

**QUARTERLY TECHNICAL PROGRESS REPORT**  
**For the period ending 31 December 2001**  
**FOR DOE/NETL GAS GENERATOR TEST PROGRAM**

**Cooperative Agreement No. DE-FC26-00NT40804**

**Project Title:**

**Design, Fabrication, and Testing of an Advanced, Non-polluting  
Turbine Drive Gas Generator**

**Reporting Period Ending: 31 December 2001**

**Program Manager:**

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## **DISCLAIMER**

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## **ABSTRACT**

The objective of this report period was to continue the development of the Gas Generator design, fabrication and test of the non-polluting unique power turbine drive Gas Generator. Focus during this past report period has been to continue completion the Gas Generator design, completing the brazing and bonding experiments to determine the best method and materials necessary to fabricate the Gas Generator hardware, continuing to making preparations for fabricating and testing this Gas Generator and commencing with the fabrication of the Gas Generator hardware and ancillary hardware.

Designs have been completed sufficiently such that Long Lead Items [LLI] have been ordered and upon arrival will be readied for the fabrication process.

The keys to this design are the platelet construction of the injectors that precisely measures/meters the flow of the propellants and water all throughout the steam generating process and the CES patented gas generating cycle. The Igniter Assembly injector platelets fabrication process has been completed and bonded to the Igniter Assembly and final machined. The Igniter Assembly is in final assembly and is being readied for testing in the October 2001 time frame. Test Plan dated August 2001, was revised and finalized, replacing Test Plan dated May 2001.

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**January 31, 2002**

**CONTRACT STATUS**

The following contract activities occurred during this report period:

1. CES and AEROJET [sub-contractor for fabrication of platelets hardware] have entered into a letter contract [LC] and a Confidentiality Agreement to initiate work activities for fabrication of the Gas Generator platelet injectors for the NETL 10 Mw Gas Generator Test Program. Final definition of these contract activities is in work and should be completed by the end of the next quarterly report period.

Fabrication activities by AEROJET [sub-contractor for fabrication of platelets hardware] have commenced.

2. CES and AEROJET [sub-contractor for testing] have entered into a letter contract [LC] and a Confidentiality Agreement to initiate work activities for the testing of the Gas Generator for the NETL 10 Mw Gas Generator Test Program utilizing the revised Test Plan dated August 2001. Final definition of these contract activities is in work and should be completed by the end of April 2002. Testing of the Igniter Assembly for the 10 Mw Gas Generator was completed during this report period. Testing Preparations [Preps] activities by AEROJET [sub-contractor for Testing] have commenced for the 10 Mw Gas Generator Test Program.
3. CES and TECMA [sub-contractor for fabrication of Gas Generator and ancillary hardware] have entered into a letter contract [LC] and a Confidentiality Agreement for fabricating all Gas Generator hardware and ancillary hardware except for the Gas Generator platelet hardware, which AEROJET [sub-contractor for fabrication of platelets hardware] is fabricating. Final definition and completion of these contract activities is in work and should be completed by April 2002. Fabricating activities by TECMA are fully underway.

**PROGRAM MANAGEMENT STATUS**

The Test Plan dated June 2000, which had been approved by DOE/NETL for the 10 Mw Gas Generator Test Program has been updated and revised to reflect the Gas Generator finalized design and testing requirements. The new revised Test Plan, dated August 2001, has been sent to NETL [Thomas J George] under separate cover. This revised Test Plan has been submitted to AEROJET [sub-contractor for testing] for their evaluation and updating of their proposal bid as required.

## **SCHEDULE STATUS**

CES expects this Gas Generator 10 Mw Testing program could still be completed near the original scheduled completion date of 5/7/02 or at worst, within the late summer to fall time frame. However a major hurdle still to be overcome in this testing phase of the program is “if” AEROJET were to be awarded additional U.S. Government high priority hot-fire testing programs for National security issues which may impact CES’ 10 Mw Gas Generator testing program. Aerojet will not commit to meeting CES’ testing schedule due to these U.S. Government high priority National security hot-fire testing programs. However, even with that condition, it is likely that CES’ 10 Mw Gas Generator testing could be done by the July-August-September time frame. Additional evaluations and assessments of the testing phase of the program will be accomplished “real time” by both CES and AEROJET on an “on-going” basis. Revised testing schedules will be prepared as required during this next report period. Hot fire testing is presently expected to begin about 10 April 2002.

## **SUBCONTRACTOR ACTIVITIES**

AEROJET [CES’ subcontractor for fabrication of the platelet injectors], AEROJET [CES’ sub-contractor for Testing] and TECMA [sub-contractor for most of the 10 Mw Gas Generator hardware and ancillary hardware fabrication] have all commenced their activities.

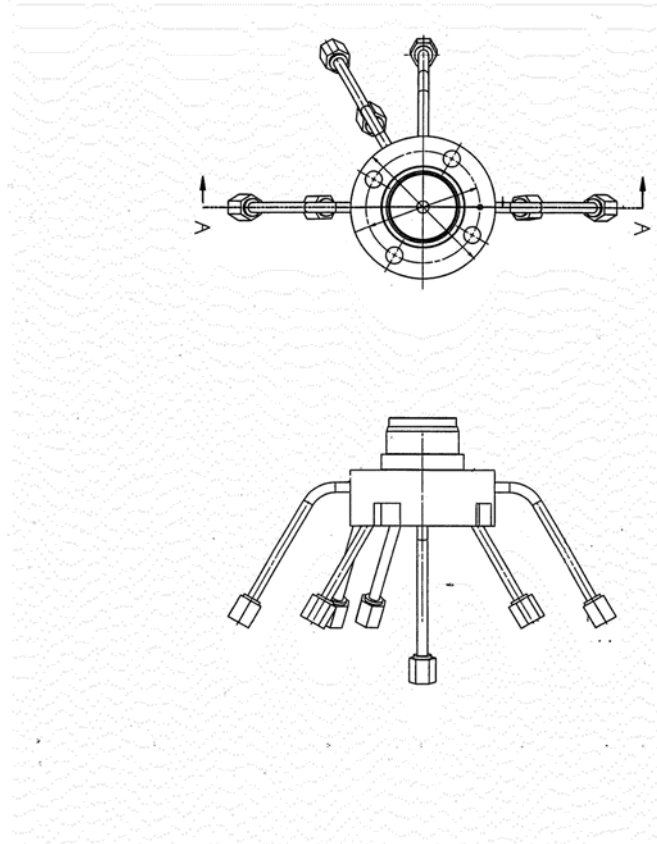
## **TECHNICAL STATUS/DESIGN STATUS**

### **Propellant Oxidation & Fuel Inlet Lines and the Propellant Inlet Assemblies [Oxidation & Fuel]**

Additional work was performed on the Propellant Inlet Assemblies [Oxidation & Fuel] and the Oxidation & Fuel Inlet Lines . Detail drawings of the Propellant Inlet Assemblies [Oxidation & Fuel] will be released with the Propellant Oxidation & Fuel Inlet Lines.

## **Igniter Assembly**

The Igniter Assembly design is shown in **Figure 1**.



**Figure 1**

The Igniter Assembly design is a spark initiated torch igniter. The Igniter Assembly is mounted from the back of the Main Injector Assembly into the center of the injector body using four [4] bolts. Photo-etched platelet washers direct the oxygen gas and methane gas in precise amounts toward the centrally located electrode. The combustion process propagates from the initial flame kernel throughout the torch chamber, ultimately igniting the main combustion chamber flow. This type of igniter is well characterized through testing and is very reliable.

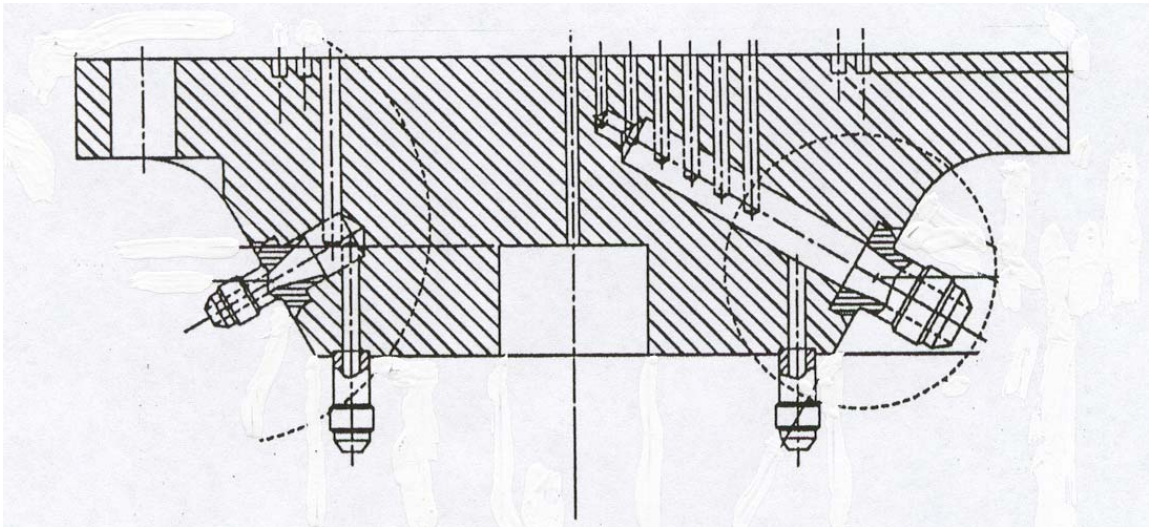
The Igniter Body, Igniter Housing and Assembly detail drawings have been completed during this report period. In addition, a steel test support bracket was designed and fabricated for supporting the Igniter Assembly for Igniter check out testing. Drawings of the photo-etched platelet washer details were also completed.

The Igniter Assembly platelets were photo-etched out of Nickel-200 during this report period. Subsequently, the two [2] Igniter bodies were then fabricated out of Monel-400. The photo-etched Nickel-200 platelets were then diffusion bonded to it's own Monel-400 Igniter bodies during separate bond runs. One [1] of these two [2] completed Igniter Assemblies will be utilized for the current cold flow testing at Aerojet.

In order to test the Igniter Assembly by itself, an Igniter Assembly Test Fixture [simulating the Main Injector Assembly] was designed and fabricated. The Igniter Assembly Test Fixture, along with the Test Support Structure, Igniter Assembly Mock-up, brackets and other ancillary hardware were assembled in the Test Area "A" Zone at Aerojet. Testing of the Igniter Assembly was conducted and completed from 30 October 2001 thru 5 November 2001.

### **Injector Assemblies**

The Injector Assembly design consists of the injector body with the option to employ three different injection patterns as discussed in the previous Technical Progress Report. The injector cross section is shown in **Figure 2**.



**Figure 2**

Injector bodies are currently being machined out of Monel-400 at TECMA because we were unable to locate Inconel-625 raw material stock as mentioned in the previous quarterly report.

Monel-400 material has been used for many gaseous and liquid Oxygen applications in the Aerospace Industry and although it is not quite as strong at elevated temperatures, it is considered more than adequate for the proposed application. Monel-400 is basically a Nickel-Copper alloy and therefore should bond well with the Nickel based Inconel-600 Injector face platelets. However, this particular bond combination has not been demonstrated in the past. We, therefore, prepared a sub-scale three [3] inch diameter diffusion bonding demonstration. The Inconel-600 [Ni-600] to Monel-400 diffusion bond experiment was conducted at Aerojet. This experiment simulated the injector land width and the channel spacing to verify adequate bonding before committing the 10 Mw Gas Generator hardware. The experiment verified an adequate leak free bond. It was subsequently pressurized to 10,000 psi at TECMA without showing any leakage or permanent deformation.

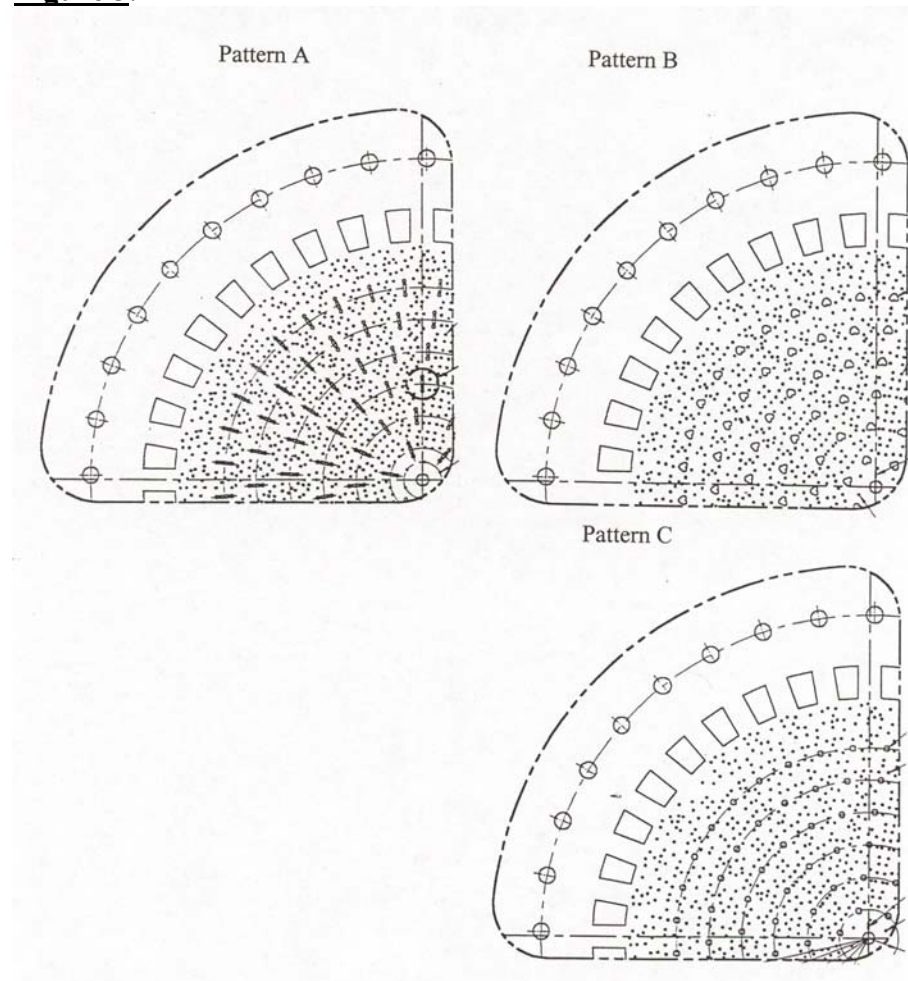
## **Injection Patterns**

As reported in the previous Technical Progress Reports, many years of gaseous and liquid rocket engine development have shown the wisdom of having multiple injection patterns available for test evaluation. For this reason three different injection patterns have been selected for the present test program. Each of the three patterns consists of 126 injection elements but each one differs in important ways. The first pattern is considered to be the most benign, the last pattern is considered the highest performing and possibly least benign.

The Inconel-600 injector platelet stock has now arrived at Aerojet[mid-October time frame]. The platelets are being fabricated in the sequence in which they will be tested i.e. Pattern A, Pattern B, Pattern C.

The engineering for these three injection patterns was completed during the previous report period. Transparencies of the proposed pattern artwork were made and inspected during this report period. Minor corrections were implemented. Working negatives were then prepared and are available for use by the Aerojet photo-etch laboratory.

The injection element layouts for the three patterns selected for test evaluations are shown in **Figure 3**.



**Figure 3**

The first pattern, i.e. **Pattern ‘A’** consists of 126 like on like impinging elements to create a gaseous fan. To promote a benign atmosphere adjacent to the injector face the methane pairs impinge subsurface to the injector face whereas the oxygen pairs impinge further from the face above the methane orifices. This allows the fuel to be close to the injector face and locates the oxidizer further away from the face. The injector face is further protected by allowing 90% of the de-ionized water to weep through the injector face in such a manner as to approximate transpiration cooling. The remaining 10% is injected from the injector face as a chamber film cooling around the periphery of the combustion chamber.

The second injection pattern, i.e. **Pattern ‘B’** consists of 126 vortex elements. The methane gas and the oxygen gas as well as 11% of the available de-ionized water is injected tangentially in the pre-mix cups in such a manner as to create a hollow cone of mixed gas and de-ionized water. Because the de-ionized water is considerably more dense than the two gases the water will hug the wall of the swirl cup and thus protect the wall from possible erosion and remain underneath the burning gases as it exits from the face. The remainder of the face is protected with an additional 79% of the available de-ionized water. This water is ejected through additional vortex elements uniformly distributed across the injector face. These elements can be considered as micro-lawn sprinklers uniformly spaced across the injector face. The remaining 10% of the available water is injected from the injector face as a film cooling around the periphery of the combustion chamber.

The third injection pattern, i.e. **Pattern ‘C’** also consists of 126 vortex elements, but the pre-mix cup configuration i.e. “dual vortex elements” is very different from the previous pattern elements in that it actually develops two adjacent swirls exiting from each pre-mix cup. In addition, the amount of de-ionized water injected into the dual swirl cup is 100% greater i.e. it is 22% of the available water. The remainder of the injector face is protected, by allowing 68% of the de-ionized water to weep through the injector face. This is accomplished in a similar manner as described for Pattern A. Pattern “C” however uses only 2/3 the amount of de-ionized water for transpiring through the face compared to Pattern “A”. Again, the remaining 10% of the available water injected from the injector face is combustion chamber periphery film cooling.

### **Injector Resonator Cavity Flange**

The Injector Resonator Cavity Flange provides for a bi-tuned configuration, i.e. it has two different cavity lengths. This configuration is achieved by bolting an Injector Resonator Cavity Plate between the Combustion Chamber and the photo-etched recessed cavities of the Injector. This type of configuration has been used successfully since 1968 in various rocket engines. Dual tune resonator cavities have been photographically proportioned to man rated flight engines and high production flight engines. The dual tune design spans 1<sup>st</sup> tangential to 3<sup>rd</sup> tangential modes and allows for film coolant water along the acoustic cavity partitions.

Longitudinal Acoustic Modes cannot be influenced by the bi-tuned configuration however it is believed that the Cool-down Diluent Injectors will provide significant damping for the Longitudinal Acoustic Modes.

### **Combustion Chamber and Cool-down Chambers (Modules)**

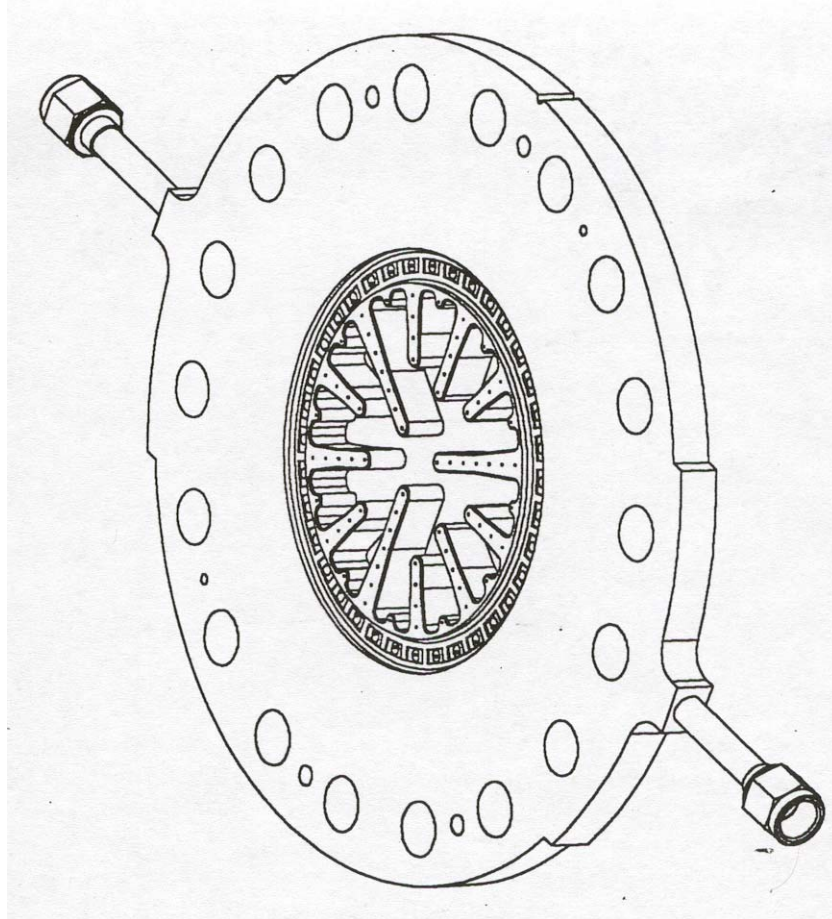
The Combustion Chamber Liner drawings and Cool-down Chamber Liner drawings were released for fabrication during the last report period. The Combustion Chamber and Cool-down liners are being machined out of Inconel-600 material. The liners have been machined to the proper outside diameter and the inside diameters have been honed to the proper inside diameter. Coolant slots will be machined into the outside of the liners at the beginning of the next report period.

The Combustion Chamber Housing drawings and Cool-down Chamber Housing drawings were also released for fabrication during the last report period. These housings are made of centrifugal castings and have been procured from a manufacturer specializing in this technique. They are currently being final machined at TECMA.

### **Diluent Water Injectors**

The Diluent Injectors drawings were completed during this report period. Transparencies of the proposed pattern artwork were made and inspected during this report period. Minor corrections have been implemented. Working negatives will be prepared early in the next report period.

As described in the previous Technical Progress Report, the Diluent Injector design selected is composed of 12 radial legs as shown in **Figure 4**.



**Figure 4**

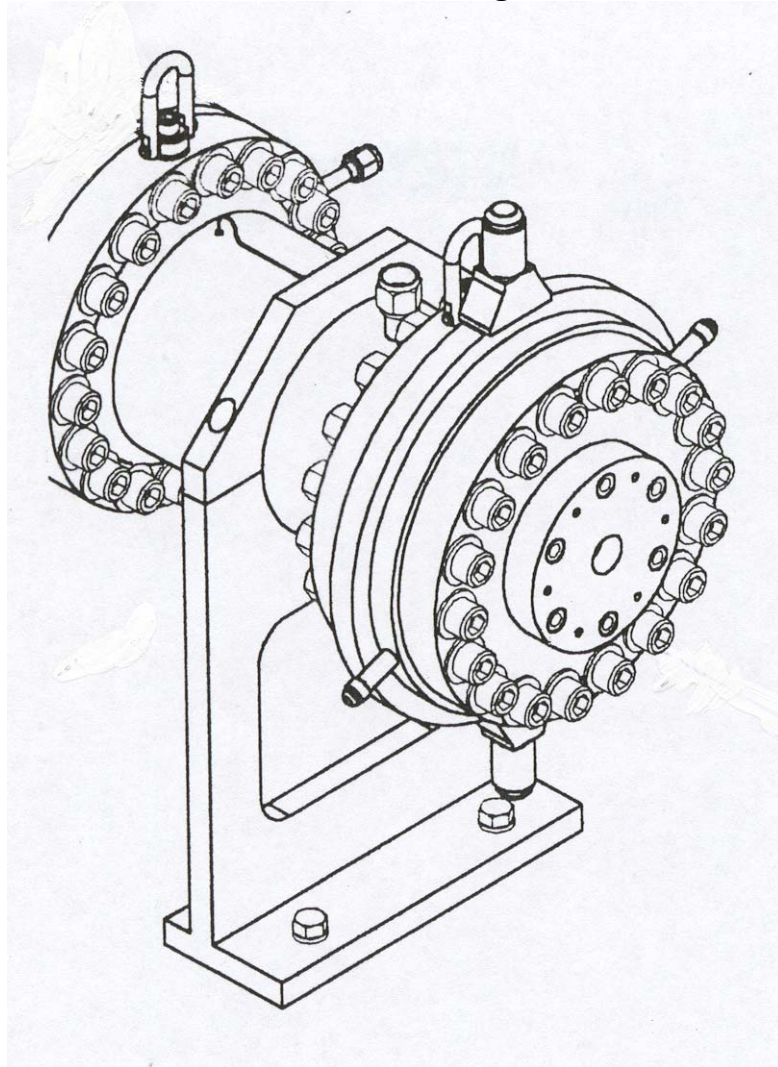
Every third leg is a different length so as to provide the best possible chance of distributing the water diluent uniformly across the four-inch diameter chamber. Platelet technology will be employed for regenerative cooling and precise flow distribution of the diluent. The Diluent Injector uniformly injects and mixes the cooling water across the chamber cross-sectional area. Because the initial hardware checkout testing will be performed using an un-cooled chamber the diluent injectors are not required as quickly as most other components. Consequently these hardware designs will be the last to be completed.

### **Water Coolant Inlet Flange and Water Coolant Outlet Flange**

The Water Coolant Inlet and Outlet Flanges were described in the previous Technical Progress Report. We currently are evaluating making a minor design modification to the water inlet flange to reduce the hot wall strain. These Water Coolant Inlet and Outlet Flange drawings were released during this Technical Report Period.

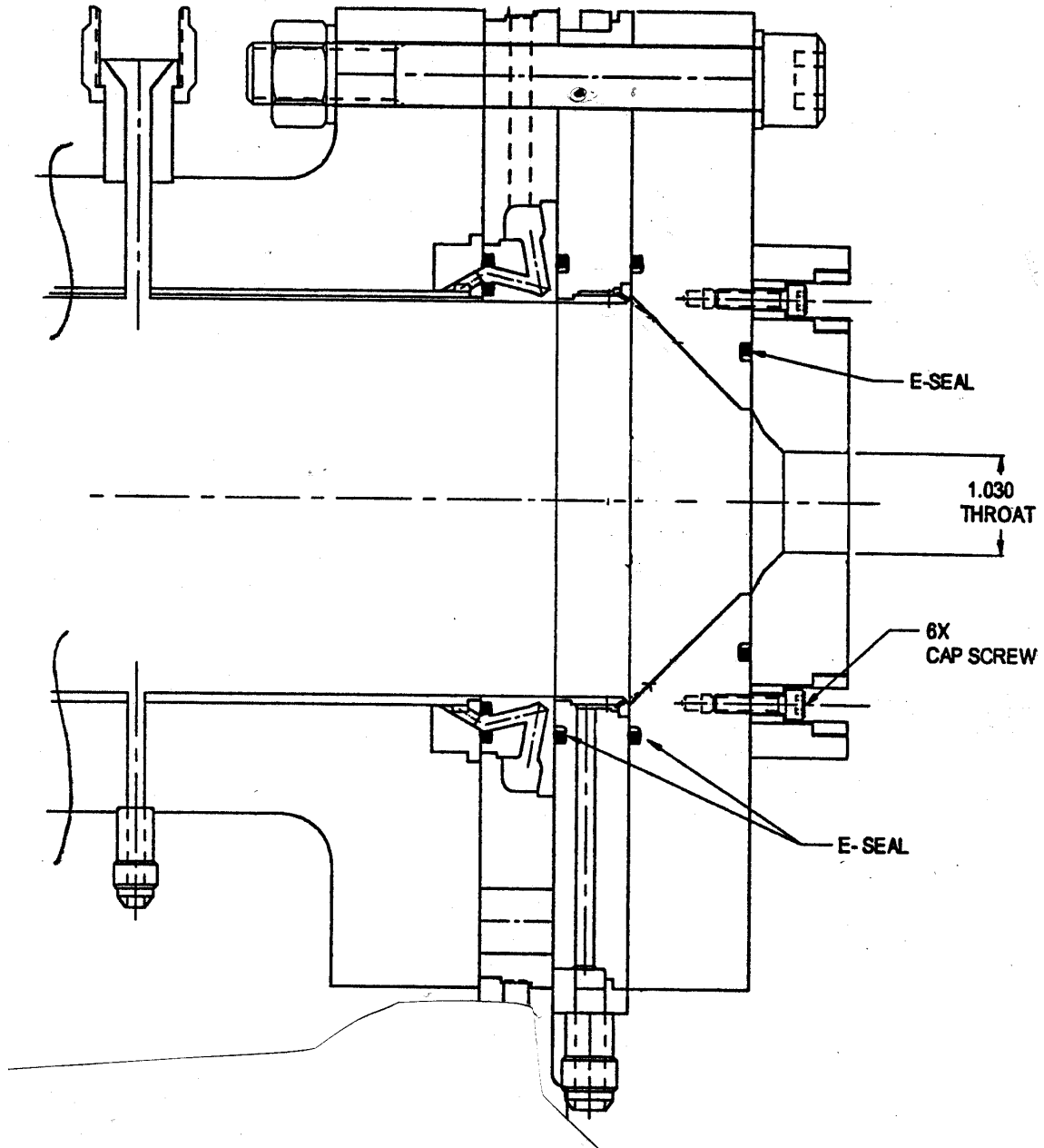
### **Turbine Back Pressure Simulator**

The Turbine Back Pressure Simulator is shown in **Figure 5**.



**Figure 5**

A cross-sectional view is shown in **Figure 6**.



**Figure 6**

Drawings were released during this report period. This component has its own water coolant supply circuit because it will not be required during an actual power generation configuration. The Turbine Back-Pressure Orifice Plate Simulator is composed of CRES 304L with a cooled Zirconium Copper hot wall. A Back-Pressure Orifice Plate is mounted immediately aft of the Convergent Wall. This plate is secured with 6 ea number 10 cap screws and six [6] Breakaway Aluminum inserts, which are sized to rupture at 3,000 psig in order to relieve the internal pressure of the Gas Generator in the event of a unanticipated pressure surge during the start or shut down transient. Drawings will be released during the next report period.

## **Ancillary Hardware (Closures, Support Stand & Instrumentation)**

### **Closures**

The specially designed closures required for performing proof and leak checks, and protecting the sealing surfaces from damage and maintaining the required levels of cleanliness are still in the process of being completed.

The closure designs for performing leak and proof testing are 95% complete, as are the protective hardware closure designs.

### **Support Stand**

The Gas Generator Support Stand structure, including various brackets [4" bracket, 10" bracket, Main Injector Interface Bracket] has been fabricated and delivered to Aerojet's Test Area "A" Zone and was used for testing of the Igniter Assembly in October – November 2001.

### **Instrumentation**

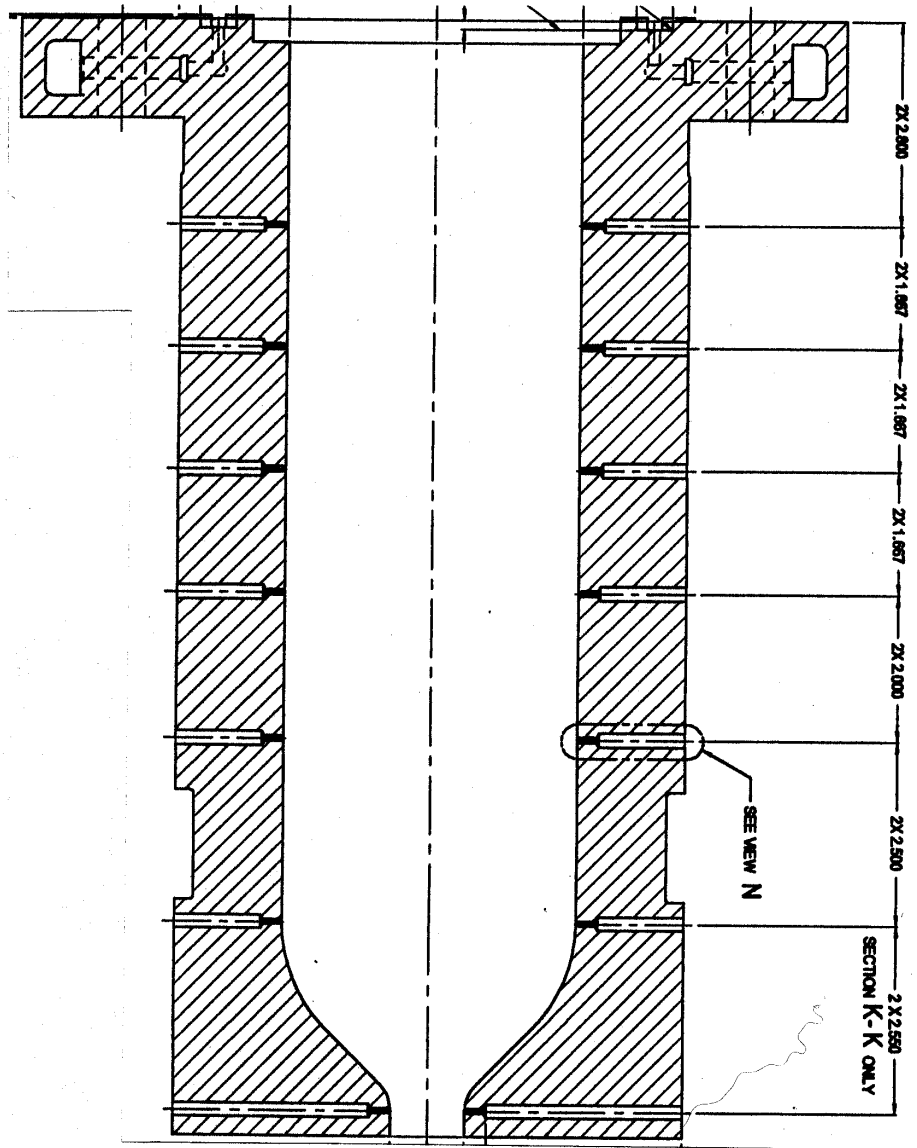
Instrumentation hardware is in the final process of being identified. Instrumentation locations and types of instrumentation and numbers of measurements are being re-evaluated as a result of the Gas Generator design being finalized.

## **Uncooled Combustion Chamber**

The Uncooled Combustion Chamber is an ancillary piece of hardware designed to be used initially only for evaluating the initial testing of the Uncooled Combustion Chamber Injector Platelet Pattern Designs. The Uncooled Combustion Chamber design is basically the normal Combustion Chamber configuration without all the intricate cooling passages incorporated. It is designed for short duration testing, because of no internal cooling, and is made from chromium copper for better heat transfer properties on short duration testing without any cooling.

This initial Combustion Chamber injector testing will provide valuable information and insight into individual injector pattern's performance characteristics. Evaluations will be made from this data on stability, streaking, and potential hot spots for each design prior to committing the real test hardware to hot-fire testing.

The Uncooled Combustion Chamber has a gas sample port and a chamber pressure and temperature port in addition to a Kistler port for measuring high frequency oscillations. The Uncooled Chamber also has rows of 6 axially located thermocouples for measuring hot gas wall temperatures as shown in **Figure 7**.



**Figure 7**

The Uncooled Combustion Chamber design has been completed and fabrication of the Uncooled Combustion Chamber is under way.

**DELIVERABLES STATUS**

With timely submission of this quarterly report, all deliverables due are delivered.

## **ASSESSMENT OF OVERALL PROJECT OBJECTIVES**

The Igniter Assembly Testing, scheduled for 1 through 5 October 2002, slipped four [4] weeks. Testing preparations commenced 15 October 2001. Actual “hot-fire” testing commenced 31 October 2001. This slip in the Gas Generator Igniter Assembly testing will have no effect on the main Gas Generator Assembly testing schedule to start on or about 10 April 2002.

All other activity seems to be progressing in an acceptable manner with the notice that some raw materials are not as available as originally thought. Obtaining necessary materials should have little or no impact on the program’s overall objectives and schedule.

## **RESULTS & DISCUSSION**

This program has completed the design phase of the 10 Mw Gas Generator Test Program and has commenced fabricating the necessary Gas Generator Testing Hardware and Ancillary Hardware.

Tests of the Igniter have been completed successfully, confirming efficacy of the design.

Since CES was not able to locate, in time for this program, Inconel-625 raw material for the Injector Main Body, but will use Monel-400 raw material. A sub-scale bonding experiment test was performed during this report period, to demonstrate and verify that the bonding between Monel-400 [Injector Main Body] and the Nickel-Based Inconel-600 [Injector platelets] would be acceptable. The sub-scale testing showed the bonding between Monel-400 and Inconel-625 to be acceptable.

An additional bonding experiment is being prepared to verify the bonding technique, scheduled for the Gas Generator liners and Gas Generator housings [i.e. Combustion Chamber and Cooldown Chambers] is also an acceptable bonding technique.

## **CONCLUSIONS**

The Bonding Sub-Scale Technique experiment showed the bonding technique scheduled for bonding the Inconel-600 and the Monel-400 materials together, to be acceptable.

The Gas Generator Igniter Testing Program was successfully completed during the Igniter Testing Phase of the 10 Mw Gas Generator Program. The following tests have been completed at the “A”- Zone Test Facility at Aerojet:

- A. Igniter S/N #1 and S/N #2 were cold flow tested using water to determine the hydraulic resistance and the visual appearance of the spray patterns. Both Igniters performed as designed.
- B. Igniters S/N #1 and S/N # 2 were cold flow tested using oxygen & methane to determine the actual resistances using gases.
- C. Igniter S/N #1 was successfully hot fire tested with no anomalies.

“This Technical Progress Report was prepared with the support of the U.S. Department of Energy under Award No. DE-FC26-00NT40804. However, any opinions, findings, conclusions, or recommendations expressed herein are those of the author[s] and do not necessarily reflect the views of the DOE.”