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Advanced Instrumentation for Next-Generation Aerospace Propulsion Control Systems

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Introduction

NEW concepts for the control of jet and rocket engines and the new hybrid engines, such as the National Aerospace Plane (NASP) hypersonic propulsion system, have introduced new instrumentation requirements. These control concepts are analyzed to determine their required measurands. Next, advanced measurement technologies from recent major NASA/Department of Defense (DOD)/industry-sponsored measurement technology development programs are compiled and, subsequently, matched with the corresponding measurands. This is followed by a ranking of the sensor technologies based on the number of their applications. This provides a list of advanced measurement technologies suggested for further development and use in advanced aerospace propulsion control systems.[1]

Control Concepts

Jet Engines

Several new concepts for the control of jet and turbofan engines have been forwarded in recent years. These ideas include active stall control, performance-seeking control, intelligent diagnostic control, tip clearance control, burner pattern-factor control, control of the normal shock in the inlets of supersonic and hypersonic aircraft, acoustic emissions control, and electromagnetic emissions control. Intelligent control concepts for jet engines encompass the management of a variety of special-purpose control modes such as those just listed, the use of reduced redundancy, and the incorporation of diagnostics and damage reconfiguration.

Rocket Engines

The emergence of the Space Shuttle main engine (SSME) as the world's first reusable rocket engine has brought about a growing interest in improving durability through new control concepts. New rocket-engine control concepts, include onboard diagnostic systems, which will monitor and interpret the health of the rocket engine and provide a real-time prognosis of wear characterization. This information is then used by a higher-level coordinator to either change the control requirements for the rocket engine or to actually change or implement the appropriate control modes of the rocket engine. The underlying idea is to use the engine in a manner that reduces component loads and minimizes the damage that accrues while still ensuring, if possible, mission success. It also requires appropriate advanced instrumentation to either measure damage directly or to measure the damage-indicating parameters such as stress/strain cycles and temperature transients.

Hypersonic Engines

Combined-cycle engines are characterized by the presence of high-speed flow in excess of Mach 1 through the entire engine. A controller for this system would also have to handle ramjet engines that can be transitioned into scramjet engines, the management of shocks, and the control of combustion under extremely adverse conditions.

Emerging Instrumentation Technologies

The recent NASA/DOD integrated high-performance turbine engine technology (IHPTET) initiative has become a driving force in the design of control systems and the development of advanced instrumentation for jet-engine propulsion systems.

Furthermore, the NASA-LeRC rocket engine maintenance study program has identified and developed several advanced measurement technologies for in-flight and between-flight hardware diagnosis and intelligent control of rocket engines. They were fiberoptic pyrometers for very high-speed blade-by-blade temperature mapping for the detection of blade fatigue cracks, fiberoptic deflectometers for hf deflection measurement for ball-bearing health-monitoring purposes and isotope wear indicators for nonintrusively monitoring the wear of parts (ball bearings, blade tips) in situ without access ports or holes.

Other major advanced instrumentation programs are the NASA Marshall SSME technology testbed engine program and the NASA Lewis multipoint multiparameter hypersonic combustion flow diagnostic system, which included remote optical monitoring of the two-dimensional distribution of the temperature, pressure, and concentration of various species simultaneously superimposed on top of each other.

Another major effort was performed by the NASP instrumentation consortium. The consortium generated a list of 22 measursands desirable for the monitoring and control of NASP hypersonic engines and initiated the development of 10 advanced measurement technologies.

Application of Emerging Instrumentation Technologies to New Control Concepts

To determine the application of the identified advanced measurement technologies to the new control concept, they were matched against the new control-concept measurands for jet, rocket, and hypersonic engines. Only new technologies that provide measurements not previously available are discussed further. This includes sensor technologies that provide increased dimensionality of measurements. Nonintrusive measurements are also included since they permit measurements in areas where conventional probe instrumentation cannot be used or reduce the number of ports required. The technologies must have the near-term potential to be flyable, implying that they must be lightweight, robust, and require a minimal amount of electrical power. In many instances, being robust means the capability of operating in extreme high-temperature environments.

Table 1 shows a ranking of selected technologies based on the combined number of applications for jet, rocket, and

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Table 1 Candidate measurement technologies

Technologies	Applications
Application ready	
Fiberoptic deflectometer	12
Brushless torque/stressmeter	11
Optical surface temperature sensor	10
Ultrasonic triducer	5
Isotope wear detector	3
Nonintrusive speed sensor	3
Optical absorption leak detector	1
Need development	
Spectrometry	8
Ultrasonic tomography	4
Optical densitometer	3
Raman H_2 leak detector	3
Nonintrusive hot-gas temperature sensor	2
Hydrogen leak sensor	1
Need further research	
Optical gas diagnostics	17
Gas anemometer	5
Exoelectron fatigue detector	3
Acousto-optic flaw detector	3

hypersonic engines. This article is meant as a means for the reader to only be appraised of new instrumentation technologies that may be of benefit to their control applications.

Discussion

For the sake of brevity, where two or more sensor technologies perform similar measurements and the maturity level is the same, the sensors have been grouped together under a more general name. These include technologies such as the fiberoptic pyrometer and the thermally assisted laser-induced fluorescence temperature sensor, which are listed together as optical surface temperature sensors. Emission spectrometry, such as plume emission and absorption spectrometry, including the Fabry–Perot and other laser-based spectrometers, are listed together under spectrometry. Optical gas diagnostics covers several of the two-dimensional gas temperature, pressure, density, and flow measurement technologies such as planar laser-induced fluorescence, Raman spectroscopy, coherent anti-Stokes Raman spectroscopy, laser-induced breakdown spectroscopy, and emission tomography. Hydrogen leak sensor refers to three single-point measurement technologies, using the resonant frequency shift or changes in surface acoustic waves in a hydrogen-absorbing palladium block or using a temperature sensor to measure the oxidation rate of hydrogen in a hydrogen-oxidizing platinum catalyst.

Although the nonintrusive hot-gas temperature sensor and the nonintrusive speed sensor do not necessarily provide any new measurements for the new control system concepts, they do provide nonintrusive measurements of very critical control parameters that otherwise might not have been considered as practical. For this reason, they were deemed appropriate for the accepted measurement technology list.

Each of these measurement technologies, with only four exceptions, crossfeeds from its original application in a specific propulsion system into applications in the other two types of propulsion systems. The first exceptions are the hydrogen leak sensors (three types) that do not apply to jet engines that use only hydrocarbon fuels. Optical absorption leak detection, a rocket-engine technology, also has no new control concept applications for jet engines. Lastly, the three optical desensitometers, hypersonic-engine technologies, have no new control concept applications for rocket engines. The remaining 22 technologies, however, have new control concept applications for all three types of engines.

Thirty advanced instrumentation technologies that are represented by the 17 listed measurements are recommended for consideration for appropriate developmental efforts. These technologies will enable implementation of the next-generation jet-, rocket-, and hypersonic-engine control systems.

For the inquisitive reader who would like to learn more about these technologies, a directory of measurement technologies and the references are included in the original paper.[1]

Conclusions

The primary contribution of this Note is in providing the reader with a database of the advanced instrumentation technologies targeted for advanced aerospace-propulsion control systems and in cross matching the available technologies from each type of engine to the control needs and applications of the other two types of engines.

Reference

[1]Barkhoudarian, S., Cross, G., and Lorenzo, C., "Advanced Instrumentation for Next-Generation Aerospace Propulsion Control Systems," AIAA Paper 93-2079, June 1993.

Experimental Flow Visualization for a Large-Scale Ram Accelerator

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Introduction

EXPERIMENTAL testing and gasdynamic modeling of the ram acceleration technique for in-bore projectile propulsion are being investigated at the U.S. Army Research Laboratory (ARL) under the Hybrid Inbore Ram (HIRAM) propulsion program.[1-4] This research program seeks to provide an efficient method of achieving hypervelocity (≥3 km/s) projectile gun-launch for use in high-speed impact testing applications. The ARL ram accelerator system uses a 120-mm (bore diameter) tube that is modeled after the 38-mm system at the University of Washington[5] where the technology was first demonstrated. Ram acceleration technology has also been successfully demonstrated at the Institute of St. Louis (ISL) in France.[6,7] In the ram accelerator system a projectile and obturator are injected at supersonic velocity into a stationary tube filled with a pressurized mixture of hydrocarbon, oxidizer, and inert gases. Flow stagnation on the obturator initiates combustion of the mixture, before it is discarded. A system of shock waves on the projectile, in conjunction with viscous heating, sustains combustion. The resulting energy release, which travels with the projectile, also generates high pressures that impart thrust to the projectile. The ARL experimental effort is reviewed in this Note, whereas the modeling effort is reviewed in a companion article. A great deal of synergism exists between the experimental and computational efforts in terms of validation and analysis.

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