Promoted Combustion Testing in Reduced Gravity

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Material flammability in enriched-oxygen environments is much different than flammability in air. Many tests have been designed to characterize combustion and determine material flammability limits. For metals, the standard flammability test is called promoted combustion, in which a vertically suspended metal rod is ignited at the bottom and burned upward in enriched oxygen. Additional tests have been developed to control variables not considered in standard promoted combustion tests; variables such as flowing gas, the temperature of the sample, and the gravitational effects on the sample.

The effects of reduced gravity on metals flammability are of interest to NASA because oxygen use is prevalent in weightless environments. Without gravity, the burning metal does not fall away from the burning sample, thereby increasing heat transfer and, thus, flammability. Promoted combustion tests in reduced gravity are performed in short duration (~ 3 s) using drop towers and longer duration (~ 25 s) using flight aircraft.

White Sands Test Facility (WSTF) has developed a reduced-gravity metals combustion test system for use on board a modified Boeing C-9B at Johnson Space Center. The aircraft is flown through a series of parabolic maneuvers, producing a reduced-gravity environment. Performing promoted combustion tests in this environment presents several challenges. To begin, hands-on testing during the flight maneuvers is stressful on personnel and equipment. Using high pressure and addressing the fire hazards of an enriched-oxygen test system also present special challenges. Additionally, the process is expensive and only a small window of time exists for testing; therefore, efficiency is extremely important. Finally, the consequences of a fire escaping the confines of the test apparatus or the occurrence of another failure during flight could be catastrophic. These challenges were addressed in the design of the test system.

The test system consists of a pressure vessel, associated tubing and valves, instrumentation, and oxygen and air supply cylinders. During the design phase, material selection was of utmost importance. The test system has a maximum allowable pressure of 3,000 psig, where most metals are considered flammable in 100% oxygen. Many standard stainless-steel test chambers can be pressurized even higher and are typically acceptable for lower-risk remotely operated tests, when an unintentional fire would not cause harm to personnel. However, because of the risks associated with hands-on in-flight testing, the reduced-gravity system requires a greater degree of conservatism.

Unfortunately, several ignition mechanisms are inherent within the system. For example, fires can be caused by heat generated from burning metals or impact from burning-metal particulate. Because of the inevitable presence of these ignition mechanisms, component materials were selected based upon their flammability in 100% oxygen at 3,000 psig. The component most vulnerable to ignition is clearly the combustion chamber, which is in direct contact with burning metals. To mitigate the risk of fire, the major parts of the chamber were made of copper and nickel alloys, which are resistant to burning in this environment. A Monel chamber was designed with a copper liner to protect it from direct contact with hot metals. The remainder of the chamber was fabricated from burn-resistant alloys (figure 1), as were many of the system components, to mitigate the risks.

The entire test system was designed, proof-tested, and certified for high-pressure gas in accordance with American Society of Mechanical Engineers (ASME) B31.3, *Process Piping*. The ASME Boiler Pressure Vessel code was applied to the chamber design using a factor of safety of 4 on ultimate tensile strength. For in-flight loading, the chamber lifting mechanism was designed with a quick-release clamp that seals the chamber during pressurization, mounting brackets that attach it to vertical shafts, and air-actuated cylinders that raise and lower the chamber for access between tests. The test system frame and components

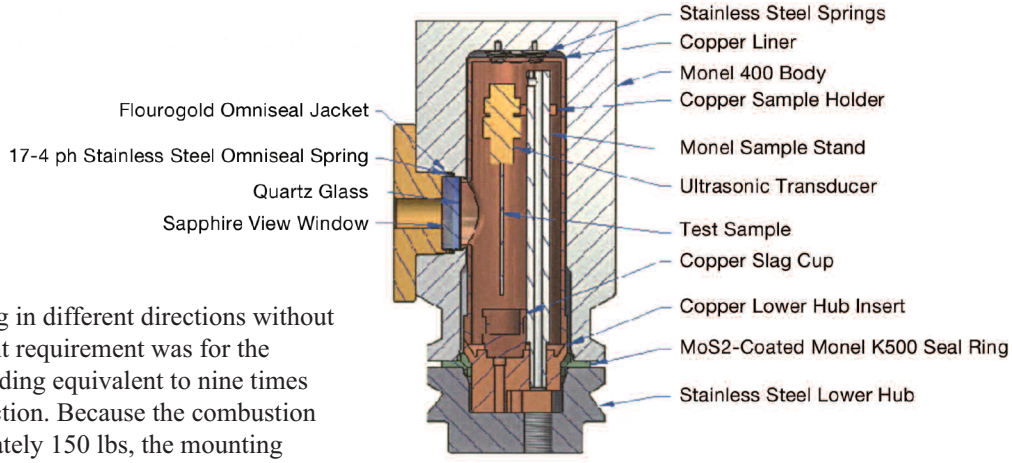

Fig. 1. Cross-section of assembled reduced-gravity chamber.

needed to withstand loading in different directions without yielding. The most stringent requirement was for the equipment to withstand loading equivalent to nine times gravity in the forward direction. Because the combustion chamber weighs approximately 150 lbs, the mounting hardware must withstand 1,350 lbs before yielding. In addition to the chamber, the k-bottles are very heavy and important to restrain properly. The bottles were found to be much more manageable when laid horizontally because they lowered the system's center of gravity, were more easily restrained, and needed less pressure tubing to reach from the bottle valve to the pressure system inlet, which is only inches away.

Fig. 2. Current reduced-gravity system configuration.

The hand-operated test equipment and the parabolic flight maneuvering can be extremely taxing on personnel, and the environment makes communication difficult. To alleviate these stresses, the system was automated as much as possible. For example, air-actuation lifted the chamber, and headsets and microphones facilitated distraction-free communication. Additionally, holders were added to handle hot posttest samples. The sample holders were mounted to the sides of the system (figure 2) and covered to contain any debris from being released into the aircraft cabin during a reduced-gravity cycle.

Testing begins near the top of a parabola when the reduced-gravity environment begins. Data acquisition includes pressure data, acceleration data (near zero during testing), regression rate, and video. The regression rate of the test sample is recorded using an ultrasonic transducer, which uses a signal generator to instantaneously detect the sample length. Test video of the sample is captured using a fish-eye lens camera connected to a digital recorder. The fish-eye lens is optimal because its viewing angle captures nearly the entire length of the sample.

By addressing the challenges associated with performing high-pressure metals flammability tests in reduced gravity, WSTF has designed and built a safe system with which efficient testing can take place. The ultimate goal of this testing is to generate data that will guide metals selection for reduced-gravity applications.