National Aeronautics and Space Administration

Propulsion

HYPERFIRE

Fast, Accurate, & Inexpensive Rocket Aerodynamics Testing

The two main sub-scale, ground-based rocket aerodynamics testing techniques – hot-fire testing and cold-flow testing – pose a series of tradeoffs. Hot-fire testing is generally much more accurate, but is often burdensome, costly, and requires long lead times due to design work, infrastructure preparation, etc. Cold-flow testing is much less expensive and has a rapid turnaround time, but conventional simulants (e.g., nitrogen, steam) used in cold-flow testing yield less accurate results (i.e., results that are not sufficiently representative of test article performance).

While researching methods to optimize such tradeoffs, engineers at NASA's Stennis Space Center discovered that ethane can be tuned to approximate rocket exhaust plumes generated by several common rocket propellants. This led NASA to develop the HYdrocarbon Propellants Enabling Reproduction of Flows in Rocket Engines (HYPERFIRE), a sub-scale, non-reacting flow test system. HYPERFIRE uses heated ethane to enable physical simulation of rocket engines powered by a broad range of propellants in an inexpensive, accurate, and simple fashion.

BENEFITS

- *Vastly reduces testing cost and timeline:* NASA's HYPERFIRE enables the end-to-end (i.e., design, fabrication, and testing) rocket aerodynamics testing process to be performed in roughly one month (~90% schedule reduction relative to hot-fire testing), and at low-cost (~98% reduced cost relative to using hot-fire testing).
- *Portable & self-contained:* The HYPERFIRE is portable, self-contained, and includes integrated control and data acquisition. It can be moved via forklift and shipped to a testing location. It plugs into a wall power outlet and requires no external components.
- *Improves testing accuracy:* Heated ethane generated and flowed through test articles by NASA's HYPERFIRE is more effective than traditional simulants (e.g., nitrogen, steam) used in cold-flow testing – thus, results using the system are more representative of the aerodynamics of the test article than conventional cold-flow testing. Error rates for the 14 tests run to date using the HYPERFIRE have been on the order of ~2% cumulatively for steady state operation, and ~5% for transient development of the plume structure.

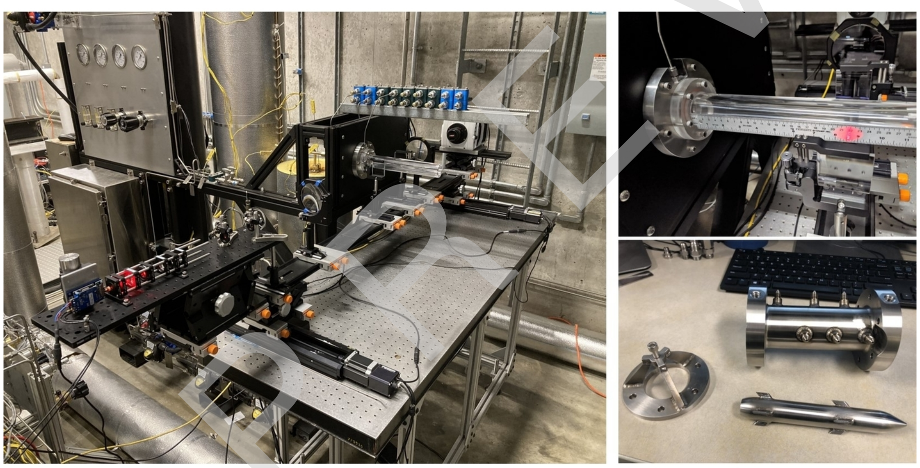
technology solution

THE TECHNOLOGY

In order to maintain the low cost, simplicity, and quick turnaround of cold-flow testing while improving accuracy, NASA evaluated unconventional gases for use as simulants. During such evaluations, NASA discovered that by adjusting stagnation temperature, the isentropic exponent of ethane can be tuned to approximate those of common rocket propellants (e.g., hydrogen, hypergols, alcohols, and hydrocarbons). Furthermore, due to ethane's high auto-ignition temperature and resistance to condensation, tuned ethane enables testing of expansion ratios much larger than conventional inert-gas testing.

To leverage this discovery, NASA developed a hardware-based system to treat ethane and obtain nozzle chamber conditions that match the appropriate aerodynamics for a specific test. The system, named HYPERFIRE, works in the following manner. Liquid ethane is transferred to a piston-style run tank, where it is pressurized. Then, the ethane is run through two insulated pebble beds where it is heated, vaporized, and stabilized. Finally, the treated ethane is transferred from the second pebble bed to a small thrust takeout structure, and through the test article. Control of valves and regulators is managed by an onboard computer, accessed via a LabVIEW™ interface. The system is mounted on a hurricane-resistant steel frame to enable transportation via forklift.

Heated ethane reproduces the aerodynamics of combustion products at low temperatures relative to alternative testing methods. Thus, test articles can be manufactured using low-cost, low temperature rated, transparent materials (e.g., acrylic). In addition to reducing testing cost, this grants optical access to internal flowfields, enabling advanced diagnostic techniques (e.g., Schlieren imaging, particle image velocimetry) not possible with hot-fire testing and less meaningful with conventional cold-flow testing.



(Left) NASA's HYPERFIRE performing flow testing with integrated Schlieren flowfield imaging. (Right) Examples of NASA HYPERFIRE test articles, including a Schlieren test article (top) and centerbody diffuser test article (bottom).

APPLICATIONS

The technology has several potential applications:

- *Rocket engine testing & development*
- *Fundamental nozzle research*
- *Simulation of combustion products (e.g., automotive testing)*

PUBLICATIONS

"Physical Simulation of Rocket Exhaust Aerodynamics Using Heated Ethane: Conceptual Foundations," Daniel R. Jones, June 2019, https://ntrs.nasa.gov/citations/20190030272

"Physical Simulation of Rocket Exhaust Aerodynamics Using Heated Ethane: Prototypical Experiments," Daniel R. Jones, October 2020, https://ntrs.nasa.gov/citations/20205009122

More Information

National Aeronautics and Space Administration

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EA42/Advanced Technology and Technology Transfer Branch
Stennis Space Center, MS 39529
202-358-7432
Agency-Patent-Licensing@mail.nasa.gov

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SSC-00598, SSC-00561
SSC-TOPS-12