NASA Contributions to Fluidic Systems

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Theme

THIS Synoptic (taken from Ref. 1) is a state-of-the-art review of fluidics technology. It emphasizes systems applications rather than theory or design. It is directed towards the nonaerospace engineering manager who is unfamiliar with fluidic systems and their potential applicability. The Synoptic draws heavily upon R & D work performed or sponsored by NASA, and therefore serves as a compilation of NASA's fluidics efforts.

Contents

The survey describes how specialized requirements of NASA and others have influenced the evolution of fluidic systems from laboratory curiosities known as fluid amplifiers in 1959 to operational systems employing hundreds of fluidic devices and fluidic integrated circuits. It delineates the contributions emanating from the various NASA Centers and points out that a dynamic and growing fluidics industry has developed which is now independent of government sponsorship. Suggestions are offered on how to apply fluidics to new uses and how firms not presently familiar with fluidics technology may evaluate its applicability and economic worth. Chapters are devoted to how to get started in fluidics and to sources of additional information. Functional characteristics of various fluidic devices are described, digital and proportional systems are compared, and digital circuit design is analyzed. The survey includes a glossary of fluidics terminology and a bibliography of 497 application-oriented references. Some representative examples of NASA sponsored aerospace fluidic systems are discussed briefly in this Synoptic.

Rocket Propulsion. Nuclear rocket engine reactor rod control requirements led to the development by Lewis Research Center of a pneumatic stepping motor with a proportional fluidic control system[2] featuring two of the earliest fluidic integrated circuits.[3] Related nuclear rocket engine studies centered about the use of fluidic servovalves[4] employing a combination of jet-interaction and vortex devices.[5]

Vortex devices have been developed for a wide variety of rocket applications. Aerojet Nuclear Systems Co., under joint NASA-AEC sponsorship, developed several vortex valves to control turbine inlet conditions for the NERVA engine.[6] Bendix Research Labs. has provided the following vortex fluidic hardware: 1) Vortex valves to control solid rocket exhaust gas at 5500°F for Langley Research Center[7]; 2) Hot gas vortex valves for secondary injection thrust vector control for Lewis Research Center[8]; and 3) Vortex servovalves used by Marshall Space Flight Center to demonstrate the feasibility of performing push-pull control of a hydraulic servoactuator in tests on a Saturn SI-B gimbal actuator.[9]

Sounding Rockets. A fluidic proportional thruster was conceived at Ames Research Center for attitude control of Aerobee-type sounding rockets.[10] General Electric subsequently developed this fluidic proportional thruster,[11] which has proven to be very accurate and which eliminates the characteristic "limit cycle" of the conventional "bang-bang" attitude control system (ACS). This same fluidic proportional thruster has been applied at Ames to an emergency ACS for vertical or short takeoff and landing (V/STOL) aircraft.

Spacecraft. A major study of design criteria and fluidic systems applicability to spacecraft propulsion requirements was performed by TRW Systems as part of the Advanced Valve Technology for Spacecraft Engines program for JPL.[12] Manned Spacecraft Center has sponsored development by Honeywell of a fluidic temperature control system for space suit cooling,[13,14] and has sponsored the feasibility demonstration by Whirlpool of a fluidic clothes washing machine for operation in a zero-g environment.[15]

Aircraft. Early NASA efforts to apply fluidics to aircraft flight control saw Flight Research Center (FRC) contract with Honeywell Inc. to design and build a three-axis fluidic autopilot to provide wing-leveling, heading hold, and altitude hold capabilities.[16] Some 30 test flights at FRC demonstrated the feasibility and reliability of this system, as well as the high-power consumption of nonminiaturized fluidic systems. More recently, Langley Research Center has been studying light aircraft stability augmentation employing a Langley-developed cast plastic vortex rate sensor and cast plastic fluid amplifiers.[17] A significant result of this effort has been the development of a laminar-flow proportional fluid amplifier with a very high signal-to-noise ratio. In addition to the fluidic proportional thruster application to V/STOL aircraft, other V/STOL stability control programs at Ames have experimented with fluidic devices such as tristable flip-flops and very large diverter valves for attitude and thrust control.

Instrumentation and Test Equipment. Lewis Research Center built and tested a fluidic system for making a digital comparison of a series of static wall pressure tap readings in supersonic jet engine inlets, as part of a program to develop a reliable shock wave position sensor.[18] Flight Research Center incorporated principles of a fluidic temperature sensor initially developed by U.S. Army's Harry Diamond Labs. and Honeywell to record the very high temperatures experienced from aerodynamic heating of the X-15 research airplane.[19,20] A fluidic temperature sensing system mounted in the upper vertical fin of the X-15-2 airplane recorded total temperatures in excess of 3000°R when the plane was flown at a Mach number of 6.7.

At the other end of the speed range, requirements for accurately measuring the very low airspeeds of V/STOL aircraft in certain flight modes led to the development of a fluidic wind sensor.[21,22] Electronic Research Center (now disestablished) contracted with Bowles Fluidics Corp. to develop the initial fluidic wind sensor. This sensor has proven

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so promising that Langley Research Center has sponsored additional development, and other agencies have evaluated its applicability to such diverse areas as meteorology, air and water pollution control monitoring, and mine safety.

Lewis Research Center investigators have made both molecular weight and humidity sensors for monitoring gases or vapors based on fluidic oscillators.[23,24] Lewis researchers have also applied fluidic systems to driving a wide variety of cardiac assist pumps and artificial hearts.[25] General Electric has developed fluidic accelerometers for gyro applications for Marshall Space Flight Center.[26] Electronic Research Center contracted with Martin Marietta Corp. to develop no-moving-part visual displays, resulting in the feasibility demonstration of both fluidic-thermochromic and plasma-fluidic display systems.[27,28]

Basic Fluidics Technology. The survey delineates over a dozen specific contributions to the technology including designs for new fluidic devices, scaling studies, and improved manufacturing techniques. The standardization work performed by General Electric between 1962 and 1967 for Marshall Space Flight Center probably will have more prolonged effect upon fluidic technology than any other single NASA-sponsored effort. The graphic symbols set forth in the Fluid Amplifier Manual[29] in 1964 have survived review by many agencies and committees and may be recognized in many subsequent fluidics references.[30–34]

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