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# FLUIDIC TECHNOLOGY AND SOME RECENT APPLICATIONS TO SPACE AND OCEANOGRAPHY

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## INTRODUCTION

This paper is presented to show the degree of advancements that fluidic technology is making in various technical disciplines. Examples are used and discussed based on the many programs sponsored by the government. The references used here represent only a small percent of the total. Individuals with specific interests or applications can expand the reference list on the choosen subject to take advantage of the considerable amount of advanced research and development already completed.

## TECHNICAL ACTIVITIES

The basis for what is now known as fluidics was established, as is well known, at the Army's Harry Diamond Laboratories ten years ago. Since that time, the government agencies have provided an important impetus for the development of the new technology.

A study of 220 contracts reveals that the Air Force has been responsible for an estimated 7 million dollars worth of contracts, although they have let only half as many contracts as the Army. Table I provides a synopsis of the study. It is estimated that this list of contracts is about 90% complete. The dollar value of these contracts, however, is based on only 49% "firm" monetary figures as reported in the Commerce Business Daily, trade journals, or other sources; 51% of the values have simply been estimated on the basis of the work involved, etc.

TABLE 1

| | Number of Contracts | Estimated Total Value | Average Contract Value |
|---|---|---|---|
| Air Force | 38 | $ 7.0 Million | $ 184K |
| Army | 78 | 4.3 | 55K |
| NASA | 45 | 4.2 | 94K |
| Navy | 55 | 4.8 | 87K |
| Post Office | 2 | .5 | 250K |
| AEC | 2 | .2 | 100K |
| | 220 | $21.0 | $ 95K |

Table 2 is a list of the four most active centers for the major departments. The list is, of course, only a partial one since 35 centers have been identified as having let contracts for the research and development of fluidic components or systems.

TABLE 2 ACTIVE GOVERNMENT AGENCIES

| | |
|---|---|
| **Air Force** | |
| Flight Dynamics Laboratory | Wright-Patterson AFB, Ohio |
| Aero Propulsion Laboratory | Wright-Patterson AFB, Ohio |
| Avionics Laboratory | Wright-Patterson AFB, Ohio |
| Weapons Laboratory | Kirkland AFB, New Mexico |
| **Army** | |
| Army Missile Command | Huntsville, Alabama |
| Harry Diamond Laboratories | Washington, D. C. |
| Aviation Labs | Ft. Eustis, Va. |
| Picatinny Arsenal | Dover, N. J. |
| **NASA** | |
| Marshall Space Flight Center | Huntsville, Alabama |
| Lewis Research Center | Cleveland, Ohio |
| Langley Research Center | Hanmpton, Va. |
| Electronic Research Center | Boston, Mass. |
| **Navy** | |
| Naval Air Systems Command | Washington, D. C. |
| Naval Air Development Command | Johnsville, Pa. |
| Naval Ships Systems Command | Washington, D. C. |
| Naval Weapons Center | China Lake, Calif. |

The 220 contracts that have been referenced have been broken down into seven technology areas as follows:

1. Fluid Flow Studies
2. Elements and Circuits
3. Inertial Sensors
4. Actuators
5. System Studies
6. Interface Devices
7. Testing

Figure 1 presents the results of the classification. Some of the contracts were difficult to identify as being specifically related to one grouping and were, therefore, not included in the figure. In addition, several contracts have been let to study the applicability of fluidics to specific areas such as missile systems, ship board equipment, and manufacturing processes; as a result, these contracts were not considered to contribute to a specific identifiable area of the technology but rather to the general advancement of the art.

When the same data are examined in relation to the application that was, presumably, anticipated at the time of signing the contract, one finds that over forty percent of the funding has been directed towards missile systems and jet engine control. Figure 2 presents the results. Miscellaneous research accounts for about one dollar in eight; this research is typified by studies of vortex flow, wall attachment, the effect of acoustic environments on flueric elements and the like. The category "Specccial Subsystems" includes such things as acoustic generators, binary counters, etc.

These contracts have resulted in some dramatic improvements in a few cases but, even more important, a steady rate of progress in almost all areas is apparent. In fact, it seems that the general acceptance of the technology, or lack of acceptance, as indicated by articles in the trade journals, for example, did not necessarily reflect the results of the work being performed in the laboratories. Instead, the technology has been characterized by promises and claims which could not be redeemed when the time came, but which were fulfilled, paradoxically, only after many of the users were disgusted. This has resulted in a popularity index, if such a term can be used, which has been up one year and down the next.

A market survey can be made with a high degree of confidence on government funded programs whereas a survey of the participation of industry in the support of the technology is more difficult. Various estimates have placed the industry supported research and development in the neighborhood of eighty to one hundred million dollars or four to five times the level of the government funding available.

An appraisal of the state to which this funding has advanced the art is presented in Figure 3 which attempts to show the status of the technology in several areas of application. Naturally, certain projects under a given area of applications will have progressed beyond other projects in that same area, but the overall generalizations implied by the chart can still be reasonably drawn.

A list of references has been developed which illustrate specific examples of the state of the art. The list has been divided into six categories that are compatible with the six classifications evaluated in Figure 3. For the most part, government contract reports are used as references because they are factual and are easily obtained through the Government Printing Office. It must be emphasized that the references and selected applications represent a small percentage of the total development and documentation which is available. Some examples from each application area will be discussed.

## ENGINE CONTROL (INCLUSIVE)

A discussion on engine controls, capable of being mechanized with fluidic circuits, if treated completely would make up a considerable report in itself. In general, controls have been developed and delivered, or nearing delivery, for most types of engines and power systems. This classification, for example, includes steam turbine (including governors), boilers, draft blower start-up, jet engines, and ramjet engines.

The extent to which some of the programs have been carried may be seen in the two referenced examples. (A-1 and A-2 of the Reference Section). Both programs, to develop a jet engine control system, were conducted by Honeywell, Inc., for the Air Force. Figure 4 is a photograph of the test engine showing some of the fluidic components. The second document (Reference A-2) is classified Confidential, however, certain unclassified conclusions may be discussed. The system consisted of an inlet control system, an engine control system, and an exhaust nozzle control system; steady state control was based on turbine speed and acceleration control was based on control of turbine inlet temperature. It was concluded that:

1. The fluidic system provided improved control over conventional systems.

2. Fluidic temperature sensors were superior in response and ruggedness.

3. No system response problems were encountered.

4. Compressor discharge pressure could be used for supply gas and contamination requirements presented no problem.

A description of work done by the Marquardt Corporation for the Air Force on a fluidic fuel control system for an advanced ramjet engine is also available (References A-3 and A-4). The system was demonstrated in 1967. The system maintained the desired fuel/air ratio over a wide range of air flow conditions. Some difficulties were experienced with the interfacing fuel valve which was an off-the-shelf spool valve; recommendations were made identifying the interface as the critical component.

A report entitled, "Study of the Feasibility of applying Fluid Controls to Turbine Generator Sets" was written in 1963 by W. A. Boothe of G.E. under contract to the Office of Naval Research (Reference A-5). Analog, digital, and hybrid techniques were considered for the mechanization of a steam turbine control system with fluidic components. A tuning fork or other stable mechanical frequency standard was recommended with analog stability compensation. Steam or water was proposed as the working fluid. Today, seven years later, an off-the-shelf fluidic speed control package is available from General Electric.

The results of another Navy program conducted by Bowles Engineering Company are described in detail (Reference A-6). A workable continuous process controller, using fluidic elements, was the general result of the program. The goals of this original program are being pursued under a separate contract with Bowles; this effort is to result in a production engineered controller for Naval Ships. A thorough testing and evaluation program is planned with the results available sometime in 1971.

In addition to the development programs referenced, a considerable amount of work has been performed on reciprocating engines, i.e., carburation, vacuum advance, etc. These last programs were performed, generally by industry and the reports are covered in most cases by the trade magazines.

## AUTOMATIC AND NUMERICAL CONTROL OF MACHINES AND PROCESSES

The area in which fluidics has been most successfully employed is in the control of machines and processes. Sunstrand, Brown and Sharpe, and Link Engineering Company (References B-1, B-2, and B-3) among many others are successfully using fluidics on their equipment. Direct analogies can be drawn between many automatic or numerical controlled functions and functions performed in tests and operations support for both space and oceanography programs such that the development that has been accomplished on machine and process controls are applicable to space and oceanography work.

At this time, there are approximately twenty machine manufacturers who are marketing equipment using fluidic controls or who at least offer this mode to their customers. In most cases, it will be found that the fluidic system offers at least one of the following advantages to the process or machine:

1. No danger of sparks in a hazardous area.
2. Superior operation in shock or vibration fields.
3. Sensing position without contact.
4. Increase operating speed of machine.
5. Convenience of compressed air.
6. Simplify and/or reduce maintenance.
7. Protect against second source encroachment.

In addition, almost all of the manufacturers have found that fluidics offered a cost savings in spite of what has been occasionally written to the contrary (Reference B-4).

Mr. J. H. Walker of Bendix has recently discussed the application of fluidics to automated inspection devices (Reference B-5). This is a particularly attractive application since the techniques of air gaging are well known and the ability to handle and manipulate the data while they are still in a fluid mode is desirable.

One of the prime reasons that the technology has been used so extensively in recent years (rather than earlier) has not been the fact that the fluidic components have finally improved but, rather, that the necessary ancillary and interface devices have become available. These are, for the most part, simple devices such as variable linear fluid resistors, fluidic indicators ("lights"), or diaphragm operated microswitches.

## EXTRAPOLATIVE GUIDANCE SYSTEMS

Four different extrapolative guidance systems using fluidic technology have been developed; several have been flown on instrumented missiles. The first system which was successfully flown was a roll-rate-stabilized Test Instrumentation Missile (TIM) using reaction jets located in the forward section of the missile. Some problems were encountered on the first flight with the interaction forces generated by the forward reaction jets being coupled to the fins at high missile velocities thus reducing control effectiveness. Moving the jets aft of the fins would solve this problem. However, the program demonstrated the feasibility of using pure-fluid systems to control missiles. The development and flight tests of this system have been well documented (Reference C-1, C-2). Figure 5 shows the forward section of this system and includes all but the power source, i.e., rate sensor, amplifiers, and reaction jets. One of the advanced roll-rate-stabilized systems (Reference C-3) is discussed and records most of the advancements made at that point in the program. The mechanization used on the advanced systems is shown in Figure 6.

Several other fluidic missile control systems were built, all using directional control incorporating integrated rate or a directional gyro sensor. A detailed study of the integrated rate technique (Reference C-4) is presented and predicts a high degree of practicability which has not been demonstrated yet. The system shown in Figure 7 was not flight tested, but passed simulated tests. Three unique systems, each an improvement over its predecessor have been flight tested. These systems used a gyroscope for the inertial sensor which in turn drove a Pulse Duration Modulation system to generate an unbalanced duty cycle of the reaction jets which would turn the missile causing it to follow the original heading. The flight tests of these systems were performed using Little John missiles for the test bed. All of the tests and the conclusions arrived at are fully documented (References C-5 and C-6). The system capability was proven conclusively and was the impetus responsible for initiating the more complex systems which have been developed since.

Some outstanding work has been performed in advancing the state-of-the-art in inertial components and other flight control problems. One example (Reference C-7), presents the technical discussion of the system analysis, actual subsystem investigations, and breadboard tests for a Re-entry Control System. This report concludes that because of their inherent resistance to high temperature, vibration, and acceleration affects, fluid flight control systems will provide the necessary long term solutions to flight control problems where these severe conditions are encountered. Some early information on the development of fluidic computers (References C-8 and C-9) is for the most part obsolete when compared with the present capabilities. The released reports are running 2-5 years behind the capabilities; one reason is that so much of the work is proprietary.

Time and again, an investigator has made a statement to the effect that this or that cannot be done with fluidics only to have someone else show the way with a new invention or a clever twist in applying the old. This has been particularly true in the area of fluidic systems for guiding missiles. As evidence of this, a short news release, recently, told of a fluidic guided, rocket assisted mortar shell having been flown.

## PERCEPTIVE GUIDANCE SYSTEMS

For the purpose of this paper, the distinction between extrapolative and perceptive guidance is that the later can make mid-course corrections based on target information received after launch from an on board sensor or a command link. Since the previous paragraphs established the capability of fluidics to perform the guidance and control functions associated with an object in flight, this section is concerned with interfacing with the external information. For particular applications, the foregoing statement may be downgraded to an assumption, but it is still well founded. Understandably, fluidic techniques cannot be used for the transmission of information over long, separated distances in a command system so an electronic transmission of information is necessary. This intelligence is then transduced from electrical to the fluidic mode and fed into the remaining system. Transducing mechanical information into some form of electrical intelligence is a familiar problem, but the reverse procedure is considerably more difficult, especially when fast response and small thresholds are desired. Another consideration, which cannot be ignored, is the amount and type of electrical power required.

For the purposes of evaluating the state of development in this category, it can safely be assumed that the fluidic portion of the system has been developed and is satisfactory. The one item requiring development is the electrical to fluidic interface. Four electrical to fluidic interface programs have been selected as representative of the work which has been done in this field.

Two of the programs (Reference D-1 and D-2) discuss magnetostrictive devices and the development pursued along these lines. In addition, Reference D-1 discusses a piezoelectric device which was also studied. In both of these programs, the objectives were set so that the component would be suitable for typical weapon systems application in aircraft, missiles, ships, and torpedoes. The devices met all of the imposed objectives and in most cases showed an improvement over the guidelines which had been established. Both devices have output scale factors of sufficient magnitude to interface directly with typical fluidic systems and are acceleration compensated. Low threshold values were obtained from both transducers (less than one percent of full scale) while their hysteresis, linearity, noise, and drift parameters are all less than three percent. The response time (45° phase lag) is less than .006 seconds for the magnetostrictive device and less than .003 seconds for the piezoelectric device. The studies concluded that all of the characteristic parameters could be improved with certain physical and geometric changes. Power requirements for both devices are very low because the piezoelectric elements are basically simple capacitors having very low leakage currents and the magnetostrictive power can be controlled by the number of turns on the input coil.

Two different type devices were also investigated (Reference D-3). One of these was a device which used electric heating wires to heat capillary tubes, thereby varying the flow for a given pressure. Another concept used moving pills; three pill configurations were fabricated from core material which was electromagnetically driven. Some work was also done at Case Institute in which the separation point of a gas jet from a curved wall was modulated by varying the wall temperature. Of all the devices tested, to date, the magnetostrictive technique shows the most promise and, therefore, least development effort required.

The program which was performed and reported on (Reference D-4) was a thorough study based on current fluidic technology as of 1969. The study synthesized a perceptive guidance and control system using a Sparrow III missile as the test bed. Torque motors (magnetostrictive devices) interfaced with electrical command signals to produce a fluidic output which was used as the input to a fluidic autopilot. The autopilot contained two identical loops, the pitch/yaw loop, and a third roll rate loop. All components in the autopilot were laminar flow fluidic devices except the servo valve which converts the pressure signal to an actuator slew rate. The total system weight, including the actuating gas and reservoir would be about 12.5 pounds and can be packaged in an envelop no larger than the conventional electronic system requires.

The general conclusions which were drawn from this study are that fluidic and flueric technology has progressed sufficiently to permit design and implementation of sophisticated control systems for airborne applications using fluidics and fluerics. There is, however, a need for further component development and refinements of existing hardware and control loops. The primary conclusion made as a result of this study is the fact that an autopilot for a Sparrow III type vehicle can be implemented fluidically and be competitive with existing electronic autopilots.

Several development programs have been conducted which proves the capability of using fluidic circuitry for machanizing an attitude control system for a solar probe spacecraft. The two environments, which nearly precludes the use of conventional electronic systems are the ambient temperature and radiation level encountered during the mission. A Phase I engineering report (Reference D-5) predicts that such a system is both feasible and very promising with no fundamental "holes." This report first describes the solar probe mission and vehicle (NASA configuration) then the attitude control system which was investigated during the study, the implementation using fluidic components and a discussion of system performances including reliability under solar environments. At the time of the study, additional development was required in the following areas in decreasing severity:

1. Power supplies, closed cycle.

2. Solar sensor.

3. Inertial sensors.

4. Electrical to fluidic/fluidic to electrical transducers.

As of this date the closed cycle power supply, if required, is the only item which would need development.

Four or five years continued research and development have perfected some of the referenced devices. For example, a solar sensor (Reference D-6) has been developed with characteristics several times better than the devices used in the previous study. The older sensors, one using two bolometers acting like variable resistors in the control ports of a fluidic element, the other using heat sensitive bimetals to move a flexible flapper to control a fluidic element were slow in operation or had high power requirements. The latest device, which is shown in Figure 8, makes it possible to design an attitude control system for spacecraft and missiles with both attitude rate and position feedback using fluidic devices only and avoiding interfaces with electro-optical devices that would otherwise be required. These sensors include a solar-radiation detector, any optical magnification and/or shading, and any fluidic amplification that may be needed. When the detector points directly at the sun, the solar image is centered in the detector face. The detector is divided into two identical halves with uniform radiation across the entire plane so that the filaments are heated to approximately the same temperature. Cold gas from a common manifold flows through dropping resistors which are sized to insure sonic flow into each chamber under all conditions. If the radiation is uniform the chamber pressures are nulled producing zero delta pressure output, with a change in sun angle, one chamber is heated further and the opposite chamber is cooled which produces a differential pressure output. With proper loading and using a high-gain fluidic amplifier, gains of 4 PSID/° sun angle have been achieved. Some noise is present but rigorous testing to determine the magnitude has not been completed.

## VEHICLE MANEUVERING AND STABILITY

This section covers the ability of fluidic technology to perform control functions other than those discussed in guidance and control during the two previous sections. Stability augmentation problems have been solved for helicopter and ship applications, maneuvering of ships has become possible with off-the-shelf hardware, and augmentation systems for aircraft have been developed to a high degree of reliability.

One of the first augmentation systems for use on aircraft (Reference E-1) is discussed and covers the development and flight tests of a system on an Aero Commander 680 FP. The long range plan was to develop a flight control system providing full time augmentation and pilot relief. If the pilot releases control, the system would return the aircraft to wings level and, if selected, altitude hold. Some problems existed with the later feature due to ambient conditions above certain altitudes. Figure 9 is a plan view of this system. This program demonstrated that a fluidic flight control system for light aircraft is possible. System performance is as good, in most cases, as similar conventional systems; in some cases, it was better. Excellent system reliability was demonstrated. In spite of the breadboard nature of the system, no failure has been experienced since flying started. Significant development and operational experience with fluidic systems was obtained. The operational system now serves both as a demonstrator and as a test bed for future work. A continuing program is being conducted to optimize system performance, particularly with respect to the altitude hold mode, and to refine the breadboard hardware.

A similar study (Reference E-2) has considered some of the additional problems associated with more advanced techniques but did not include flight tests and was done one year earlier. This study was performed for a V/STOL type aircraft.

A third example of a fluidic flight control system was investigated (Reference E-3). The design goal was to increase the yaw axis damping ratio of the UH-1B helicopter from 0.30 unaugmented to 0.60 augmented. The control problem was analyzed, component hardware designed, fabricated, and bench tested. The program objectives were accomplished and the system is feasible for helicopter control system mechanization. The operational mode consists of using fluidic sensing, amplification and signal shaping techniques to mechanize a single-axis, rate feedback damper system. Feasibility was demonstrated by performing closed-loop system bench tests, with an analog computer simulating a UH-1B helicopter. Additional development is required to reduce the temperature null drift which occurs between cold start and final operating temperature of the hydraulic system. One note of interest is that the performance of hydraulic fluidic systems, using hardware of the same type as used in this program, can be predicted in advance of fabrication with reasonable correlation between performance and predicted performance.

The most conclusive and best documented study (Reference E-4) on helicopter augmentation systems using fluidics had only one item they considered needing additional development. After many hours of flight testing the Chinook helicopter, under all conditions, the only adverse comment about the system was the lack of visual displays for critical parameters in the pilots compartment. The system was designed so that the pilot retained his feel of the controls when flying hands-on and furnish stable hold characteristics when released. Packaging of the system was somewhat bulky, but the flight item had some breadboarded components which are being refined.

So far in this section, we have discussed aircraft controls, but a considerable amount of work has been done on stabilizing and maneuvering ships. Two good documents (References E-5 and E-6) cover the hydrofoil and fin control systems using a fluidic mechanization. A typical test on the hydrofoil is shown in Figure 10 and this particular system proved to be quite feasible in terms of realistic components and low power consumption. Lift is controlled by this system through controlling the dynamic angular relationship of a pivoted foil with respect to flow incidence angle, with foil actuation effected by means of one or more fluid operated pistons. This type of system may be used to control the center section of the PC(H) foil assembly with a power consumption of approximately 0.4% of the available power plant output. This pivoted hydrofoil under control of a fluid type lift sensor, computer circuit and foil actuator, was subjected to wave motion simulating that encountered by full scale hydrofoil craft. Performance of the system during dynamic testing followed closely that predicted by design theory. Acceleration force was reduced by as much as 65% with the possibility of greater attenuation indicated.

The object of the fin control study (Reference E-6) was to provide a system which will minimize ship roll in both moderate and heavy seas, and require no more maintenance than that required by conventional bilge keels. This fluidic system used four fixed fins which are standard NACA air foil profiles, modified by the addition of span wise ventilation notches containing air ports arranged to distribute air to the upper or lower surfaces of the foil. Location of the fins are shown in Figure 11. Considering the nonventilated as a standard for lift force, then ventilation of the lower surface will increase lift, while ventilation of the upper surface will decrease lift. The four fins are commanded independently by a fluidic circuit. Inputs to this control circuit are roll rate as monitored by fluidic roll rate sensors and roll angle which is monitored by a roll angle sensor. The stabilization system appears extremely promising (and much more reliable than movable fins) which requires no delicate equipment.

A unique application of the fluidic technology is shown in Figures 12, 13, and 14. The manufacturer of this device, known on the market as a bow thruster, has off-the-shelf units for most applications. They have developed a fluidic component for use on large vessels which permits positive control of the bow for maneuvering. Many of the on-board ship systems could, or do, incorporate the fluidic control systems discussed earlier in this paper, i.e., propulsion systems, augmentation, autopilot, etc.

## SAFING, ARMING, AND FUZING

When one considers the stringent requirements placed on those devices relative to reliability, hardness to ECM and environment sensitivity, the solution almost dictates the use of fluidic techniques for a wide spectrum of applications. Many tests have been conducted to establish reliability characteristics in terms of time to first failure, but the data is inconclusive for the most part due to test equipment failures. Components and circuits have been cycled millions of times with no indication of failure, but the sampling lot is not sufficient to establish quantative data for analysis. A bibliography (Reference F-1) was printed in 1967 with 24 programs identified with this subject. All of the reports for these programs indicate very favorable conclusions to the degree that fluidic devices can achieve the necessary system characteristics. The advantages over conventional devices outweighs the disadvantages by several magnitudes.

## CONCLUSIONS

It was the intent of this paper to present certain good reference material available on each of the subjects that would be most interesting. Many subjects have not been covered simply because of the arbitrary selection. Practically every conceivable area of application has had some work accomplished and can often be traced through the Government Printing Office. The easiest way for an interested party to locate reference material is to order a Bibliography Search for any title they desire, from the Department of Defense document center. The bibliography will furnish all the necessary information for obtaining the program reports for specific development programs.

One point that has not been stressed is that fluidic technology can be used for nearly all control, monitoring, sequencing, and signal processing problems with very little development required for specific applications. Most of the hardware required can be purchased off-the-shelf to mechanize all systems with the exception of miniaturized flight guidance and control units which need special development and would be custom integrated units.

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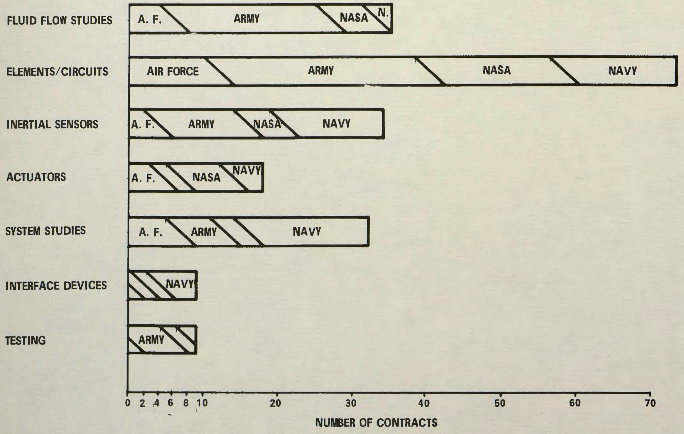
FLUID FLOW STUDIES
A. F.
ARMY
NASA
N.
ELEMENTS/CIRCUITS
AIR FORCE
ARMY
NASA
NAVY
INERTIAL SENSORS
A. F.
ARMY
NASA
NAVY
ACTUATORS
A. F.
NASA
NAVY
SYSTEM STUDIES
A. F.
ARMY
NAVY
INTERFACE DEVICES
NAVY
TESTING
ARMY
0
2
4
6
8
10
20
30
40
50
60
70
NUMBER OF CONTRACTS

Figure 1.

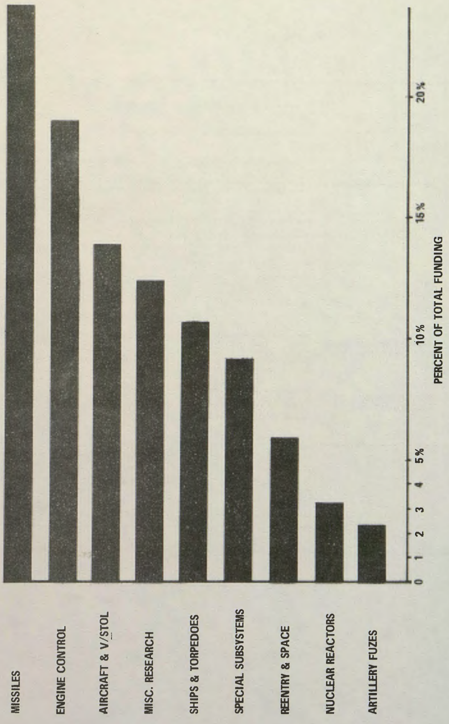
MISSILES
ENGINE CONTROL
AIRCRAFT & V/STOL
MISC. RESEARCH
SHIPS & TORPEDOES
SPECIAL SUBSYSTEMS
REENTRY & SPACE
NUCLEAR REACTORS
ARTILLERY FUZES
0
1
2
3
4
5%
10%
15%
20%
PERCENT OF TOTAL FUNDING

Figure 2.

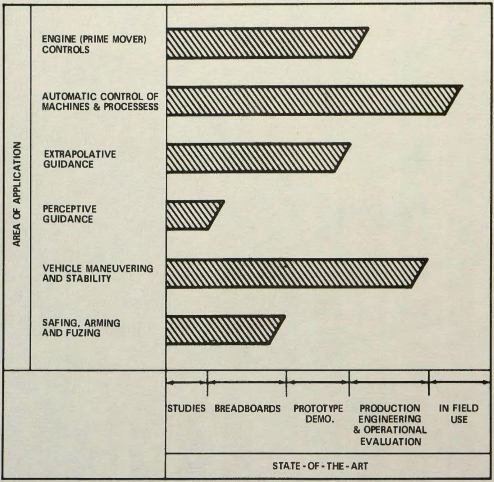
AREA OF APPLICATION
ENGINE (PRIME MOVER) CONTROLS
AUTOMATIC CONTROL OF MACHINES & PROCESSESS
EXTRAPOLATIVE GUIDANCE
PERCEPTIVE GUIDANCE
VEHICLE MANEUVERING AND STABILITY
SAFING, ARMING AND FUZING
STUDIES
BREADBOARDS
PROTOTYPE DEMO.
PRODUCTION ENGINEERING & OPERATIONAL EVALUATION
IN FIELD USE
STATE-OF-THE-ART

Figure 3.

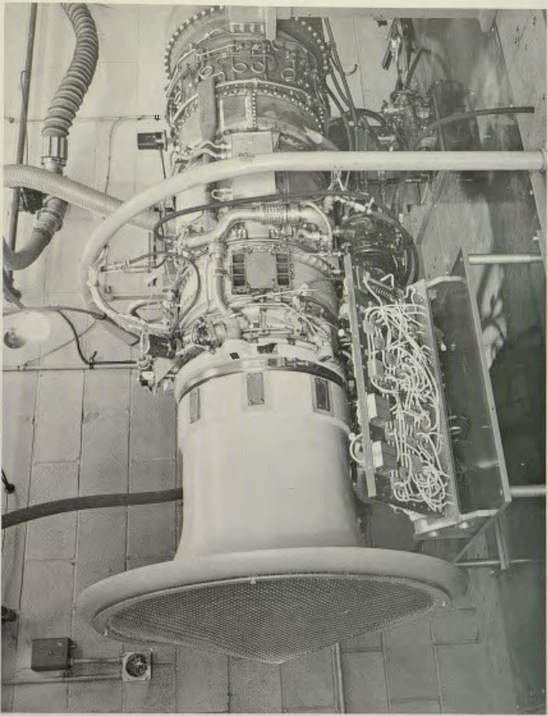

Figure 4.

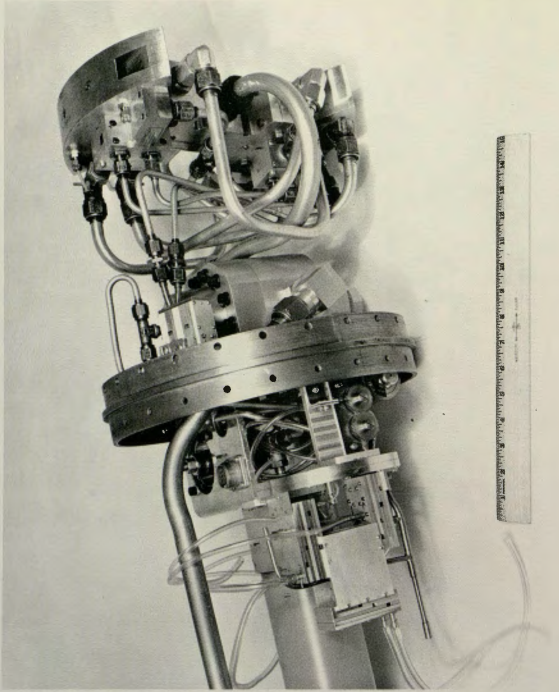

Figure 5.

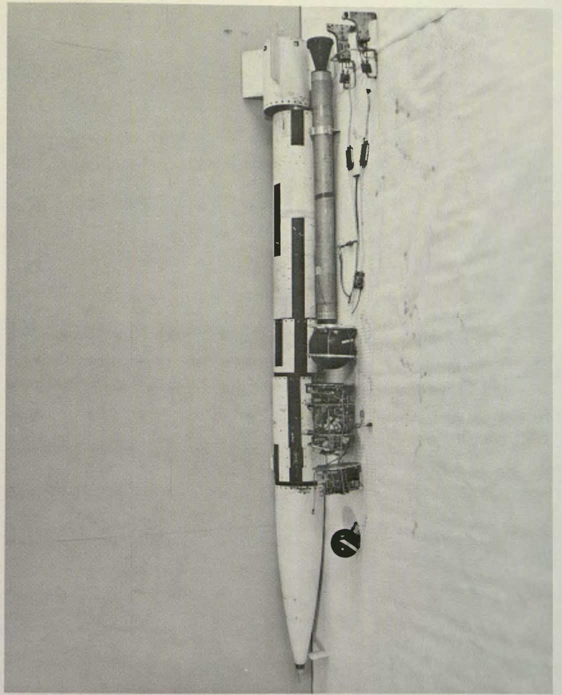

Figure 6.

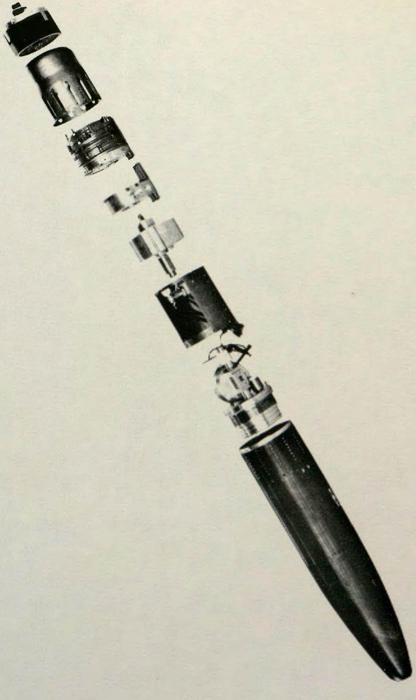

Figure 7.

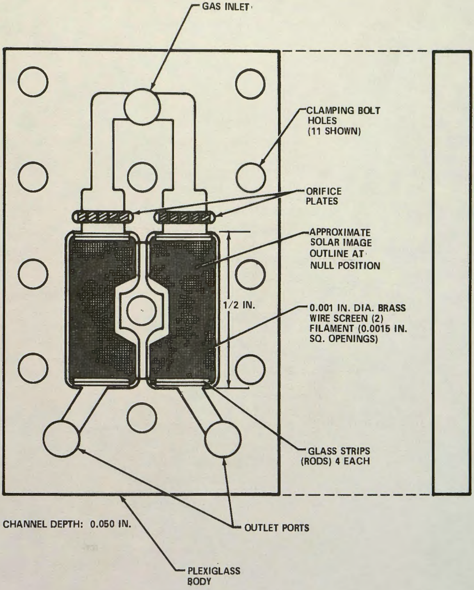
GAS INLET
CLAMPING BOLT HOLES (11 SHOWN)
ORIFICE PLATES
APPROXIMATE SOLAR IMAGE OUTLINE AT NULL POSITION
1/2 IN.
0.001 IN. DIA. BRASS WIRE SCREEN (2) FILAMENT (0.0015 IN. SQ. OPENINGS)
GLASS STRIPS (RODS) 4 EACH
CHANNEL DEPTH: 0.050 IN.
OUTLET PORTS
PLEXIGLASS BODY

Figure 8.

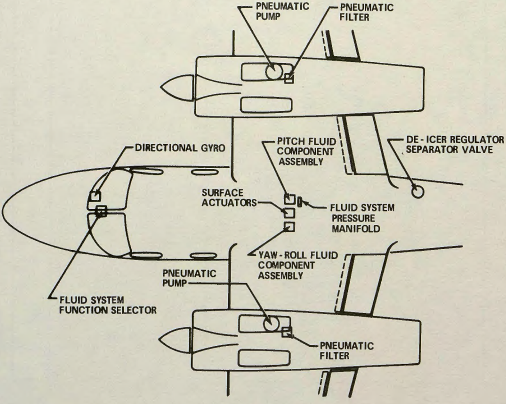
PNEUMATIC PUMP
PNEUMATIC FILTER
DIRECTIONAL GYRO
PITCH FLUID COMPONENT ASSEMBLY
DE-ICER REGULATOR SEPARATOR VALVE
SURFACE ACTUATORS
FLUID SYSTEM PRESSURE MANIFOLD
YAW-ROLL FLUID COMPONENT ASSEMBLY
PNEUMATIC PUMP
FLUID SYSTEM FUNCTION SELECTOR
PNEUMATIC FILTER

Figure 9.

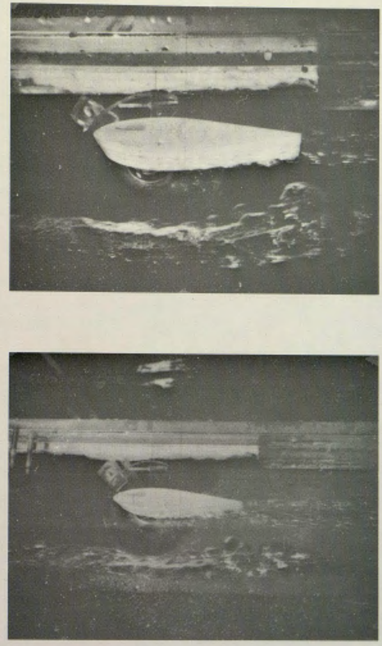

Figure 10.

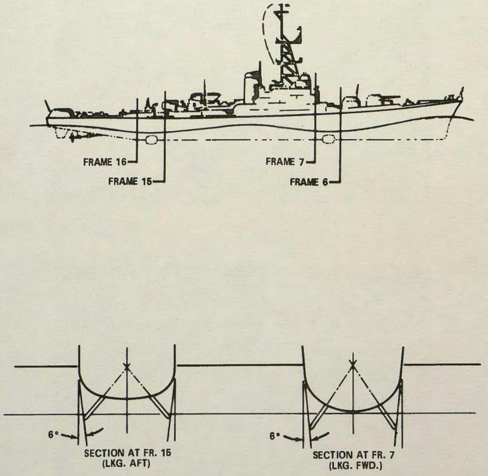
FRAME 16
FRAME 15
FRAME 7
FRAME 6
6°
SECTION AT FR. 15
(LKG. AFT)
6°
SECTION AT FR. 7
(LKG. FWD.)

Figure 11.

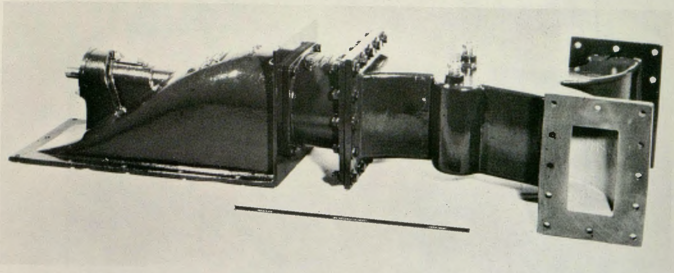

Figure 12.

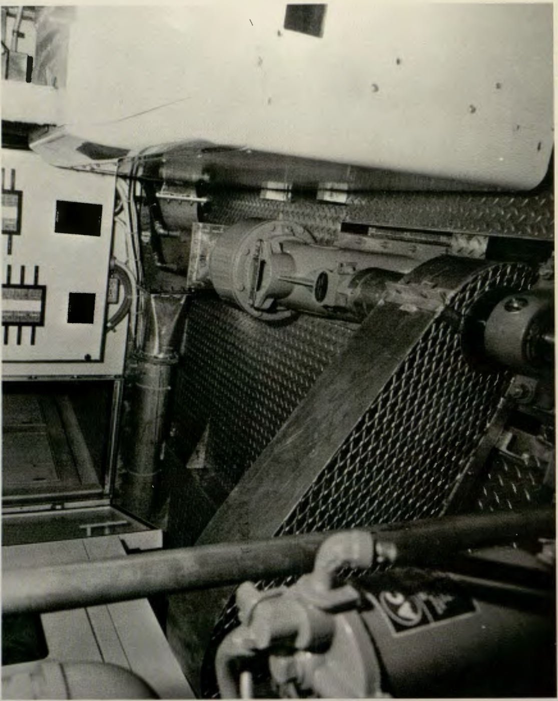

Figure 13.

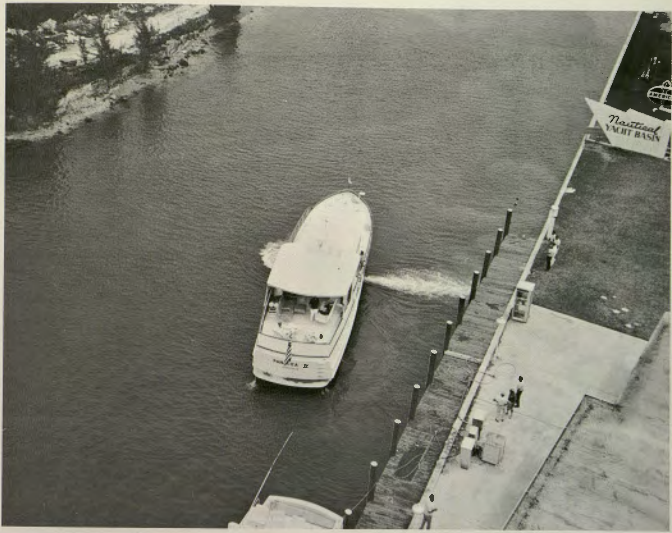

Figure 14.