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Aerospace Propulsion Technology—A Fertile Source of Issues in Basic Fluid Mechanics

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It is a defensible proposition that the advance of aerospace propulsion technology underlies the striking improvement in both performance and economy of commercial and military aerospace operations over the past fifty years. It is less well recognized that propulsion, as a result of the innovation that led to these advances, has introduced a large number of new, stimulating areas of inquiry in each of the basic disciplines of engineering science that form the basis of this technology. Of these, I believe that fluid mechanics and materials are the greatest benefactors. Here our interest is in the former and a few examples will clarify fluid mechanics indebtedness to the stimulation of propulsion technology.

Mixing Processes. The laminar or turbulent mixing between two streams of gas is an essential process of most propulsion systems; mixing of fuel injected into a combustor, mixing of core and fan air in a gas turbine and mixing of rocket exhaust with the ambient air are typical examples. These issues have not only provided powerful incentives in the fundamental studies of mixing layers, wakes, and other classical problems, but have stimulated the extension of these investigations to mixing between gases of different densities and to mixing between streams at high relative Mach numbers. Equally important, propulsion challenges have stimulated the investigation of innovative means to accelerate, or more generally to control, mixing processes with low loss.

Chemically Reacting Flows. Before the prominence of combustion problems in gas turbine and rocket motors, combustion research had little presence in the domain of fluid mechanics. The recognition, in the mid 1940's, that gas dynamic processes were dominant, or at least of great importance, in most of the technological combustion processes, revolutionized the studies of combustion and profoundly enriched the field of fluid mechanics.

The chemical reaction between two or more gases requires that these gases be mixed on the molecular scale, inasmuch as molecular interaction is essential to changes in molecular structure that constitute the combustion process. In many cases of technological interest, the diffusion processes leading to molecular mixing, rather than the chemical reaction rates, controlled by progress of combustion. As a consequence, the investigation of exothermic reactions in boundary layer-like regions became a "classical" problem in fluid mechanics. As usual, turbulent flows presented its unique difficulties. In gases the molecular mixing occurs only in the small wave-length of the spectrum where viscosity is dominant and hence the diffusion processes necessary for combustion are active. This feature has provided novel incentives for turbulence research and powerful challenges in the development of rational turbulence models and their computational implementation.

Aerodynamic Noise. It is fair to say that the technological issue of noise generated by propulsion systems transformed acoustics research from the comfortable realm of architectural acoustics into an exciting branch of contemporary fluid dynamics. Jet noise, fan and propeller noise, noise associated with the motion of nonuniform gases, each drew upon skills acquired in the disciplines of compressible flow and thereby immensely enriched fluid mechanics. The basic mechanisms and descriptions of turbulence generated noise, noise from rotating blade row interference, and combustion generated noise and other propulsion sources occupy important places in the spectrum of gas dynamic research.

Instrumentation and Computation. Immense advances in computational power and techniques and equally striking innovation in optical and non-invasive instrumentation have added new dimensions to research in fluid mechanics. To a considerable extent, propulsion technology is responsible for the urgency of non-invasive measurements and for setting the most exacting goals for computational fluid dynamics. As CFD and computer capacity continue to develop, we shall be able to cope rationally with flow fields in gas turbine engines—blade wake interaction, unsteady interaction of blade rows, blade tip leakage—for which detailed measurement is out of the question. In fact, without computational exploration we should not even be sure what to measure.

In combustion systems, reliable optical measuring techniques are gradually allowing resolution of questions that for generations were inaccessible due to poor time resolution and probe interference. Of equal importance they encourage experiments of very short time duration—shock tubes, pulsed combustion systems, blowdown turbomachinery experiments—thereby making these fields accessible to the modest budgets we associate with research in fluid mechanics.

Numerous other issues—particulate and droplet laden gases, resolution of nonequilibrium effects in hypersonic flow, ultra-

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rapid mixing for low-NOX combustors—raise issues that are both vital to propulsion technology and stimulating to basic fluid mechanics. A final and most significant general problem should be mentioned: fluid mechanics problems related to active control of propulsion systems. While most current efforts involve the control of stall and surge of compression systems and the control of combustion oscillations, a host of other areas of "Smart Engine" applications are on the horizon. The issue here is that most of these instability problems have a fluid mechanical origin and unless this mechanism is recognized and quantitatively understood, the control of its consequences becomes a more complicated, more energy consuming, and possibly an impossible task.

It is very appropriate for this contribution to appear in the issue commemorating Professor William Sears' 80th birthday because he is one of the researchers who first employed rational fluid mechanical modeling to practical problems in turbomachinery flows and in aeroacoustics.