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SUMMARY REPORT
AIResearch TURBOGENERATOR POWER SUPPLY
PICATINNY ARSENAL SUBCONTRACT
DA-04-495-ORD-3208

M-1607-R June 20, 1963
1. SECTION 1

1.1 Object - This report summarizes the work accomplished by the AiResearch Manufacturing Company, a Division of the Garrett Corporation, toward the design and development of a miniature solid-fuel turbo-generator as an adaptation Kit Power Source, Project TN2-8108, under Picatinny Arsenal Subcontract DA-04-495-ORD-3208, during the period from March 27, 1961 thru October 31, 1962.

1.2 Summary - A solid-fuel turbine-electrical power supply, delivering approximately 150 watts for 100 seconds, was designed and built by the AiResearch Manufacturing Company. Four turbogenerator assemblies and 25 gas generator assemblies, plus spares, were built during the program. Two of these units were underwent development tests at AiResearch and TKM Electric Corporation. Later these two units were refurbished and included in the delivery of four units to Picatinny Arsenal. Engineering tests during the development program demonstrated that the units were capable of performing to the specification. The complete assembly, including a loaded gas generator, weighed 3.81 pounds.
1.3 Conclusions - AiResearch Power Supply, P/N 551566-2, weighing 3.81 pounds, successfully met the specification "Requirements for a Solid Fuel Turbo Generator Power Supply" included as Appendix A to the Scope of Work, Control Number PA-SW-61-3.

1.4 Recommendations - It is recommended that the units be subjected to further tests by Picatinny Arsenal, and that they undergo flight test evaluation.

2. SECTION 2

2.1 Introduction - On March 27, 1961 the AiResearch Manufacturing Company, a Division of the Garrett Corporation, received a subcontract from Picatinny Arsenal to execute Phase 1 of a feasibility program toward development of a miniature turbo-generator power supply meeting the requirements of Picatinny Arsenal work statement DA-SW-61-3. These requirements were for a solid fuel turbo generator power supply capable of supplying 150 watts of electrical power for 100 seconds duration at 6.8 and 115 volts ac, 10,000 cycles per second, and 9 and 28 volts dc. This power supply will be used primarily in a one-shot missile application where small size and weight, ruggedness, reliability, and no field preparation or testing are first priority considerations. This report summarizes the work accomplished by AiResearch Manufacturing Company during the period from March 27, 1961 thru October 31, 1962 in initiating and implementing the scope work required by the subcontract.
2.2 Summary of Prominent Activity - A preliminary design was completed in June 1961 and was reviewed at AiResearch by representatives from Picatinny Arsenal on June 29 and 30th. As a result of this review, certain design changes were made and a second design review meeting was held at Picatinny Arsenal on July 20th. As a result of this meeting, Picatinny Arsenal approved continuance of this program into the parts fabrication phase. During the next three months alternators and regulator packages were fabricated by TKM Electric Corporation, turbines, gas generators, and miscellaneous parts by AiResearch Manufacturing Company, and propellants by Picatinny Arsenal. In November 1961, twenty-five gas generators were shipped to Picatinny Arsenal for loading with propellants. In December 1961, the first alternator was received by AiResearch from TKM Electric Corporation, and turbo alternator development tests commenced. The first loaded gas generators were received from Picatinny Arsenal in February 1962 and solid propellant testing of the complete turbo-generator unit was started.

During the next three months the entire turbo-generator unit was subjected to a large number of development tests, including environments of temperature extremes, vibration, and shock. During these tests it was found that the air gap on the alternator was insufficient to provide adequate clearance under all environmental and operating conditions. Therefore, the alternator was redesigned with a more powerful magnet which would permit a larger axial air gap. The first reworked alternator was received at AiResearch in May 1962. All of the alternator and regulator packages were received from TKM Electric Corporation by September 1962.
The first turbo-generator assembly, S/N 42-R4, was shipped to Picatinny Arsenal in June 1962. Two additional turbo-generator assemblies, S/N 42-R2 and S/N 42-R3, were shipped to Picatinny Arsenal in October 1962. Also shipped at this time were all of the remaining spare parts and test equipment which might be useful in the test at Picatinny Arsenal.

Status of the work was reported monthly in a series of progress reports prepared by AiResearch. A summary of these progress reports, showing the prominent activities, is shown in Table I.
### TABLE I

**SUMMARY OF TURBOGENERATOR POWER SUPPLY AS DESCRIBED IN MONTHLY REPORTS**

<table>
<thead>
<tr>
<th>MONTH</th>
<th>APRIL</th>
<th>MAY</th>
<th>JUNE</th>
<th>JULY</th>
<th>AUGUST</th>
<th>SEPTEMBER</th>
<th>OCTOBER</th>
<th>NOVEMBER</th>
<th>DECEMBER 1961</th>
<th>JANUARY 1962</th>
<th>FEBRUARY</th>
</tr>
</thead>
<tbody>
<tr>
<td>DESIGN ANALYSIS</td>
<td>TURBOMACHINER</td>
<td>LAYOUT</td>
<td>GENERATOR</td>
<td>SPEC.</td>
<td>SELECT ALTERN.</td>
<td>VENTOR</td>
<td>FABRICATION</td>
<td>DRAWINGS</td>
<td>DETAILS</td>
<td>RELEASED</td>
<td></td>
</tr>
<tr>
<td>DELIVERIES</td>
<td>LAYOUT OF LIGHT-WEIGHT UNIT COMPLETED AND SUPPLIED TO PICATINY ARSENAL</td>
<td>DETAIL DRAWINGS FOR COMPLETED</td>
<td></td>
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</tr>
<tr>
<td>FIGURES</td>
<td>ADDITIONAL FABRICATION ON 25 GAS GENERATORS</td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>PICATINY ARSENAL ACTIVITY</td>
<td>SELECTED AS FABRICATE NEEDS DELAYED</td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>INHS ACTIVITY</td>
<td>SUBCONTRACT TO TURBOMACHINER FOR ELECTRICAL COMPONENTS ORDERED</td>
<td></td>
<td></td>
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<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>PHOTOGRAPHIC</td>
<td>GAS GENERATOR FABRICATION</td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CURVES, FIDDLERS, ETC.</td>
<td>ALTERNATOR TYPES DESIGN</td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DELIVERIES</td>
<td>25 GAS GENERATORS SHIPPED TO PICATINY ARSENAL</td>
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<td></td>
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**Notes:**
- M-1564-R
- M-1565-R
- M-1566-R
- M-1567-R
- M-1568-R
- M-1569-R
- M-1570-R
- M-1571-R
- M-1572-R
- M-1573-R
- M-1574-R
- M-1575-R

**Summary Notes:**
- Report No. M-1564-R
- Design analysis, layout, and generator specifications.
- Select alternate ventilator.
- Fabrication details completed.
- Release drawings.
- Light-weight unit completed and supplied to Picatinny Arsenal.
- Additional fabrication on 25 gas generators.
- Selectled as fabricate needs delayed.
- Subcontract to Turbomachiner for electrical components ordered.
- Gas generator fabrication.
- Alternator types design.
- 25 gas generators shipped to Picatinny Arsenal.
<table>
<thead>
<tr>
<th>TABLE I</th>
<th>SUMMARY OF BGENERATOR POWER SUPPLY PART 551566 (PICATINNY ARSENAL) DESCRIBED IN MONTHLY PROGRESS REPORTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>[Data Table]</td>
<td>[Data Table]</td>
</tr>
<tr>
<td>[Notes and Details]</td>
<td>[Notes and Details]</td>
</tr>
</tbody>
</table>
2.3 Specification Summary

2.3.1 Performance Requirements

Output:

<table>
<thead>
<tr>
<th>Watts</th>
<th>Volts</th>
<th>Power Output</th>
<th>Duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>35</td>
<td>115 vac 0.8 pf</td>
<td>10,000 cycles</td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>6.8 vac 0.8 pf</td>
<td>10,000 cycles</td>
<td></td>
</tr>
<tr>
<td>28</td>
<td>28 vdc</td>
<td>10,000 cycles</td>
<td></td>
</tr>
<tr>
<td>72**</td>
<td>9 vdc</td>
<td>100 seconds</td>
<td></td>
</tr>
</tbody>
</table>

Duration:

- Hot gas: 100 seconds
- Cold gas: 5 minutes

Endurance:

- Hot gas: 10 duty cycles
- Cold gas: 75 duty cycles (approx. 6 hrs.)

Acceleration time:

0.75 seconds

Load Schedule:

**TABLE I**

<table>
<thead>
<tr>
<th>Volts</th>
<th>Power Output</th>
<th>Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>115 vac</td>
<td>35 watts</td>
<td>0-100 secs</td>
</tr>
<tr>
<td>6.8 vac</td>
<td>15 watts</td>
<td>0-100 secs</td>
</tr>
<tr>
<td>28 vdc</td>
<td>28 watts</td>
<td>0-100 secs</td>
</tr>
<tr>
<td>9 vdc</td>
<td>72 watts</td>
<td>80-100 secs</td>
</tr>
</tbody>
</table>

**9 volt circuit to also supply parasitic load circuit of 0 to 125 watts.**
Environmental Requirements

Operational:

- Temperature: -65 to +165°F
- Humidity: To 100% plus frost and condensation
- Pressure: 2 to 45 inches mercury absolute
- Acceleration:
  - Longitudinal: 100 g for 2 seconds
  - Laterally: 20 g

Non-operational:

- Vibration:
  - 10-23 ops: 1.5 g
  - 23-75 ops: 0.072 inch
  - 75-2000 ops: 20 g
- Shock: 150 g
- Other: Salt spray, rain, sand and dust, and fungus

Storage: 5 years
2.4 Description of the Unit - The unit consists of these major subassemblies:

- Main Stage Gas Generator
- Turbine Assembly
- Alternator-Regulator Assembly
- Boost Gas Generator
- Air Nozzle

The relationship of these subassemblies is shown in Figure 1. These subassemblies are so designed that the physical interfaces coincide with the functional interfaces. This makes each component readily adaptable to component test and subassembly replacement can be accomplished without disturbing the calibration of the complete unit.

The main stage gas generator is approximately 1 1/2 inches in diameter and 12 inches long. At the outlet end is located the igniter, turbine nozzle, the safety plug and a screen. There is a removable closure at the opposite end to enable the gas generator to be reused for multiple firings. The turbine nozzle is an integral part of the gas generator; consequently all items which affect the performance of the gas generator are a part of that component and will be tested in the same manner as is the gas generator. This enables the maximum of control over this very critical part.

The boost gas generator, which will also contain its own nozzle, is screwed into another boss in the turbine housing. This same boss is also used for the air run-up fitting. It has been mutually agreed between AiResearch and Picatinny Arsenal to postpone development of the boost gas generator until somewhat later in the program, thus this relatively simple device can be designed after the units are built and the exact requirements are better known. Without the boost gas generator the unit will require approximately five seconds to obtain operating speed.
The turbine is of the lightest practical design having a titanium spot face wheel. The high temperature gas passages are held to minimum size and are well isolated from the remainder of the turbine assembly. These heat dams are sufficient that no heat sinks are provided to maintain the cooler parts of the turbine assembly within the desired operating range of less than 300°F.

An axial air gap permanent magnet alternator built by the TKM Electric Corporation was used. Speed control was obtained by a Zener diode parasitic load on the 9 volt D-C circuit. The alternator and regulator package was built as an integral assembly. Heat sink for the Zener diodes was obtained by submerging the diodes in a hermetically sealed wax reservoir. Wax, with a melting point of 195°F, was used because of its relatively high heat of fusion. It will not require replacement or other servicing throughout the life of the unit as it is completely sealed within a tank in the alternator-regulator housing.

The complete turbo-generator assembly, P/N 5515662, is shown in Photo 45994-1. An electrical schematic diagram is shown in Figure 2.

2.5 Weight, Volume, and Center of Gravity

2.5.1 Weight - A weight breakdown of the Turbo-generator Assembly, P/N 551566-2, is shown in Table II, and a breakdown for the Alternator-Regulator Package is shown in Table III. It is estimated that further weight savings could be accomplished to reduce the weight to 3.31 pounds as shown in Table IV.
### TABLE II

**Weight Breakdown For APU-551566-2**

<table>
<thead>
<tr>
<th>Component</th>
<th>Weight in Pounds</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gas Generator</td>
<td></td>
</tr>
<tr>
<td>Propellant, etc.</td>
<td>.685</td>
</tr>
<tr>
<td>Metal Parts</td>
<td>.605</td>
</tr>
<tr>
<td>Turbine Assembly with Alternator Rotor</td>
<td>.450</td>
</tr>
<tr>
<td>Regulator and Alternator Stator</td>
<td>1.550</td>
</tr>
<tr>
<td>Nozzle Housing</td>
<td>.560</td>
</tr>
<tr>
<td>Mounts</td>
<td>.147</td>
</tr>
<tr>
<td>Bolts</td>
<td>.010</td>
</tr>
<tr>
<td><strong>Total Pounds</strong></td>
<td><strong>3.807</strong></td>
</tr>
</tbody>
</table>

### TABLE III

**Weight Breakdown For Alternator-Regulator Package S/N 701-2**

<table>
<thead>
<tr>
<th>Component</th>
<th>Weight in Pounds</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stator w/o Compensator</td>
<td>.142</td>
</tr>
<tr>
<td>Compensator</td>
<td>.119</td>
</tr>
<tr>
<td>Electrical Connector</td>
<td>.026</td>
</tr>
<tr>
<td>Regulator Package End Bell</td>
<td>.084</td>
</tr>
<tr>
<td>Regulator Barrel w/ Tru-arco Bng</td>
<td>.203</td>
</tr>
<tr>
<td>Alternator Housing</td>
<td>.159</td>
</tr>
<tr>
<td>9-Volt Heat Sinks (2)</td>
<td>.045</td>
</tr>
<tr>
<td>28-Volt Heat Sinks (2)</td>
<td>.046</td>
</tr>
<tr>
<td>Tank Assembly w/o Wax and Zener Diodes</td>
<td>.186</td>
</tr>
<tr>
<td>Zener Diodes (3)</td>
<td>.110</td>
</tr>
<tr>
<td>Rectifiers w/ Hardware (10)</td>
<td>.180</td>
</tr>
<tr>
<td>Wax</td>
<td>.100</td>
</tr>
<tr>
<td>Wire, Filters, Capacitors, Tape, etc.</td>
<td>.150</td>
</tr>
<tr>
<td><strong>Total Pounds</strong></td>
<td><strong>1.550</strong></td>
</tr>
<tr>
<td>Part</td>
<td>Present Weight Lbs.</td>
</tr>
<tr>
<td>------</td>
<td>---------------------</td>
</tr>
<tr>
<td>Gas Generator (Mainstage)</td>
<td>1.290</td>
</tr>
<tr>
<td>Propellant, Inhibitor, Insulation and Igniter Case</td>
<td>(.685)</td>
</tr>
<tr>
<td>Alternator (w/o rotor)</td>
<td>.420</td>
</tr>
<tr>
<td>Control Package</td>
<td>1.130</td>
</tr>
<tr>
<td>Turbine Assembly w/ Alternator Rotor</td>
<td>.450</td>
</tr>
<tr>
<td>Nozzle Housing</td>
<td>.360</td>
</tr>
<tr>
<td>Mounts</td>
<td>.147</td>
</tr>
<tr>
<td>Misc. (bolts, etc)</td>
<td>.010</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>3.807</td>
</tr>
</tbody>
</table>

**TABLE IV**
POSSIBLE WEIGHT REDUCTION
P/N 551566-2
2.5.2 **Volume** - The net volume of the Turbo-generator Assembly, complete with Gas Generator, is approximately fifty cubic inches. The installation drawing, 551566, is shown as Figure 3.

2.5.3 **Center of Gravity** - The center of gravity of the unit is as shown in Figure 4.

2.6 **Test Program**

2.6.1 **Scope** - The test program included these phases:

A. At TKM Electric Corporation:
   1. Electrical Tests of the alternator and regulator package.

B. At Picatinny Arsenal:
   1. Propellant evaluation tests in heavy-wall gas generators.
   2. Gas generator tests using AiResearch supplied gas generator cases.

C. At AiResearch:
   1. Turbine efficiency tests.
   2. Turbine assembly temperature tests.
   3. Turbo-generator performance tests using compressed air to drive the turbine.
   4. Turbo-generator performance tests using solid propellant gases to drive the turbine.
   5. Turbo-generator performance tests, using solid propellants, at temperature extremes.
   6. Vibration test of complete assembly.
   7. Shock test of complete assembly.
   8. Functional test before delivery.
COMPLETE ASSEMBLY C.G.
COMPONENT C.G.

2
Figure 4:
CENTER OF GRAVITY
P/N 551566-2

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2.6.2 Tests at TKM - AiResearch supplied TKM with an air-driven turbine assembly to drive the alternator during these tests. Thus the complete alternator-regulator package was quite thoroughly developed and tested before it was delivered to AiResearch. The AiResearch electrical load bank, shown in Photo 42920, was shipped to TKM for final testing to insure compatibility at the two test sites.

2.6.3 Test at Picatinny Arsenal - These tests are not reported here in as they are already better known by Contractor than by the Contractee.

2.6.4 Tests at AiResearch

2.6.4.1 Turbine Efficiency Tests - The turbine assembly was run, using a flywheel to absorb its output, through several tests using both cold gas and solid propellant gases, to determine the turbine efficiency. The result was slightly above that predicted for the design, and is shown in Figure 5.

2.6.4.2 Turbine Temperature Tests - The turbine assembly and a prototype alternator were completely insulated externally and subjected to several hot runs using the decomposition products of ethylene oxide (1800°F) as a driving fluid. Thermocouples located at several places through the unit showed that the turbine bearings and the alternator rotor were not subjected to excessive temperatures.

2.6.4.3 Performance Tests - A large number of runs were made, both with hot and cold gas, to determine the overall performance of the unit. Exact measurements of the outputs was somewhat difficult because of the high frequency (10,000 cps). As far as could be determined, the unit provided the correct outputs into the specified simulated loads.

A summary of the number of runs made on each unit is shown in Figure 6.
Run #1 Gas Generator 120 F

Run #2 170 F

Run #3 170 F

Reference Air 960 psia 150 F

Turbine Efficiency Percent

Predicted Performance

Design Range

Performance of 355253 Turbine on Solid Propellant

Airesearch Manufacturing Co.

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Summary of Test Runs Made

Turbo Generator P/N 551566-2

- Solid Fuel Acceleration
- Solid Fuel Operation
- Shipped to Picatinny Arsenal
2.6.4.4 Vibration Tests - The unit, with a dummy propellant in the gas generator, was subjected to a vibration scan and then vibrated at the resonant frequencies. A failure of the rear mount bracket was experienced, and this was modified twice to obtain a structure adequate to withstand this environment.

2.6.4.5 Shock Test - The unit was subjected to the specified shock environment, and no failures were experienced.

2.6.5 Development Problems

2.6.5.1 Bearings - In the original design double-shielded grease-pack bearings were used. It was found that the shields would be forced from their positions at high rotational speeds. The design was modified so that only the outer shield, with respect to the mating bearing, was used and the volume between the bearings was packed with grease. This was satisfactory.

2.6.5.2 Balance - The first units were assembled unbalanced as the rotating assemblies were quite light and were inherently fairly well balanced. However, occasional unbalance problems were experienced, so later all of the assemblies were dynamically balanced after assembly.

2.6.5.3 Rotor-Stator Clearance - This unit has an axial air gap alternator; the nominal air gap in the original design being 0.010 to 0.015 inch. The stator assembly was mounted on a temperature-sensitive diaphragm that causes axial displacement as a function of temperature to compensate for the reduction in magnetic strength with temperature increase. It was found that when the unit was run hot (solid propellant at +165°F ambient), the compensator would displace the stator into the rotor and cause a rubbing failure. This was aggravated by the bearing mounting design which permitted the axial play to decrease the gap from nominal. This
problem was corrected by 1) increasing the magnet size and strength, thereby permitting a larger air gap (0.020 nominal), and 2) changing the retention method on the bearings so that the axial play tended to increase the gap from the nominal.

2.7 Deliveries

2.7.1 Gas Generators - Twenty-five gas generator cases, complete with miscellaneous mechanical parts, were delivered to Picatinny Arsenal in November of 1961. Several of these were shipped back to AiResearch after they were loaded at Picatinny Arsenal, and additional propellants and igniters were supplied for reloading at AiResearch. All of the gas generators were returned to Picatinny Arsenal at the end of the program.

2.7.2 Turbo generator Assemblies - Complete Turbogenerator assemblies, with unloaded gas generators, were shipped to Picatinny Arsenal on these dates:

- June 1962  S/N 42-R4
- August 1962 S/N 42-R2
- August 1962 S/N 42-R3
- October 1962 S/N 42-R1

2.8 Reports - Monthly Progress Reports were submitted which describe the activities in considerable detail. Full use of these reports can be readily accomplished through the summary which is included as Table I of this report.