IMPROVEMENTS IN COMBUSTION SMOOTHNESS AND EFFICIENCY

IN A LARGE SHOCK-TUBE DRIVER

by

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INTRODUCTION

Ames Research Center is developing two large hypervelocity free-flight wind-tunnel facilities. The airstreams for both of these facilities are provided by combustion-driven tailored-interface shock tubes. In the operation of these facilities it is particularly desirable that the stagnation region of doubly shock-heated air at the entrance to the hypersonic nozzle of the wind-tunnel test section be as quiescent and disturbance-free as possible, so that the wind tunnel can be run with air which has known and constant properties. Quiescent operation can be achieved only if combustion in the driver tube proceeds smoothly, for if any extraneous disturbances are generated in the driver, they will be propagated to the stagnation region. One type of disturbance which has been common and troublesome in the driver tube of the prototype (ref. 1) for these facilities is a pressure oscillation moving from end to end of the tube (e.g., p. 19 of ref. 1 or Fig. 13(c) of ref. 2). It is the purpose of the present paper to describe a probable cause for this disturbance (other than poor mixing of the driver gases) and the steps which have been taken to minimize the disturbance in one of the new facilities.

DESCRIPTION OF DRIVER TUBE AND INSTRUMENTATION

The facility under discussion is the smaller of the two large facilities previously mentioned and is known as the Ames Hypervelocity Free-Flight Radiation Facility. The driver tube is a reworked 14-inch naval gun, with geometry as sketched in Fig. 1. The gun was shortened to 32 feet, the rifling removed, and a new stainless-steel liner with a 13-inch ID inserted. A new seal was machined for the breech, but otherwise the original breech mechanism was used. For the tests described here, a blank-off plate was installed to prevent flow into the driven tube, and the driver tube was operated as a closed combustion chamber. Under normal operation the blank-off plate would be replaced by a diaphragm.

To promote good mixing, gases are introduced into the chamber through a manifold drilled with small holes, which runs the length of the chamber. In operation, the tube is first evacuated, and gases are introduced in the following order: first, approximately 10 percent of the helium; then all of the oxygen; then approximately 20 percent of the helium; then all of the hydrogen; and, finally, the remainder of the helium. The final helium is introduced at high inlet pressures to mix the gases thoroughly.

Gases are ignited by heating a 0.010-inch-diameter tungsten wire strung axially on centerline from end to end of the tube. The wire is electrically heated by the discharge of a 90 μF capacitor bank charged initially to 8 or 10 kV. The heating pulse does not explode or break the wire.

Ports for measuring transient pressure in the chamber are provided in two sidewall locations (see Fig. 1), one at the muzzle end and one at the breech end of the tube. Pressures were measured with Kistler Corporation quartz crystal piezoelectric transducers (type 601A). The faces of the cells were recessed about 0.030 inch and covered with General Electric Company type 102 RTV silicone rubber for heat protection. Output signals were amplified, and recorded photographically from an oscilloscope.

GAS MIXTURES AND LOADING PRESSURES

To date, tests in the facility have been made at an initial pressure (before burn) of 96 psia. The two gas mixtures used are shown in the table below.

Mix	Parts by volume		
	O_2	H_2	He
1:3:8	1	3	8
1:2:9	1	2	9

RESULTS AND DISCUSSION

The first runs in the chamber were conducted with the 1:3:8 mix and with a large strut in the muzzle end of the chamber (see Fig. 1). The purpose of this strut was to hold a piercing mechanism for the diaphragm between the driver and driven tubes. A record from one of these runs is shown in Fig. 2. The upper oscilloscope trace is from the breech end of the tube and the lower trace from the muzzle end. The sweep time is 10 msec per division and the vertical sensitivities are shown on the figure. A small pip shows approximately 12 msec after the start of the record; this is the initiation of capacitor discharge. The record shows a strong, double-humped pressure disturbance which started near the muzzle of the tube and propagated back and forth through the tube, finally forming into two shock waves after about five cycles of oscillation. Accompanying this pressure disturbance is a bulk motion of the gas - a sloshing from end to end in the tube. At the slight pause in the breech record, just prior to arrival of the first double-humped disturbance, the pressure is 85 percent of the theoretical afterburn pressure for constant-volume combustion with this mixture. After burning is complete (approximately 28 msec after the start of the trace) the pressure drops with an average rate (dp/dt) of about -2.5 psi per msec. (For constant volume, dp/dt is proportional to the rate of heat loss from the tube.)

Since the disturbance in this and similar tests originated near the muzzle, it was felt that the strut might be the cause. As can be seen in Fig. 1, the ignition wire is terminated at the end of the strut toward the breech and there is a large pocket of gas around the strut in which burning cannot proceed two-dimensionally and radially outward from the center of the tube to the walls. The burning process in this region is hypothesized as follows. Because of the longer flame path length in this gas and the fact that the pressure pulse due to burning precedes the flame front, this gas is compressed more before it burns than the gas in other parts of the chamber. Therefore, the gas in this pocket burns to higher final pressures and creates the disturbance shown in the records. To check this hypothesis, the strut was removed and the wire strung as closely as practical to the end of the tube. From Fig. 3, which shows a record obtained, it is evident that the pressure disturbances have been greatly reduced in magnitude. In this record the afterburn pressure is 93 percent of the theoretical afterburn pressure. The pressure drop per unit time has been reduced to -1.5 psi per msec, 60 percent of its earlier value. This is because, with the reduction in pressure disturbance, the bulk motions of the gas are also reduced and therefore the convective heat transfer to the walls due to these bulk motions is reduced. The time required for the small pressure fluctuations remaining in the record to complete one round trip of the tube provides a measurement of the speed of sound in the burned gases - 7200 ± 150 fps - in excellent agreement with the value predicted for 93 percent of the theoretical pressure rise - 7120 fps. It should be noted that low disturbance records such as in Fig. 3 were obtained in most, but not all, tests with the strut removed - the reasons for this are not known at present. However, for every test with the strut installed, disturbances starting near the muzzle end occurred.

A similar relatively disturbance-free record was obtained for the 1:2:9 mix (with the strut removed), and is also shown in Fig. 3. This mix has two advantages for shock-tube operation over the 1:3:8 mix. First, it burns to a slightly higher temperature and gives, therefore, slightly better shock-tube performance; and second, since the mix is stoichiometric, the problem of burning of excess hydrogen at the interface between the driver and driven gases is eliminated. This mix also burned to 93 percent of its theoretical pressure.

CONCLUSIONS

From the results of these preliminary tests in a 32-foot-long, 13-inch-diameter combustion chamber, it can be concluded that obstructions to two-dimensional radial burning are likely to produce strong pressure disturbances, which will increase heat-loss rates from the driver gas, and perhaps lead to erratic shock-tube performance. With no large obstructions to radial burning, nearly disturbance-free combustion has been demonstrated and pressures have reached 93 percent of theoretical.

REFERENCES

1. Seiff, Alvin: Ames Hypervelocity Free-Flight Research. Astronaut. Aerospace Eng., vol. 1, no. 11, Dec. 1963.

2. Wilkins, Max E., and Carros, Robert J.: Combustion Tests of Oxygen-Hydrogen-Helium Mixtures at Loading Pressures up to 8000 Pounds Per Square Inch. NASA TN D-1892, 1963.

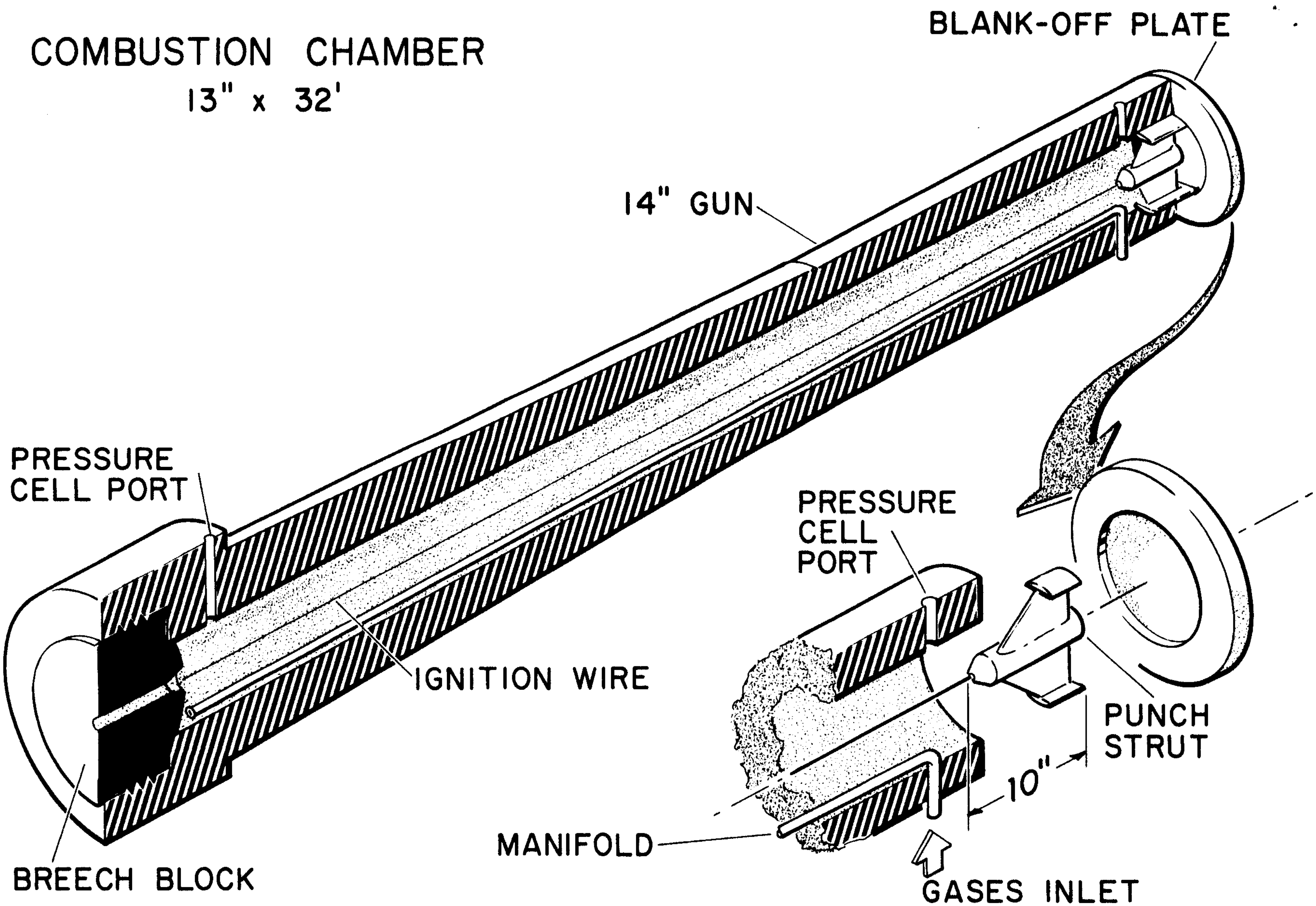


Fig. 1.- Schematic drawing of combustion chamber.

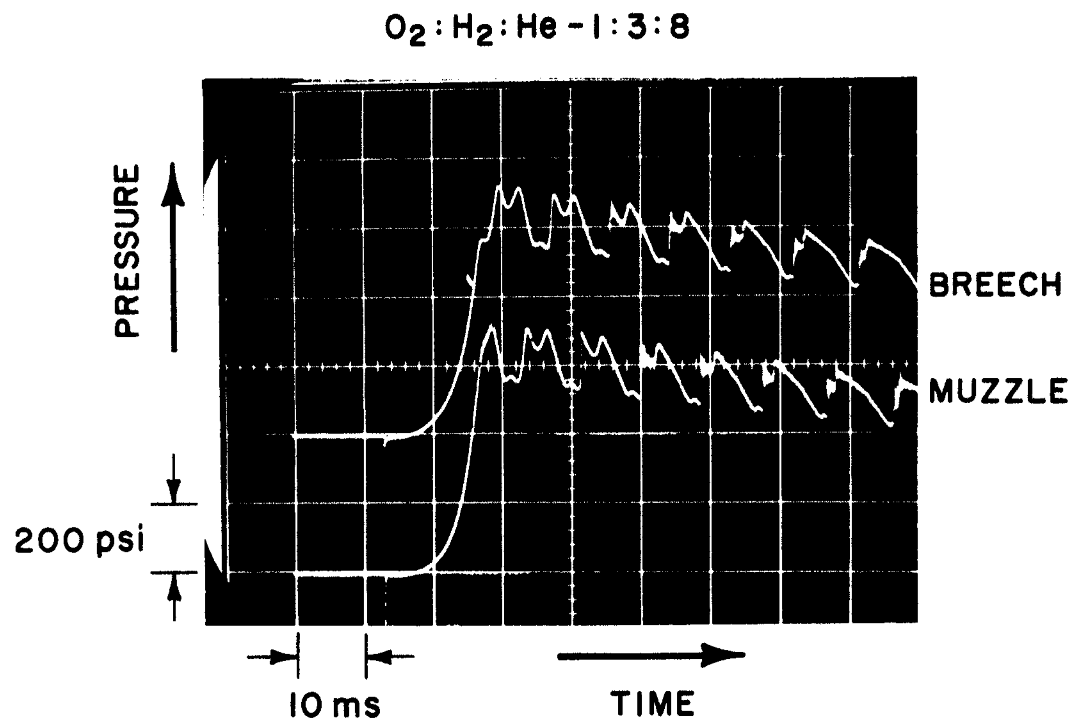
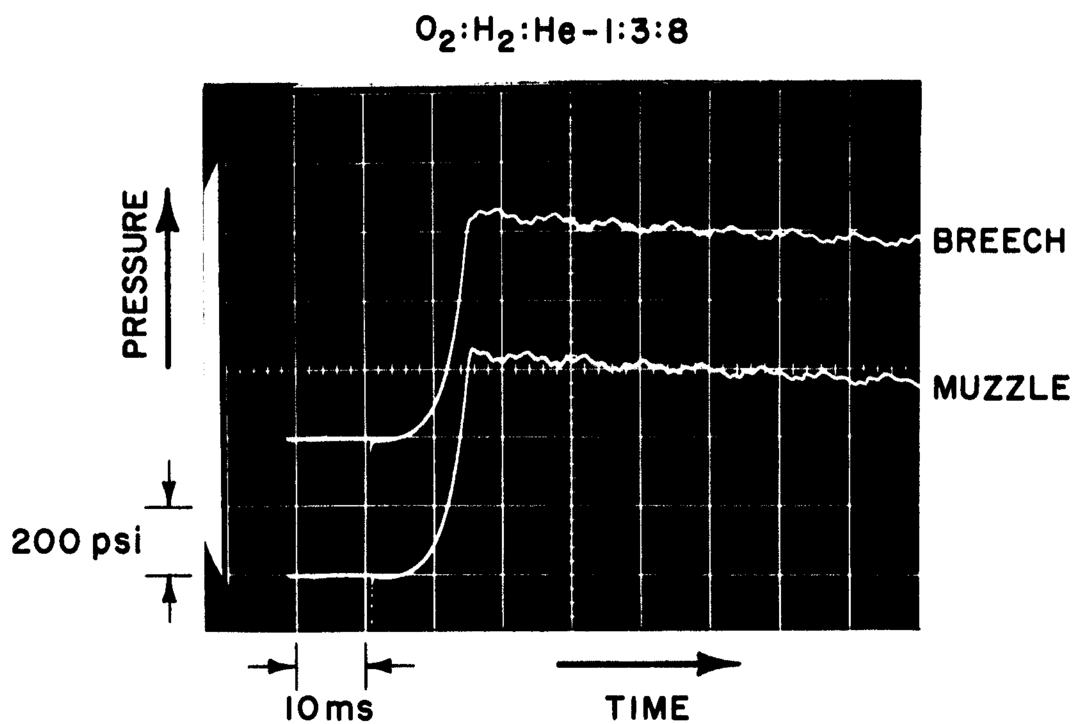
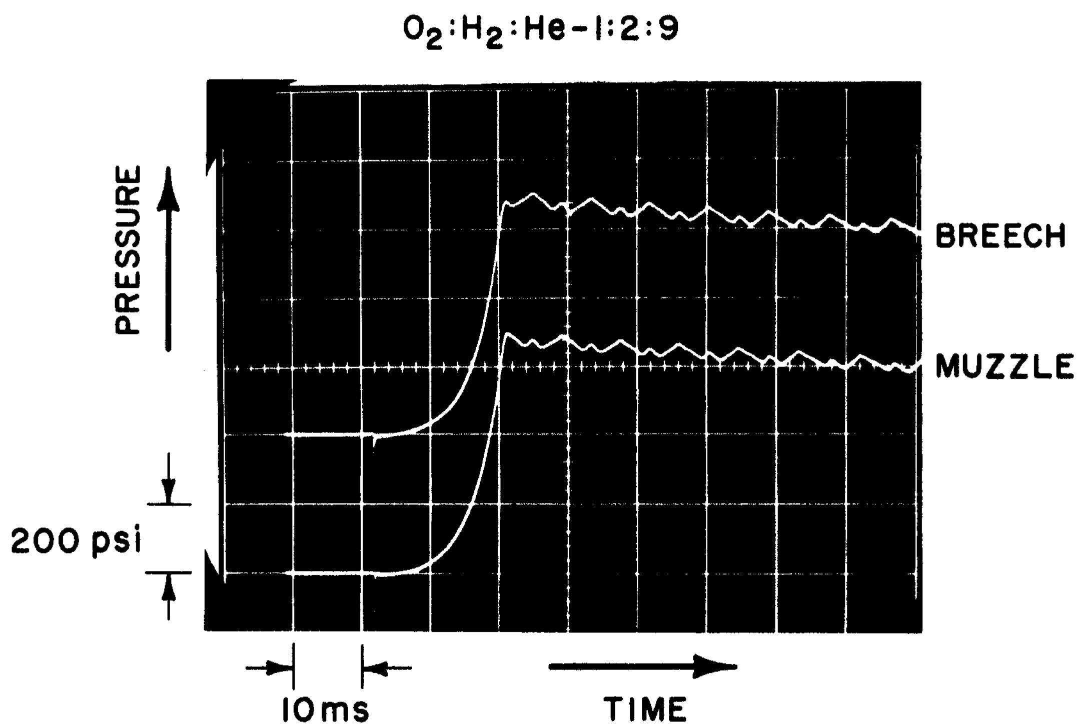


Fig. 2.- Combustion record with large strut in tube. 1:3:8 mix; initial pressure, 96 psia.



(a) 1:3:8 mix

Fig. 3.- Combustion record with large strut removed from tube; initial pressure, 96 psia.



(b) 1:2:9 mix

Fig. 3.- Concluded.

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