. Copies of Estimated Manhour graphs with actual efforts indicated by parallel plots are shown in Appendix C.

DETAILED PROGRESS STATEMENT BY TASK

TASK 1 FURNISH 7 ENGINES

Procurement and Component Preparation

Difficulty continued to be experienced in the procurement of engine hardware. Acquisition of acceptable castings has been the major difficulty with the gas generator bearing support and the power turbine nozzle outer shroud being the most significant critical items. Current vendor promise dates indicate availability of the remaining program hardware required to begin assembly of Engine 5 by mid-August with the exception of the machined power turbine nozzle shroud and the diffuser plate. No definite date for the shroud can be determined until the casting source is able to produce acceptable parts. Three weeks will be required to machine the shroud, after receipt and acceptance of a casting. A part from existing inventory is presently being inspected, and this shroud will be made available to the program if it proves to be usable. In an effort to accelerate availability of the diffuser, Chrysler has authorized procurement of parts from a second source. This vendor's tooling is in process of approval inspection.

The following are the latest vendor commitments:

P/N	Description	Promise Date
2803102	Engine Housing (5th Engine)	8/17/73
2803188	C/T Nozzle	7/28/73
2803348	Wheel, Regenerator Drive	8/ 1/73
2803349	Worm, Regenerator Drive	8/ 1/73
2804109	Compressor Bearing Housing	7/27/73
2804113	Diffuser Plate	No Date
2804447	Shroud, P/T Outer	No Date
2803136	Shroud, P/T Inner	7/ 2/73

Fabrication, brazing, and machining of regenerator cores has been proceeding. Development of the new brazing slurry progressed to permit brazing three new cores during the period. Two of these exhibited voids in the rim to expansion strip joint. The third core was acceptable as is. The Metallurgical Research Department repaired the two unsatisfactory units. All cores assembled from now on will have the rim to expansion strip areas pre-coated with a copper suspension to avoid this problem. The supply of cores is sufficient to support the engine assembly schedule.

Burner Development (Chrysler Funding)

Final development of the burner for the Baseline Engine is nearing completion. The major area of concern was carbon formation sustained at 100% speed. This has been reduced to trace amounts by a minor redesign of the region near the fuel nozzle. The design is shown in Figure 1. Durability tests of this burner will begin shortly, and starting tests at cold ambients are in progress.

Emission tests of a Chrysler turbine vehicle with the baseline burner have been performed to determine test-to-test variability and the effects of various engine variables on emissions. Results are being analyzed. Experience is being gained with a heated FID for determination of hydrocarbons in turbine exhaust.

Test Cell Preparation

Conversion of the second engine test cell was completed during the reporting period. This effort included finalizing the lubrication and fuel system plumbing and the electrical and instrumentation requirements. The cell was initially checked out with Engine 2, the second Chrysler loaner. When all checkout and debugging activities were complete, program Engine 4 was installed.

Engine 2

An engine performance run was made on this powerplant prior to its being installed in the second converted test cell in order to provide a basis for evaluation of the new facility. The engine has subsequently been removed from the new cell, returned to the Build-Up Room and disassembled for inspection. Its suitability for future use on the program will be dependent upon the results of the inspection.

Engine 3

Completion of the assembly of Engine 3, the NASA powerplant occurred the final week of May. This effort included the installation of the basic instrumentation required by the NASA program. Three thermocouples and three total pressure probes were installed in the interstage ahead of the power turbine nozzle. One pair of these is shown in Figure 2. Four platinum-rhodium thermocouples were installed at the first stage turbine inlet, and a burner discharge total pressure probe was installed in the vortex downstream of the burner exit. In addition to the above, compressor inlet and outlet temperature and pressure instrumentation was installed; and provisions were made for installation of regenerator temperature measuring grids. The grids were fabricated but not installed. Figure 3 illustrates this instrumentation package.

During the initial run-in period, horsepower was low (approximately 15 horsepower) and could not be stabilized. In bringing the engine up to power:

1. Regenerator seals were freed up (stability, +5 hp).

2. Repair work was done incidental to an oil pump failure (made with incorrect material).

3. An assembly error resulting in irregularly set power turbine nozzle vanes was corrected (+5 hp).

4. A compressor rotor made from new tooling was replaced by an older one from stock with less sharp leading edges (+5 hp). This matter is currently being investigated.

Results of final performance and emissions tests are shown in Figures 4, 5, 6, 7, and 8. It should be noted that the engine was qualified and will be operated initially at NASA Lewis with the older three-piece Chrysler combustor, not the current released lower emissions design which meets the 1975 Federal Emissions Standards. This approach was taken because the newer burner is still in development for consistency of operation and demonstration of life. As soon as the NASA facility is operating, the burner delivered with the engine will be replaced with the later version.

The engine was removed from the test cell on July 20 and shipped to the NASA Lewis Research Center on July 25. They are being supplied with a complete set of engine records and documentation.

Engine 4

A decision was made to use the engine housing which had been sent to Solar and subsequently returned as the basis for Engine 4 rather than the housing which had been started through assembly. The returned housing, not required at Solar at this time due to changes in the program, was equipped with a complete second stage nozzle whereas the original Engine 4 housing lacked this assembly and hardware. Deliveries of the nozzle details were behind schedule. Assembly of the engine was completed utilizing a substitute existing gas generator, and the engine was delivered to the test cell. The gas generator substitution was required due to the difficulty experienced in obtaining gas generator bearing support castings as reported above. The present program schedule shows this engine retrofitted with the latest gas generator hardware by the end of the first week in August. Testing to date has shown the engine to be producing marginally acceptable power (approximately 145 hp) and otherwise operating satisfactorily. A complete performance map will be taken with the final hardware installed. The engine will be installed in Vehicle "A".

TASK 2 FURNISH 3 VEHICLES

Vehicle Installation Design

The powerplant-to-vehicle installation design effort was completed during this quarter. Completion of the air intake system adaptation and details of the engine and transmission oil coolers and the air conditioning condenser in the Plymouth vehicles were the major items finished. Additionally, design efforts in support of the electrical system, air conditioning and heating system, and other vehicle interface details were made. Figure 9 illustrates the final installation design.

Vehicle Modification

All structural and sheet metal modifications were completed by the vendor on Vehicles "A", "B", and "C" during the reporting period. Vehicles "A", "B", and "C" were delivered to the Applied Research Development Department on June 15, July 13, and July 27 respectively. These modifications included, in addition to the structural and sheet metal changes, installation of the suspension and steering linkage systems and the build up and installation of body related portions of the air intake systems.

Vehicle Build-Up and Assembly

Engine and vehicle system installation efforts have been proceeding on Vehicle "A". A mock-up powerplant was installed in the car immediately upon its receipt at the laboratory. This required some minor "fitting" due to a close vertical stack-up between the vehicle structure, required ground clearance, and the existing hood line. The hydraulic brake booster and master cylinder was installed, and the brake system plumbing adapted.

Engine and transmission oil coolers were mounted; and the hydraulic lines necessary for power steering, brake booster, and engine and transmission cooler plumbing were mocked-up. These models are being used for the fabrication of the required appropriate types and grades of hose assemblies for final installation. The steering column assembly was completed which adapts the "can" type energy absorbing column to the revised steering gear location, and the unit was installed in the vehicle. Numerous details of bracketing, plumbing, and mounting of control and accessory items have taken place.

Engineering Support

The Instrument Panel Department completed the instrument cluster for Vehicle "A". Buildup of the remaining clusters is near completion.

The Air Conditioning and Heater departments have built the first vehicle system and have been supporting the initial installation of the system components in the car. This has included revising the porting on the gas-to-water heat exchanger to facilitate installation in the available space and the fabrication of plumbing and brackets required to make the system operable. In the meantime, life testing of the heater/air conditioning controls has been taking place with particular emphasis on the hot gas control valve and automatic water temperature control components.

The Transmission Department has assembled and tested the three vehicle transmissions and delivered these to the program.

The Brake Department acquired the hydraulic booster system components. Initial testing revealed a hysteresis problem necessitating return of the components to the vendor for rework. This was done and the parts re-tested, accepted, and delivered to the program.

The Wiring Department has commenced build-up of the first engine compartment harness. The vehicle body harness also is being revised to reflect the relocation of some items, the additional heater and air conditioning system components, and the changed routing of the headlight harness due to the intake system.

The Sound and Vibrations Department has been fabricating body sound barrier details and assisting in their installation. This will result in the program vehicles being upgraded to the same or higher level as planned for Corporate 1975 "B" body intermediate cars with regard to passenger compartment noise control.

Miscellaneous

The powerplant for Vehicle "A" is expected to be available by the end of the second week in August. The car is scheduled to operate for the first time approximately August 20.

TASK 3 SUPPORT TO THE GOVERNMENT

Training

A NASA Lewis technician spent in excess of four weeks at the Applied Research Development Department of Chrysler in order to become familiarized with the sixth generation gas turbine. He was exposed to both build-up procedures and engine operation during the time spent in the department and was provided with soft-ware required to support his activities at NASA Lewis.

EPA Contractors' Coordination Meeting

A presentation on gas turbine emissions, discussing burner fixture versus cycle characteristics, and a three-part progress report on the Baseline Engine Program were made in support of the EPA June 1973 Contractors' Coordination Meeting in Ann Arbor. In addition, two Chrysler Turbine Cars (a 50-car program vehicle and the sixth generation engine powered Dodge) were made available for demonstration ride-drive programs during the three-day conference.

Surplus Material

Per direction of the Government Property Officer, the three original vehicle piston engines were shipped to NASA Lewis. The shipment included the complete powerplants with transmissions, cooling systems, and accessories.

TASK 4 ENDURANCE

The endurance engine and facility continued to be utilized for the evaluation of the proprietary molded insulation. The engine was operated for approximately 40 hours with the replacement power turbine insulation biscuit. Inspection showed the biscuit to be in very good condition with the exception of one small area of distress again attributable to a tool mark. The vendor, after examining the part, requested a minor design change which will permit easier removal of the mold and eliminate the source of the tool marks. This change was made, and parts are to be fabricated in the next several weeks for further evaluation. The burner cover biscuit has acquired approximately 42 hours of operation and is in good condition. Temperature data indicate a requirement for more extensive instrumentation in order to properly evaluate the insulating characteristics of the material. Further activity is planned after a new power turbine biscuit is available and the burner cover more thoroughly instrumented. In the meantime, preliminary discussions have been held with the vendor with regard to procuring insulation biscuits for the main engine housing.

Currently on test are the new coarse pitch regenerator drive gears. Following 200 hours of endurance testing, inspections showed no measurable wear on the pinions but some wear on the gears. The parts were re-installed, and a third 100-cycle test segment started.

At the completion of this third 100-hour segment, one of the ring gears will be replaced with one having an electroless nickel plate to evaluate this process as an aid in wear reduction. The endurance engine now has accumulated 3,267 hours of running including 26,699 starts and 2,777 endurance cycles.

TASK 5 COMPONENT DEVELOPMENT AND EVALUATION

5.1 Variable Geometry Combustor Control

The proprietary variable burner was installed in Engine 2 (second loaner) for continued efforts towards the development of a variable burner control. Testing was started to determine the optimum control positions for burner emissions. Tests were run from 50% to 75% gas generator speed. Higher speed tests could not be conducted due to durability problems with the development burner assembly. Additional efforts will take place when either the proprietary burner development has progressed to the point where continued testing is practical or Solar hardware is available.

5.1 Solar Combustion System

A review of Solar's progress and program was held on July 11, 1973. Their Phase II variable geometry combustor is scheduled to be delivered to Chrysler by October 1. The unit as currently configured will require an eleven-inch diameter chamber. Consequently, for initial evaluation on control system development, it will be adapted exterior to the engine housing.

5.2 Ceramic Regenerator

An all-ceramic regenerator program has been formulated. It consists of procuring and evaluating state-of-the-art cores, seals, and drives. Testing will be done in fixtures, engines, and vehicles; and based upon the results, an improved matrix may be specified, procured, and similarly evaluated.

All outside vendors and/or subcontractors pertinent to the execution of this sub-task have been contacted.

Initial testing will involve state-of-the-art cores from two vendors. An advanced matrix ceramic core is contingent upon the outcome of this testing and vendor capability.

A supplier of high-temperature elastomers has been contacted. They have offered their full cooperation in the design and fabrication of an elastomer mount for a metal drive gear on a ceramic regenerator core. They have given us samples of the materials necessary to fabricate the elastomer for our own experimentation.

A vendor has been contacted to treat our inner rubbing seal substrate materials with a coating to make them compatible with ceramic regenerator cores. They will use state-of-the-art $NiO-CaF_2$ coatings since this should provide adequate service life for the purposes of the program. However, vendor facility and equipment modifications will delay an initial delivery until October.

Most of the hardware design has been completed. Two different methods have been designed to mount the drive ring gear to the ceramic regenerator core. One design (Figure 10) is mechanical in nature and is a re-work of a ceramic core drive that was utilized previously for a regenerator test fixture. Alterations were necessary to use it in the Baseline Engine. The chances of success with this drive are very high since it is basically the same as that used earlier; however, it is not the preferred design due to mechanical complexity. This design has been laid out but must still be detailed. The other design (Figure 11) incorporates the elastomer material mentioned earlier. This high temperature silicon rubber serves both to transfer the drive torque from the gear to the core and also to take up the difference in thermal expansion between the metallic gear and the ceramic core. This gear mount is preferred over the mechanical because it is much simpler and should be less expensive. The supplier of the elastomer material gives the design a good chance of success. The detail drawings of this drive are nearly complete. Both gear mounts are interchangeable on the cores supplied by both vendors.

Engine adaptation of these assemblies requires slight seal modifications, a new center bearing, and spacer plates. Most of the necessary design work has been completed. Regenerator test fixture adaptation design has started.

5.3 Integrated Control System

Initiation of work by a subcontractor has been delayed pending resolution of effort, cost, and scheduling adjustments associated with additions to the scope of work. These additions were primarily due to contract Modification 3 (fuel economy improvement) which necessitated that an Upgraded system include control of variable inlet guide vanes and water injection. However, also specified was early delivery of a preprototype unit to establish required control parameters, and to evaluate emissions and driveability associated with various control concepts.

5.4 Low Cost Turbine Wheel Evaluation

The turbine wheel to be evaluated under this task is to be furnished from a separately funded EPA Technology Contract with Pratt Whitney. Fabrication is to be by means of their hot, isothermal forging process (Gatorizing). However, the ribbing under the rim of the wheel disc poses them with a difficult problem. To circumvent this, Pratt Whitney proposes that a solid disc design be considered. Ribbing is necessary in cast wheels to maintain integrity as low cycle fatigue rim cracking is encountered. However, measurements on material from their forging process indicate much higher levels of ductility than on castings. They are, therefore, providing Chrysler with complete sets of material properties from which solid disc designs will be attempted.

For this, a two-dimensional elasto-plastic stress analysis program is being written following a procedure outlined in a NACA paper by S. S. Manson. This program, which will include the effects of plastic strain and creep, will be used to study the low cycle fatigue behaviour of various disc profiles.

The elastic portion of the program is operational and the results have been verified. Programming of the plastic portion is currently in process.

5.6 Rotary Nozzle Actuator

The initial unit was tested after being repaired. Figure 12 shows the schedule of input and output angles. During this checking, the unit showed a deterioration in response. Inspection revealed contamination with sealing materials previously used to repair the unit. The actuator was disassembled, cleaned, and re-tested. Operation is now leak free with proper response. It will be functionally tested when one of the program engines is available for this development.

5.7 Torque Converter Lock-Up

The Transmission Design Department has determined that the most practical and economical method to evaluate the concept of a Torque Converter Lock-Up device is to adapt a commercially available unit to the turbine car transmission. This unit can be equipped with a control system which is switch actuated and may be operated at different throttle or speed conditions, providing the most flexibility for test operation.

The use of an off-the-shelf device, not considered suitable for normal passenger car application but capable of demonstrating actual performance and fuel consumption effects, will permit a proper and valid evaluation to be made at minimum cost and within the shortest possible time. The necessary hardware for this task has been ordered, and the program schedule indicates that the first unit will be ready for test by the first of October.

5.8 Free Rotor

Free Rotor is the identification given to the concept whereby all accessory drives (engine or vehicle) are removed from the gas generator rotor. A schematic of such an arrangement is shown in Figure 13. Apparent advantages of such a system would be:

- Reduced overall engine noise.
- Simplified gas generator design.
- Improved cold starting.
- Potential use of gas bearings.

Some apparent disadvantages are:

- Need for a variable speed power turbine accessory drive.
- Obsoletes use of low cost Baseline Engine control, which is a reliable, mechanically governed unit.
- May require starting aid (i.e. oil and air).

To date, evaluation of this concept has consisted of:

1. Comparative engine response tests.
2. Comparative low speed engine characteristics tests.
3. Variable power turbine accessory drive design and cost study.

1. Engine Response Tests

Engine response (torque vs. time) is of fundamental importance to an automotive gas turbine. It relates directly to vehicle driveability, and the most significant portion of emissions test cycle NOx is formed during the gas generator acceleration fuel delivery mode.

Initially, Chrysler funded a design analysis in support of this program which indicated that removing the accessory train from the gas generator would have little effect on response time. However, because of the importance of this conclusion and because the design analysis was based on an unproven quasi-steady-state characterization, an experimental verification program was undertaken.

A schematic of the powerplant, instrumentation, power turbine loading device and engine auxiliaries drive system for this test program is shown in Figure 14.

The engine output shaft is coupled to an automatic transmission, which is locked in direct drive.

For the free rotor mode, engine auxiliaries are driven by a 5 hp electric motor in line with the air pump drive shaft. Load simulation of engine auxiliaries transferred to the power turbine is accomplished by a D.C. generator and associated load bank. This generator is driven no-load for comparative geared rotor testing.

Both the response of the gas generator and engine output torque were measured. For the latter, the dynamometer shaft was locked to the case stalling the torque converter output. Torque converter input speed and stall torque were measured versus time.

An independently driven constant speed open loop fuel control meters the fuel for both geared and free rotor concepts. By changing a control orifice, four acceleration fuel schedules were provided (Figure 15). Schedule 3 is representative of the normal engine control. Since the fuel control is isolated from the engine, an electronic speed switch simulates governor fuel cut-off as the gas generator speed approaches its design value.

Typical transient results are shown in Figures 16, 17, and 18. Figure 18 are data traces for a free rotor engine acceleration. Figures 16 and 17 are comparative geared rotor traces for acceleration from comparable levels of idle temperature and idle power respectively. All three tests used the same fuel schedule, and all show a gas generator response time of 1.2 seconds (slope intercept method). Additionally, all showed a time to maximum torque converter stall of about 1.6 seconds indicating equivalent vehicle response.

Figure 19 shows the complete matrix of acceleration data. For geared rotor tests, the idle position of the nozzle was set to cover a range of T8. Each value of T8 was indicative of a specific idle power level, and would result in a higher torque converter input speed. At each T8 level, response was measured for each of the four fuel schedules.

For free rotor tests, idle nozzle position was set to give a desired level of power into the accessory load simulating generator. Torque converter input speed was held at approximately 600 rpm.

The main significance of Figure 19 is that with a hotter idle, a given acceleration fuel schedule will produce a higher T5 and a faster acceleration. When the power turbine nozzle moves from its idle to power position at the initiation of acceleration, the heat capacity of the regenerator maintains the burner inlet temperature at its idle level. Viewed in terms of maintaining a given level of acceleration temperature, running a hotter idle by a concept such as variable inlet guide vanes should result in less acceleration fuel flow. A lower level of fuel flow in itself would reduce NOx. Additionally, with a hotter burner inlet temperature, there is the possibility of additional NOx reduction by taking advantage of the potential for leaner combustion.

Another derivation of these tests is illustrated in Figure 20. This shows the compressor collector pressure during acceleration to be significantly higher than levels representative of steady state operation. The difference is attributable to cooling of the compression process by metal components as they absorb heat in approaching steady state temperatures.

The Baseline Engine hydromechanical control has limited adaptability for this type of test program. Consequently, Chrysler, on its own funding, is procuring an electronic acceleration fuel control which will incorporate a closed loop T5 control, with the level of T5 adjustable. Any future testing on this phase of this task will utilize this equipment.

2. Low Speed Engine Characteristics

Theoretical analysis indicated that a free rotor system has potential for lower idle fuel flow. Observation of data prior to rotor acceleration tests indicated a mixed trend. For clarification, therefore, the transmission was removed and complete BSFC maps were run for both concepts at 50% speed. T8 was varied from 1000°F/85 to 1300°F/85 at prop shaft speeds of 300, 600, 900, and 1200 rpm. The results are shown in Figures 21, 22, and 23. For Free Rotor test points, the normal gas generator driven engine auxiliaries (regenerator, lube pump, fuel control and air pump) were driven externally. This required approximately 1 hp at 50% speed; an amount of power which must be subtracted from measured free rotor output power for comparison with measured geared rotor data.

Such a comparison for points representative of 10 and 20 mph vehicle speed is tabulated in Figure 24. This shows no significant difference in fuel flow for comparable points. It is therefore concluded that the change in turbine stage power split associated with transfer of engine auxiliaries from compressor to power turbine has no significant effect on turbine efficiency.

Figure 25 is a layout of a fixed ratio belting arrangement for driving engine accessories, from the power turbine at 50% speed. This will be evaluated under Chrysler funding for the purpose of verifying assumptions regarding the load transferred from compressor to power turbine for a Free Rotor system.

3. Variable Speed Power Turbine Accessory Drive Design and Cost Study

A preliminary design and cost study of several proposed mechanisms to drive the engine and vehicle accessories on a Free Rotor engine has been made. Since the optimum speed range of the regenerator is from 10 to 30 rpm, it was necessary to devise a variable drive which would have a range of about 2.5:1 compared to the power section speed range of about 7:1. Many configurations of mechanical, electrical and hydraulic drives utilizing various combinations of belts, chains, gears, and clutches have been and are being investigated. These include two-speed gear and chain drives, variable friction drives, constant and variable speed electric motors, slip clutches, and hydraulic pump and motor drives. A hydraulic drive system was investigated and discarded as it would require a variable displacement pump to obtain reasonable efficiency. Systems of this type are both too large and too expensive for this application. Friction and/or controlled slippage clutch drives were abandoned due to size requirements and their inherent low efficiencies. Also considered and discarded was an electrical drive. The required sophistication and size of the motor was prohibitive.

Three of the most promising schemes are the "Variable Ratio Belt", "Selective Dual Chain", and "Dual Ratio Gear". These systems are shown schematically in Figures 26, 27, and 28. These systems would drive the fuel pump, lube pump, regenerator cores, air pump (if required), alternator, air conditioning compressor, and power steering pump.

In the Variable Ratio Belt system, Figure 26, a large cross-section V-belt running on pulleys with variable pitch diameters is used to drive the ancillary shaft. The driving pulley is driven by a gear in mesh with the intermediate gear in the compound reduction gear set. A chain from the ancillary shaft is used to drive the regenerator/lube pump shaft. A mechanical governing system to vary the drive speed is required. Service life of the drive belt under the temperatures and fluctuating speeds and loads is questionable.

The Dual Ratio Gear system, Figure 28, utilizes a planetary gear set mounted on the regenerator/lube pump shaft to give an automatic speed range selection at a predetermined output shaft speed. A sprocket on the planetary output is used to chain drive the ancillary shaft. The planetary system is governed by a hydraulic clutch via engine oil pressure similar to that used in automatic transmissions.

The Selective Dual Chain system, Figure 27, is similar to the Dual Ratio Gear system described above except that the planetary system is replaced by a simple hydraulic clutch mounted on the transmission input shaft. The hydraulic clutch operates in conjunction with an overrunning clutch to select one of two chain drives to the regenerator/lube pump shaft. From this shaft, an additional chain is taken to drive the ancillary shaft.

This combination of a free rotor and a variable speed accessory drive presents some significant functional implications:

1. A potential problem may exist as the lube and air pumps will not be operating during the starting cycle.

2. The drive systems are relatively complex

   (a) to control or govern,
   (b) to assemble, and
   (c) to service.

3. The drive systems will simplify the gas generator section.

   (a) Eliminates requirement for a separate bevel gear oil sump.

   (b) Elimination of worm gear and shaft housing complexities.

   (c) Shaft dynamics may be improved since worm diameter will not be a limiting factor on shaft stiffness.

   (d) Burner vortex design will not be compromised for the worm wheel.

A preliminary study was made of the relative cost of implementing the various systems based on a volume of 10^6 units/year not including tooling cost. It was assumed that there would be no fuel control cost change and no starting aid required.

Cost savings possible in the accessories, if they are driven through the variable ratio system, appear to be relatively small although an improvement in air conditioning performance is anticipated. A higher AC compressor speed at idle could increase the cooling capacity of the system at low speeds where additional cooling is desirable. This assumes that additional condenser capacity is available. No increase in maximum speed would result. A detailed analysis could indicate some cost savings in the clutch since the pulley size may be changed to permit more freedom in the clutch design.

A higher alternator speed at idle could permit the use of a lower capacity unit with a small savings in copper.

The final conclusion was that without considerable system integration, in the trade-off between a variable speed drive and a high speed gas generator reduction train, the former would be at a slight cost penalty. Of the three free rotor proposals, the variable ratio belt system incurs the least penalty (about 1% of engine cost) but has the lowest confidence rating. The penalty for the other two systems figured to be about 2% of engine cost. The dual ratio gear system offers the most positive drive system, has the least probability of failure, and would be the easiest system to design.

FUTURE ACTIVITIES

In the next period, it is anticipated that:

1. The first vehicle engine will be delivered to the program.
2. The first vehicle will be operated, and baseline testing will begin.
3. The 3500-hour endurance goal on the present endurance engine will have been attained.
4. Fixture evaluation of ceramic cores will be in process.
5. The control system sub-contract will be finalized, and work will commence.
6. The elasto-plastic stress analysis program will be complete, and design effort will be underway on the low cost turbine wheel.
7. Engine testing of the rotary nozzle actuator will take place.
8. Free rotor testing will continue (under internal funding) with particular emphasis on idle and light part-load fuel consumption effects.
9. Contract Modification 3 will be finalized, and design and procurement efforts started with particular emphasis initially on variable inlet guide vane evaluation.

APPENDIX A

FIGURES

Figure 1

BASELINE ENGINE BURNER

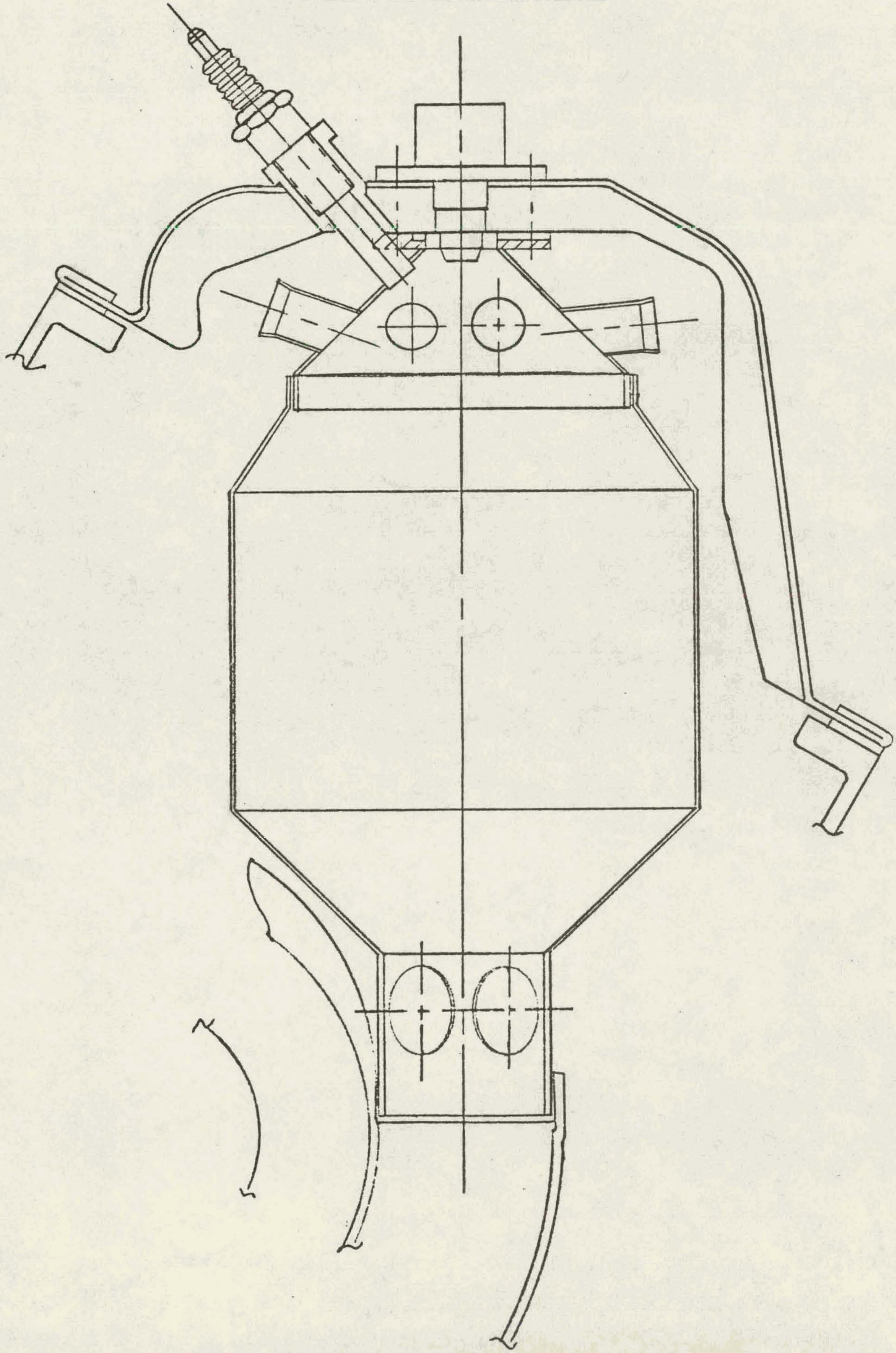
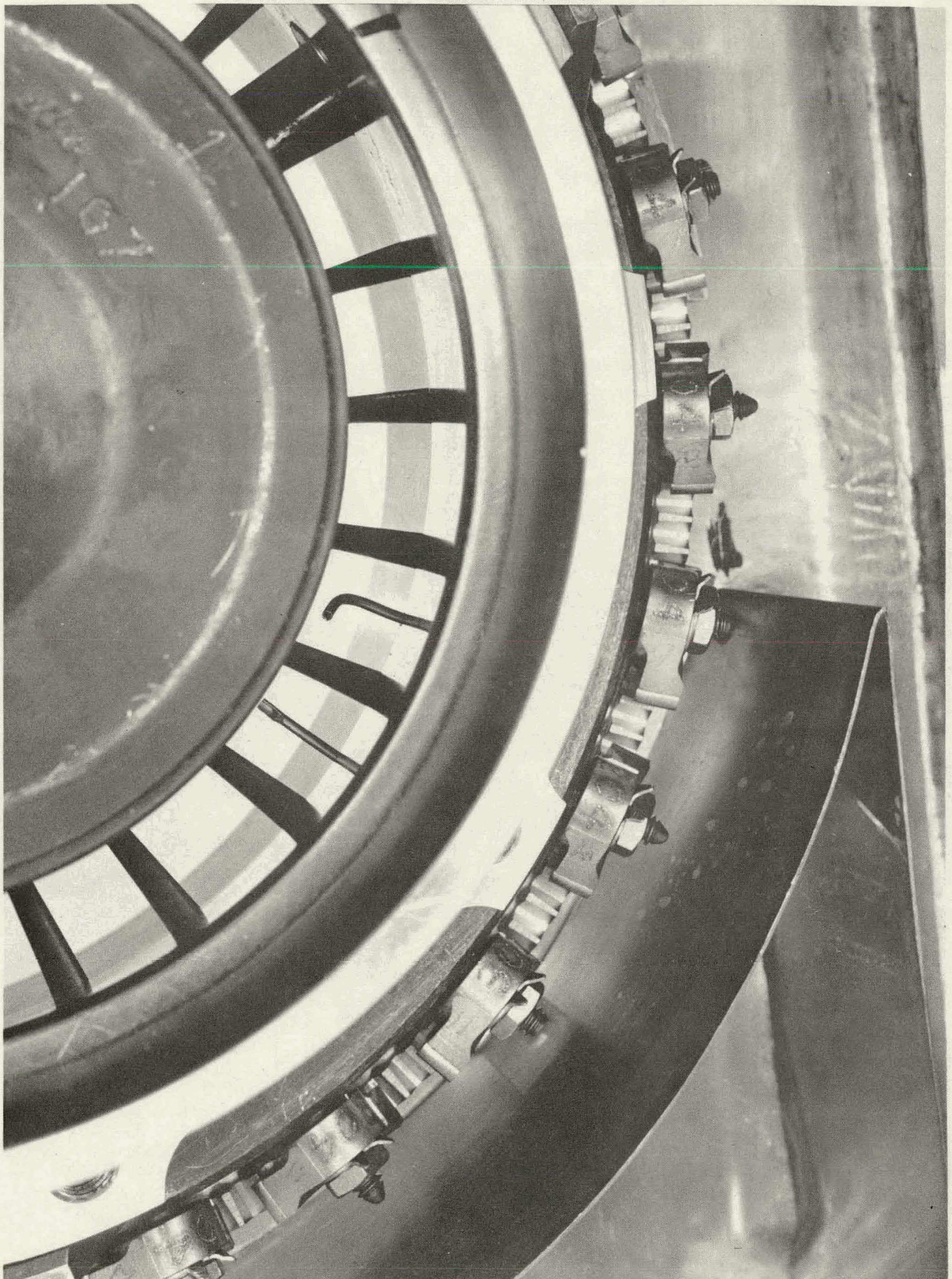
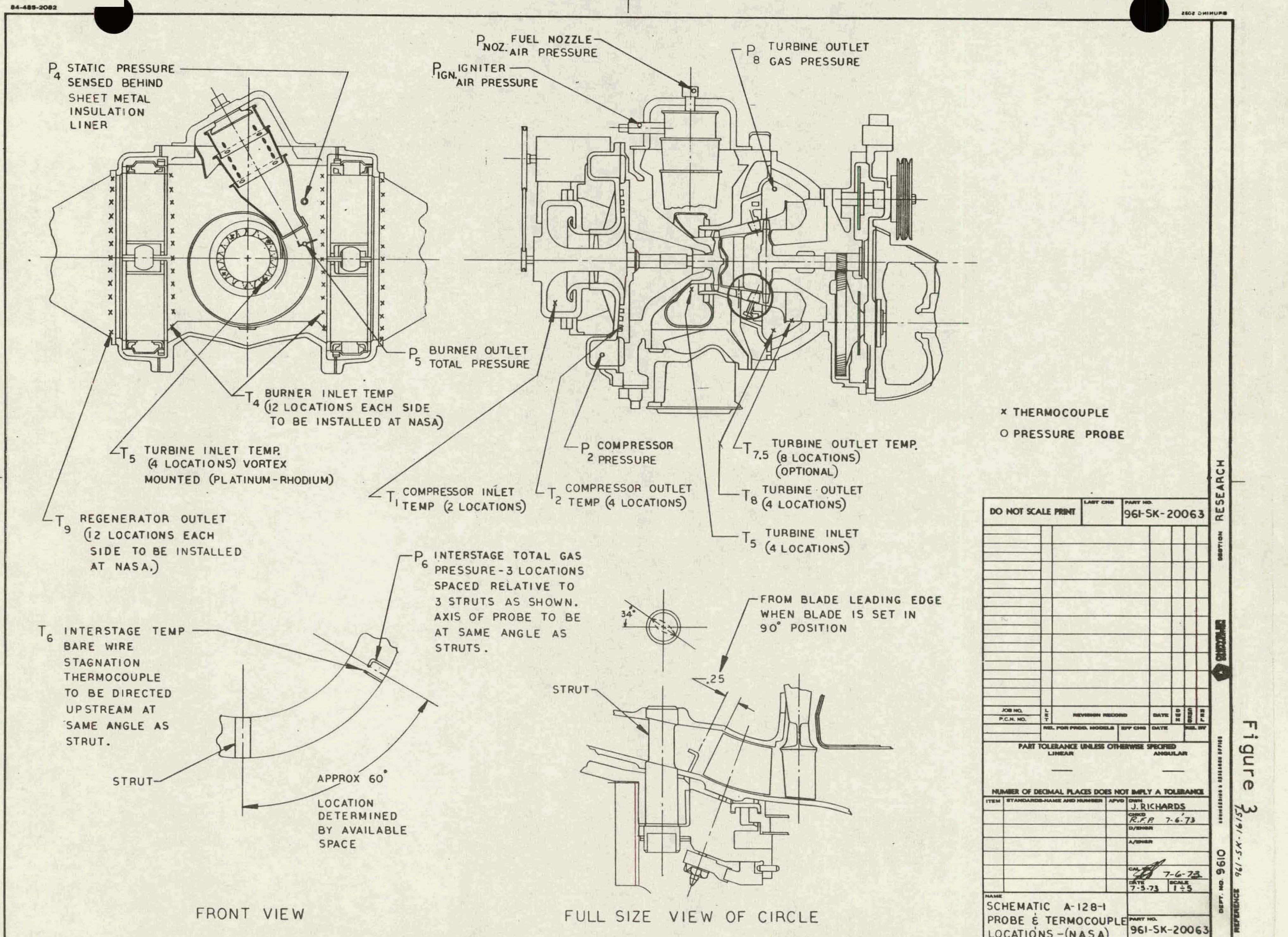


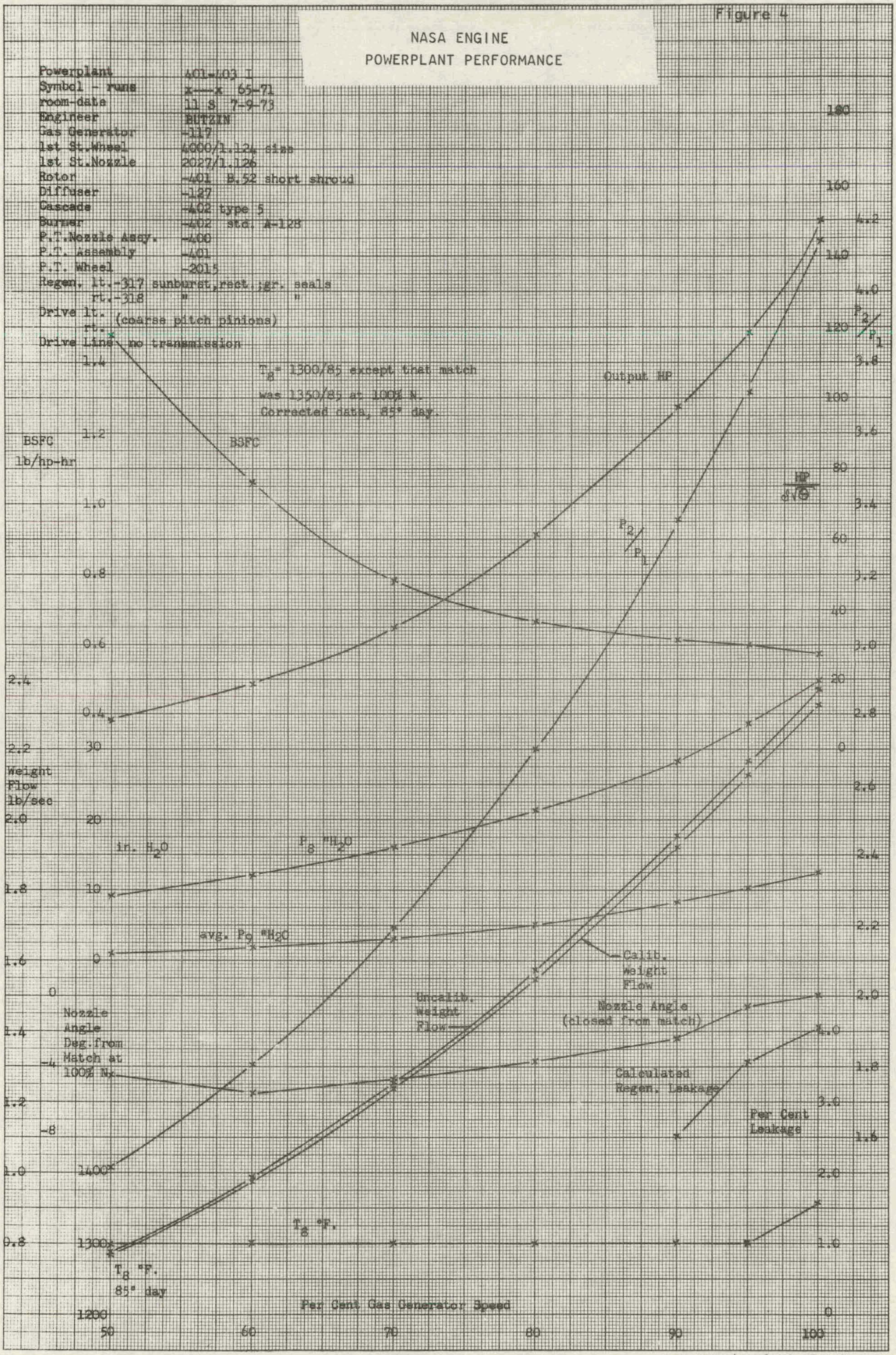
Figure 2

NASA ENGINE
INTERSTAGE INSTRUMENTATION





NASA ENGINE, INSTRUMENTATION SCHEMATIC



E, 2, HWPN, 7-9-73, GT, 9520
E 584

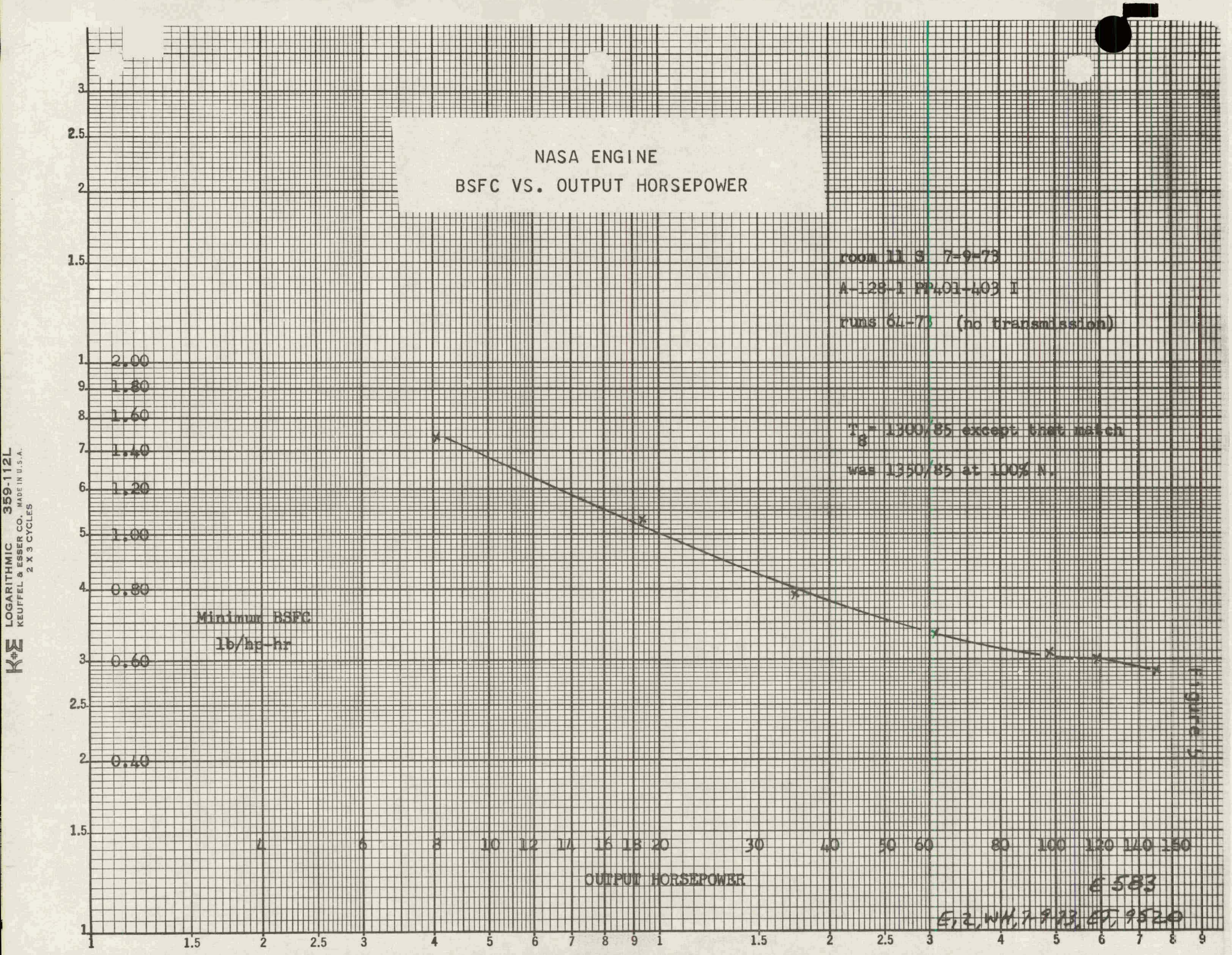
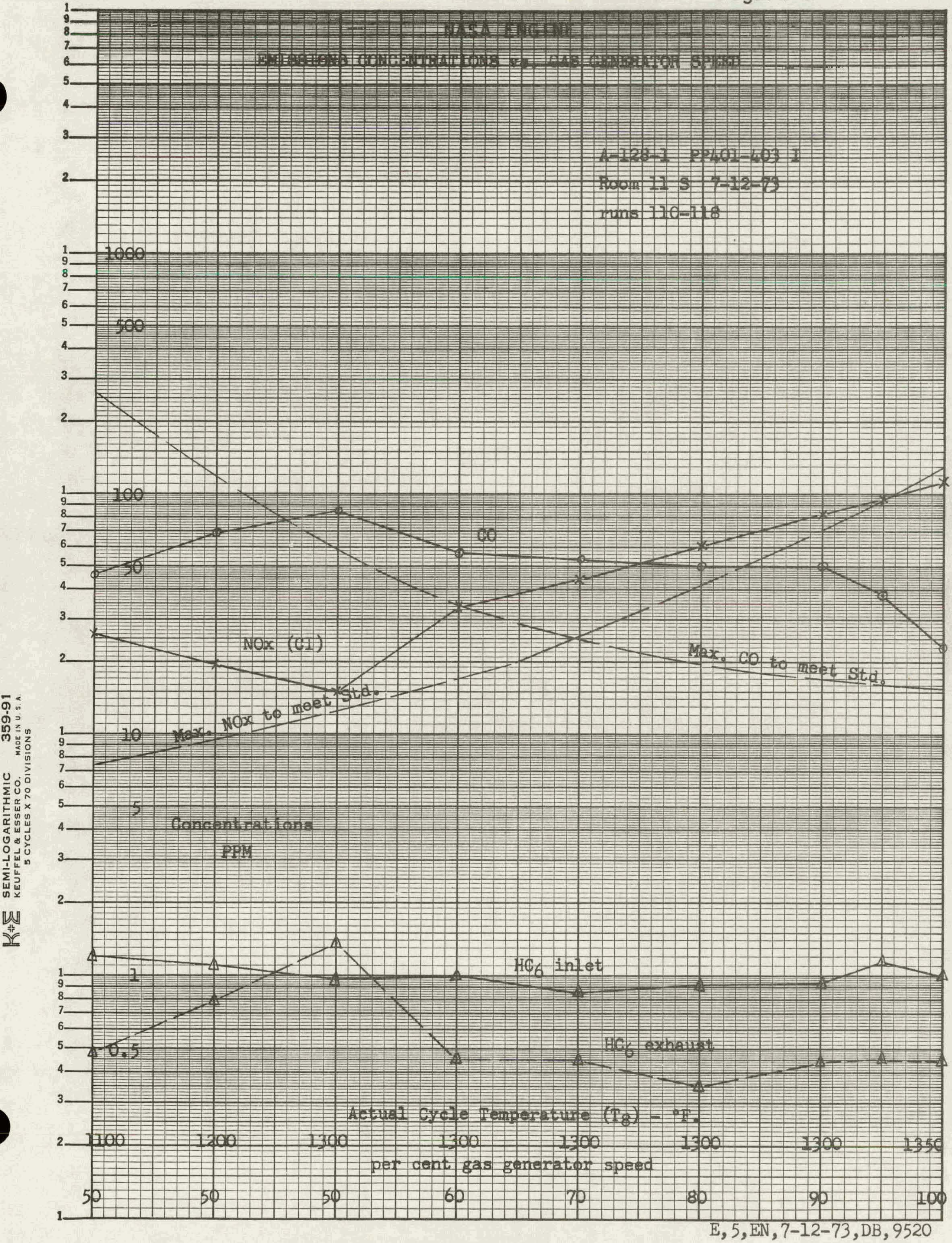

NASA ENGINE
BSFC VS. OUTPUT HORSEPOWER
room 11 S 7-9-73
A-128-1 PP401-403 I
runs 64-73 (no transmission)
T_8 = 1300/85 except that match
was 1350/85 at 100% N.
Minimum BSFC
lb/hp-hr
2.00
1.80
1.60
1.40
1.20
1.00
0.80
0.60
0.40
4 6 8 10 12 14 16 18 20 30 40 50 60 80 100 120 140 150
OUTPUT HORSEPOWER
E583
Figure 5
KE LOGARITHMIC 359-112L
KEUFFEL & ESSER CO. MADE IN U.S.A.
2 X 3 CYCLES

Figure 6



E,5,EN,7-12-73,DB,9520

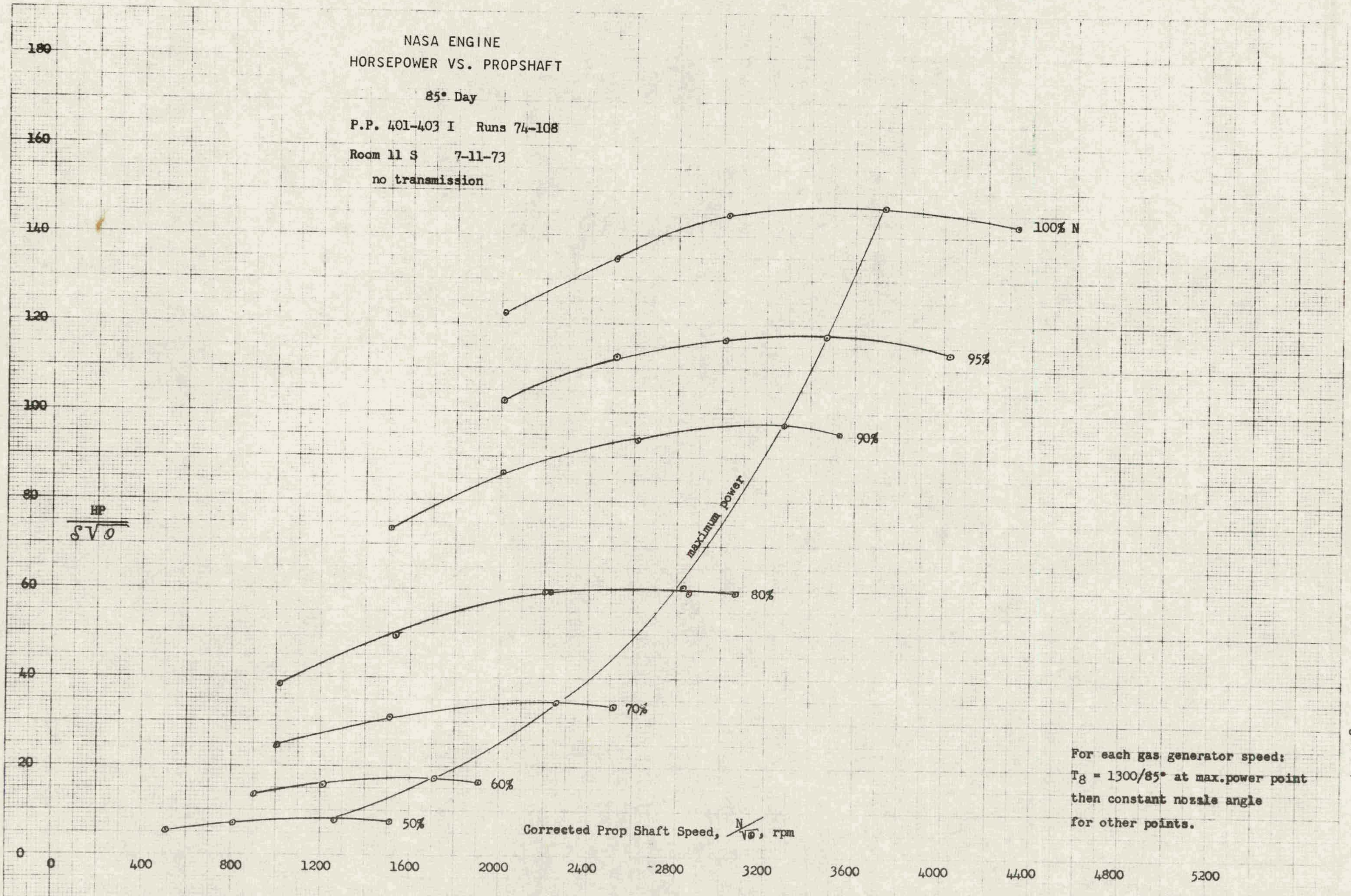


Figure 7

E,2,HN,7-11-73,DB,9520
E574

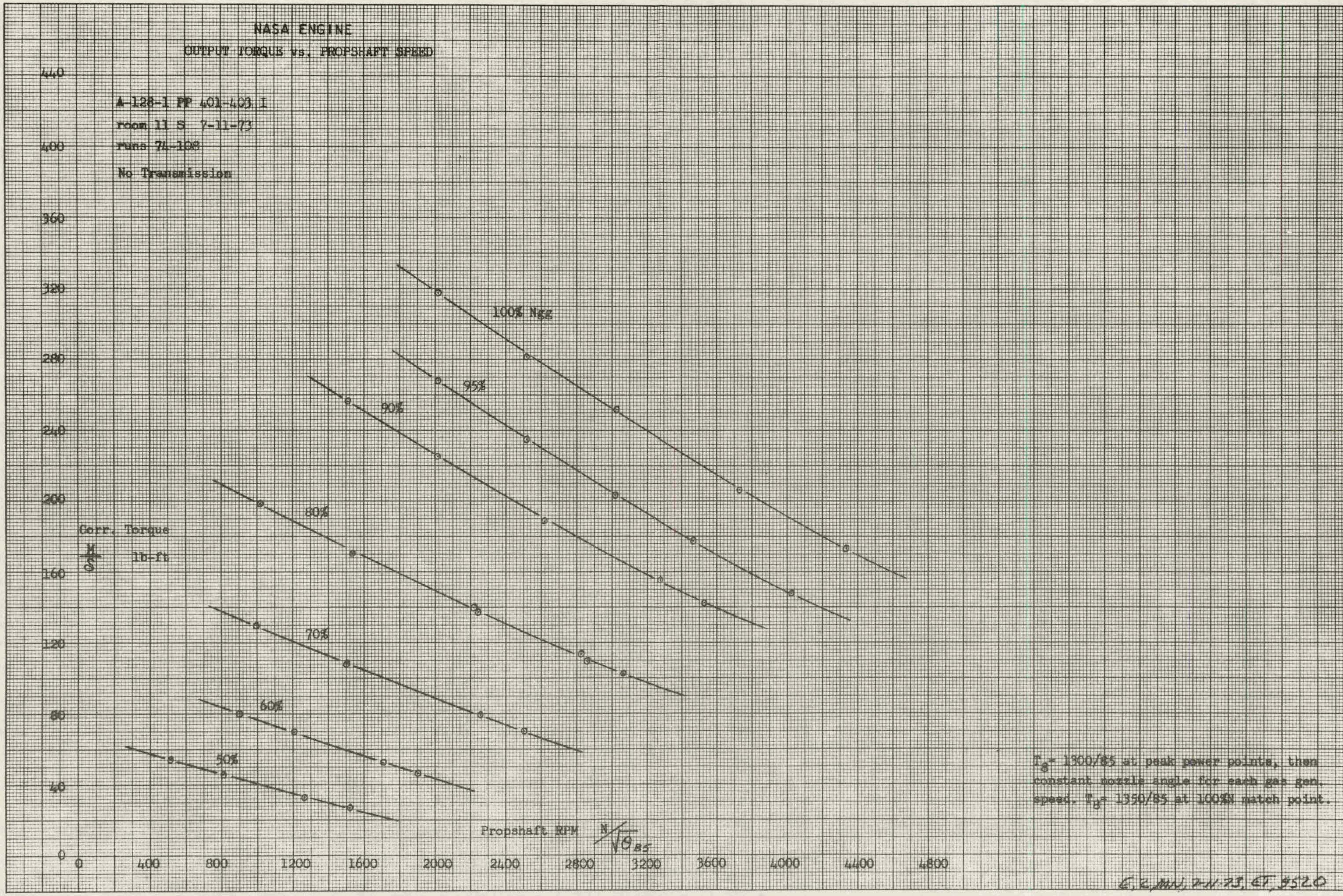
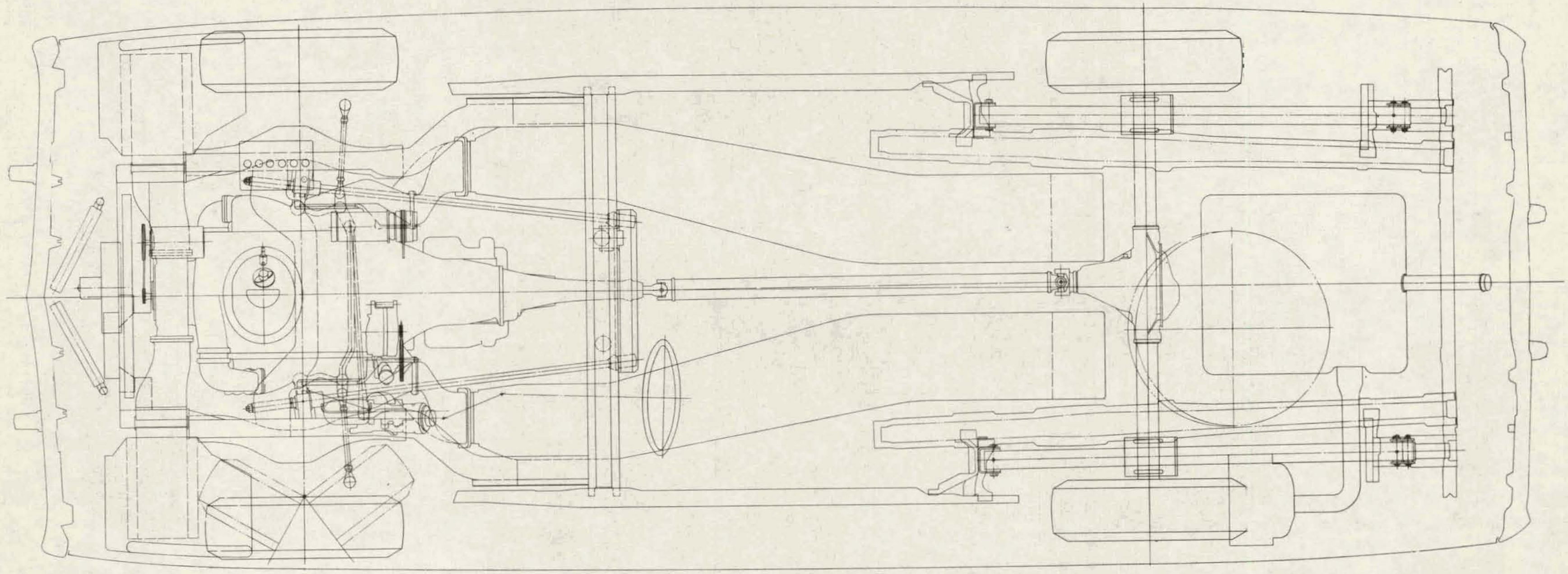


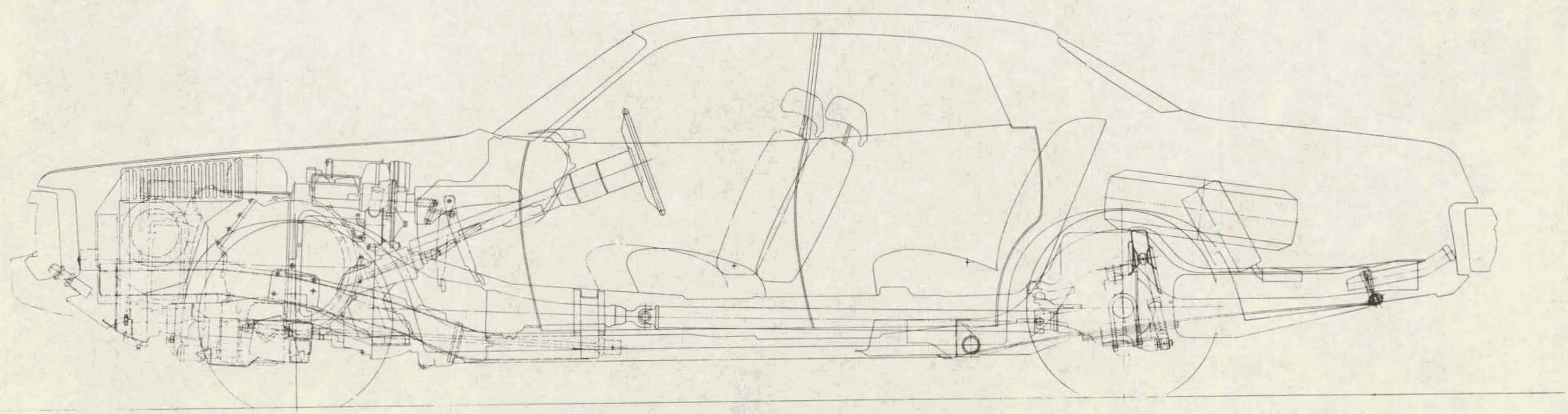
Figure 8

E-7411 7-11-73 ET 9520
E624

BASELINE TURBINE POWERED VEHICLE



Top View



Side View

Figure 9

CERAMIC REGENERATOR DRIVE

MECHANICAL RING GEAR DRIVE

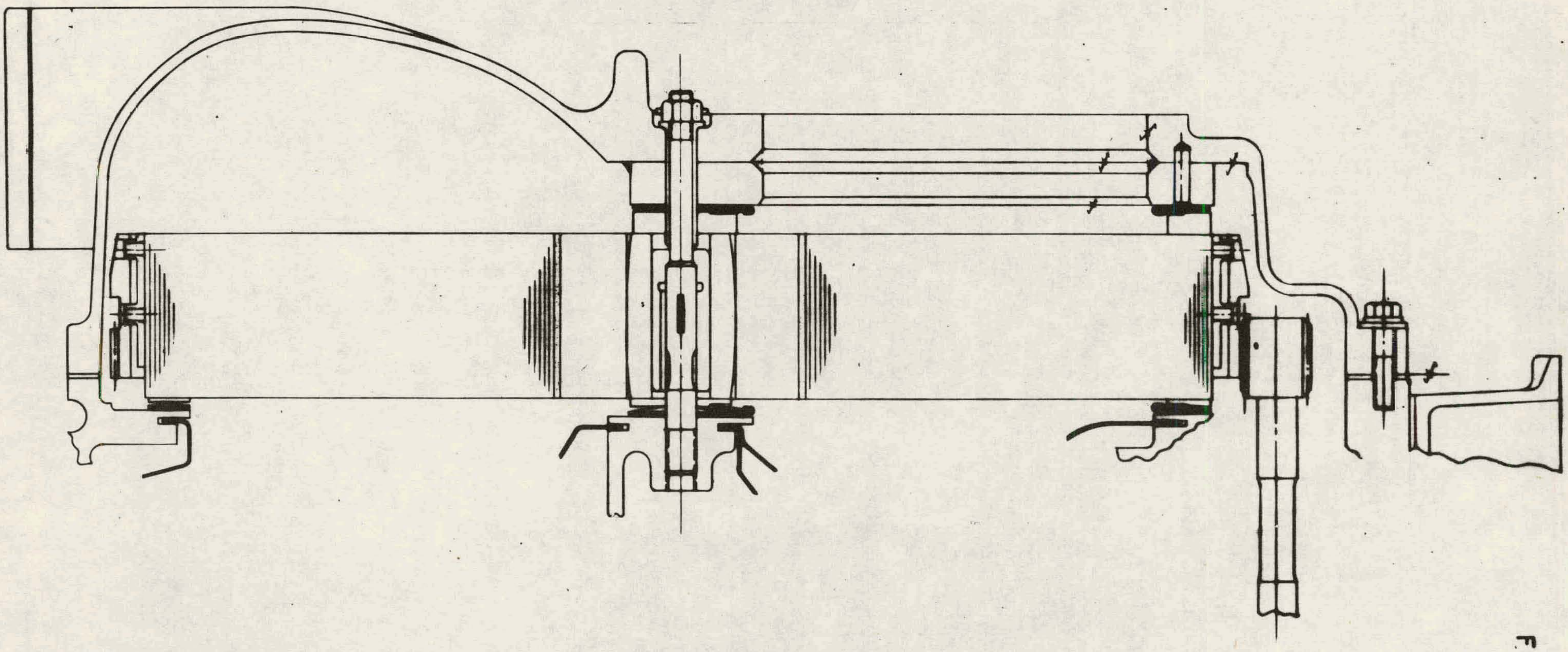


Figure 10

CERAMIC REGENERATOR DRIVE

ELASTOMER RING GEAR MOUNT

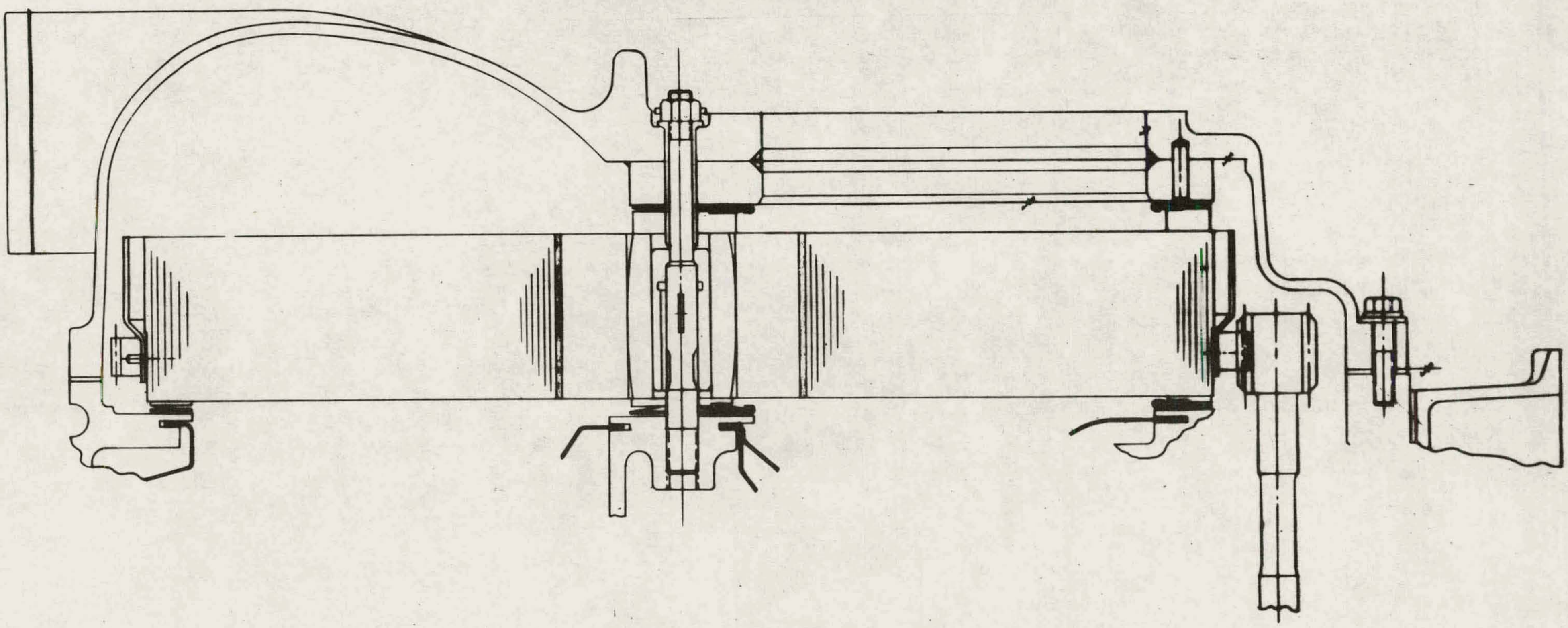


Figure 11

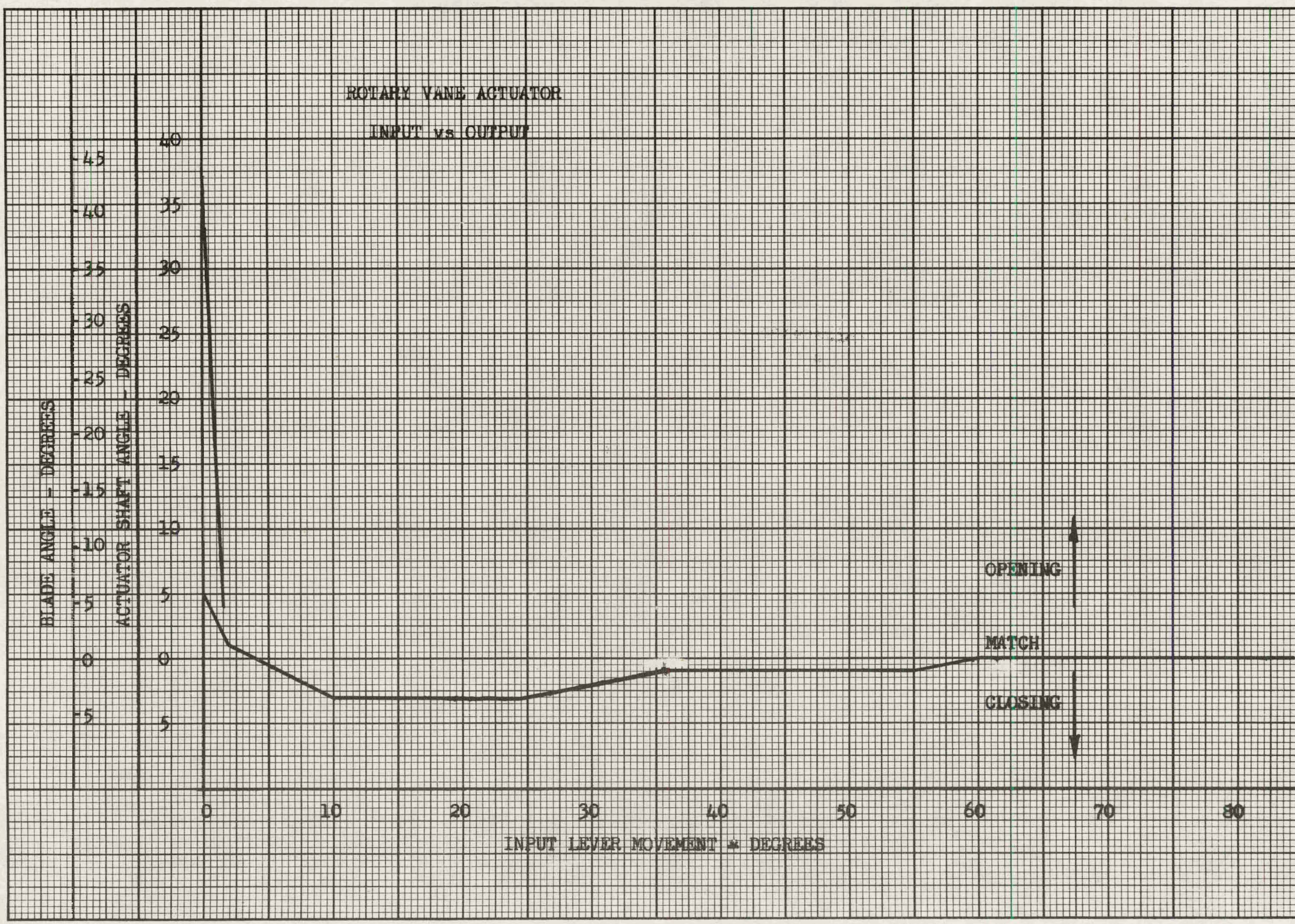

ROTARY VANE ACTUATOR
INPUT vs OUTPUT
BLADE ANGLE - DEGREES
ACTUATOR SHAFT ANGLE - DEGREES
INPUT LEVER MOVEMENT - DEGREES
OPENING
MATCH
CLOSING
45
40
35
30
25
20
15
10
5
0
5
0
10
20
30
40
50
60
70
80

Figure 12

CHRYSLER GAS TURBINE

FREE ROTOR CONCEPT

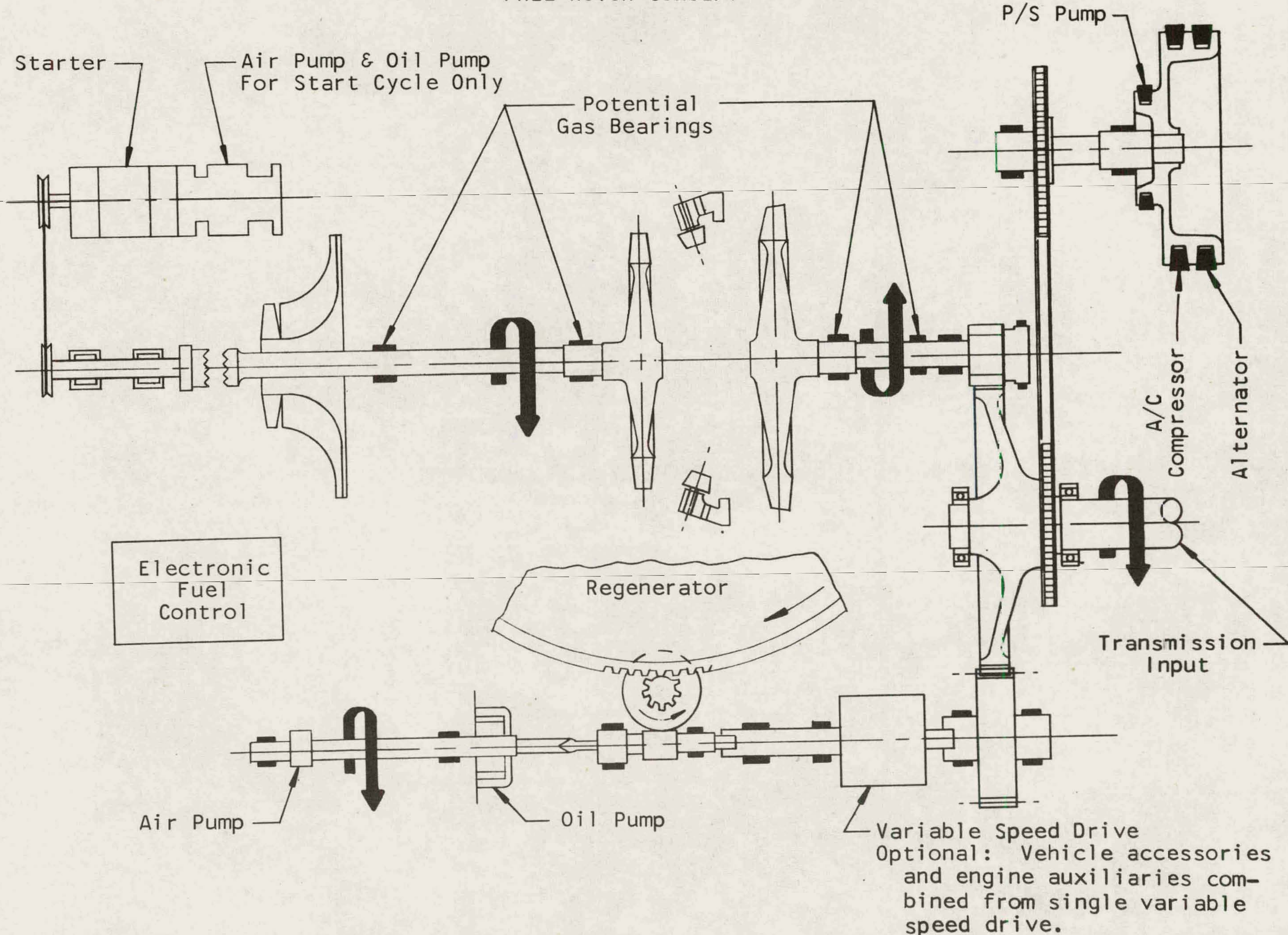


Figure 13

SCHEMATIC FOR FREE ROTOR TEST INSTRUMENTATION

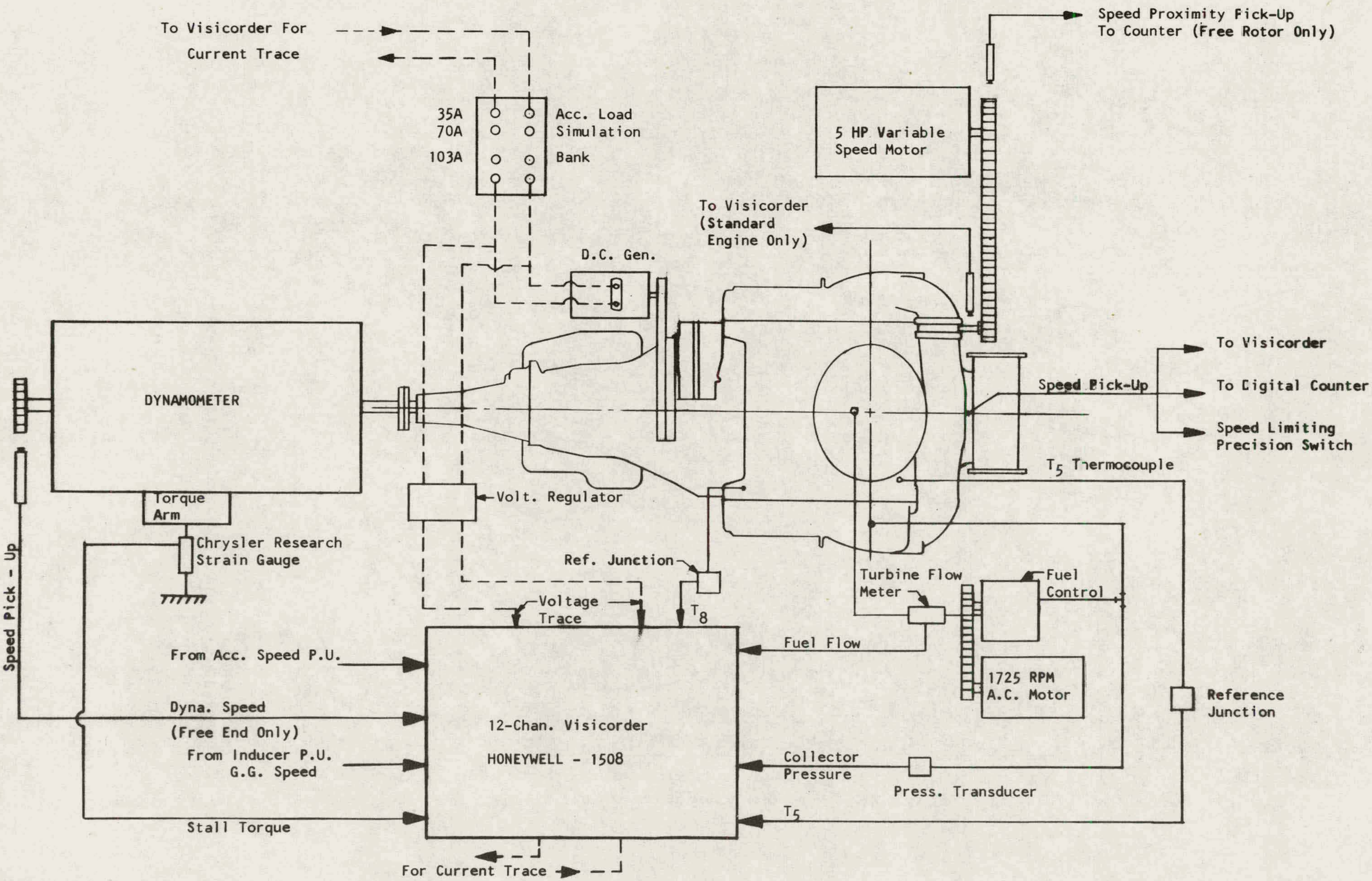


Figure 14

K+E 10 X 10 TO THE CENTIMETER 18 X 25 CM. 46 1513 MADE IN U.S.A. KEUFFEL & ESSER CO.

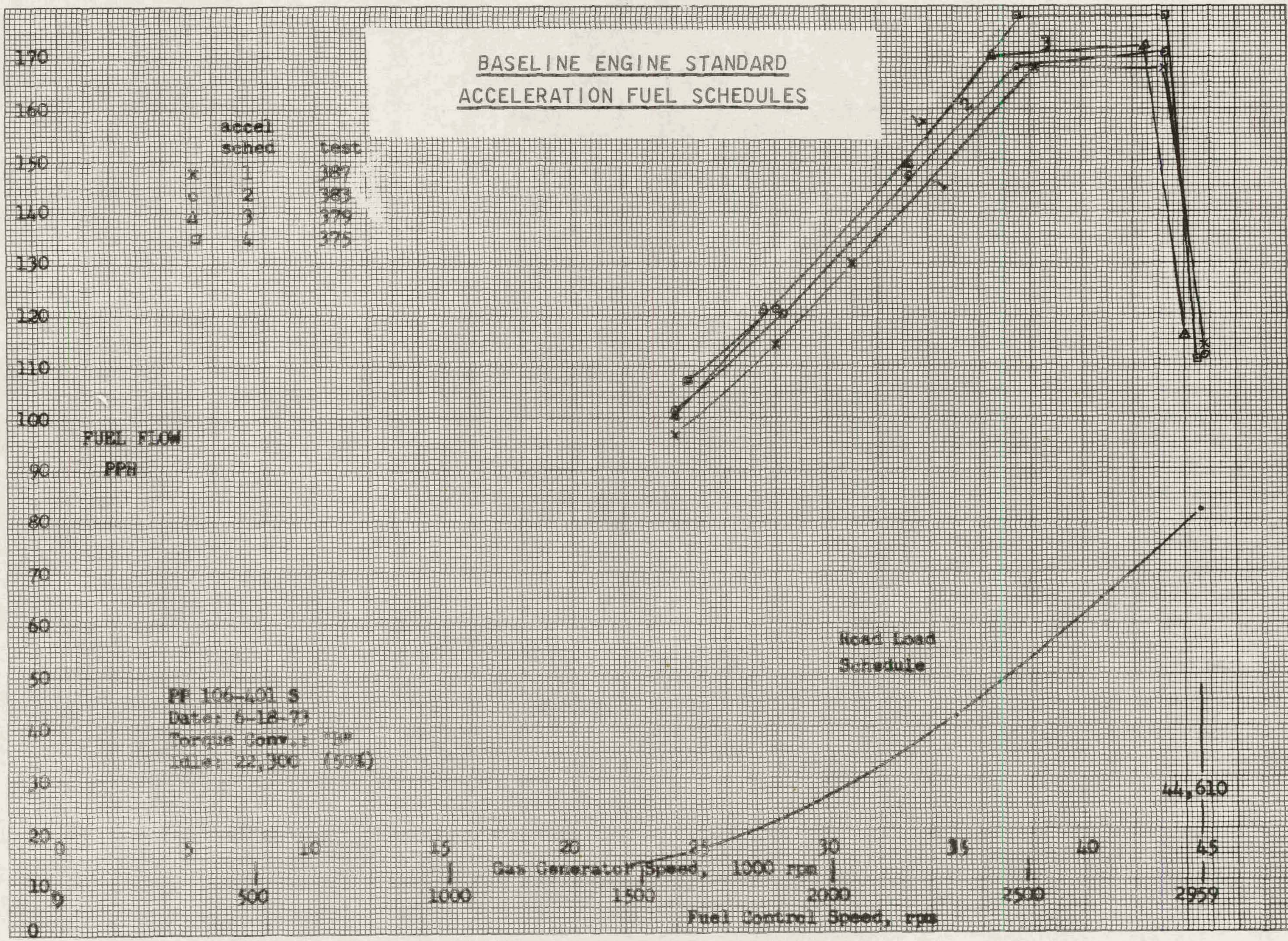


Figure 15

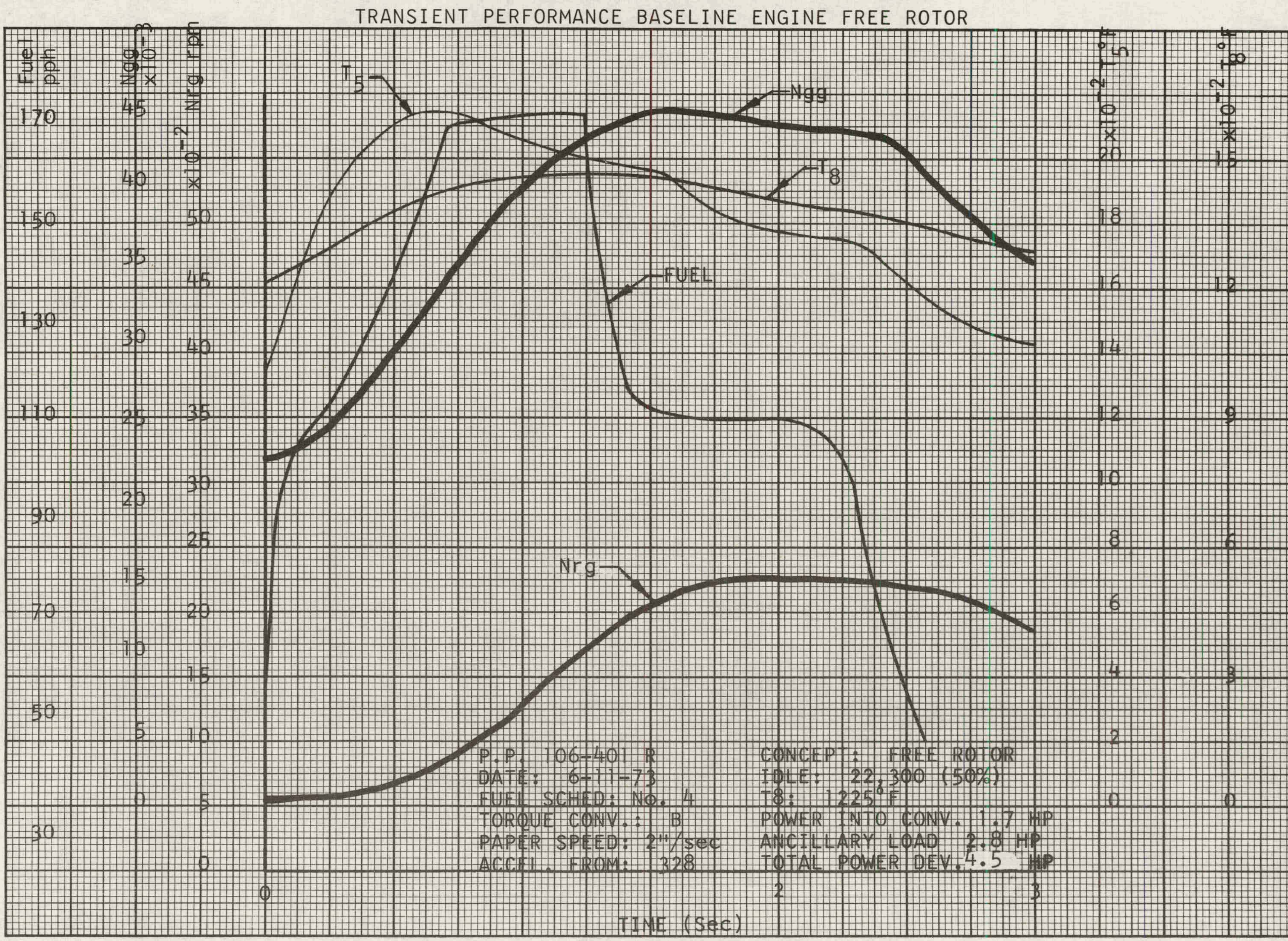

TRANSIENT PERFORMANCE BASELINE ENGINE FREE ROTOR
Fuel pph
Ngg x10^-3
x10^-2 Nrg rpm
x10^-2 T5 °F
x10^-2 T8 °F
T5
Ngg
T8
FUEL
Nrg
P.P. 106-401 R
DATE: 6-11-73
FUEL SCHED: No. 4
TORQUE CONV.: B
PAPER SPEED: 2"/sec
ACCEL. FROM: 328
CONCEPT: FREE ROTOR
IDLE: 22,300 (50%)
T8: 1225°F
POWER INTO CONV. 1.7 HP
ANCILLARY LOAD 2.8 HP
TOTAL POWER DEV. 4.5 HP
TIME (Sec)

Figure 16

TRANSIENT PERFORMANCE BASELINE ENGINE STANDARD

Figure 17

TRANSIENT PERFORMANCE BASELINE ENGINE STANDARD

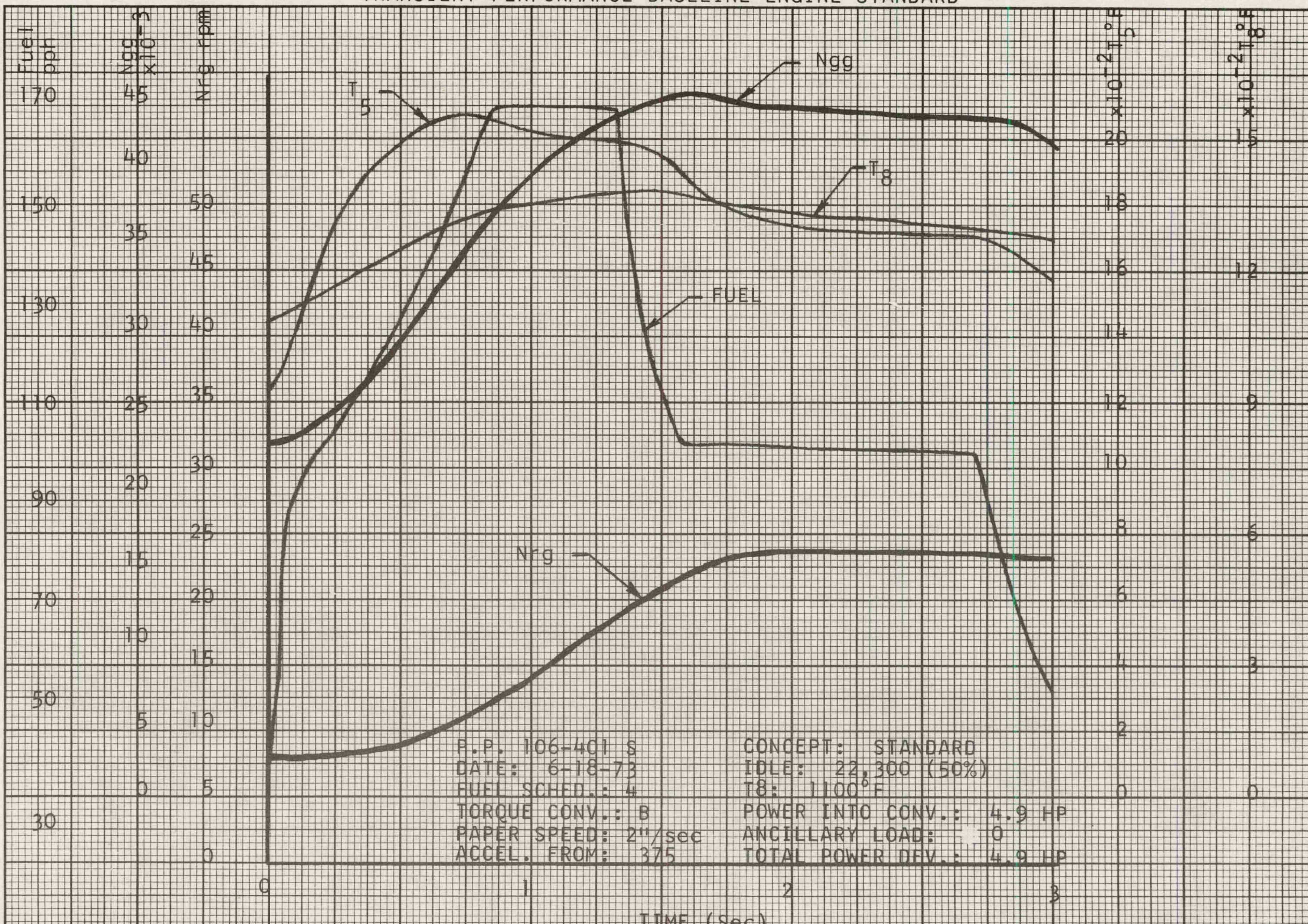


Figure 18

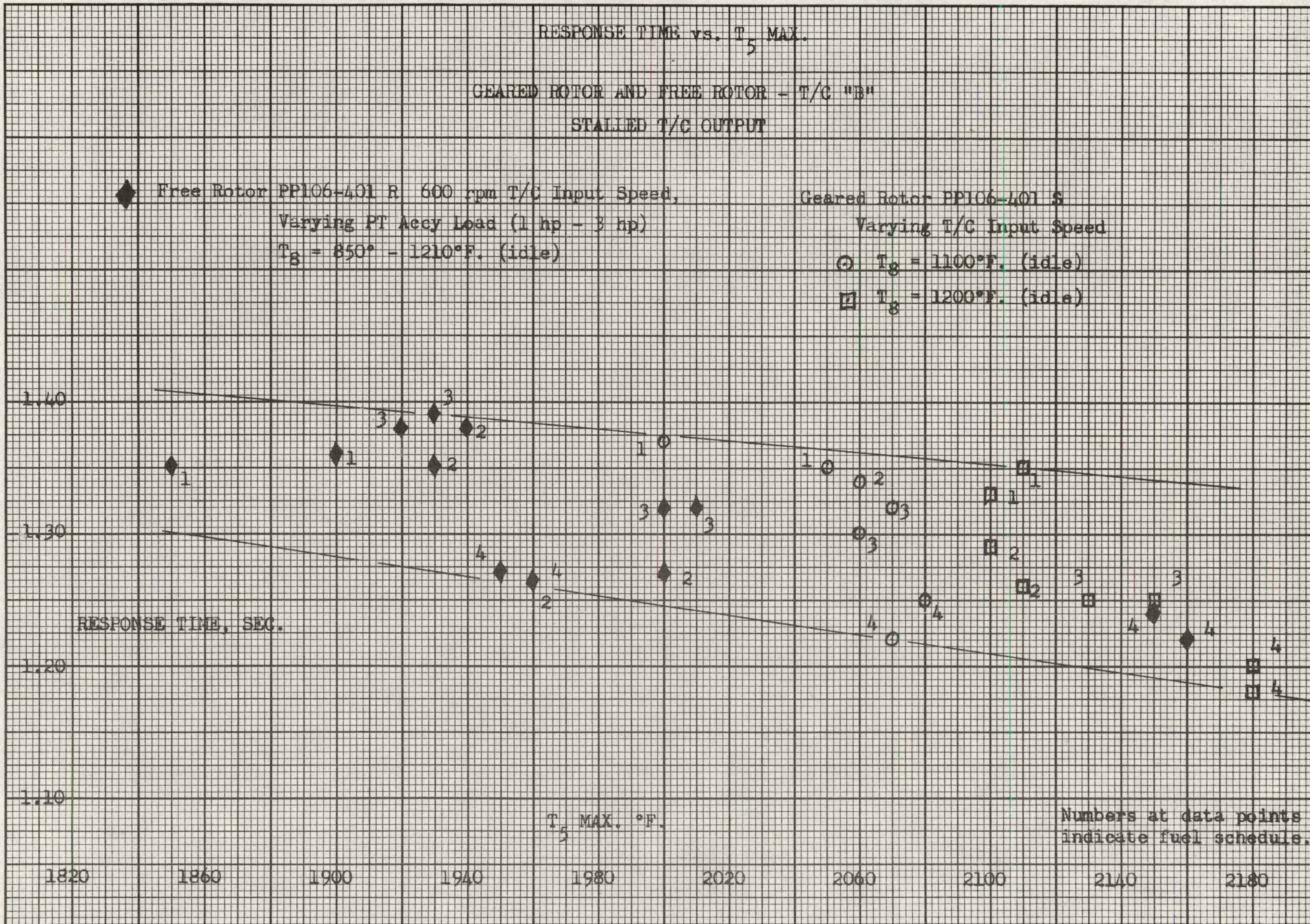
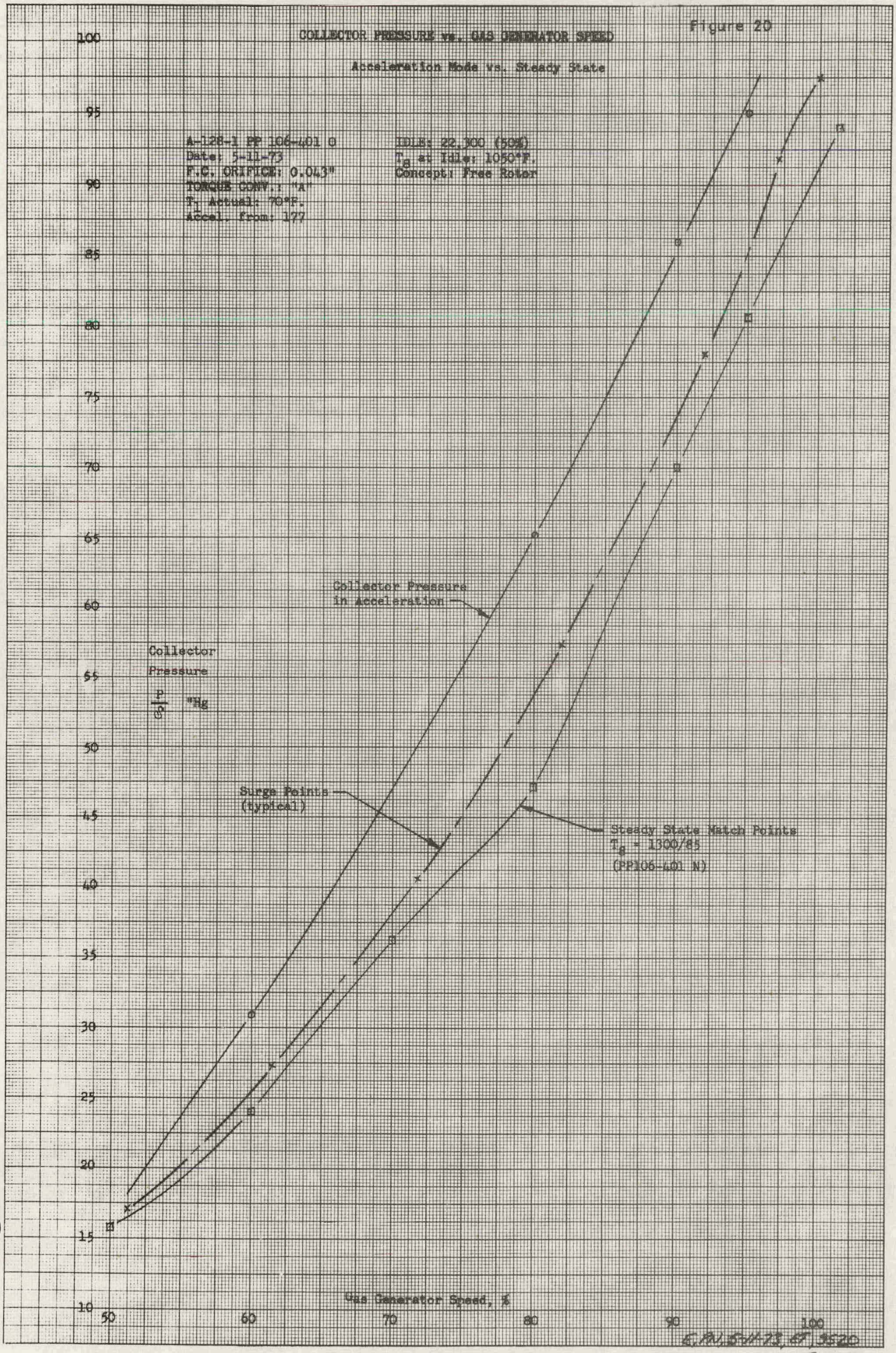

RESPONSE TIME vs. T5 MAX.
GEARED ROTOR AND FREE ROTOR - T/C "B"
STALLED T/C OUTPUT
Free Rotor PP106-401 R 600 rpm T/C Input Speed,
Varying PT Accy Load (1 hp - 3 hp)
T8 = 850° - 1210°F. (idle)
Geared Rotor PP106-401 S
Varying T/C Input Speed
T8 = 1100°F. (idle)
T8 = 1200°F. (idle)
1.40
1.30
1.20
1.10
RESPONSE TIME, SEC.
T5 MAX. °F.
1820
1860
1900
1940
1980
2020
2060
2100
2140
2180
Numbers at data points indicate fuel schedule.

Figure 19



E.P.W. 5-11-73, ET, 3520

E 629

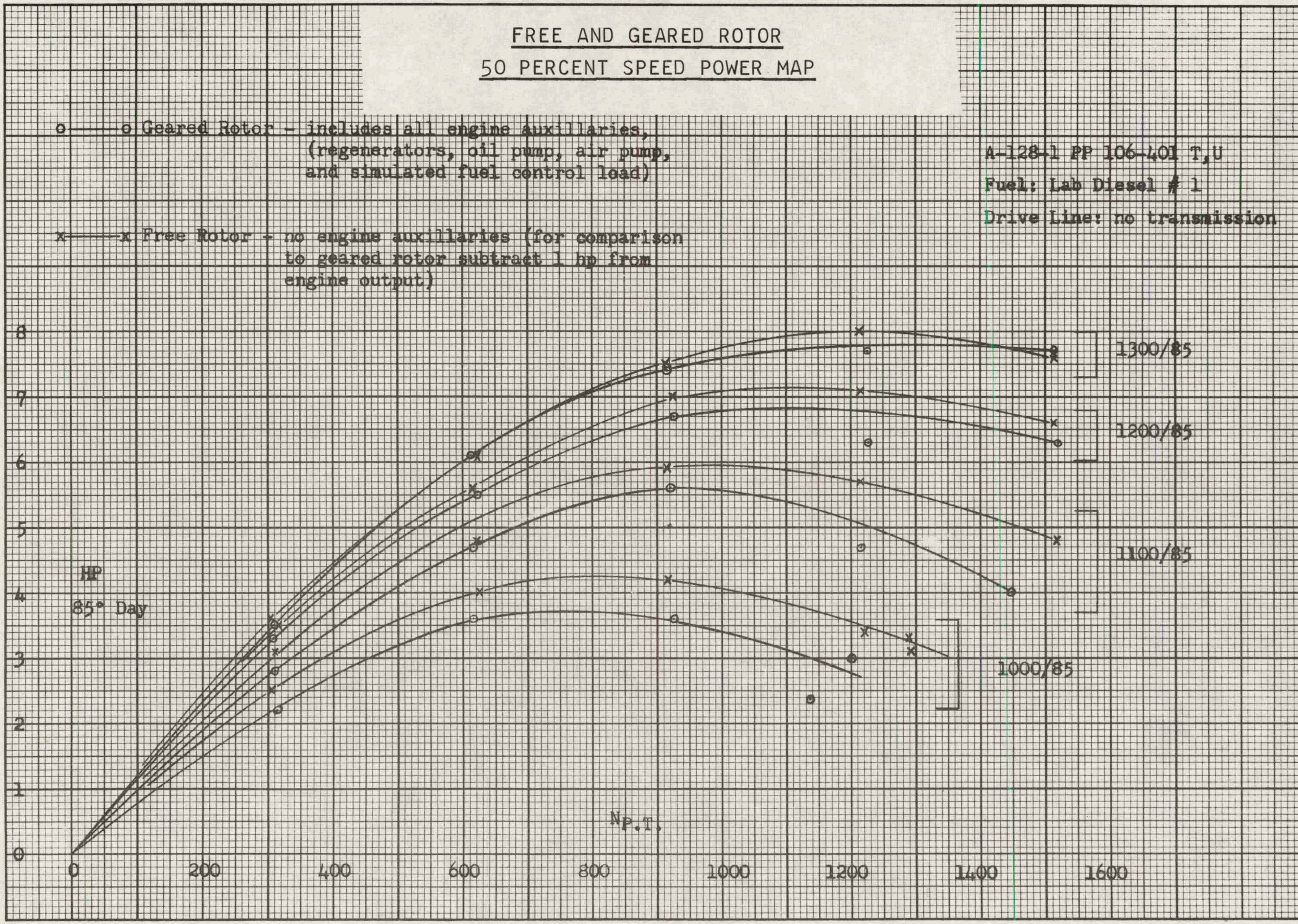

FREE AND GEARED ROTOR
50 PERCENT SPEED POWER MAP
o——o Geared Rotor - includes all engine auxillaries, (regenerators, oil pump, air pump, and simulated fuel control load)
x——x Free Rotor - no engine auxillaries (for comparison to geared rotor subtract 1 hp from engine output)
A-128-1 PP 106-401 T,U
Fuel: Lab Diesel # 1
Drive Line: no transmission
1300/85
1200/85
1100/85
1000/85
HP
85° Day
$N_{P.T.}$
0
1
2
3
4
5
6
7
8
0
200
400
600
800
1000
1200
1400
1600

Figure 21

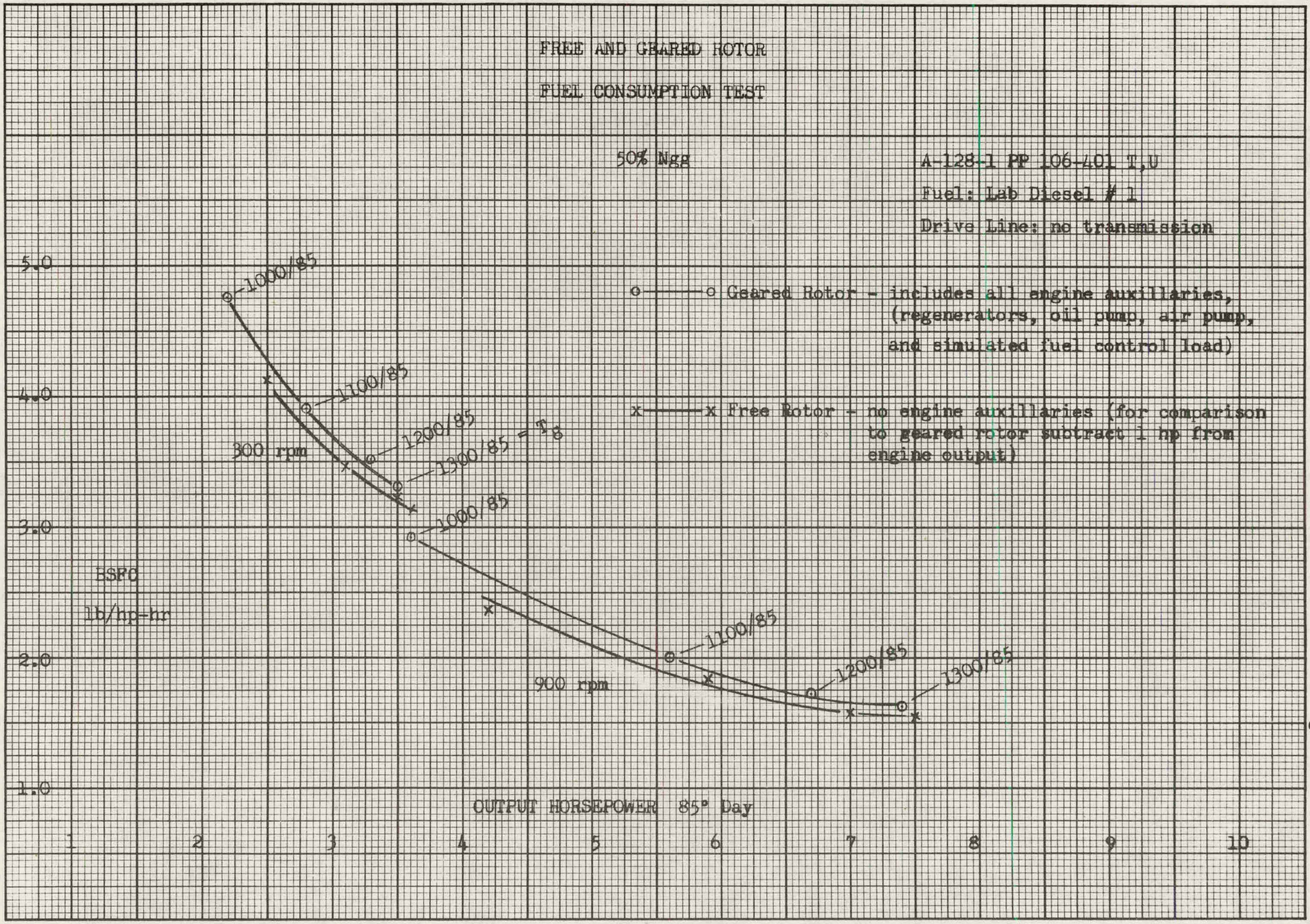

FREE AND GEARED ROTOR
FUEL CONSUMPTION TEST
50% Ngg
A-128-1 PP 106-401 T,U
Fuel: Lab Diesel # 1
Drive Line: no transmission
o——o Geared Rotor - includes all engine auxillaries, (regenerators, oil pump, air pump, and simulated fuel control load)
x——x Free Rotor - no engine auxillaries (for comparison to geared rotor subtract 1 hp from engine output)
1000/85
1100/85
1200/85
1300/85 = T8
300 rpm
1000/85
1100/85
1200/85
1300/85
900 rpm
BSFC
lb/hp-hr
5.0
4.0
3.0
2.0
1.0
OUTPUT HORSEPOWER 85° Day
1
2
3
4
5
6
7
8
9
10

Figure 22

Figure 24

FREE VERSUS GEARED ROTOR FUEL FLOW AT

50 PERCENT SPEED ROAD LOAD POINTS

FOR BASELINE VEHICLE

			Minimum Accessory		Full Accessory (Including A/C)	
RPM	MPH		Power Turbine Horsepower	Fuel Flow #/Hr	Power Turbine Horsepower	Fuel Flow #/Hr
600	10	Geared Rotor	2.4	10.4	5.2	11.1
		Free Rotor	3.4**	10.4	6.2**	11.4
900	20	Geared Rotor	5.2	11.0	*	
		Free Rotor	6.2**	10.9		

* Requires higher gas generator speed.

** Includes additional 1 hp accessory allowance for externally driven engine auxiliary drive (regenerator, lube pump, fuel control, atom. air pump).

50 PERCENT SPEED FIXED RATIO POWER TURBINE DRIVE RIG FOR ENGINE ACCESSORIES

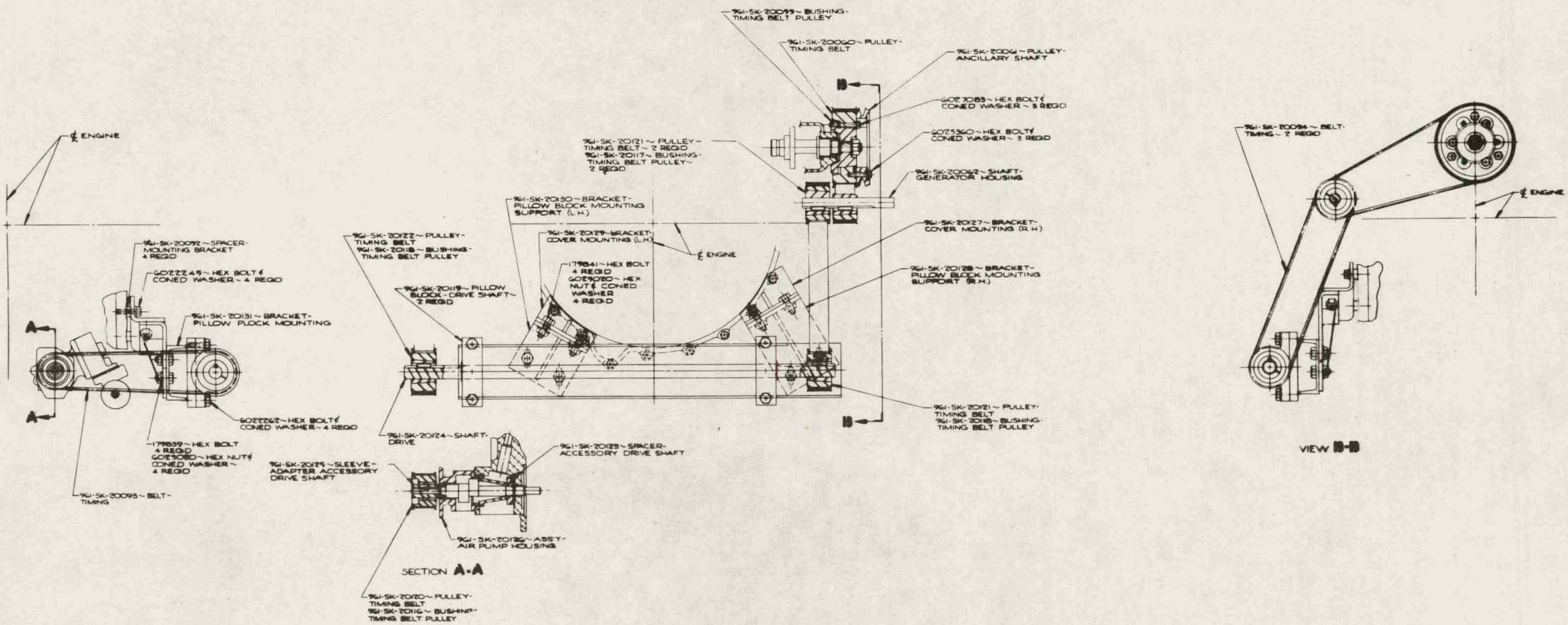


Figure 25

VARIABLE RATIO BELT SYSTEM

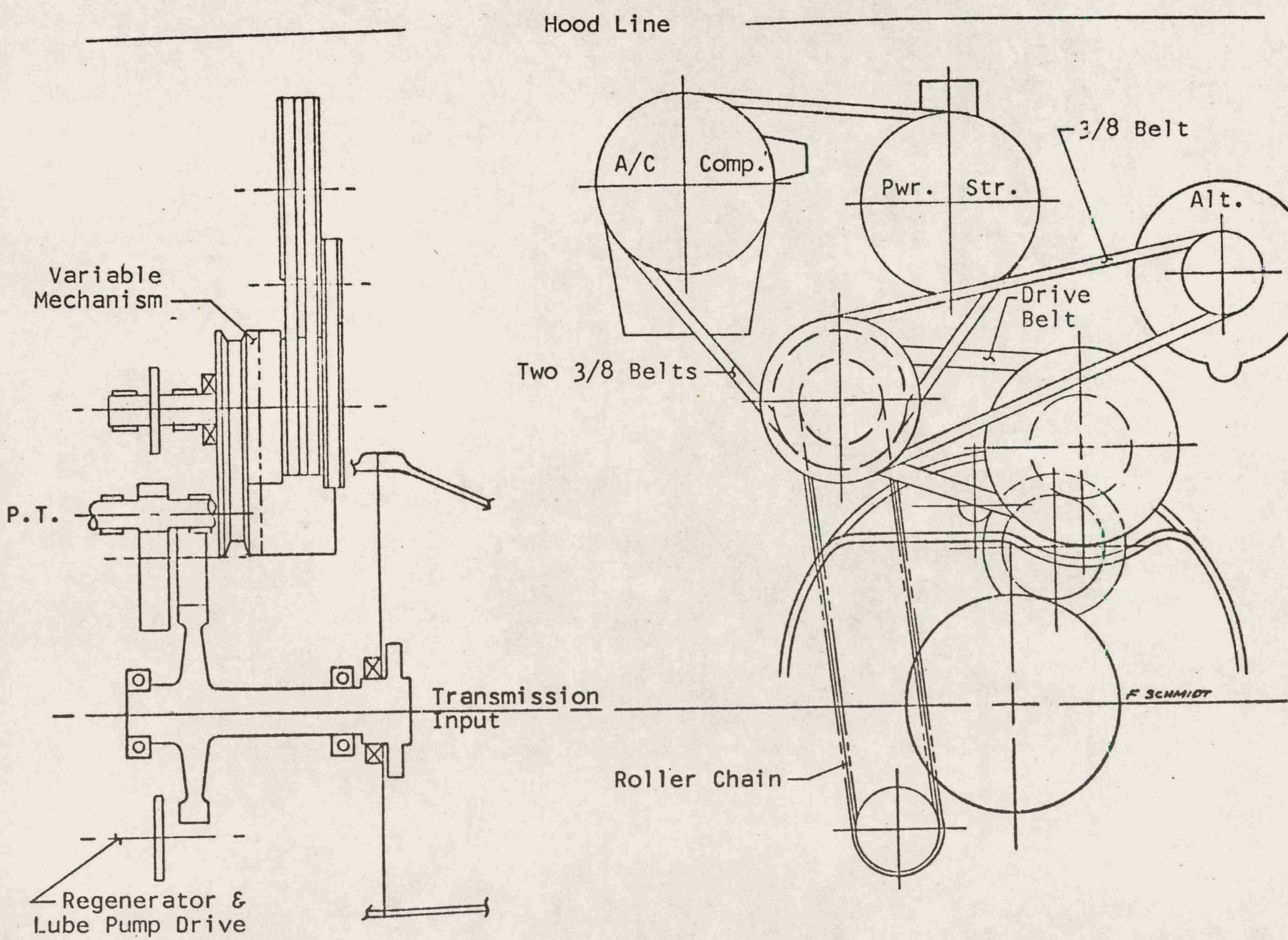


Figure 26

SELECTIVE DUAL CHAIN SYSTEM

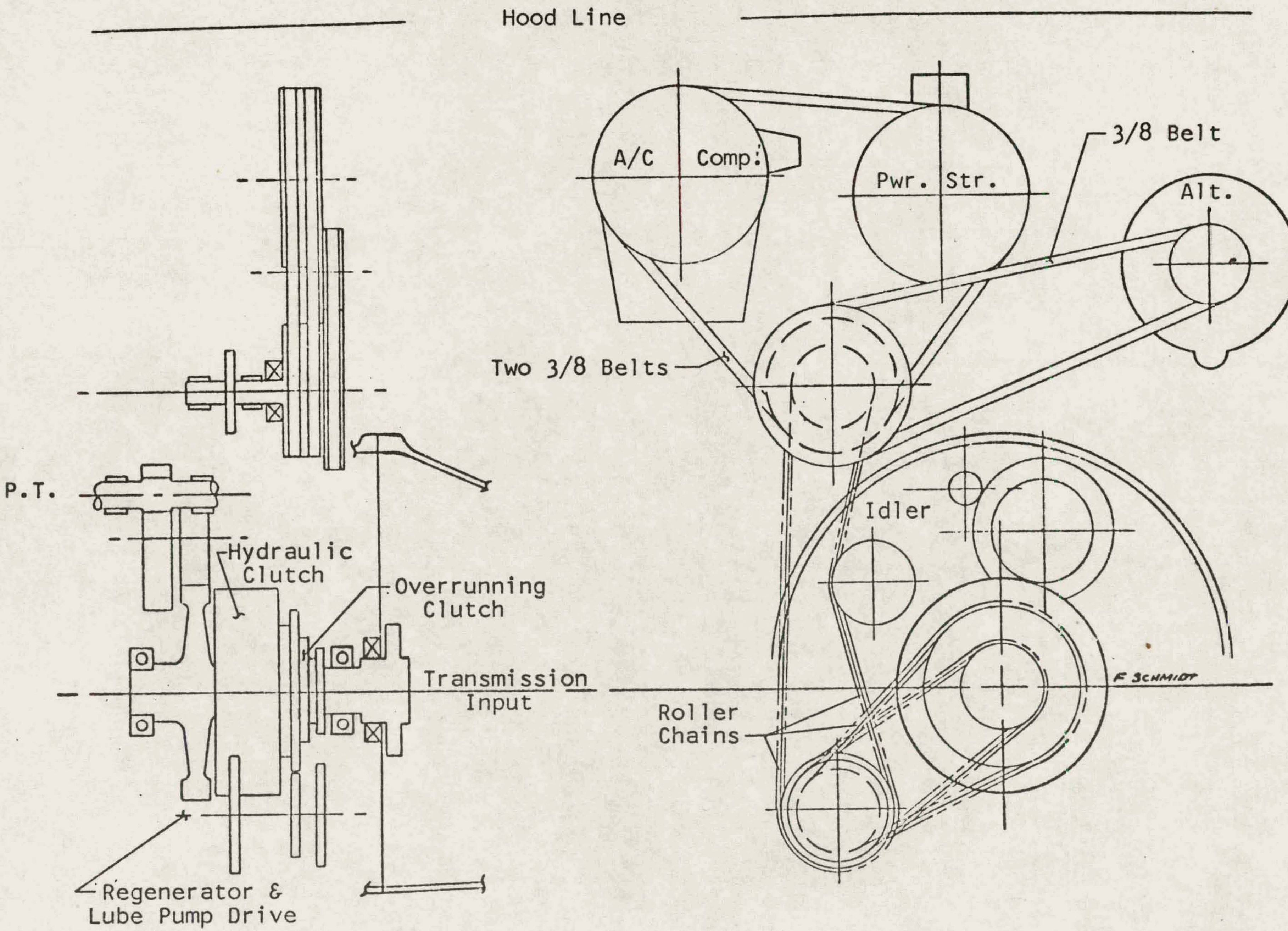


Figure 27

DUAL RATIO GEAR SYSTEM

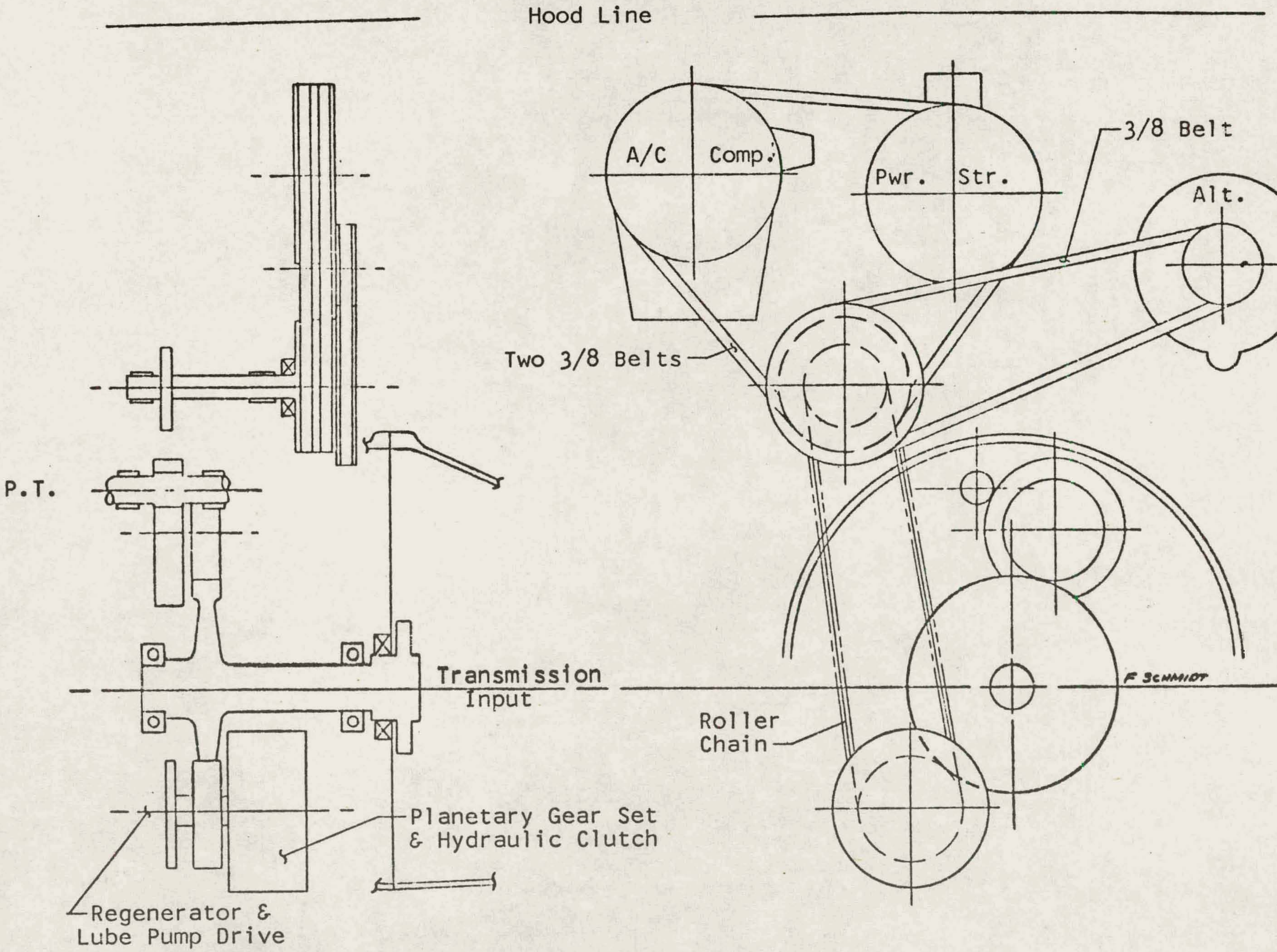
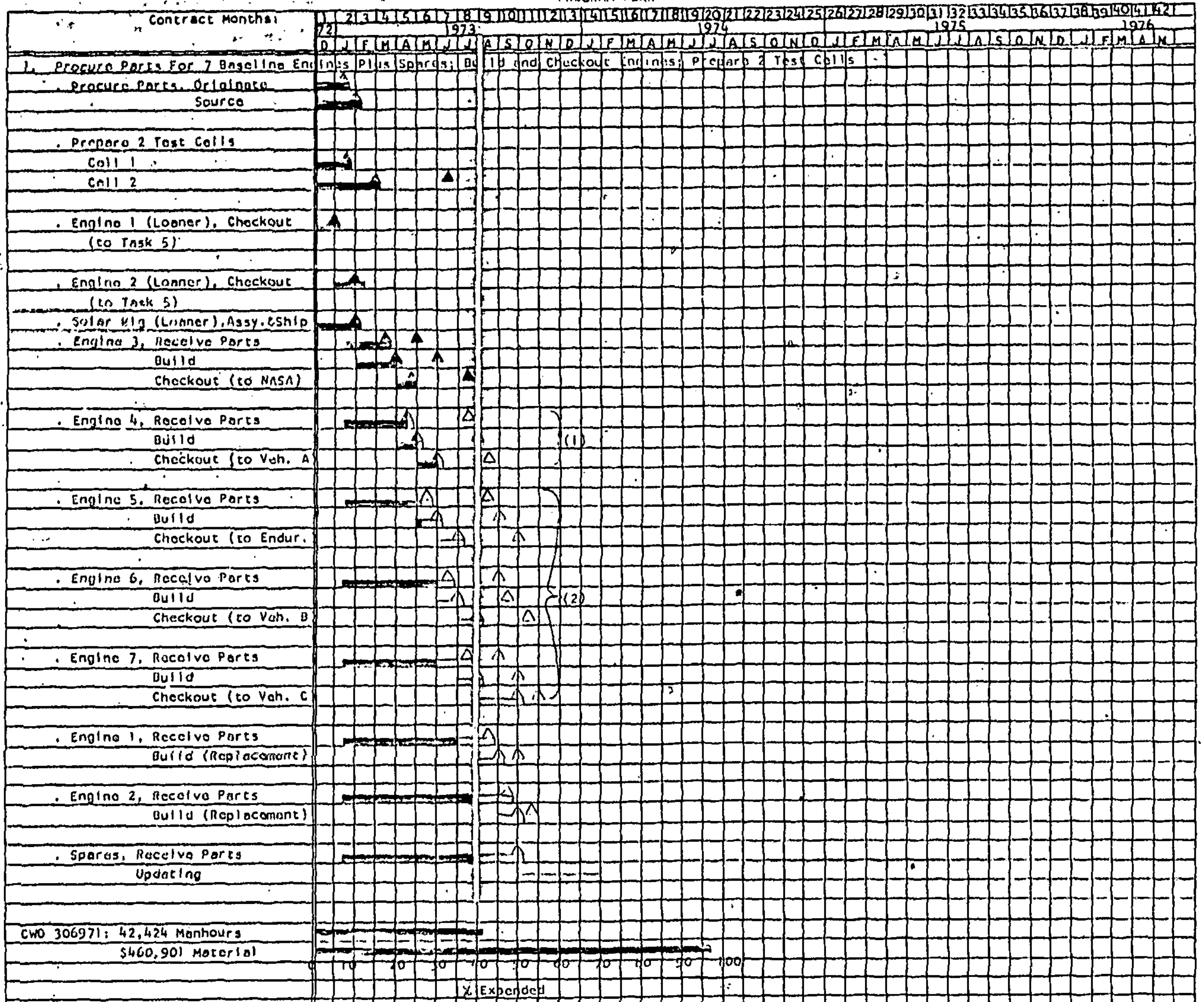


Figure 28

APPENDIX B

PROGRAM PLAN PROGRESS CHARTS

EPA CONTRACT 68-01-0459
BASELINE GAS TURBINE DEVELOPMENT
PROGRAM PLAN



Slippage:
(1) Engine assembly delayed due to late gas generator bearing supports.
(2) Engine assembly delayed due to late power turbine housing castings and details, and gas generator bearing supports.

EPA CONTRACT 68-01-0459
BASELINE GAS TURBINE DEVELOPMENT
PROGRAM PLAN

Contract Months: 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42

1972 1973 1974 1975 1976

D J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S O N D J F M A M

2.1-2.2 Design Vehicle Installation; Procure 3 Production Vehicles; Modify Vehicles; Install Powerplant; Checkout

- Vehicle Installation Design
  - Chassis and Body
  - Heating and A/C
  - Transmission
  - Wiring
- Build Vehicles
  - Procure Vehicle A
    - Vehicle B
    - Vehicle C
- Modify Chassis and Body
  - Build Tooling
  - Modify Vehicle A
    - Vehicle B
    - Vehicle C
- Steering, Suspension, Brakes
  - Procure and
  - Install, Vehicle A (2)
    - Vehicle B
    - Vehicle C
- Heating, A/C, Interior
  - Procure Parts
  - Install, Vehicle A
    - Vehicle B
    - Vehicle C
- Procure and Build Transmission (3)
- Install Powerplant, Incl. Transmission & Electrical
  - Procure Parts
  - Install Vehicle A (1)
    - Vehicle B
    - Vehicle C
- Exhaust System
  - Build and Install Vehicle A
    - Vehicle B
    - Vehicle C
- Refinish, Vehicle A
  - Vehicle B
  - Vehicle C

CWO 306972: 17,555 Manhours
$102,925 Material

0 10 20 30 40 50 60 70 80 90 100
% Expended

Slippage:

[redacted]

(1) Engine installation paced by availability per Task 3 schedule.

(2) Installation paced by vehicle and parts availability, and final adaptation details.

(3) Units complete for vehicles.

2.3 Verify and Deliver Vehicles

- Performance, Economy, Emissions
  - Vehicle A
  - Vehicle B
  - Vehicle C
- Cold Starting
- Underhood Temperature
- Deliver to EPA, Vehicle A
  - Vehicle B
  - Vehicle C

CWO 306973: 3,370 Manhours

0 10 20 30 40 50 60 70 80 90 100
% Expended

Slippage:

Contract Months: 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42

72 — 1973 — 1974 — 1975 — 1976

Task — D J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S O N D J F M A M

3. Provide Support To The Government In The Areas Of Engine & Vehicle Testing, Maintenance, Repair and Demonstration
- Shows
- Training
- Service Engine
- Service Vehicles

CWO 306974: 12,213 Manhours

0 10 20 30 40 50 60 70 80 90 100
% Expended

4.1 Prepare and Maintain Endurance Cell and Related Equipment
- Maintain
- Modify Cycler, For EPA Cycle

CWO 306975: 2,255 Manhours

0 10 20 30 40 50 60 70 80 90 100
% Expended

4.2 - 4.4 Complete 3500 Hours Endurance As Installed, Run 3500 Hours Endurance on Engine 5
- Complete 3500 Hours (4th Loaner)
- Inspection (2)
- Run
- Run Endurance on Engine 5 (1) (1) (1) (1) (1)
- Inspection (1000 Hours) & Install
- Performance Check (Weekly) (1)
- Endurance Cycling

CWO 306976: 9,285 Manhours

0 10 20 30 40 50 60 70 80 90 100
% Expended

(1) Rescheduled due to engine availability.
(2) Delays to evaluate molded insulation and coarse pitch pinions.

EPA CONTRACT 68-01-0459
BASELINE GAS TURBINE DEVELOPMENT
PROGRAM PLAN

Contract Months: 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42

1972 1973 1974 1975 1976

D J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S O N D J F M A M

5.1a Design, Procure and Manufacture A Variable Geometry Combustor Control in Conjunction with Evaluation of A Proprietary Combustion System

. Measure S.S. Control Parameters

. Design and Build Control (1)

. Develop Control

CWO 306977: 6,247 Manhours
$16,000 Material

0 10 20 30 40 50 60 70 80 90 100
% Expended

(1) Indefinite delay, insufficient range combustor

5.1b Evaluate and Develop Solar Combustion System

. Establish rig evaluation procedure for combustor

Phase I

*. Design Preliminary Variable Geometry Control

. Design Engine Adaptation

. Modify Engine and Assemble

*. Measure S.S. Control Parameters

*. Design Actuator

*. Build Actuator

. Evaluate and Develop

* Charge to CWO 306977

Phase II

. Design Engine Adaptation

. Modify Engine and Assemble

. Evaluate and Develop

CWO 306978: 6,010 Manhours

0 10 20 30 40 50 60 70 80 90 100
% Expended

5.2 Evaluate And Develop Ceramic Regenerator/Seal System

State-Of-The-Art Matrix

. Analyze and Specify

. Design Drive

Seal

Engine Adaptation

Fixture Adaptation

. Procure Cores

Drive

Seals

Engine Parts

Fixture Parts

. Assemble Cores

. Evaluate in Fixture

"A" Cores

"B" Cores

. Evaluate in Engine

"A" Cores

"B" Cores

Advanced Matrix

. Analyze and Specify

. Procure

. Design Drive & Adaptation

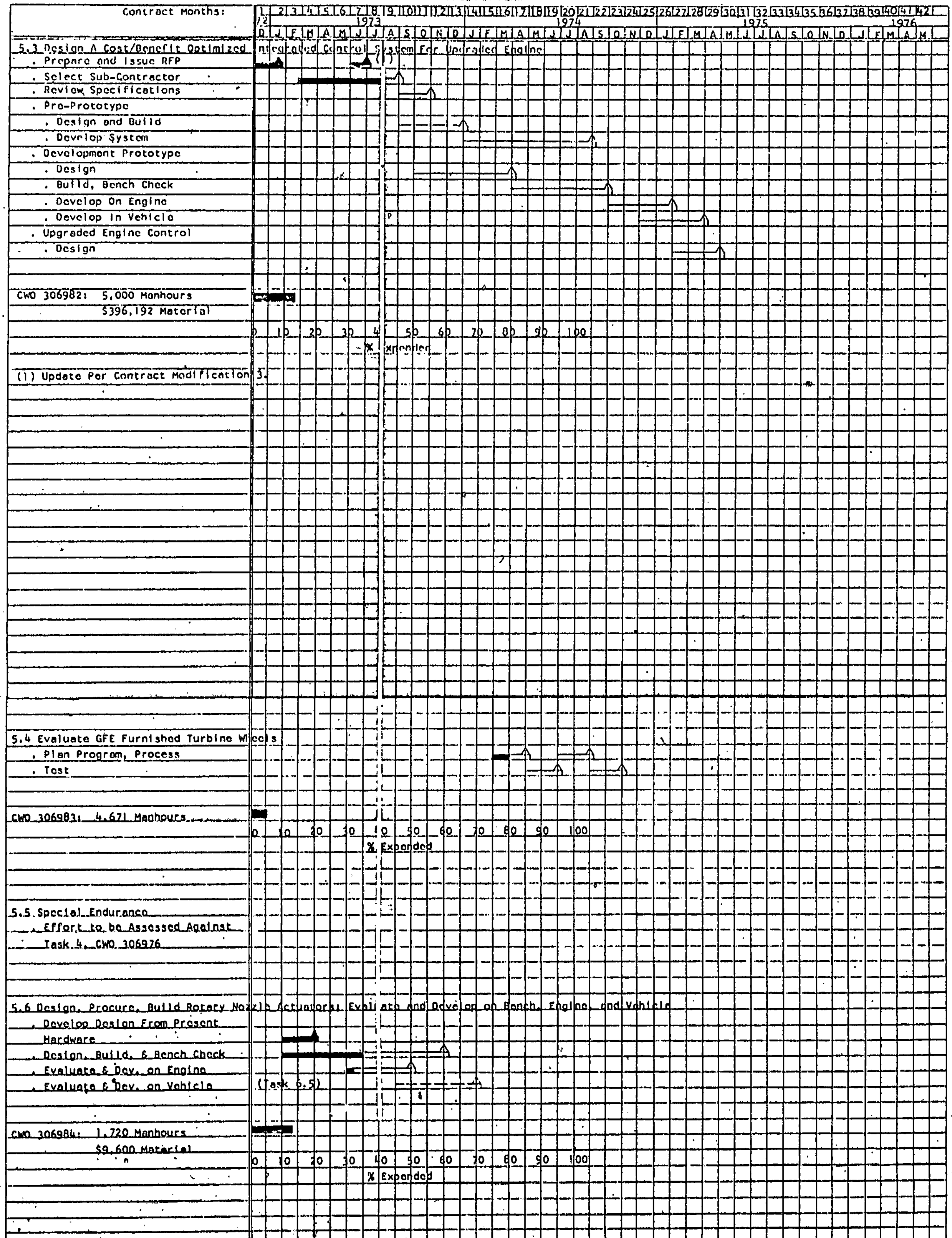
. Fixture Evaluation

. Engine Evaluation

CWO 306981: 9,375 Manhours
$187,347 Material

0 10 20 30 40 50 60 70 80 90 100
% Expended

EPA CONTRACT 68-01-0459
BASELINE GAS TURBINE DEVELOPMENT
PROGRAM PLAN



Contract Months: 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42

1972 / 1973 / 1974 / 1975 / 1976

Task | D J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S O N D J F M A M

5.7 Design, Procure, Build A Torque Converter Lock-Up Device to Prevent Power Turbine Underspeed And Improve Fuel Economy
- . Establish Concept
- . Design and Build (1)
- . Vehicle Evaluation (Task 6.6)

CWO 306985: 1240 Manhours
$8,000 Material

0 10 20 30 40 50 60 70 80 90 100
% Expended

(1) Initial concepts beyond funding allotment; alternative program scheduled

5.8 Free Rotor Concept Evaluation
- . Design Evaluation Scheme and Control
- . Build Cell Evaluation Scheme
- . Evaluate in Cell
- . Modify Scheme for Veh. Eval.
- . Evaluate in Vehicle (Task 6.7) (1)
- . Integrated Powerplant Design
- . Cost Analysis

CWO 306986: 3,665 Manhours
$1,600 Material

0 10 20 30 40 50 60 70 80 90 100
% Expended

(1) Schedule change due to continued evaluation testing requirements.

6.1 - 6.2 Modify Engines and Vehicles to Verify Task 5 Improvements in Vehicles
- . Combustor (a)
- . Regenerator (a)
- . Control
- . Rotary Nozzle Actuator
- . Torque Converter Lock-Up
- . Free Rotor

CWO 306987: 6,650 Manhours

0 10 20 30 40 50 60 70 80 90 100
% Expended

6.3 - 6.7 Evaluate Task 5 Improvements in Vehicles
- . Combustor (a)
- . Regenerator (a)
- . Control
- . Rotary Nozzle Actuator (Car 20)
- . Torque Converter Lock-Up (1)
- . Free Rotor

CWO 306988: 12,785 Manhours

0 10 20 30 40 50 60 70 80 90 100
% Expended

(1) Schedule dictated by Task 5.7

7.1 Design Upgraded Engine
- . Concept Studies (Combustor Vol.) (Review)
- . Layout (Review)
- . Engine Housing & Liners
- . Gas Generator
- . Burner and Vortex
- . Interstage/Variable Nozzle
- . Power Turbine, Veh. Acc.
- . Engine Acc. & Oil System
- . Regenerator/Seals
- . Control

CWO 306989: 15,320 Manhours

0 10 20 30 40 50 60 70 80 90 100
% Expended

2-14-73

(a) Contingent upon Task 5 evaluation results.

Contract Months: 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42

Task — 72: D | 1973: J F M A M J J A S O N D | 1974: J F M A M J J A S O N D | 1975: J F M A M J J A S O N D | 1976: J F M A M

** 7.2 – 7.4 Build and Checkout 7 Upgraded Engines
- . Procure Parts
  - Engine Housing & Liners
  - Gas Generator
  - Burner and Vortex
  - Interstage/Variable Nozzle
  - Power Turbine
  - Regenerator/Seals
  - Oil System & Engine Acc.
  - Control
  - Vehicle Accessories
- . Build Engines
- . Checkout Engines

O – Originate
S – Source
C – Casting

CWO 306990: 35,497 Manhours
$344,000 Material

0 10 20 30 40 50 60 70 80 90 100
% Expended

** 7.5 – 7.6 Corrective Design, Development, and Endurance Evaluation of Upgraded Engine
- . Corrective Design
- . Corrective Development
  - . General
  - . Combustion System
  - . Control System
- . Endurance
  - . Installation & 1000-Hr. Insp.
  - . Performance Checks
  - . Endurance Cycling

CWO 306991: 21,031 Manhours

0 10 20 30 40 50 60 70 80 90 100
% Expended

** 8.1 Design 1975 Vehicle Installation of Upgraded Engine, Estimate Cost
- . Design Chassis Adaptation
- . Design Exhaust System
- . Design Intake System
- . Design Body Adaptation
- . Design Control System
- . Design Heater/AC System
- Make High-Volume Cost Estimate

CWO 306992: 7,550 Manhours

0 10 20 30 40 50 60 70 80 90 100
% Expended

** To be rescheduled per contract modification 3

2-14-73

Contract Months: 1–42 (1972: D; 1973: J F M A M J J A S O N D; 1974: J F M A M J J A S O N D; 1975: J F M A M J J A S O N D; 1976: J F M A M)

Task

** 8.2 - 8.3 Procure and Modify 2 1975 Vehicles; Adapt One 1973 Vehicle; Install Upgraded Engine; Checkout

. Procure 2 1975 Vehicles (D,E)
. Modify Chassis and Body
. Modify Steering and Suspension
. Build Heater/AC System
. Build Exhaust System
. Build Wiring and Linkage
. Install Engine
. Checkout and Adjust
. Adapt 1 1973 Vehicle (A)
. Build Wiring and Linkage
. Build Exhaust System
. Install Engine
. Checkout and Adjust

CWO 306993: 12,954 Manhours
$18,700 Material

0 10 20 30 40 50 60 70 80 90 100
% Expended

** 8.4 Verify and Deliver Vehicles
. Performance
. Economy
. Emissions
. Starting
. Underhood Temperature
. Noise
. Endurance
. Deliver to EPA, D & E

CWO 306994: 12,657 Manhours

0 10 20 30 40 50 60 70 80 90 100
% Expended

9 Prepare Reports and Reviews
. Plan of Performance
. Monthly Reports
. Quarterly Reports
. Final Report
. Oral Presentations
. Documentary Film

CWO 306995: 7,430 Manhours

0 10 20 30 40 50 60 70 80 90 100
% Expended

ALL TASKS: 263,479 Manhours
1,389,418 Material

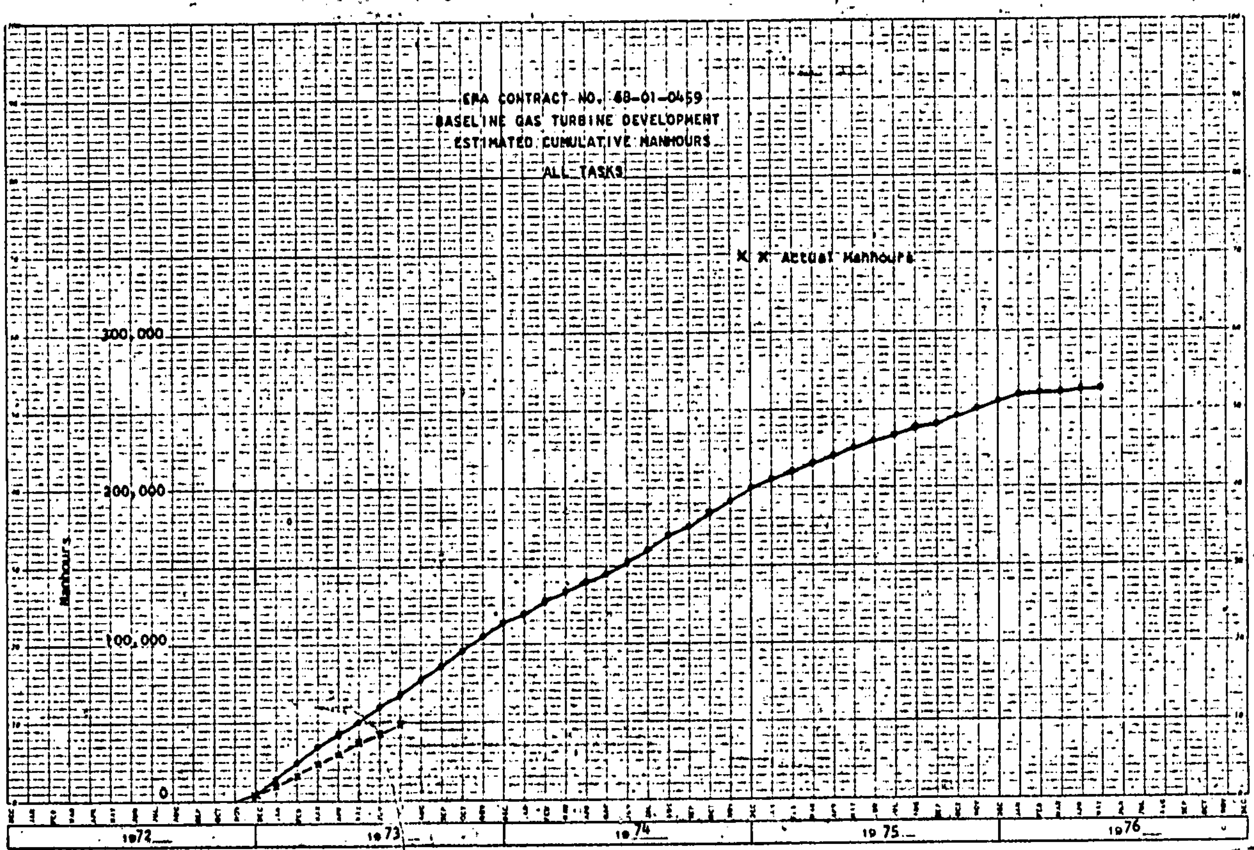
0 10 20 30 40 50 60 70 80 90 100
% Expended

** To be rescheduled per contract modification 3

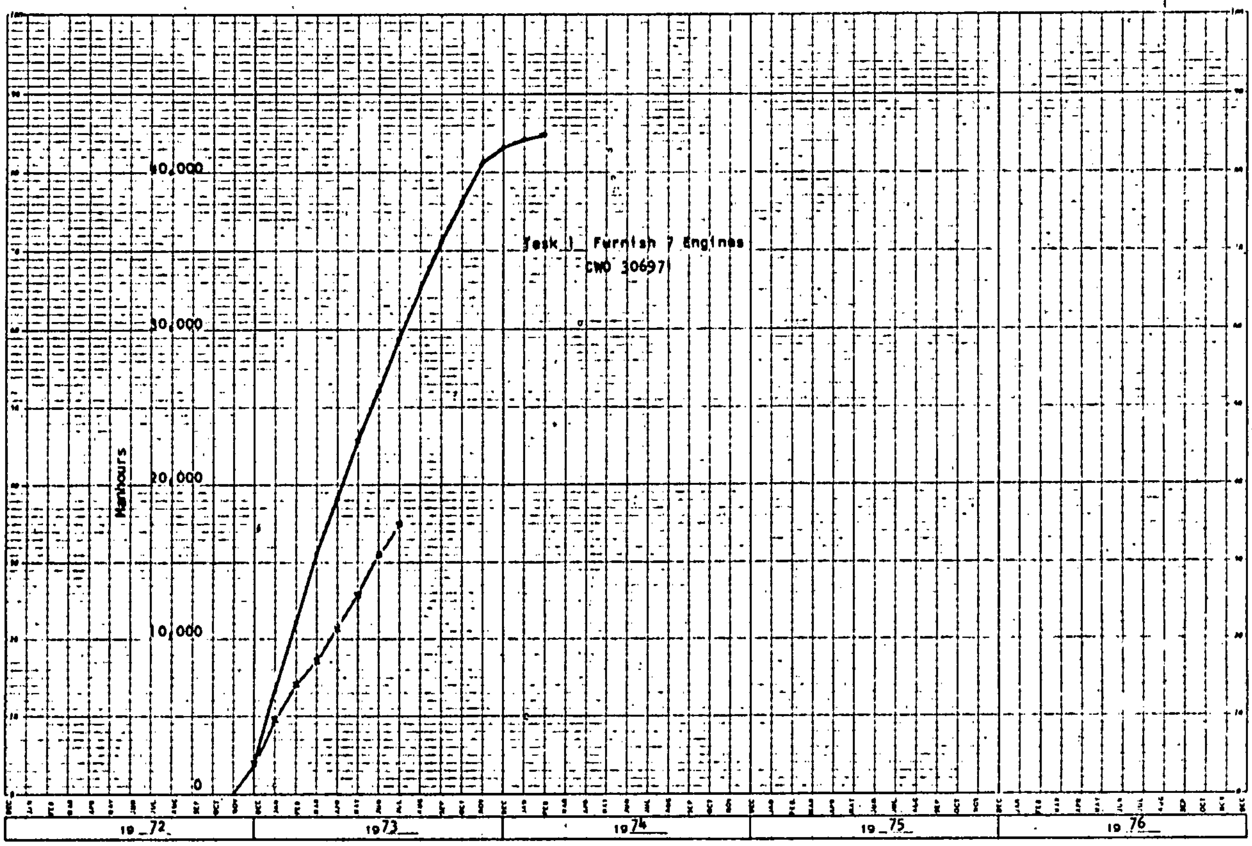
APPENDIX C

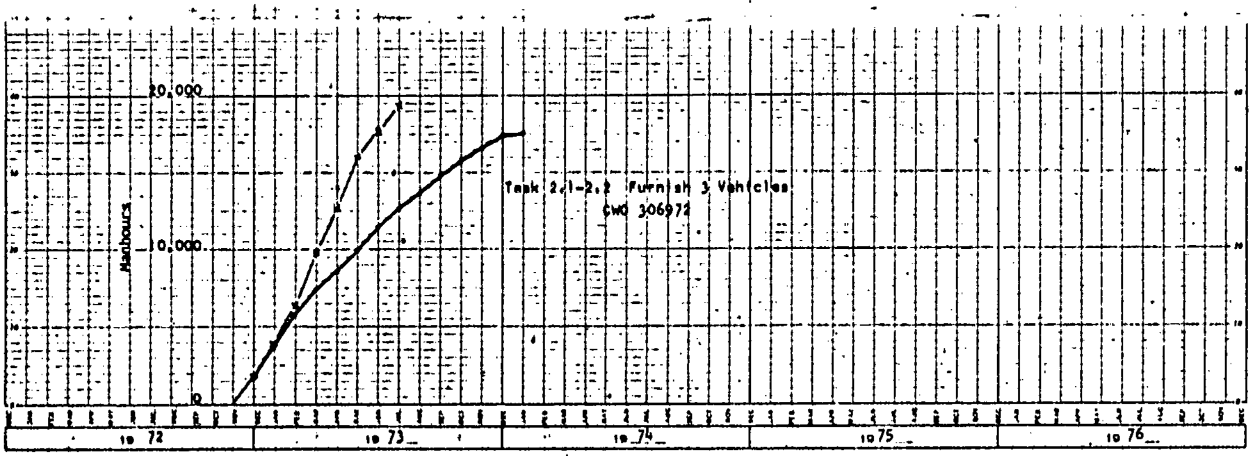
CUMULATIVE MANHOUR GRAPHS

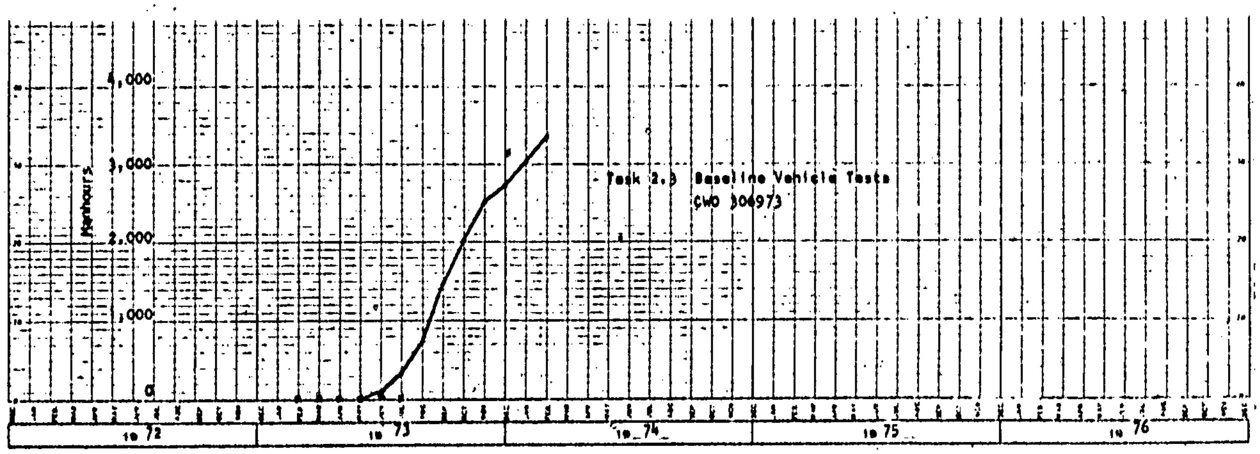
C-1



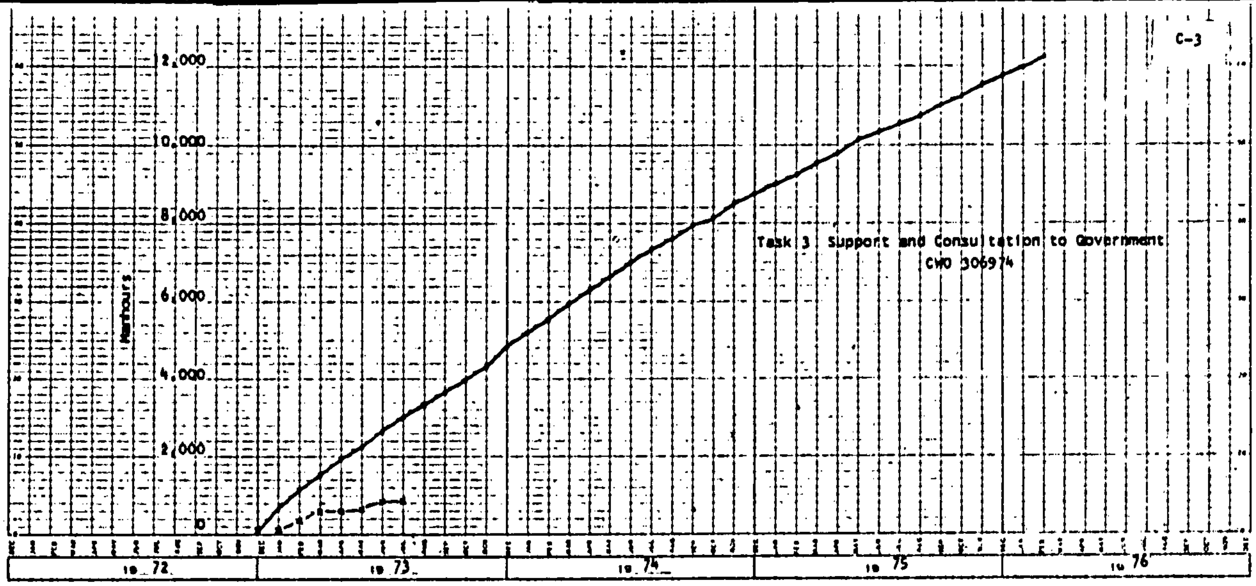
EPA CONTRACT NO. 68-01-0459
BASELINE GAS TURBINE DEVELOPMENT
ESTIMATED CUMULATIVE MANHOURS
ALL TASKS
X X Actual Manhours
Manhours
300,000
200,000
100,000
0
1972
1973
1974
1975
1976

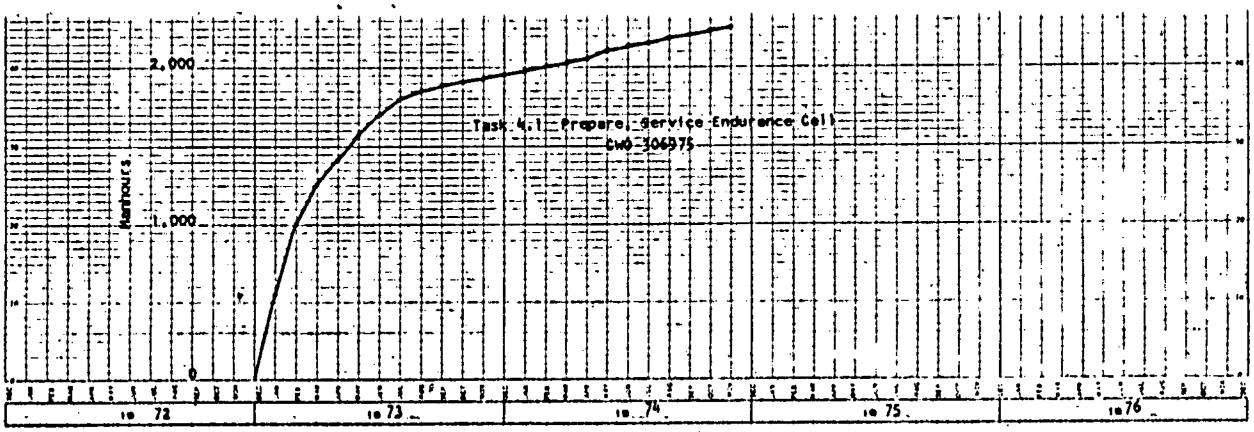

40,000
30,000
20,000
10,000
0
Manhours
Task 1 Furnish 7 Engines
CWO 306971
19 72
19 73
19 74
19 75
19 76

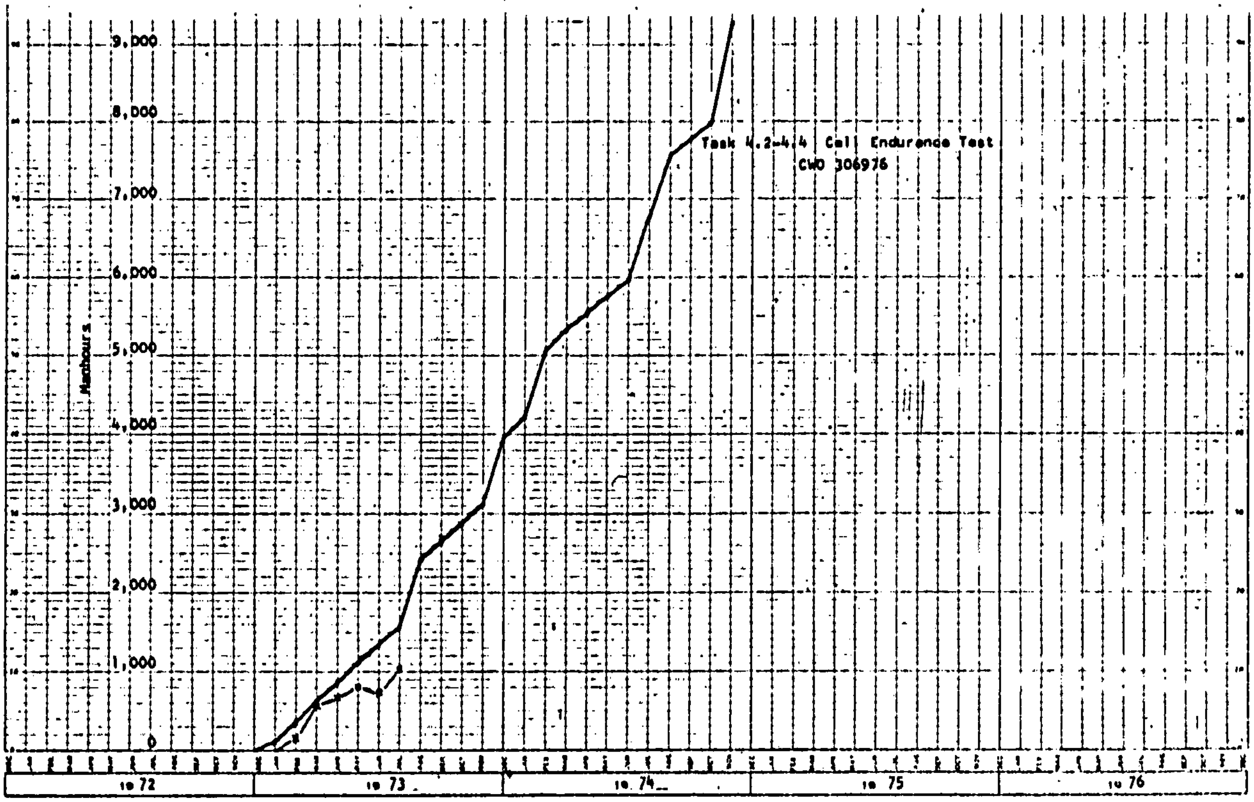

20,000
10,000
0
Manhours
Task 2.1-2.2 Furnish 3 Vehicles
CWO 306972
19 72
19 73
19 74
19 75
19 76

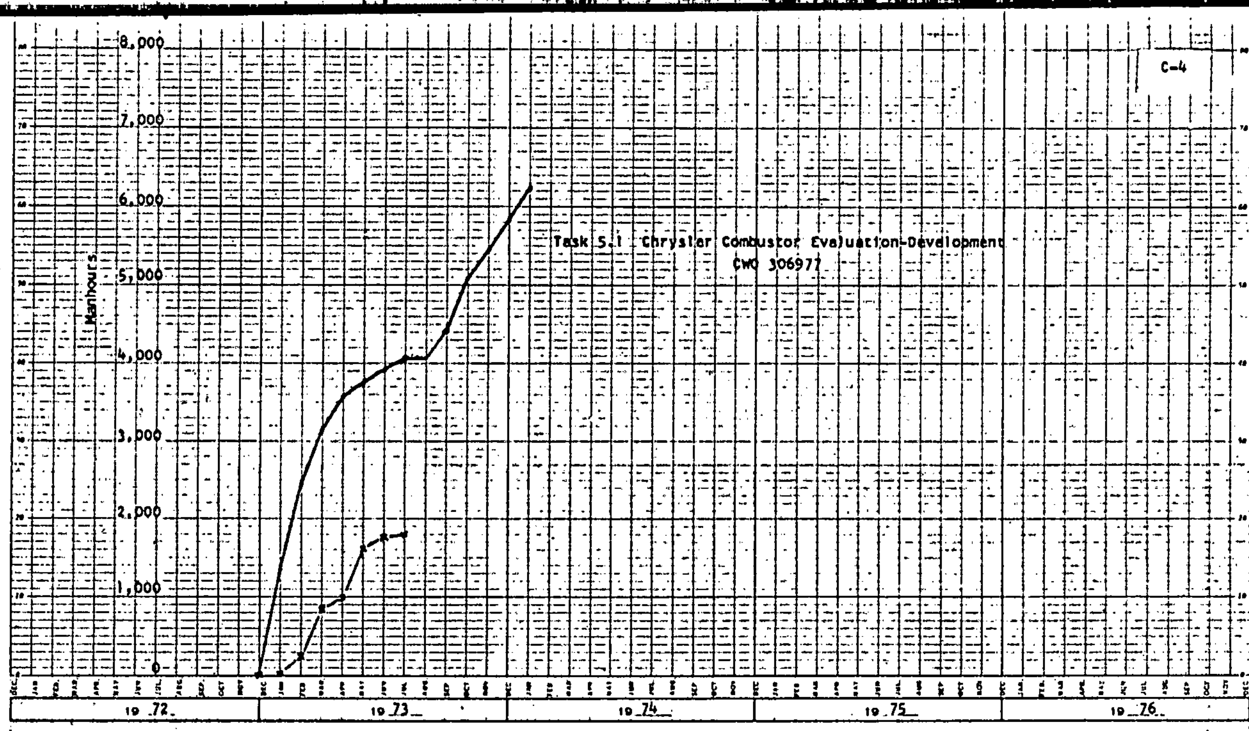

4,000
3,000
2,000
1,000
0
Manhours
Task 2.3 Baseline Vehicle Tests
CWO 306973
19 72
19 73
19 74
19 75
19 76

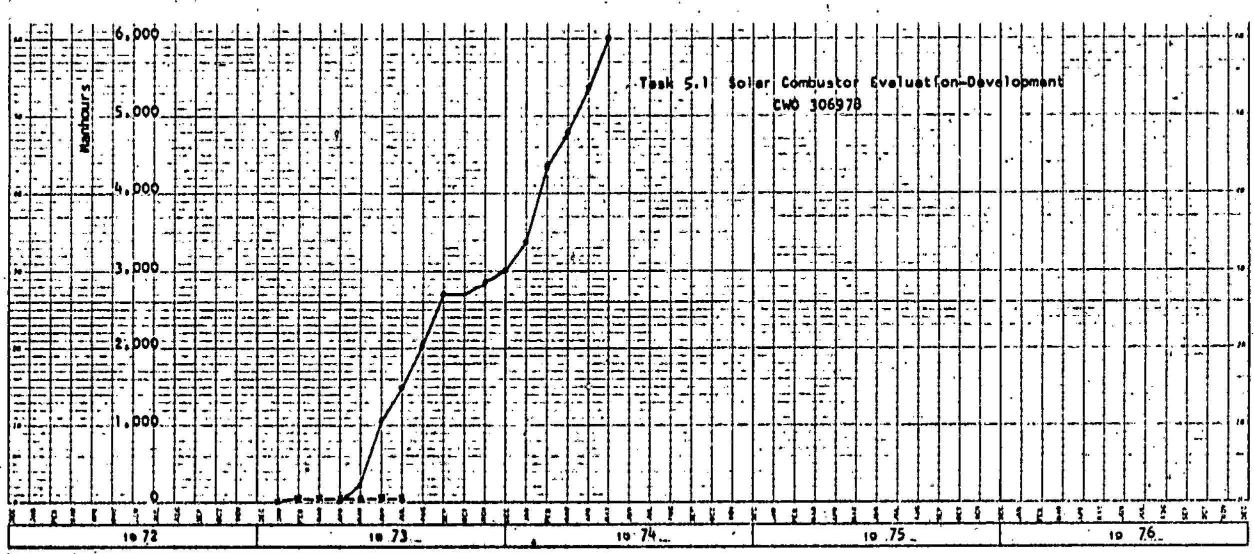
C-3

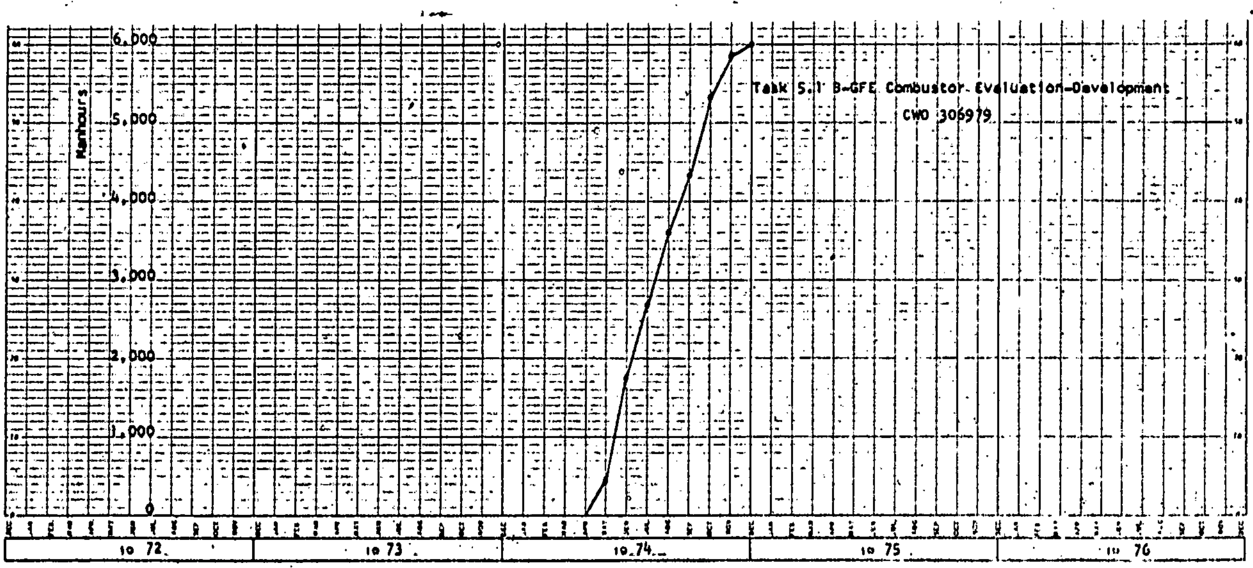

12,000
10,000
8,000
6,000
4,000
2,000
0
Manhours
Task 3 Support and Consultation to Government
CWO 306974
19 72
19 73
19 74
19 75
19 76

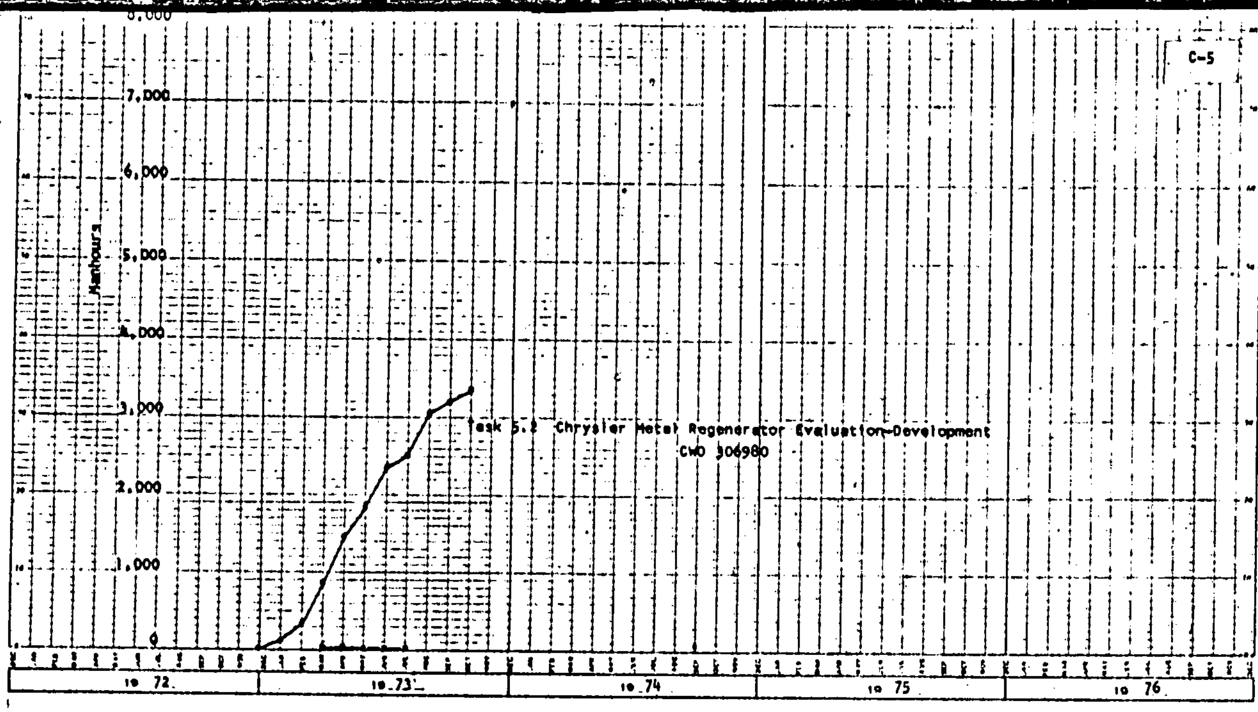

2,000
1,000
0
Manhours
Task 4.1 Prepare, Service Endurance Cell
CWO 306975
19 72
19 73
19 74
19 75
19 76

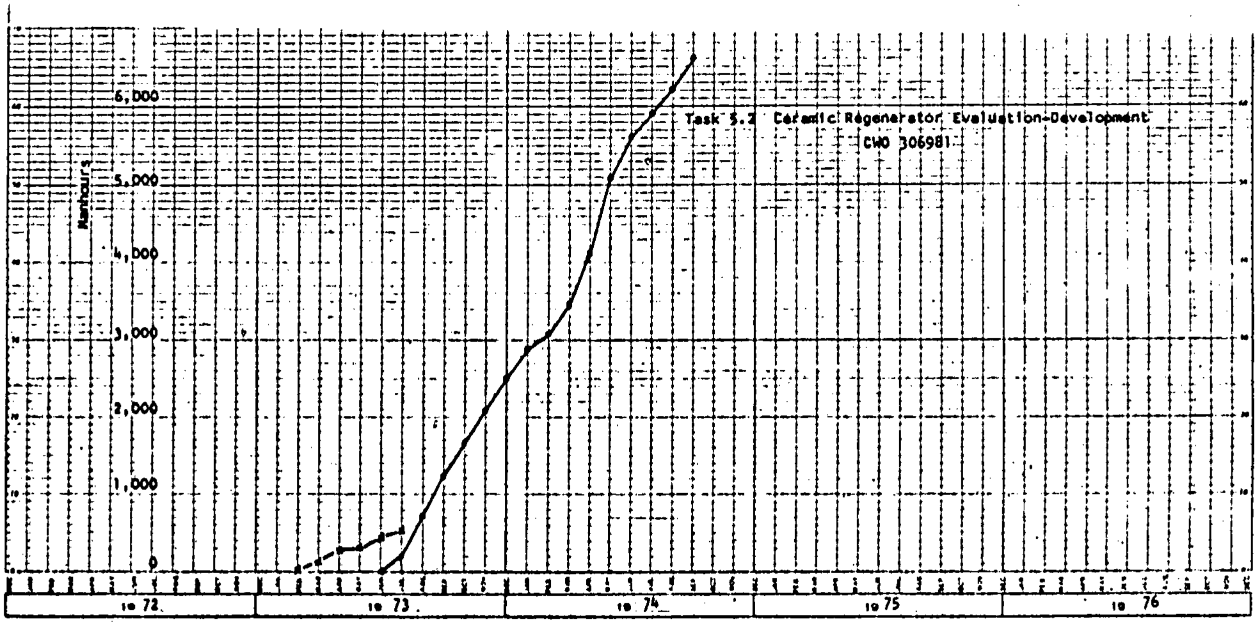

9,000
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
Manhours
Task 4.2-4.4 Cell Endurance Test
CWO 306976
19 72
19 73
19 74
19 75
19 76

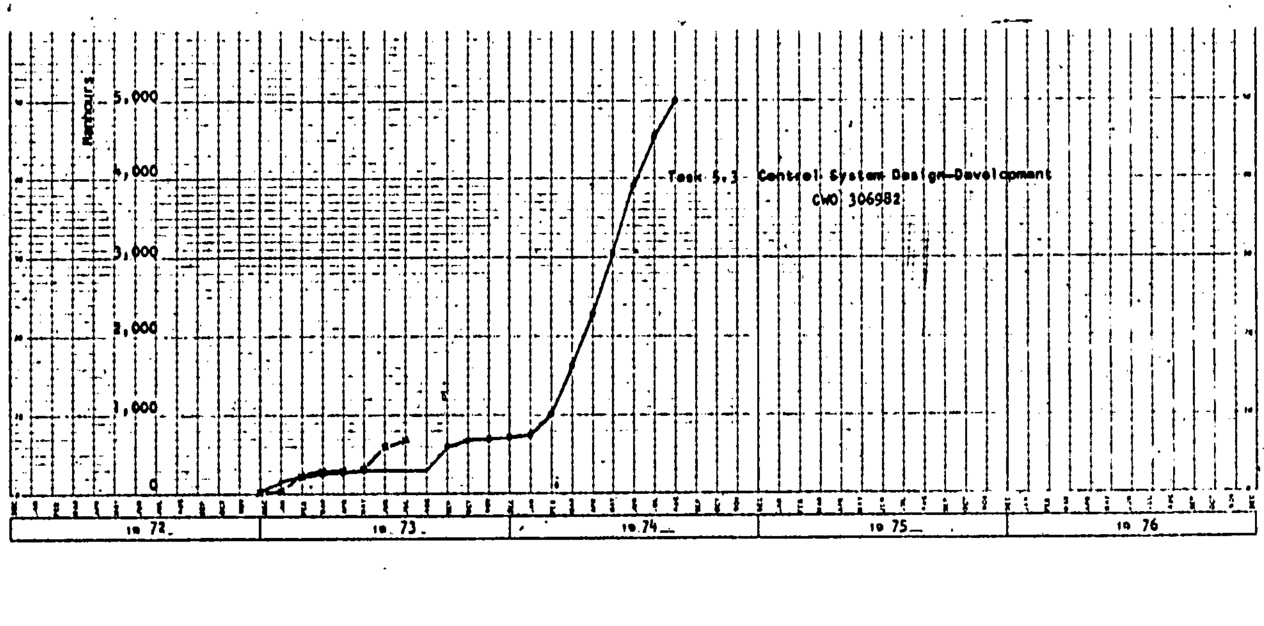

Task 5.1 Chrysler Combustor Evaluation-Development
CWO 306977
Manhours
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
19 72
19 73
19 74
19 75
19 76

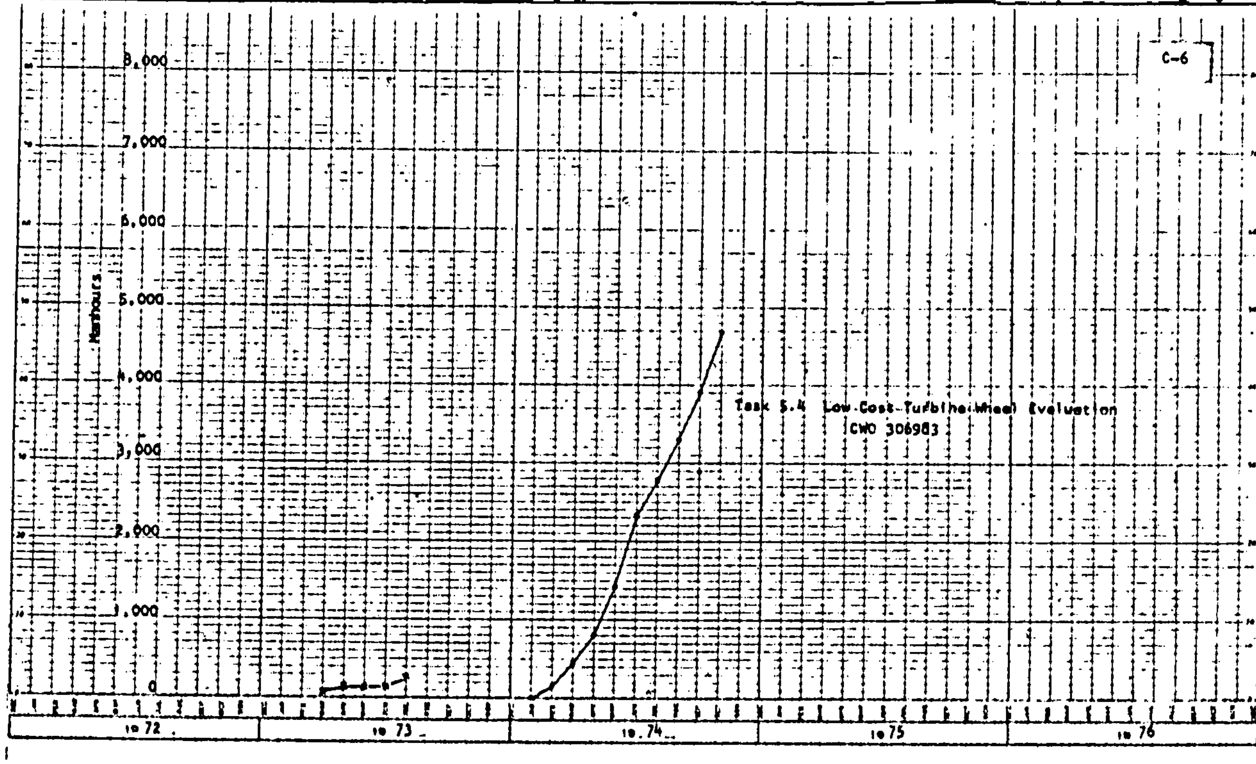

Task 5.1 Solar Combustor Evaluation-Development
CWO 306978
Manhours
6,000
5,000
4,000
3,000
2,000
1,000
0
19 72
19 73
19 74
19 75
19 76

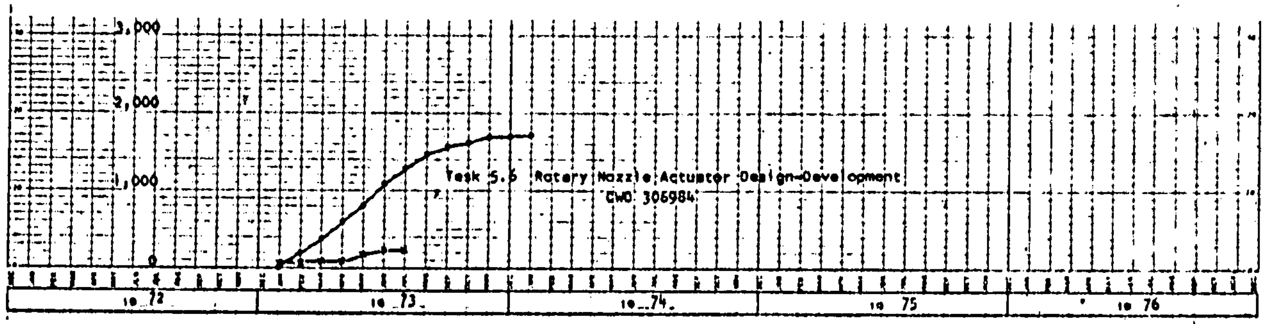

Task 5.1 B-GFE Combustor Evaluation-Development
CWO 306979
Manhours
6,000
5,000
4,000
3,000
2,000
1,000
0
19 72
19 73
19 74
19 75
19 76

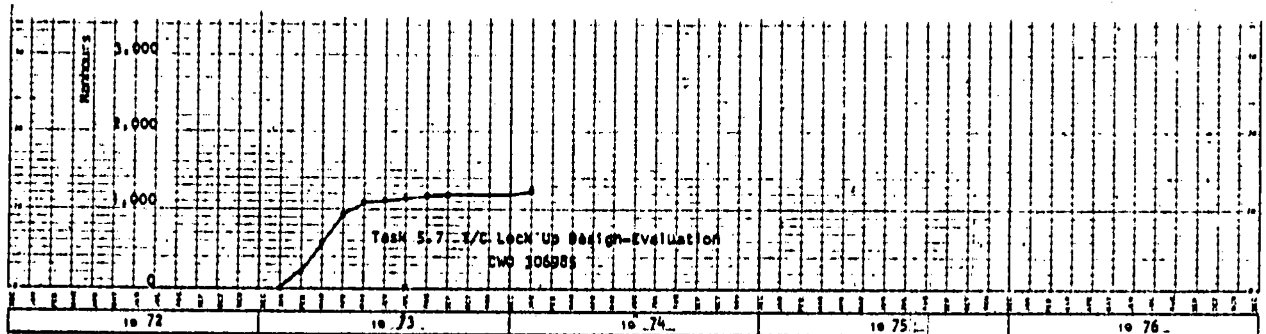

Manhours
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
Task 5.1 Chrysler Metal Regenerator Evaluation-Development
CWO 306980
19 72
19 73
19 74
19 75
19 76

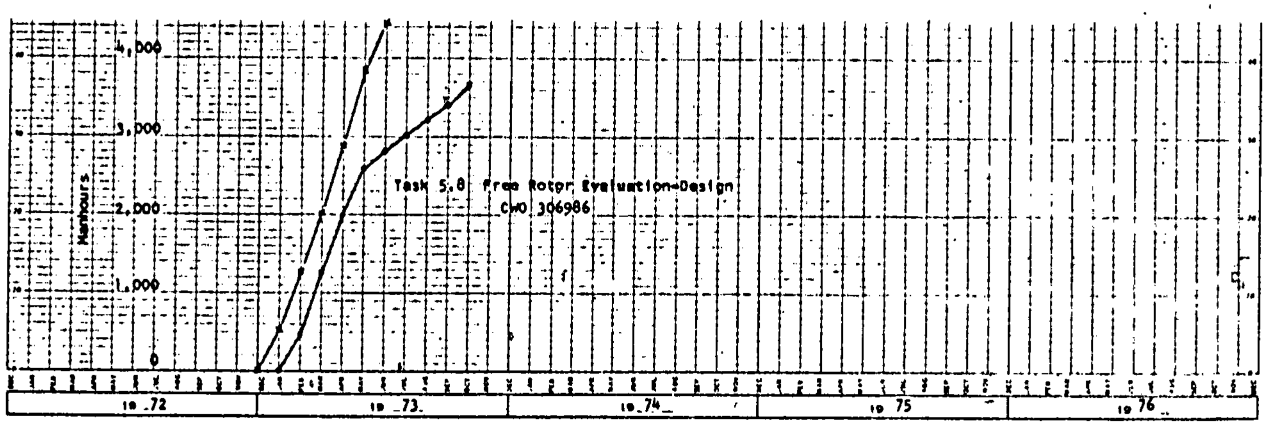

Manhours
6,000
5,000
4,000
3,000
2,000
1,000
0
Task 5.2 Ceramic Regenerator Evaluation-Development
CWO 306981
19 72
19 73
19 74
19 75
19 76


Manhours
5,000
4,000
3,000
2,000
1,000
0
Task 5.3 Control System Design-Development
CWO 306982
19 72
19 73
19 74
19 75
19 76

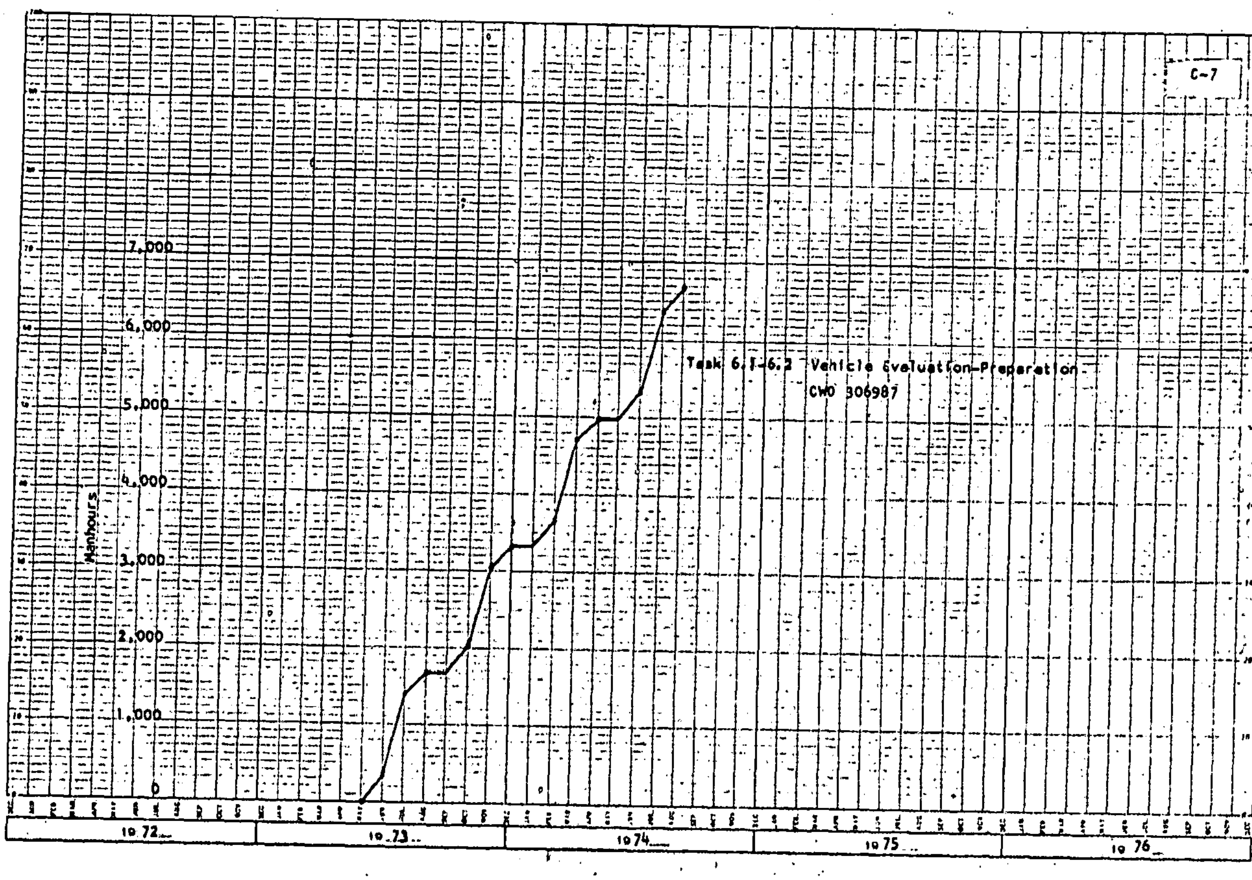

Manhours
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
Task 5.4 Low-Cost Turbine Wheel Evaluation
CWO 306983
19 72
19 73
19 74
19 75
19 76

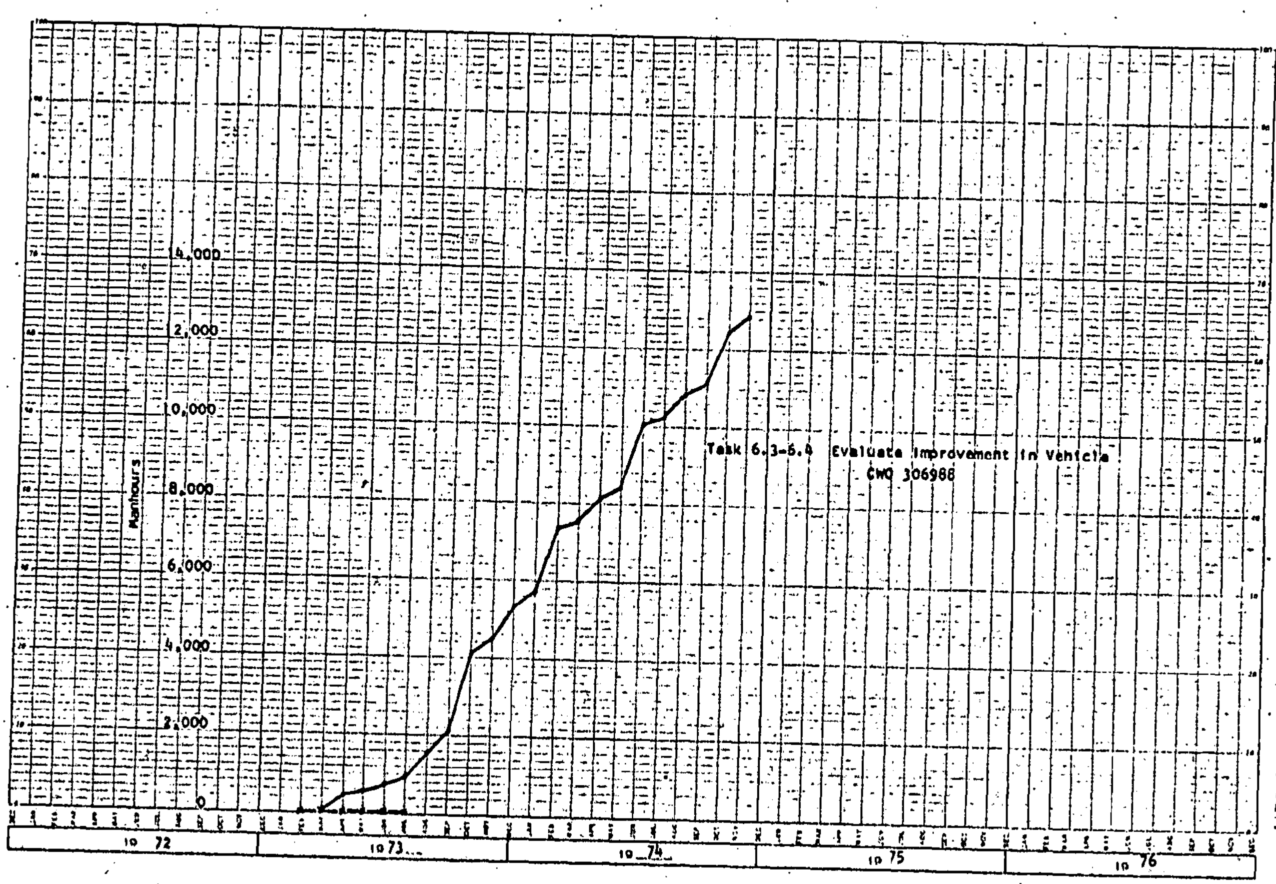

3,000
2,000
1,000
0
Task 5.6 Rotary Nozzle Actuator Design-Development
CWO 306984
19 72
19 73
19 74
19 75
19 76

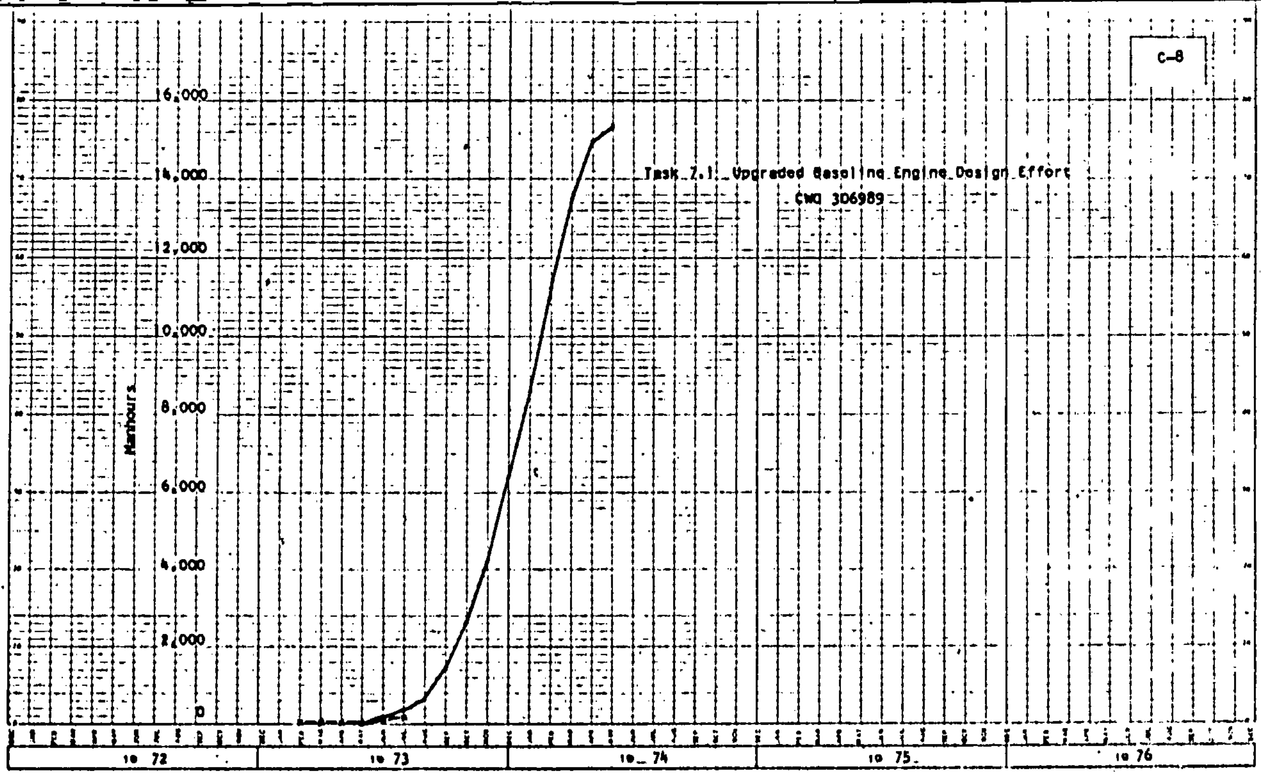

Manhours
3,000
2,000
1,000
0
Task 5.7 T/C Lock Up Design-Evaluation
CWO 306985
19 72
19 73
19 74
19 75
19 76

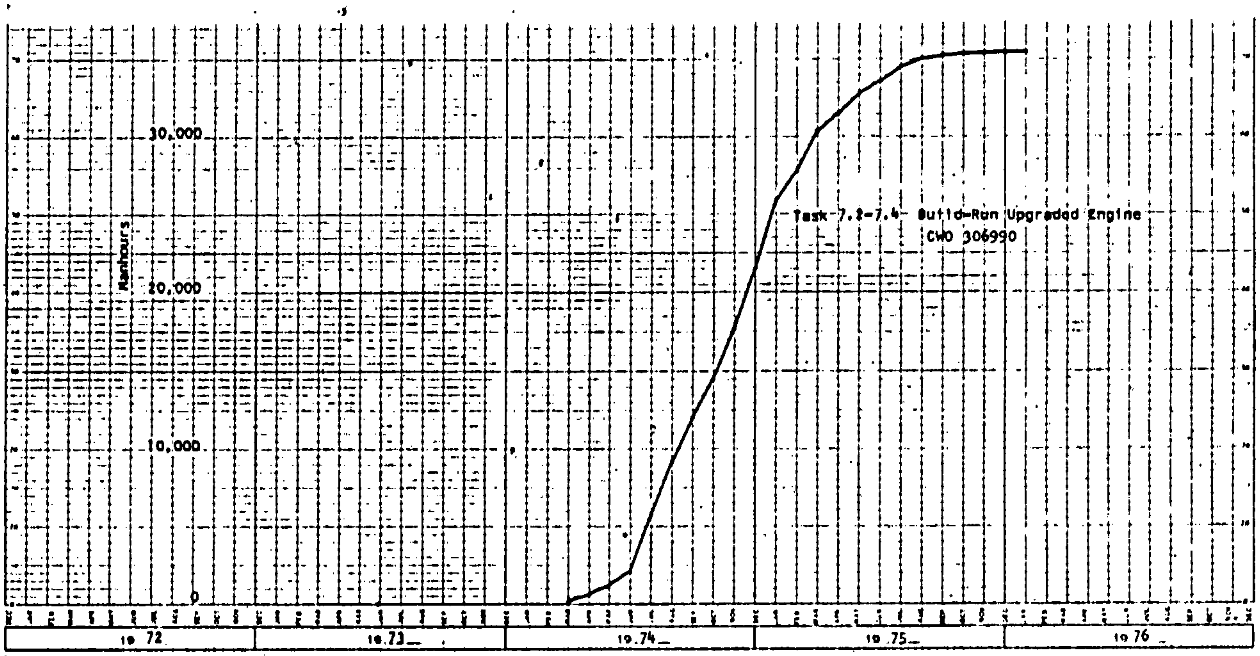

Manhours
4,000
3,000
2,000
1,000
0
Task 5.8 Free Rotor Evaluation-Design
CWO 306986
19 72
19 73
19 74
19 75
19 76

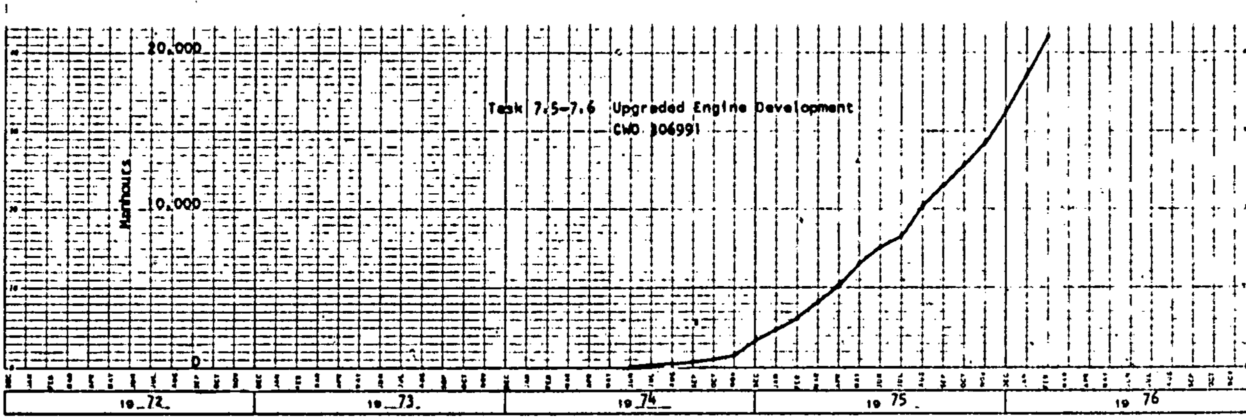
C-7

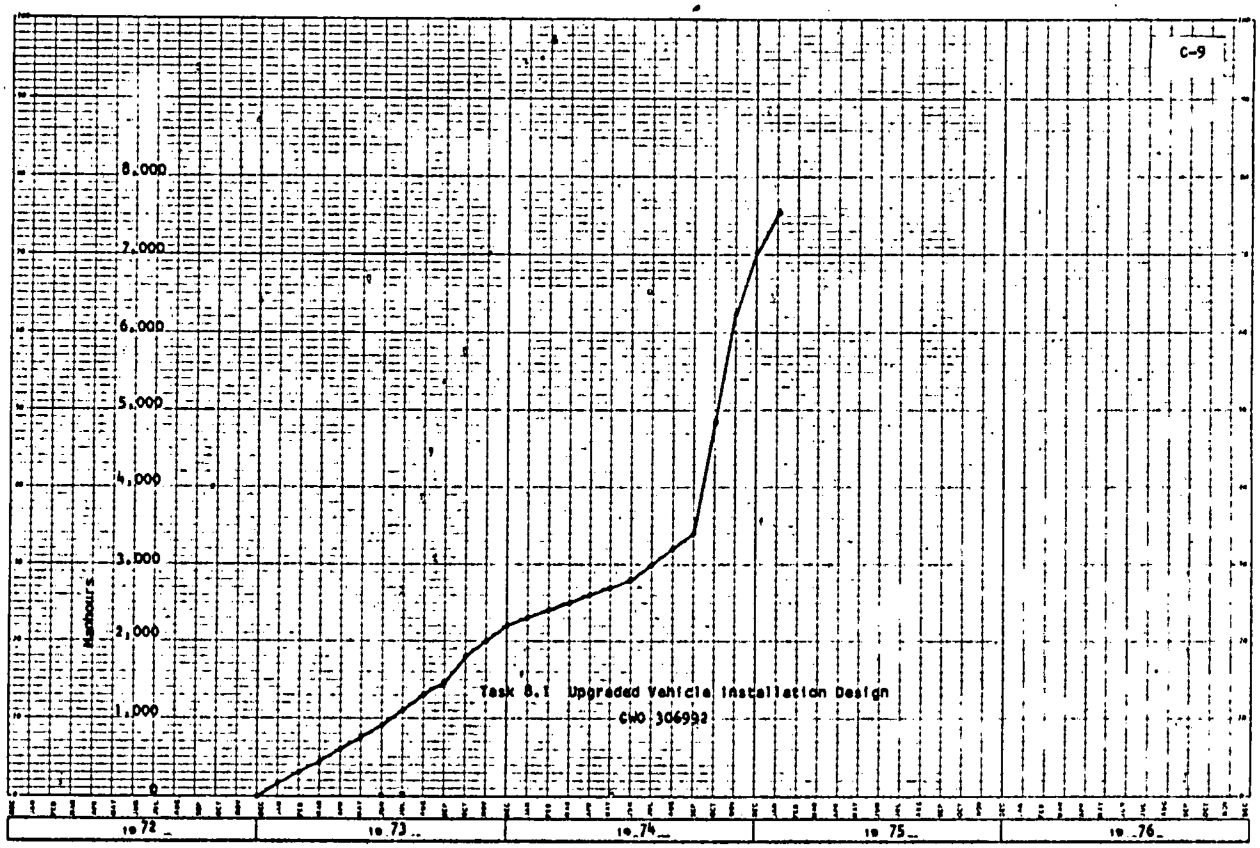

7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
Manhours
Task 6.1-6.2 Vehicle Evaluation-Preparation
CWO 306987
19 72
19 73
19 74
19 75
19 76

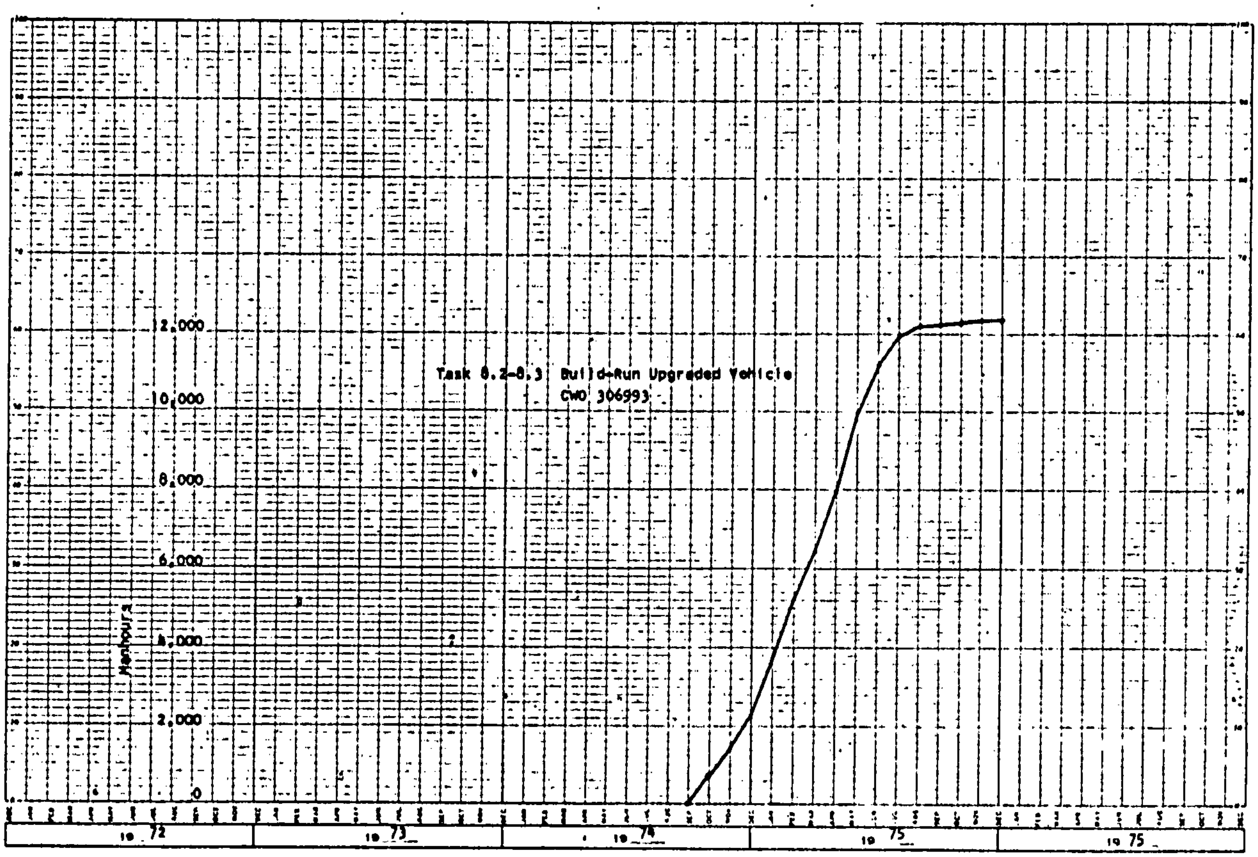

4,000
2,000
10,000
8,000
6,000
4,000
2,000
0
Manhours
Task 6.3-6.4 Evaluate Improvement in Vehicle
CWO 306988
19 72
19 73
19 74
19 75
19 76


Task 7.1 Upgraded Baseline Engine Design Effort
CWO 306989
Manhours
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
19 72
19 73
19 74
19 75
19 76


Task 7.2-7.4 Build-Run Upgraded Engine
CWO 306990
Manhours
30,000
20,000
10,000
0
19 72
19 73
19 74
19 75
19 76


Task 7.5-7.6 Upgraded Engine Development
CWO 306991
Manhours
20,000
10,000
0
19 72
19 73
19 74
19 75
19 76


8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
Manhours
Task 8.1 Upgraded Vehicle Installation Design
CWO 306992
19 72
19 73
19 74
19 75
19 76


12,000
10,000
8,000
6,000
4,000
2,000
0
Manhours
Task 8.2-8.3 Build-Run Upgraded Vehicle
CWO 306993
19 72
19 73
19 74
19 75
19 75

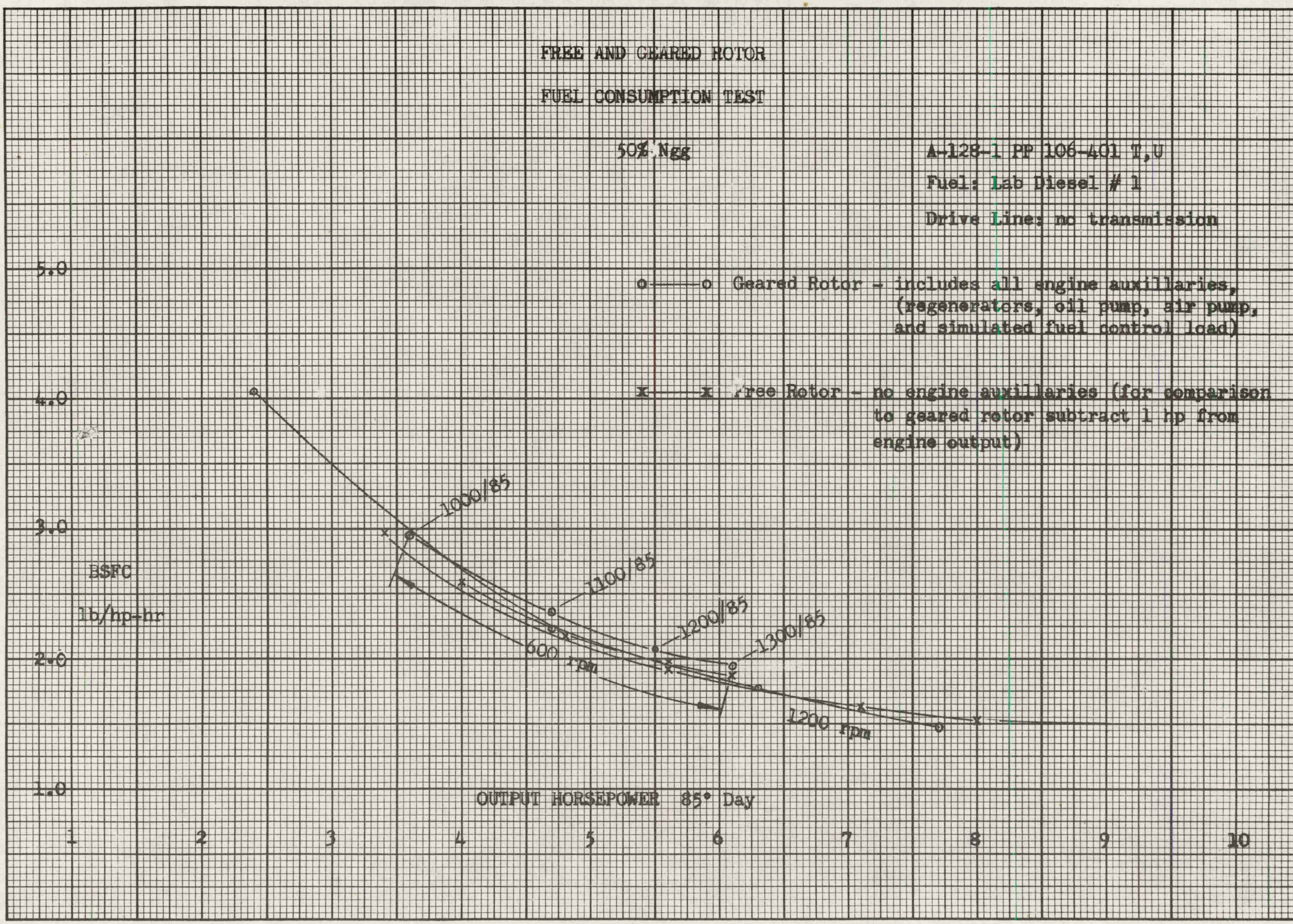
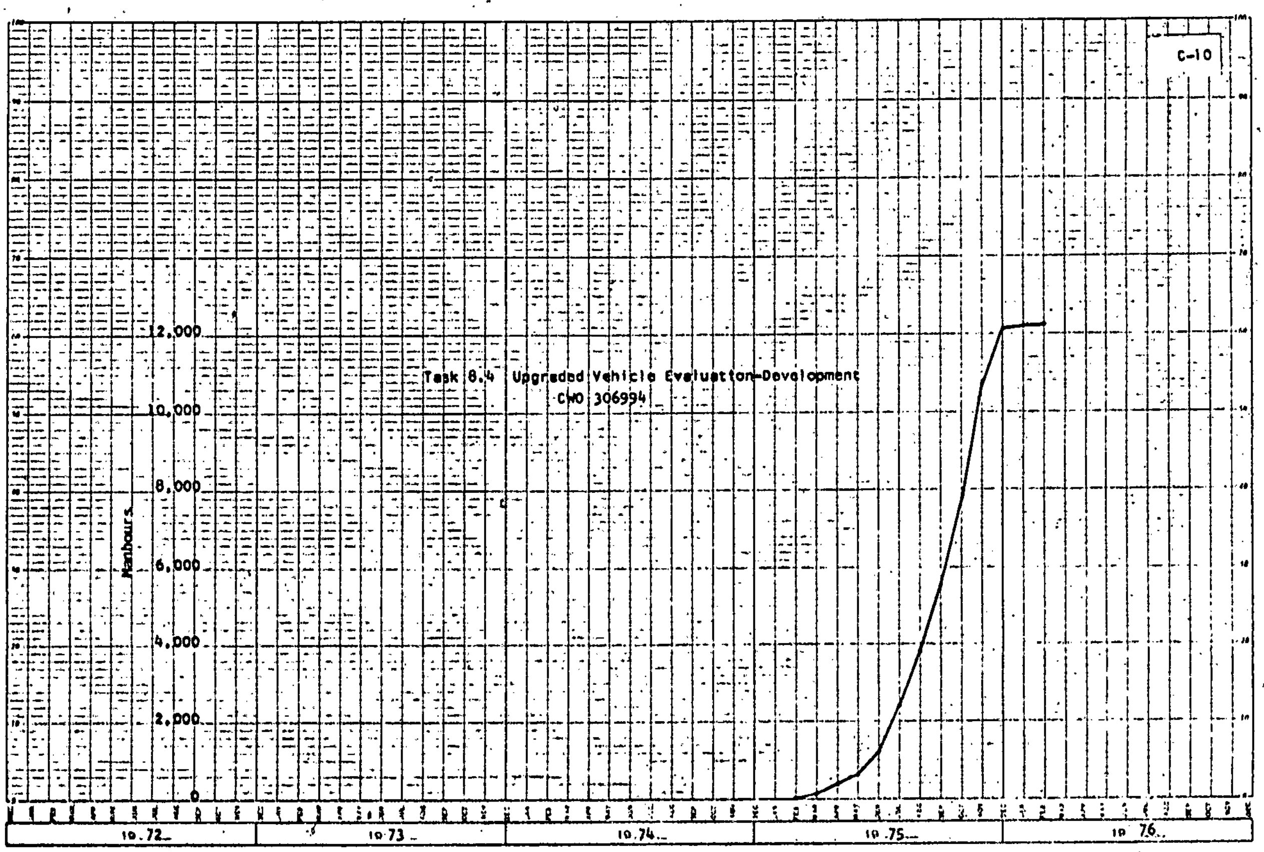
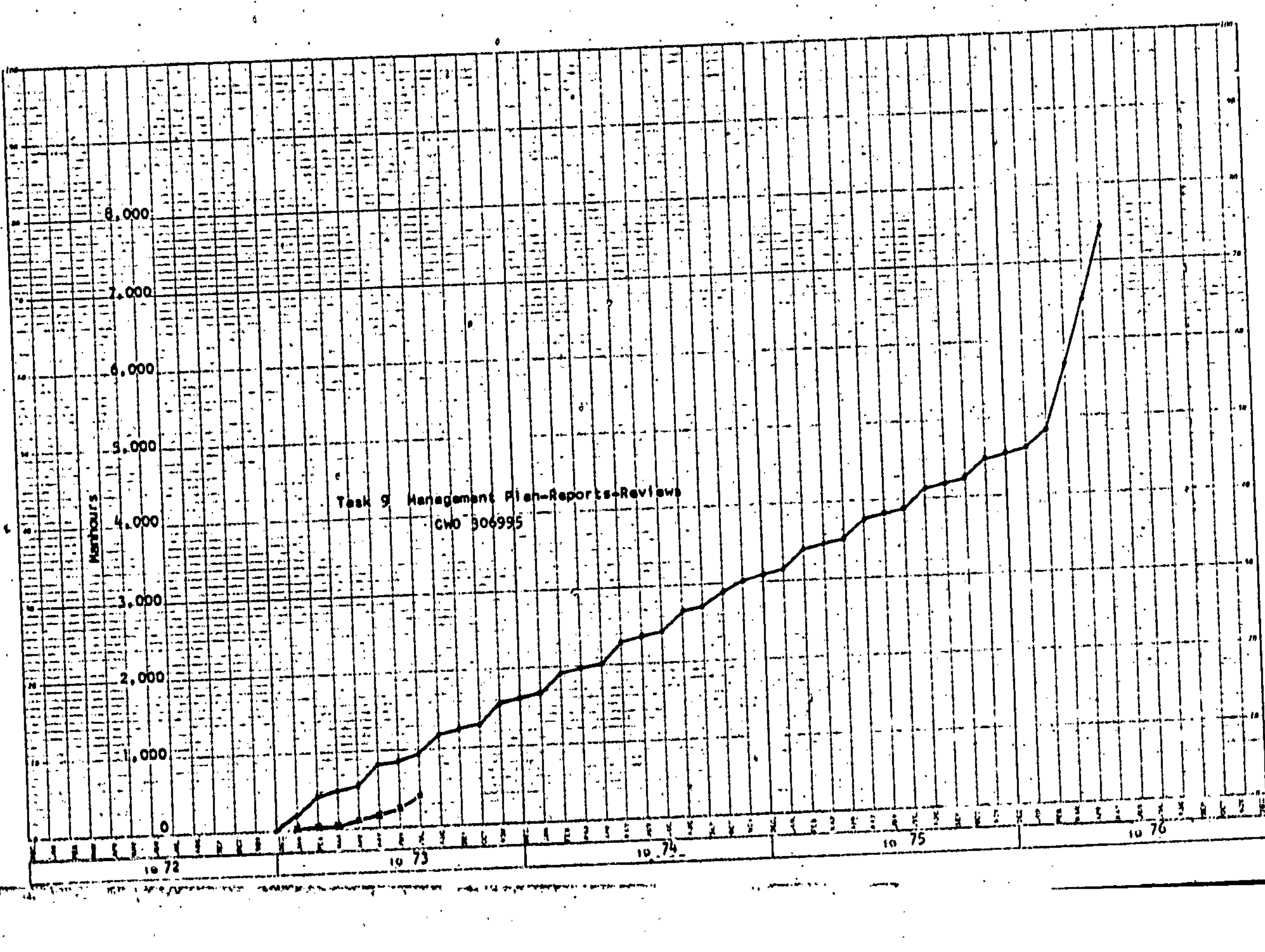

FREE AND GEARED ROTOR
FUEL CONSUMPTION TEST
50% Ngg
A-128-1 PP 106-401 T,U
Fuel: Lab Diesel # 1
Drive Line: no transmission
o——o Geared Rotor - includes all engine auxillaries, (regenerators, oil pump, air pump, and simulated fuel control load)
x——x Free Rotor - no engine auxillaries (for comparison to geared rotor subtract 1 hp from engine output)
BSFC
lb/hp-hr
5.0
4.0
3.0
2.0
1.0
1000/85
1100/85
1200/85
1300/85
600 rpm
1200 rpm
OUTPUT HORSEPOWER 85° Day
1
2
3
4
5
6
7
8
9
10

Figure 23

C-10


Task 8.4 Upgraded Vehicle Evaluation-Development
CWO 306994
Manhours
12,000
10,000
8,000
6,000
4,000
2,000
0
19 72
19 73
19 74
19 75
19 76


Task 9 Management Plan-Reports-Reviews
CWO 306995
Manhours
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
19 72
19 73
19 74
19 75
19 76