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A HYBRID BRAYTON ENGINE CONCEPT

L. Six and R. Elkins
AiResearch Manufacturing Company of Arizona
Phoenix, Arizona

ABSTRACT

A first generation open cycle Brayton engine concept for use in full-scale solar module testing, was defined in NASA/JPL study contract DEN 3-69. This concept has been extended to include solar/fossil hybrid capability. The combustion system defined for hybrid operation consists of a wide range combustor liner, a single airblast atomizer, an ignitor and a high-voltage ignition unit. Wide range combustor operation would be achieved through combining pilot and primary zones.

The hybrid control mode and the solar only control mode are both based on the concept of maintaining constant turbine inlet temperature and varying the engine speed for part-power operation. In addition, the hybrid control concept will allow the operator to set a minimum thermal power input to the engine by setting a corresponding minimum engine speed. When the solar thermal power input falls below this minimum, fossil fuel would be utilized to augment the solar thermal power input.

INTRODUCTION

A concept definition study (NASA/JPL Contract Den 3-69) defined a first generation open cycle Brayton engine for use in full scale solar module testing originally scheduled to commence late in 1980. The engine concept has been presented at previous DOE review meetings. It is also described along with other engine concepts and supporting study results in a final report now being readied for release (1). This initial engine concept includes the use of an existing turbocompressor from the Garrett/AiResearch (Phoenix) GTP36-51 gas turbine engine to minimize the procurement duration and costs. The engine concept was designed to operate with solar energy only, using the solar Brayton receiver being built at Garrett/AiResearch (Torrance) under JPL contract.

Subsequent to initiating the NASA/JPL study contract, a new requirement was added based on the fact that JPL's Second Engineering Experiment (EE2A) would be a hybrid system. This required adding a combustor to the engine concept to provide for solar/fossil hybrid capability. This presentation's purpose is to describe the combustor and corresponding controls formulated to convert the initial Brayton engine concept to the current MOD-O Hybrid Brayton engine concept.

COMBUSTION SYSTEM

The combustion concept is presented in Figure 1 and consists of a wide range combustion liner, a single airblast atomizer, an ignitor and a high-voltage ignition unit. This system was chosen because it would provide simple low-cost design features and a proven wide operation range.

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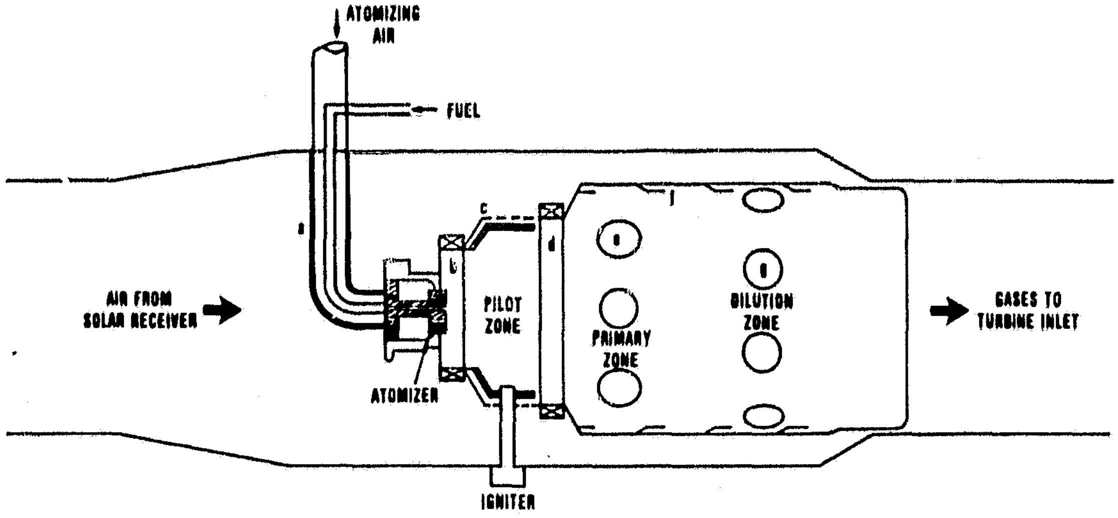

FIGURE 1. COMBUSTOR CONCEPT

The wide range combustor system is considered a conventional type because it has neither fuel staging nor variable geometry. The wide range would be achieved through a combination of pilot and primary zones. The system would rely on strong recirculation in the pilot zone for flame stabilization. At low fuel flow rates, the flame front would be confined to the pilot zone. The flame front would expand into the primary zone for operation at the higher fuel flow rates. This burner would also take advantage of the airblast atomizer characteristics to obtain satisfactory spray quality over an estimated eight to one fuel flow range. Atomization would be achieved through the use of a high velocity air stream to shear the fuel film into small droplets. This type of atomizer is currently in use on several AiResearch gas turbines. Cooling to keep the maximum liner skin temperature levels below operating limits would be accomplished by using conventional film cooling skirts in the primary and dilution zones, and a combination of impingement cooling and a thermal barrier in the pilot zone.

Fuel system design must also address the possibility of fuel thermal decomposition in both the manifold and the atomizer due to the high inlet air temperature to the burner. Operating temperature of these parts would be minimized by routing the fuel in the inner of the two concentric passages leading to the fuel atomizer. Low temperature air bled from the compressor discharge for use by the airblast atomizer would be ducted through the outer concentric passage. The outer surface of the outer concentric passage which is exposed to the hot air from the solar receiver would be treated with a thermal barrier coating similar to that used in the combustor pilot zone.

The system can be designed to operate on a variety of fuels including unleaded gasoline, jet-type kerosenes, diesel fuels and natural gas. It is currently planned to design the first units to use JP-4 fuel.

CONTROL CONSIDERATIONS

Addition of a fossil fuel combustor will significantly increase the flexibility of, and the opportunities for utilizing the solar Brayton module. For instance, prior to installing the module on the concentrator, fuel could be used to start and check out hybrid power conversion module operation without requiring a solar receiver and the attendant radiant energy source to supply the input thermal power. Also, when little or no insolation is available such as for night-time maintenance or for night-time and cloudy day power generation, the combustor would allow the module to be fully operable. Again, the combustor could be used to prevent module shutdown during cloud passage on an otherwise sunny day, or the combustor could also be used to provide makeup input energy during periods of low or intermittent insolation to maintain some pre-selected power delivery rate. For example, the combustor could be used to supplement the energy from insolation and provide rated power.

The control and power conditioning concept is shown in Figure 2. Dashed lines indicate the additions to the solar only control concept required to describe the hybrid control concept. The control concept will maintain the turbine inlet temperature T_7 at a constant value and increase or decrease the engine speed N_T as the insolation to the receiver increases or decreases respectively. The engine speed will be varied by commanding the control rectifier to change the electrical load on the engine generator. The desired engine speed is that speed at which the engine air flow will be heated to a pre-selected value (1500°F) at the outlet of the receiver. For this control concept to function, the 60 Hz utility grid or bus bar must be prepared to accept all of the electrical power generated. If it cannot, excess power wasting must be accomplished until the grid load can be increased, or the solar power module deactivated. A concept for accomplishing this function is presented in the left side of Figure 2.

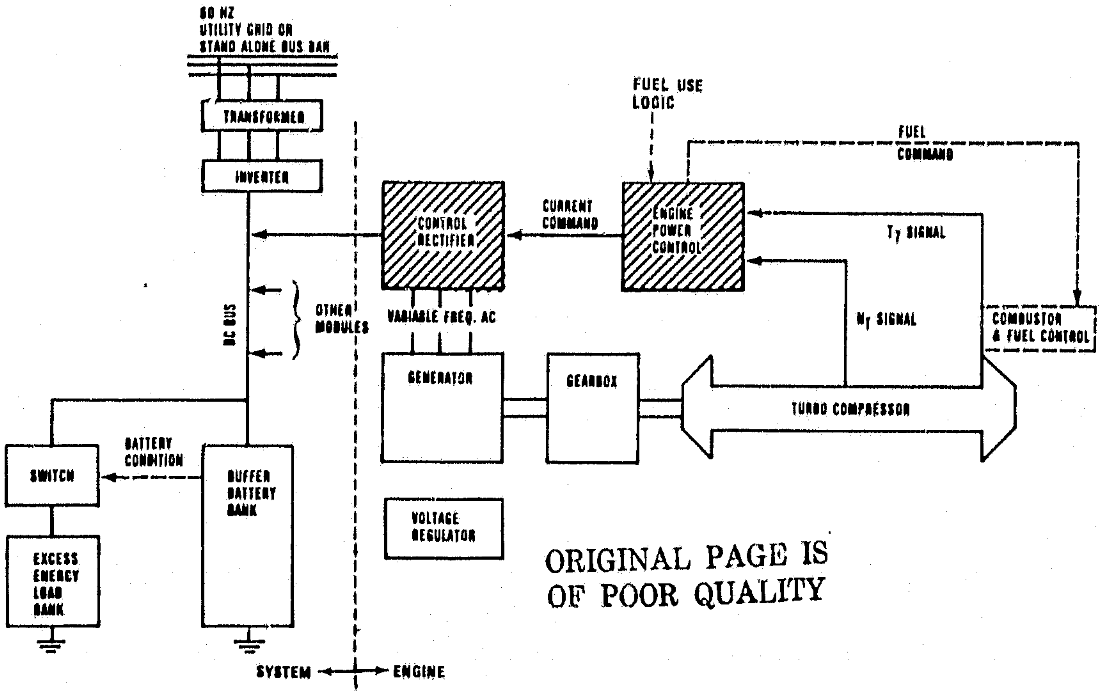

FIGURE 2. CONTROL AND POWER CONDITIONING CONCEPT

In the hybrid control system concept, fossil fuel would be utilized to augment solar thermal input. Figure 3 shows an approximate representation of how the engine rotor speed and pertinent temperatures would behave if subjected to a simplified insolation schedule shown in Figure 3(a). In this case fossil fuel is used to complement the insolation during certain periods of the day identified along the abscissa by the terms "fossil only", "hybrid" and "solar only". The fuel use logic input picked for illustration is one in which the solar module would be adjusted to operate continuously at rated output power starting before sunrise and continuing at rated power until after sunset except when the insolation exceeds rated intensity. This selected power level at which the module would be required to operate when using fossil fuel would be established by setting an adjustable speed reference called N_{set} shown in Figure 3(b). N_{set} in turn would be bounded by a small speed tolerance band in the control module identified by N_{high} and N_{low}. When increased insolation would be experienced during hybrid operation it would first tend to cause the receiver outlet temperature to increase and this would cause a fuel flow reduction until some previously established fuel flow would be reached, as at "d" in Figure 3. The engine speed would then increase until it reached N_{high} as at "e" which would shut off the fuel flow. The control would then behave in the same manner as a solar only control in the region between "f" and "g".

When the engine speed falls to N_{low} because of decreasing insolation, fuel flow would be resumed as at "h" in Figure 3. The control would be designed to avoid a requirement for the fuel atomizer to operate over an excessively large fuel flow range by appropriate choice of a minimum fuel flow. The effect of this minimum fuel flow value is shown on the three curves of Figure 3 by small perturbations in the regions identified by "d-e-f", "h", "i", and "k-l". Figure 3(c) shows that the turbine inlet temperature stays constant throughout the assumed daily schedule of input thermal power as a result of the complementary action of the receiver temperature rise and the combustor temperature rise. Through the action of N_{set}, the engine can be adjusted to operate at rated power as shown in Figure 3, or it can be set at other values higher or lower, depending on the application requirements and the fuel consumption economics. Choosing N_{set} at a value corresponding to maximum power level would involve the use of larger fuel quantities. Setting N_{set} at a value slightly above self-sustaining would minimize fuel consumption and still avoid restarts following cloud passage.

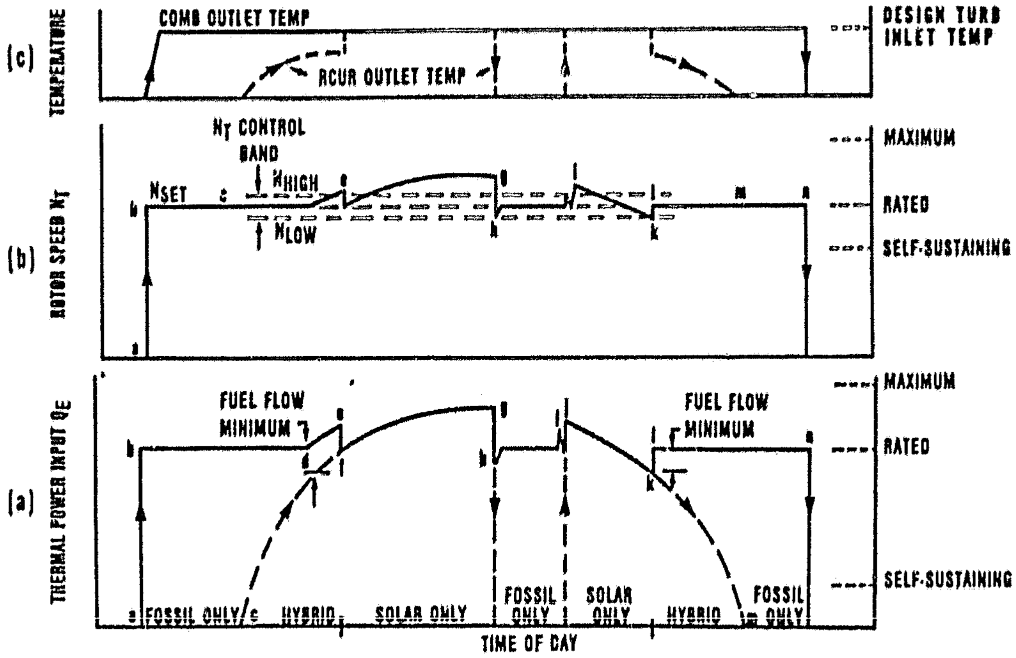

FIGURE 3. HYBRID CONTROL CONCEPT-TYPICAL DAY

SUMMARY

An isometric view of the hybrid MOD-O engine is presented in Figure 4 which shows the combustor assembly installed between the receiver outlet and the turbine inlet. The combustor addition will cause thermodynamic performance to drop by about 1.3 efficiency points at the engine shaft because of added pressure drop, and a small percentage of bleed flow which bypasses the recuperator in order to provide fuel line cooling and fuel atomization.

Features or advantages of adding hybrid capability to the Brayton engine concept are identified as follows:

- Retains constant turbine inlet temperature control for good part load efficiency
- Adds option for continuous operation at rated power independent of insolation
- Adds option for operation at turbine inlet temperature higher than the receiver's capability
- Provides operation during cloud passage
- Adds option for operation at night for power generation or maintenance

The combustion system and control concept described will be subjected to analysis and design in the NASA/JPL contract for the MOD-O engine.

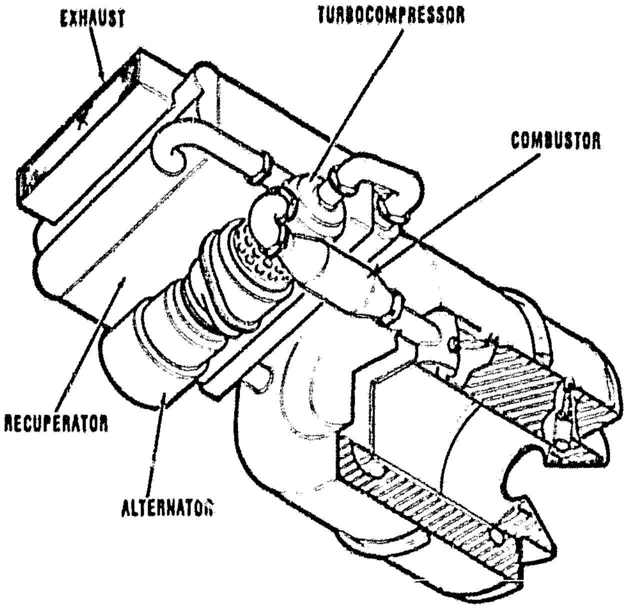

FIGURE 4. BRAYTON ENGINE GENERATOR AND CAVITY RECEIVER ASSEMBLY

REFERENCES

1. L. D. Six, et. al., Concept Definition Study of Small Brayton Cycle Engines for Dispersed Solar Electric Power Systems, NASA CR 159592, (January 1980.)