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Becon Burner Rig at the NASA Glenn Materials Research Laboratory

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Introduction

The state-of-the-art Burner Rig Facility is located within the Materials Research Laboratory at the National Aeronautics and Space Administration's Glenn Research Center (GRC) at Lewis Field. It is used for materials research including oxidation, corrosion, erosion and impact. Within the facility are seven identical Mach 0.3 computer controlled jet-fueled combustors in individual test cells (Ref. 1). In 2006 it was determined to add another type of burner rig. The primary focus of this Technical Memorandum is to present an overview of the newer Becon burner rig and discuss its capabilities and use to date. This facility is primarily used in test programs for NASA Fundamental Aeronautics Programs.

1.0 Description and Operation of Becon Burner Rig

The design of the rig and its patent originated at Pratt & Whitney (East Hartford, Connecticut), and the sole licensee of the product is Becon, Inc (South Windsor, Connecticut) (Ref. 2). Other Becon burner rigs are located domestically at NAVAIR (Maryland) (Ref. 3), ABB (Connecticut), Solar Turbines (California), Allison Transmission (Indiana), and the U.S. Army Aberdeen Test Center (Maryland). Internationally, rigs are located at the National Research Council of Canada Institute for Aerospace Research (Ottawa, Ontario), the German Aerospace Center (DLR) (Refs. 4 and 5), the National Aerospace Laboratory (The Netherlands) (Refs. 6 and 7) and GE India.

An overview photograph of the Becon burner in its test cell is presented in Figure 1. The standard exhaust nozzle diameter is 5.1 cm (2 in.) in diameter, though a 1.9 cm (0.75 in.) diameter nozzle has also been used. Maximum sample temperature that can be achieved on a rotating carousel of superalloy samples is nominally 1200 °C (2200 °F). The rig utilizes 800 kPa (120 psig) filtered shop air supplied via the GRC central air system. Air flow is measured with two Sponsler (Lake Bluff, Illinois) SP11/2 precision turbine flow meters mated to SP720-2 modulated carrier amplifier/transmitters. Airflow is approximately 33 lb/min. Air is preheated to 425 °C (800 °F) to minimize coking within the combustor can, and it is delivered through 3.8 cm (1.50 in.) diameter lines. Jet fuel is provided from a 15,000 liter (4000 gal) underground storage tank. A low pressure fuel pump (240 kPa/35 psig) delivers filtered fuel to the building. A high pressure pump (2.4 MPa/350 psig) then delivers fuel to the test cell, where it is injected into the combustor using an aircraft-type fuel nozzle located in the center of a swirl plate. As configured, the fuel nozzle delivers a maximum 18 liters/h (4.8 gal/h). The fuel can be heated to a maximum temperature of 120 °C (250 °F) with a circulation heater (Indeeco, St. Louis, Missouri) located within the test cell.

* Currently on the faculty at Lorain County Community College (Elyria, Ohio).

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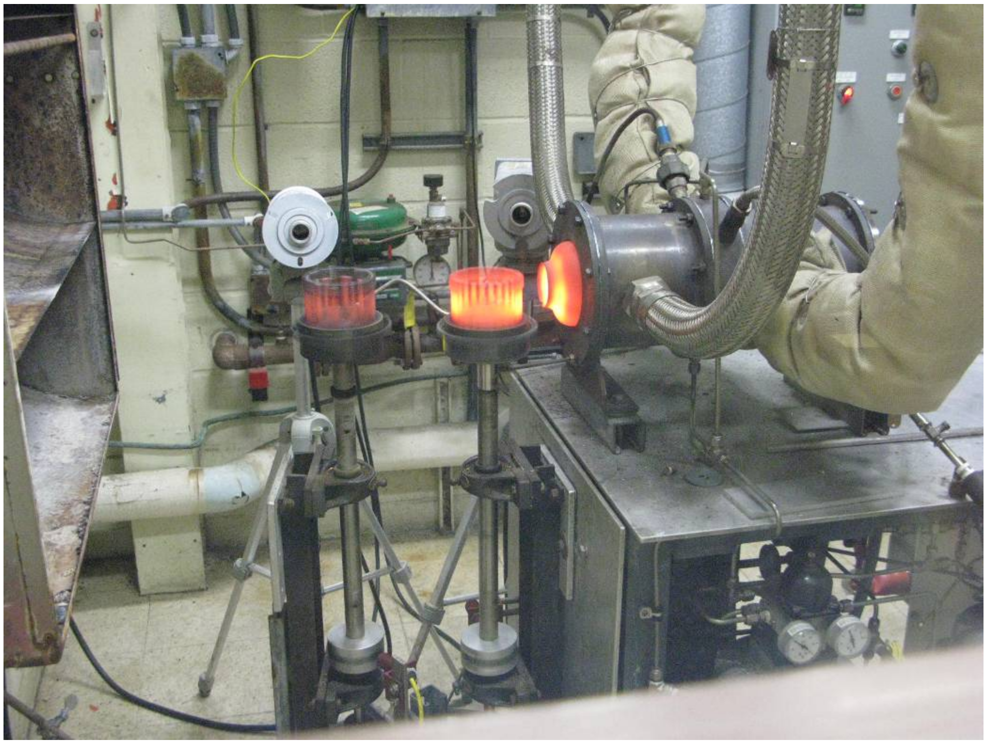

Figure 1.—Becon burner with two rotating sample carousels. Samples closest to the 5 cm (2 in.) diameter exhaust nozzle in the rightmost carousel are at 1010 °C (1850 °F). The leftmost are at 760 °C (1400 °F). Temperatures are measured with the two-color optical pyrometers, which can be seen in the background.

An in-depth presentation of the combustor design is found in Reference 2. To summarize, both the primary and secondary sections are composed of an annular diffuser and a burner liner which control the air flow and combustion in the respective zones. The inner Hastelloy X superalloy liners are of modular design, with their outer diameters cooled with bypass air. An instrumentation ring is located between the two sections. It contains an aircraft-type igniter to initiate combustion as well as a Fireye (Derry, New Hampshire) detector to confirm the presence of a flame. Pressure within the combustor is measured with a transducer (GE Druck, South Burlington, Vermont) and is usually to 1 to 2 psi above ambient with the burner lit. Each of the two sections is independently fed with air to allow adjustment of flows within the combustor. Additional photographs of rig hardware are located in the Appendix (Figure 13 to Figure 19). Sample temperature is measured with optical pyrometers (Modline 3, Ircon, Santa Cruz, California) as illustrated in Figure 1. The rig is housed in a test cell that has a 3- by 3-m (10- by 10-ft) footprint and is ~3.5-m (12-ft) high.

Unlike the Mach 0.3 burner rigs wherein the burner can be pivoted on-and-off the sample for thermal cycling, the Becon rig is fixed in place with only isothermal exposures possible. As described in Section 2.0, single samples can be fixed in place and impinged on by the flame. If flat plate specimens are tested, the flame impingement angle can be varied. If a number of cylindrical specimens are to be tested, one or two spinning (~200 rpm) sample carousels are utilized as in Figure 1. Carousels are fabricated in-house according to customer needs. It should be noted that a single cylindrical specimen can be rotated in the flame, if desired.

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Figure 2.—Current means used to add alternate fuel (e.g., Fischer–Tropsch) to the primary jet fuel is with a positive displacement, reciprocating piston pump.

The infrastructure was built with the capability to add alternate (e.g., synthetic) fuel to the main fuel line feeding the burner rig. Alternate fuels cannot be mixed in with the standard JP8 fuel in the 4000 gal underground tank as it is used to feed the other Mach 0.3 burner rigs as well within the facility. Therefore, a 275 gal above ground tank was initially used to premix JP8 and alternate fuels. This arrangement proved to be cumbersome, so an alternative way to add a synthetic fuel to the main fuel flow was developed. The alternate fuel is now held in a 20 liter jerry can (Figure 2) and added to the main fuel flow using a positive displacement, reciprocating piston pump (Eldex, Model 3HM, Napa, California).

The computer control and data acquisition system consists of Wonderware software (Lake Forest, California) on a Pentium-class computer (Figure 3 and Figure 4). Through a suitable interface, the PC acquires specimen temperatures (via optical pyrometers), fuel pressure, fuel flow, burner can pressure, and other rig parameters. Also included in the computer control functions are safety features such as emergency shutdowns, test condition measurements, record keeping of test data, display of testing status, and mathematical calculations.

The operator of the Becon rig utilizes a mode that maintains a specific fuel-to-air ratio throughout the test, with regard to the desired temperature. Pyrometers are used to monitor temperature, but there is no feedback loop to the PC software to adjust fuel and air. This differs significantly from the standard Mach 0.3 burner rigs wherein specimen temperature is controlled by digital adjustment of fuel flow using a PID control algorithm.

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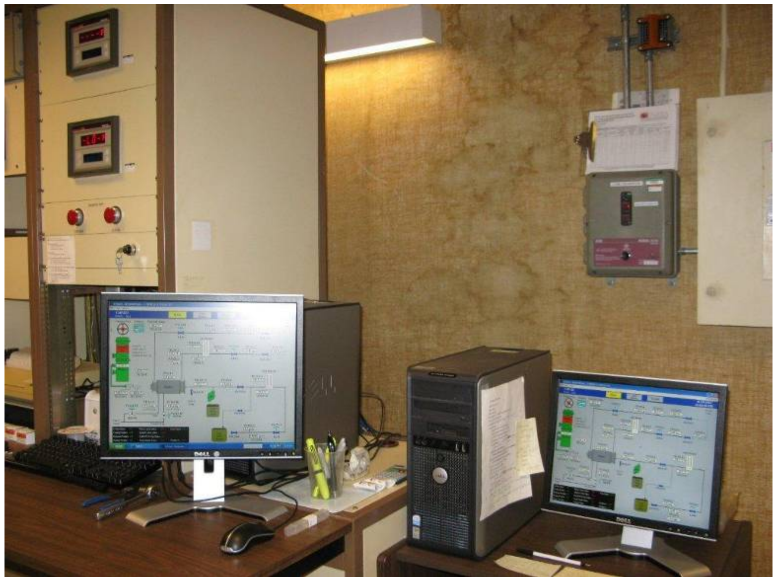

Figure 3.—Control PC using WonderWare software.

Figure 4.—Burner rig facility control room. The burner rig is housed in test cell behind the operator as he sits at the control PC.

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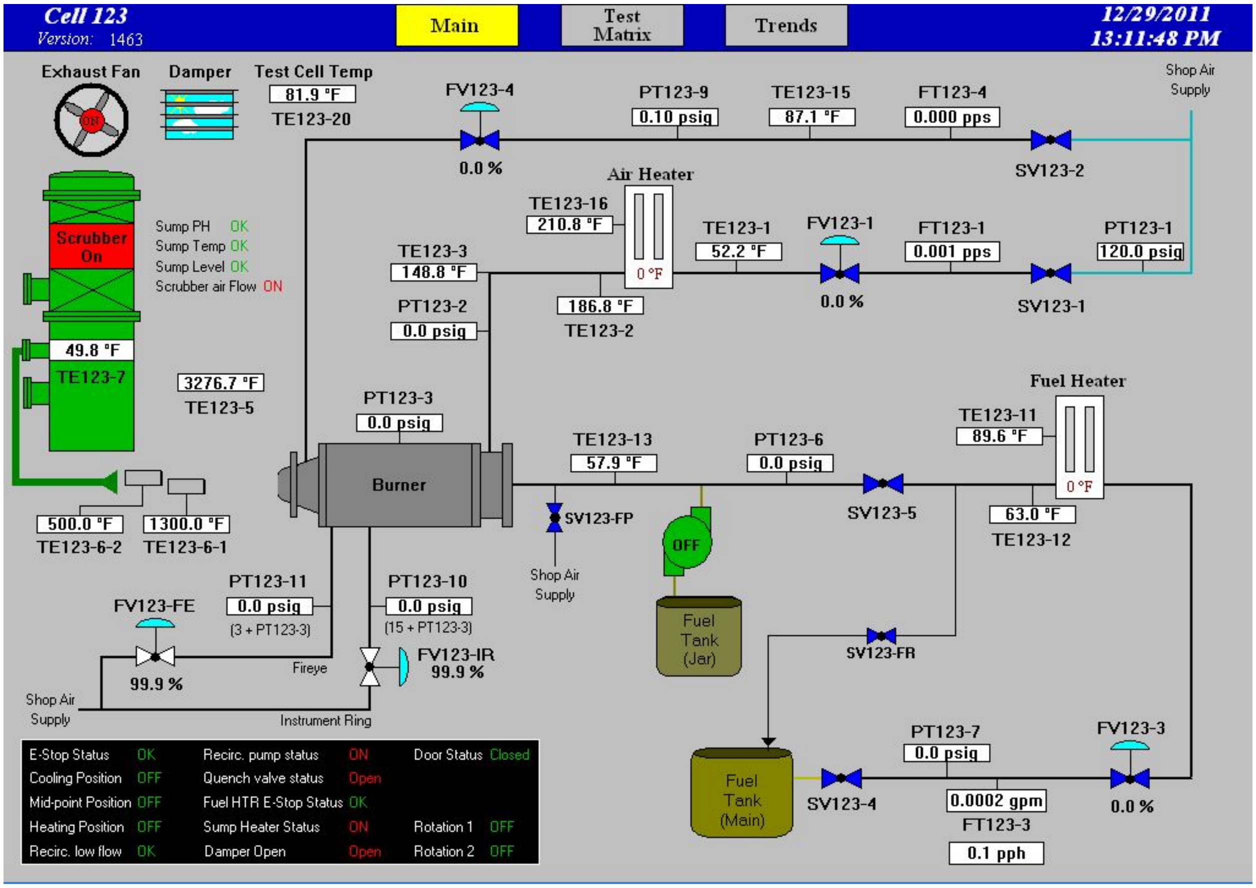

Figure 5.—Main user interface screen.

The **Main** user interface screen (Figure 5) is used by the operator for a number of tasks. A simple mouse click on a screen graphic activates a drop-down menu. For instance, to begin preheating the combustion air the operator: 1) chooses SV123-1 to open the shut-off valve; 2) selects flow valve FV123-1 and sets the flow from 0 to 100 percent while monitoring flow transducer FT123-1 (measured in lb/sec); and 3) clicks on the air heater graphic and sets the desired temperature to 427 °C (800 °F) as measured by thermocouple TE123-2.

Pressure in the burner can is measured with pressure transducer PT123-3 (psig). Cooling air to the Fireye and instrument ring is set with FV123-FE and FV123-IR, and is held at 3 and 15 psig above can pressure, respectively. While fuel is preheated to the desired temperature it is circulated back to the main fuel tank.

Sample temperature is monitored with optical pyrometers TE123-6-1 and TE123-6-2 (Modline 3, Ircon, Santa Cruz, California). Their temperature ranges are 700 to 1370 °C (1300 to 2500 °F) and 260 to 980 °C (500 to 1800 °F), respectively. When lower temperatures are to be measured, a hand held optical pyrometer is used (Heat Spy, Palmer Wahl, Asheville, North Carolina).

The burner is always lit in the manual mode to tweak fuel and air flows to bring sample(s) to their desired temperature(s). If this is done for a first time with a new sample arrangement, calibration or "dummy" samples are used. Once desired temperatures are attained, the operator can click on the topmost banner in Figure 5 to select the "Test Matrix" button.

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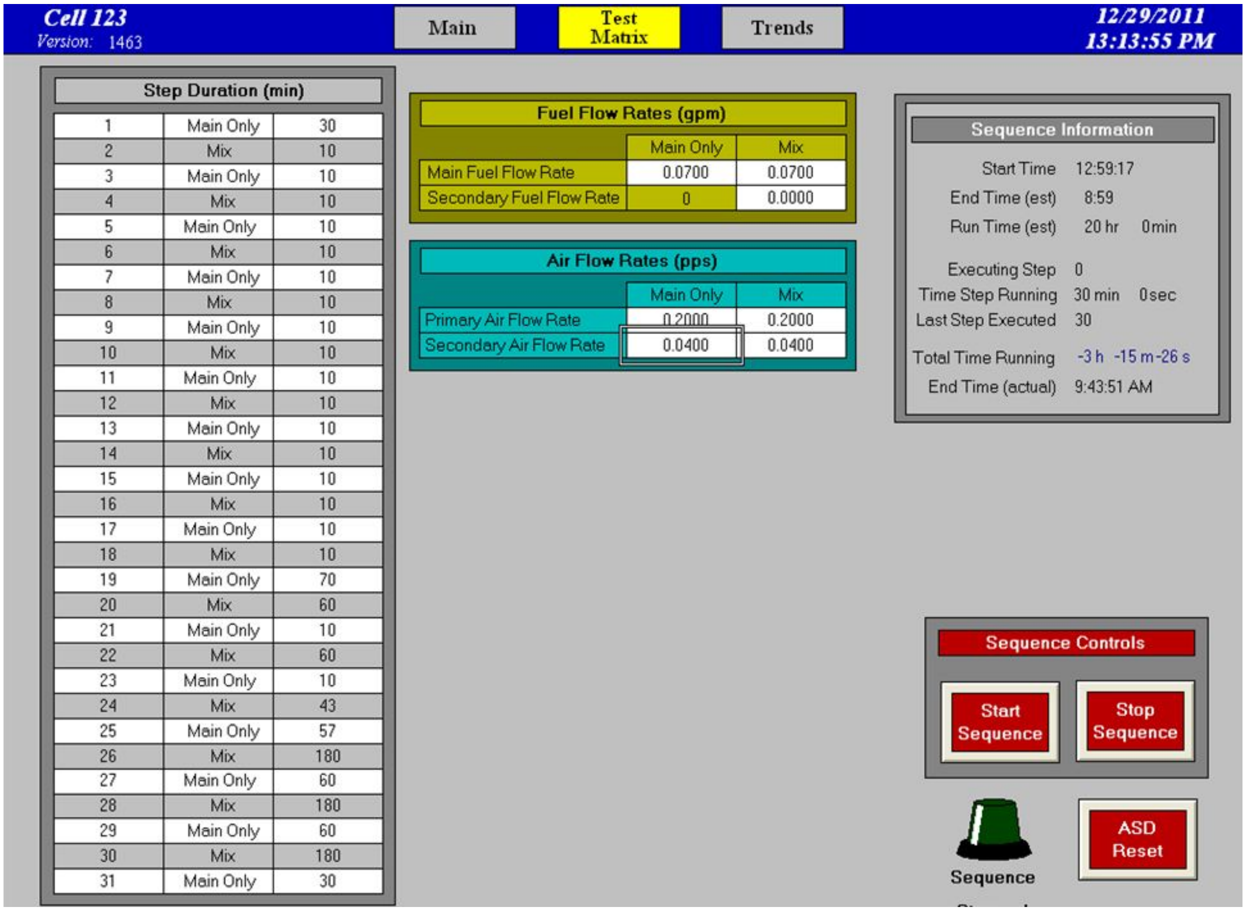

Figure 6.—Test matrix user interface screen; test configured for a 20 h “block”.

The **Test Matrix** user interface screen (Figure 6) is used by the operator to set the conditions for unattended, automatic operation. Three rates are set: fuel flow, preheated primary air flow and secondary air flow. The secondary air (un-insulated lines in Figure 1; SV123-2 air line in Figure 5) is used to input a minimal flow of room temperature air into the secondary combustion chamber to tweak test sample temperature by a few degrees centigrade. The spreadsheet to the left is used to input the number of minutes in each of 31 operational steps. If only JP8 fuel is used, time is input into the “Main Only” rows. If a synthetic fuel is mixed in with the main fuel for certain steps, that time would be input in the “Mix” rows. To date, the majority of runs have been conducted for a 20-h time block. This allows for a four-hour window in which samples can be allowed to cool, removed, weighed, photographed and reinstalled.

Throughout the test, the operator can visually monitor any of the temperatures, pressures and valve opening settings illustrated in Figure 5. An example for a 20-h run is shown (Figure 7) with 11 readings monitored. In addition, all instrument readings are continuously recorded. Post-test, the operator exports the data into a Microsoft Excel (Microsoft Corporation) spreadsheet.

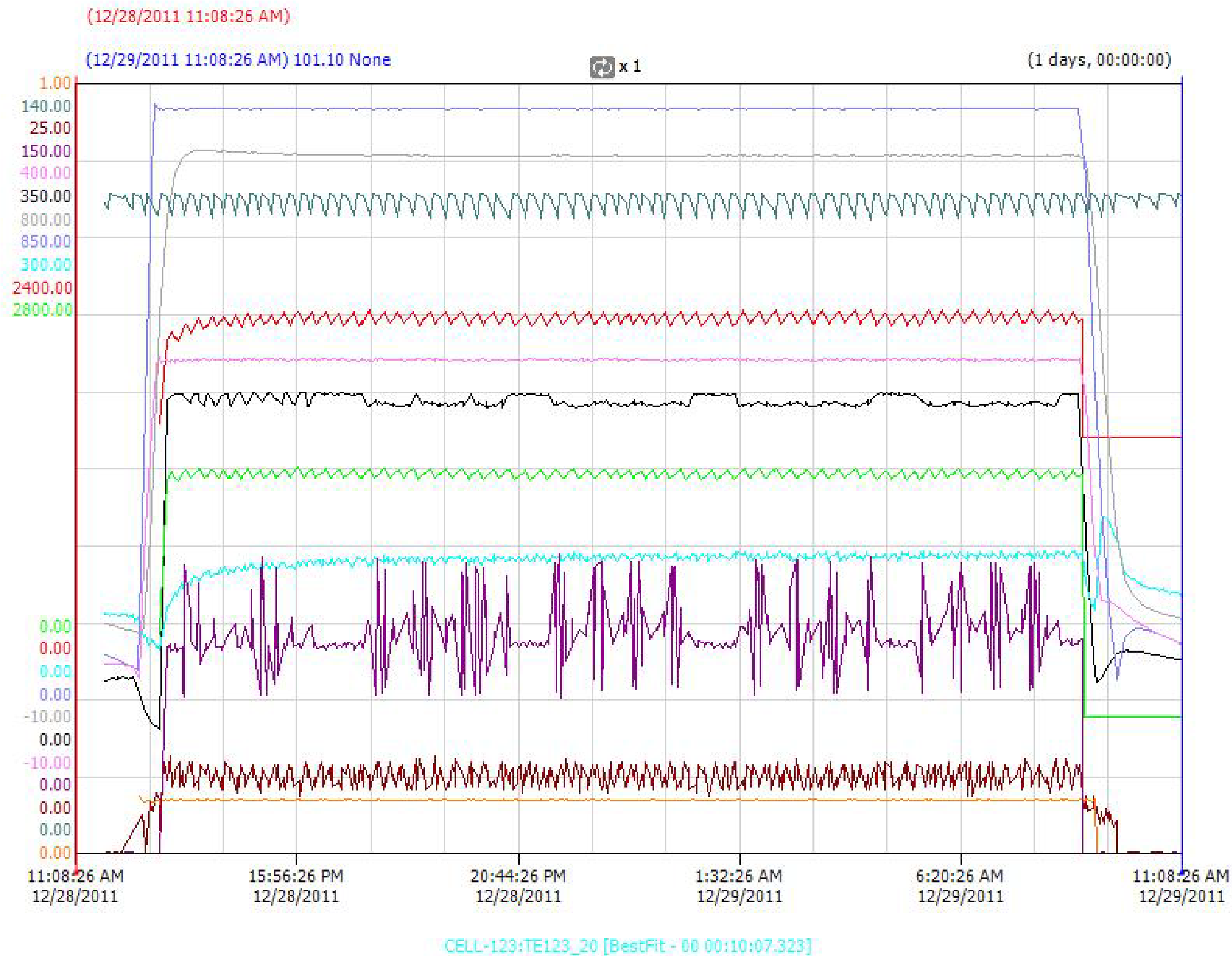

Figure 7.—Monitoring screen of test instrument readings.

2.0 Current Research and Specific Test Cell Configurations

As mentioned previously, the Becon rig is fixed in place with only isothermal exposures possible. In this section, the various types of sample configurations are discussed.

2.1 The 3- by 3-in. Plate Coating Durability

Superalloys are metals used at high temperatures in the hot sections of gas turbine engines. This class of material retains significant strength to temperatures near 1000 °C (1800 °F). An understanding of the oxidation and hot corrosion behavior of superalloys is of great importance. In this demanding application, components such as turbine blades and vanes are often protected with Thermal Barrier Coatings (TBCs).

These thin (5 to 10 mil thick) zirconia-based ceramic coatings, when coupled with internal air cooling, allow the components to be operated at temperatures 40 to 90 °C (100 to 200 °F) higher than bare components. At the same time, component life is extended by reductions in oxidation and thermal fatigue.

TBCs are applied to the superalloy substrate using the plasma spray technique. A zirconia powder is introduced into a plasma jet emanating from a torch, the temperature of which is on the order of 2800 °C (5000 °F). The powder melts and is propelled towards a superalloy substrate, wherein molten droplets of the ceramic solidify to develop the desired coating. There are a large number of variables in this technique including powder type/size, powder manufacturer, plasma gas composition, gas flow rates, energy input,

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standoff distance from the torch to the substrate, and powder deposition rate. The life of the coating is a function of all of these variables.

Life prediction studies of TBCs and their metallic bond coats are conducted in this rig. In such a test, a square oxidation sample (coated or uncoated) is held at a 45° angle to the flow direction (Figure 8 to Figure 10) and held in a superalloy "picture frame." Samples can be exposed for hundreds of hours.

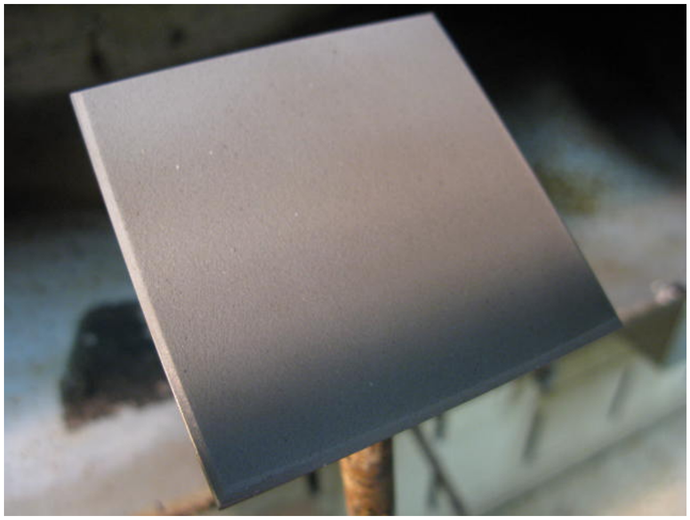

Figure 8.—The 7.5- by 7.5-cm (3- by 3-in.) TBC-coated superalloy sample mounted at a 45° angle to the flame.

Figure 9.—Durability testing of a TBC-coated 3- by 3-in. superalloy plate (at left in photo), carried out at the same time as two fixed superalloy "dog bone" specimens. Exhaust nozzle diameter is 1.9 cm (0.75-in.).

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Figure 10.—Same set up as that in Figure 9 with photo taken along centerline of burner. Note lower 3- by 3-in. superalloy plate positioned to be impinged upon by flame. Upper 1.5-by 3-in. rectangular sample mounted to the duct is polymeric.

2.2 Carousel Oxidation/Corrosion

Oxidation of a superalloy has little impact on residual mechanical properties. This is due to the growth of a protective oxide (alumina or chromia). Corrosion, however, is an accelerated attack experienced by both superalloys and silicon-based ceramics that is initiated by the deposition of condensed sodium sulfate (Na_2SO_4) or acids on engine parts. The source of the salt is direct ingestion with intake air or by its formation during combustion from sodium chloride-contaminated air and sulfur in the fuel. Most superalloys/ceramics are susceptible to corrosion attack to some extent. The phenomenon depends on many factors, including temperature, cyclic conditions, material composition, impurities in and pressure of air ingested into the engine, and impurities in the fuel.

In order to obtain statistically significant mechanical property data from samples after oxidation or corrosion exposure, it is wise to run a number of samples at one time. In this test configuration samples are normally held in a rotating sample carousel. The right hand carousel in Figure 11 holds 12 superalloy “dog bone” pins nominally 1.1-cm (0.43-in.) diam. by 7.6-cm (3-in.) long (0.64-cm (0.25-in.) diam. by 3.8-cm (1.5-in.) long in the gage section). The left-hand carousel holds that same number and size, as well as six more notched samples in the inner diameter nominally 0.76-cm (0.3-in.) diam. by 5.7-cm (2.25-in.) long (0.64-cm (0.25-in.) diam. by 2.5-cm (1-in.) long in the gage section). Carousels are fabricated in-house according to customer needs. The size range of carousel “dog bone” superalloy tensile specimens tested to date is presented in Figure 12.

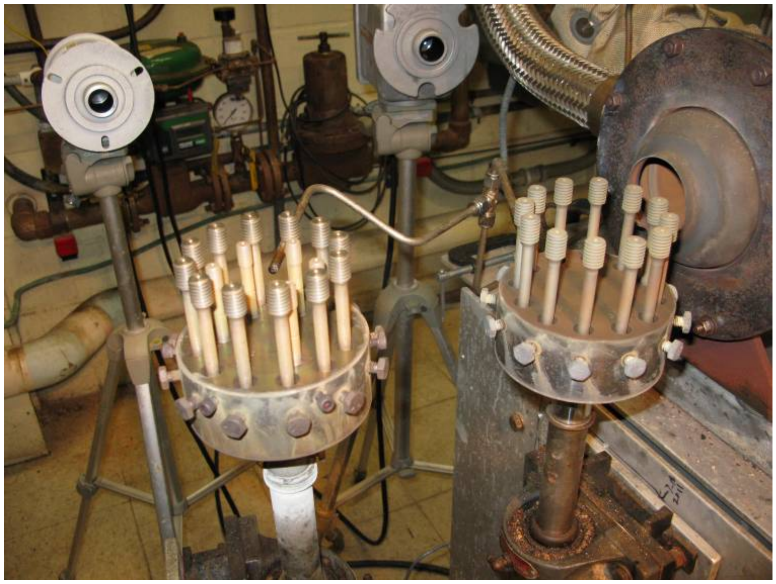

Figure 11.—Carousels holding superalloy tensile specimens. Samples were subjected to corrosive species to determine the effect on mechanical properties.

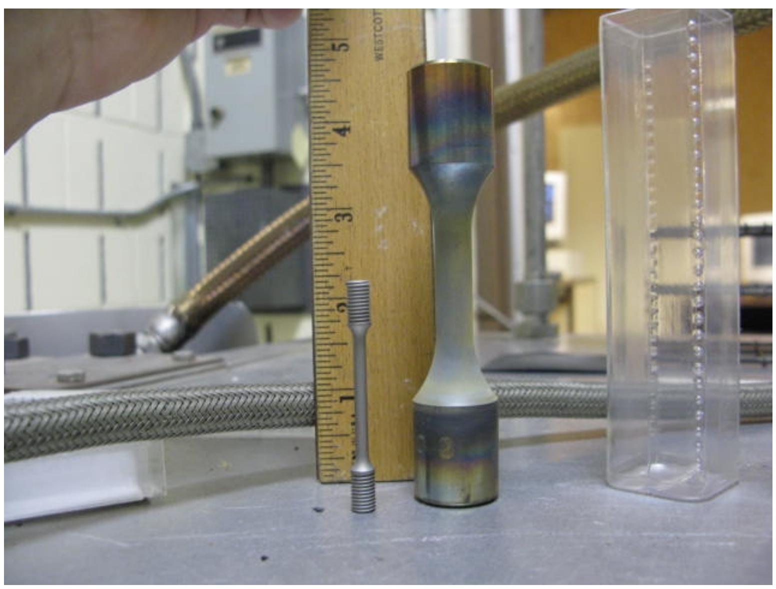

Figure 12.—Size range of carousel “dog bone” superalloy tensile specimens tested to date.

3.0 Summary

The focus of this Technical Memorandum was to present an over view of the Becon burner rig housed within the state-of-the-art Mach 0.3 Burner Rig Facility. The rig is used as an efficient means of subjecting advanced aircraft engine/exhaust materials to high temperatures and high velocities that closely approximate actual operating environments. Materials of various geometries and compositions have been evaluated at temperatures from 100 to 1100 °C (~ 200 to 2000 °F). Many tests are conducted on bare superalloys, but the rig is also used to study the behavior and durability of protective coatings applied to that material class. This facility is primarily used in test programs for NASA Fundamental Aeronautics Programs.

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Appendix

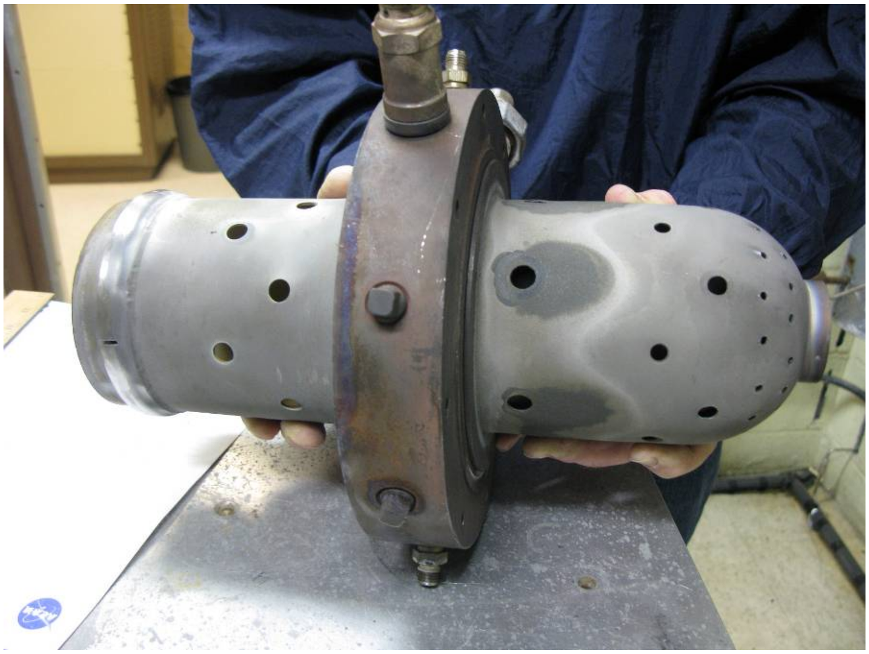

Figure 13.—Inner liners as mated to mid ring. Flame direction right-to-left. Primary liner is at right, secondary liner at left. Mid-ring is air cooled and houses the spark igniter and the Fireye flame detector.

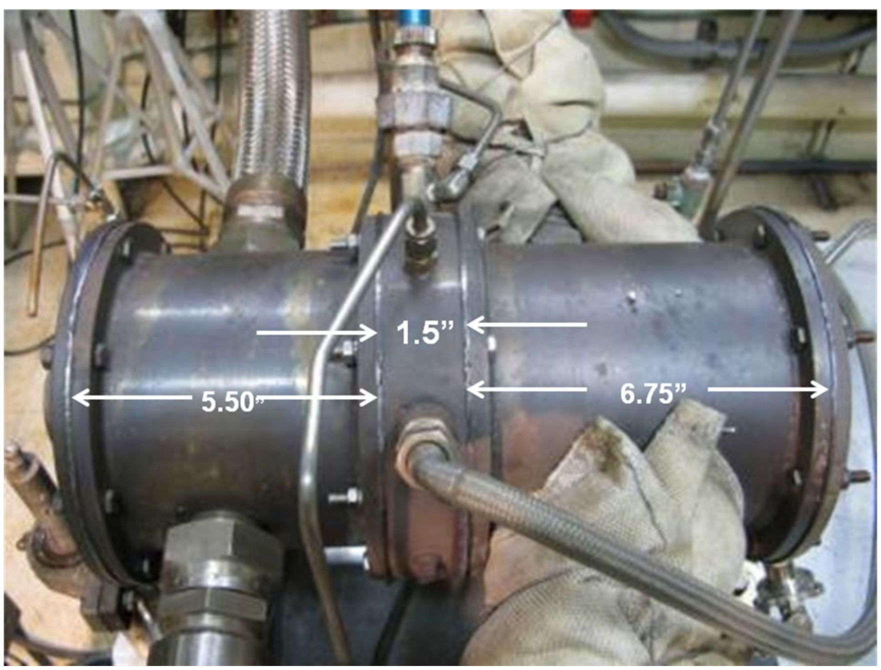

Figure 14.—Approximate dimensions of outer combustor can. Preheated air lines are insulated.

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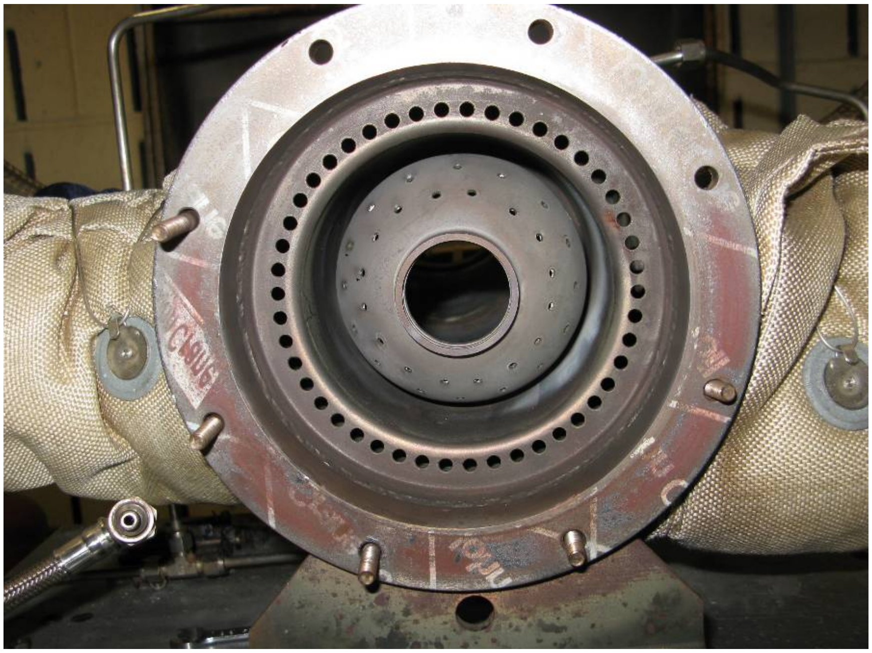

Figure 15.—Primary liner sans swirler installed in outer combustor can. The fuel nozzle plate seals against graphoil gasket.

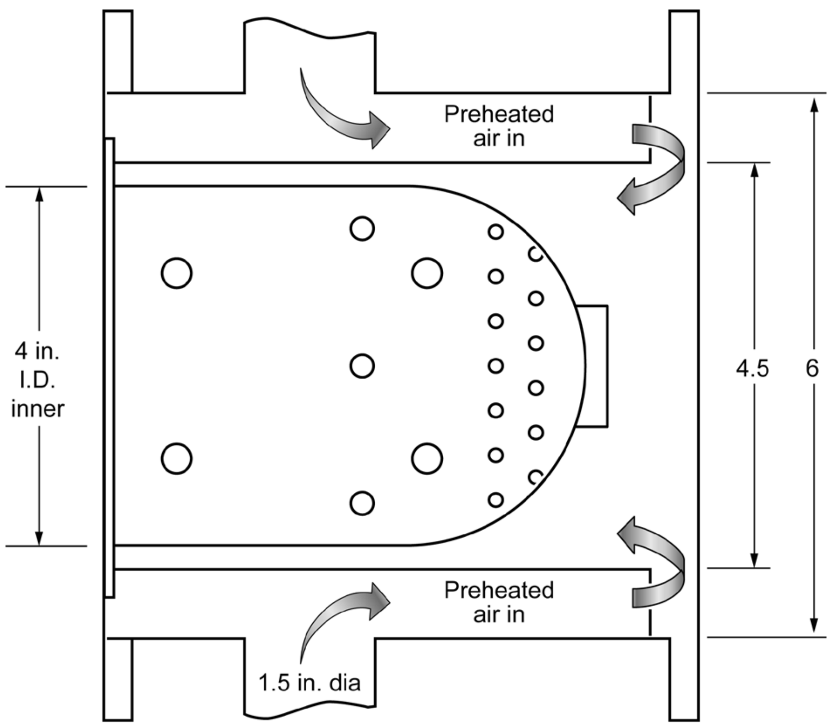

Figure 16.—Preheated air flow through 3.8-cm (1.5-in.) diameter ports to the inner primary liner.

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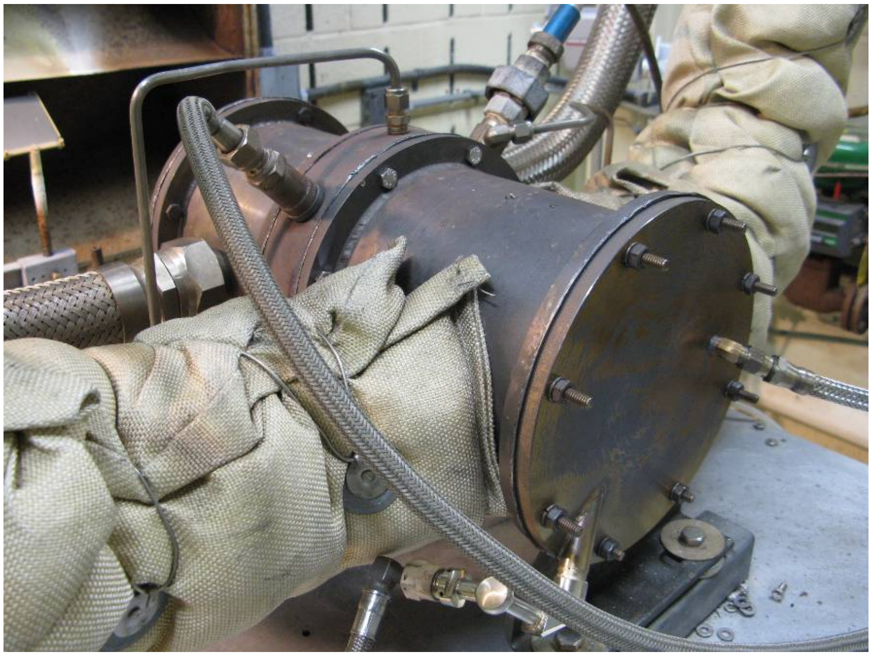

Figure 17.—Fuel nozzle plate installed. Braided hose in plate leads to a pressure tap.

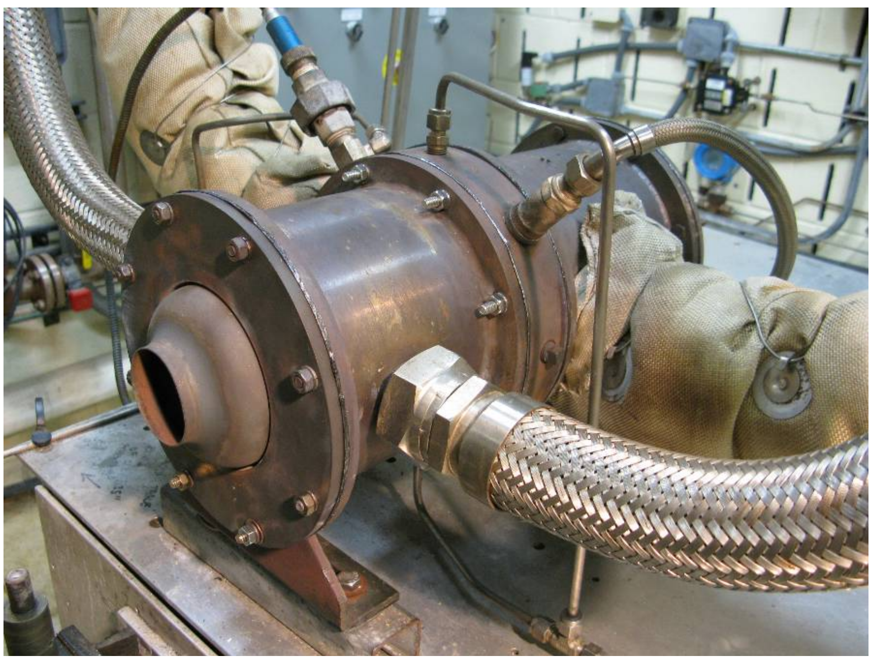

Figure 18.—The business end of the burner. Exhaust nozzle 5-cm (2-in.) in diameter. The foreground braided lines feed the secondary inner liner with ambient temperature air. This air is used for fine-tuning of sample temperature.

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Figure 19.—A 5-cm (2-in.) diameter exhaust nozzle.

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13. SUPPLEMENTARY NOTES

14. ABSTRACT
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