there is practically no effect on solvent viscosity or turbulent fluctuations.

Conclusion

The main conclusion to be drawn from the previous discussion is that the effect of the polymers in solution is to damp the oscillations or eddies of turbulent flow, and that the size of eddy damped increases with the concentration. This apparently accounts for the choking out of turbulence in tubes at sufficiently high additive concentration. Thus, the additive has the property of a low-pass filter. The concept of a macromolecular fixed thickness per concentration within which velocity oscillations are damped is analogous to the hydraulic roughness of rough surfaces.

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Engineering Notes

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Technological Interrelationships between Aerospace and Hydrospace

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Introduction

CURRENT technological pursuits in aerospace and hydrospace, although conducted in two distinct natural environments, reveal interrelationships with a certain commonality as well as a number of dissimilarities. These interrelationships can provide the engineer and scientist with a test and analytic expediency and sources of valid analogy applicable to either field. In general, both fields require equal technological skill. Unquestionably, there are sufficient similarities between the two fields that acquired knowledge may be utilized to the mutual benefit of personnel working in either aerospace or hydrospace. However, engineers and scientists schooled in one field are cautioned not to rush to the other with visions of providing a panacea for problems encountered by their counterparts there. To support these premises, this Note presents examples drawn from materials behavior, fluid mechanics and heat transfer, and solid body dynamics, all measured within the system context of weight constraint, time constraints, environmental phasing, life, reliability, and human safety. Finally, there is a brief commentary on the chronological development of each field.

Three years ago, Congressman Joseph E. Karth of Minnesota, offered this advice to the aerospace community: "While there are many specific technological areas in which space offers much promise in our assault on the oceans, I believe a note of caution is necessary. Study the field carefully and be patient . . . ."

Although, as the title of this Note suggests, there are possibilities and benefits of a transfer of knowledge from one field to the other, the aerospace field must approach hydrospace cautiously and, above all, with humility.

In viewing these technological interrelationships from a perspective which includes participation in both aerospace and ocean programs, it is difficult to see any broad array of ready-made spinoffs from one field to the other. A transfer of knowledge is possible. Some practical applications have occurred, especially from aerospace to hydrospace. Yet it seems that the most important transfers, and therefore the strongest area for interrelationships, have occurred in two areas, neither of which is purely technological. The cautionary note, therefore, should be: aerospace engineers and scientists should not presume to have off-the-shelf answers for problems confronting their hydrospace counterparts; and hydrospace engineers and scientists must not come to believe that they do.

Certainly aerospace-developed techniques and technologies have paved the way for better understanding and exploitation of the ocean environment. However, lessons learned from aerospace, rather than providing "pat" answers for hydrospace problems, offer the building blocks from which progress can be constructed in the hydrospace field. Therefore, in a very real way, aerospace research and development does offer hydrospace engineers and scientists a "way to go."

Technical Talent Pool

Consider, for instance, that the aerospace program in the United States created a technical talent pool unprecedented in the history of this or any other nation. There is now more technical competence available to attack a broader range of problems than at any time in history. This pool, of course, was not always available.

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When General Electric received the first rocket development contract let by the Army, in November 1944, they began with a handful of people. In those days, many of the questions were not understood, let alone the answers. Today, literally hundreds of thousands of people are involved and contributing to aerospace progress. Equally impressive and important, other thousands of aerospace-trained people are turning their talents to the comparatively new arena of hydrospace. Of course, variances exist in approaches to structural design, materials, fluid mechanics, heat transfer, and other technologies, depending on whether the ultimate application is for aerospace or hydrospace. So, while it is true that specific techniques, technologies, or hardware to solve the problem may not be transferable, still, the people who can develop the knowledge to solve the problem are trained and available.

Systems Approach

In addition to this tremendous talent pool, the aerospace program developed a second benefit which is directly transferable to hydrospace activities. That, of course, is the systems approach and management techniques—an aerospace achievement of the 1950's. Without the systems approach, it is doubtful there would be an aerospace program as it is known today. Similarly, it is doubtful that there can be a meaningful hydrospace program unless or until such an approach is adopted for ocean endeavors.

The systems approach dictates that we begin at the highest identifiable level of the problem and clearly and specifically define what must be done. By establishing objectives and identifying the constraints—money, time, manpower, facilities, and technical limitations—one comes to understand the problem and can then begin to grapple with potential solutions.

The talent pool and the systems approach constitute two significant resources available to hydrospace system planners. However, confronting matters in a historical context, it is clear that the position of the United States today in the field of oceanographic development is similar to our position in guided missile development in the early 1950's, and here, again, some lessons learned from aerospace may be useful. Then, as now with hydrospace, our efforts were fractionated, and a multitude of opinions were gratuitously offered by the experts in various fields.

Technological Focal Point

In the early 1950's, before the Department of Defense decided to pursue the development of the intercontinental ballistic missile, there was considerable uncertainty as to the capability for developing such a missile. Additionally, many people questioned the utility of an ICBM, assuming that one could be developed. Further complicating the situation, three major groups—government, industry, and science—vigorously vied for any and all funds available for guided missile work. In addition, the problem was being investigated by various government agencies, committees, special study groups, and advisory councils. In all of these ways, the situation was much like the one in ocean development today.

In fact, there are only two notable dissimilarities between the situation then and now. First, there was a central, powerful agency, the Department of Defense, with broad authority over defense systems. Second, Congressional and Executive branch responsibility in the field of guided missiles was considerably more concentrated than it is in ocean programs.

The early guided missile program was fractionated and had no agreed upon criteria for decisions. In its own way, it was almost unmanageable. Gaps in scientific understanding contributed to the dilemma. Military doctrine was scarce and disparate. However, because of the concentration of authority and responsibility in the Executive branch and in Congress, it was possible to recognize rather quickly that the problem was unique. The next step was to evolve a unique solution.

The Pentagon decision makers did just that. They let a memorable study contract, the first major weapon system study, to a new and unusual sort of company. The Ramo-Wooldridge Corporation analyzed the problem as a system problem and subsequently designed a system development plan that has stood as a classic in a highly dynamic field.

The plan identified the mission, related that mission to the system elements or subsystems, identified the areas of major technological risk, accounted for all scientific and engineering uncertainties, and defined the extra effort and kinds of assurance required to assuage logical doubts. In addition to satisfying the needs of ICBM program decision makers, the plan also pointed out an interesting opportunity to produce an intermediate-range ballistic missile which, in view of the ICBM development work, could be produced with little additional technical effort or cost.

Just as the problem in the early phases of guided missile development had parallels with the problem of ocean development today, so the solution reached was a kind of prototype for the solution needed now in "wet space." And that solution would appear to be an over-all program—one similar in basic concept, if not in content, to the guided missile program.

The guided missile program, and subsequently the space program, provided a focal point, an objective, and therefore an impetus for relatively rapid and dramatic advances in technological achievement. The ICBM program of the 1950's and the Apollo program of the 1960's caused tremendous resources, intellectual as well as financial, to be brought to bear on a single objective. Unquestionably, this same kind of effort must be applied to the hydrospace field to obtain a meaningful program.

In fact, the Commission on Marine Science, Engineering and Resources, in its report titled "Our Nation and the Sea," puts it even more strongly:

> How fully and wisely the United States uses the sea in the decades ahead will affect profoundly its security, its economy, its ability to meet increasing demands for food and raw materials, its position and influence in the world community, and the quality of the environment in which its people live.

Because the Commission's concern is shared, and because it is believed that technological developments will come only from clearly defined and properly structured programs (again, where there is a significant objective to be attained and where there is a focal point for activity), the General Electric Company, for example, focuses its technical preparation on a major system undertaking.

From Space to the Sea—Project Bottom-Fix

The project called Bottom-Fix is General Electric's focal project for the development of deep ocean system capabilities. The objective is to develop the technologies, systems, subsystems, and hardware required to permit manned occupation of the ocean bottom at depths to 20,000 ft.

In developing this system, it will be necessary to develop capabilities applicable to a wide variety of future deep ocean missions. The initial function of the ocean-bottom station—the modularly configured key structure—will be to serve as a test bed for deep ocean system design, operational methods, and scientific investigations at 12,000–20,000 ft. Because of its modular configuration, the ocean-bottom station permits on-site assembly and variable system volume. Modules can be added, removed, or exchanged as the need arises.

The spherical structural module, jointly developed by General Electric and Corning Glass Works, is a basic building block for the ocean-bottom station. Each module is made up of pentagonal segments of Pyroceram† glass ceramic contained in a lattice of titanium alloy. External shells of fiberglass and titanium provide protection against impact and corrosion. Each module could be from 8 to 12 ft in diameter and has a weight-displacement ratio of 0.5.

The material selection for the spherical structural modules was dictated by the need for a high strength-to-weight ratio to permit maximum payload weight without the use of external buoyancy materials. Pyroceram glass ceramic has a compressive strength on the order of 300,000 psi. Furthermore, Pyroceram and titanium have compatible elastic properties.

Recently, Phase I of the Bottom-Fix project was completed. Tests on $\frac{1}{8}$ scale models proved that the sphere can withstand pressures of 5400 psi, equivalent to an ocean depth of 12,000 ft.

Pyroceram originally was used for re-entry applications because of its high heat resistance. However, further studies revealed that it had high elastic modulus, corrosion resistance, and high strength—qualities which were ideal for ocean applications. In addition, another aerospace material, titanium, combines low weight, relatively high elastic modulus, high strength, and low density. Although the high strength and low density were of prime interest in aerospace applications, these properties, combined with corrosion resistance, make titanium a very desirable material for ocean applications. Studies revealed that in many respects the Pyroceram and titanium matched and complemented each other, and a materials system combining both materials was a key factor in the Bottom-Fix design.

Other aerospace materials are being explored for applicability in ocean technology. Boron composites and graphite composites are prime candidates. We also are considering many ceramic materials, whose primary use in aerospace is based on heat resistance, for potential applications in advanced oceanic structures. Because of their low density, high strength, and corrosion resistance, alumina, fused silica, and boron nitride appear most attractive.

Bottom-Fix, then, illustrates how aerospace technologies can be utilized under the sea. However, the Tektite I program shows how the situation is reversed.

From the Sea to Space—Project Tektite

Tektite I was sponsored jointly by the U.S. Navy, NASA, Department of the Interior, and General Electric, with participation by the U.S. Coast Guard. General Electric, as prime contractor, provided the undersea habitat and assisted in the program planning and scientific mission coordination. This was the first undersea program to be undertaken by a group of federal agencies in cooperation with private industry.

The purpose of Tektite I was to perform a scientific research mission on the ocean floor under saturated living conditions for a long period of time. Four marine scientists from the Department of Interior comprised the Tektite I crew. Their 2-month mission in the Tektite I habitat was conducted at a depth of approximately 50 ft.

Tektite I resulted from a study performed by General Electric for NASA in 1967. That study concluded, in part, that data obtained from a prolonged manned underwater mission would apply to manned space missions. Previous experience in zero-gravity simulation experiments, and with a 30-day manned space cabin test conducted in the environmental chamber, contributed significantly to this study. The common features of comparable crew size, a real rather than a simulated mission, and psychological stresses caused by four men living together in physical isolation from the outside world and doing work in a hostile environment, led to a mission definition for Tektite I that would provide valuable data to NASA.

Tektite I also provided new evaluations of several pieces of equipment designed for the manned space program. In the case of the EEG cap, used to monitor sleep studies, a redesign will be accomplished by NASA as a result of the Tektite I experience.

Conclusion

There are, of course, some areas of specific technology transfer: computers, solid-state electronics and microcircuitry, power generation, heat transfer, and communications are among the most obvious. And while there are dissimilarities in applying some of these technologies, depending on whether your interest is aerospace or hydrospace, there is sufficient commonality in terms of skills and knowledge required to make the prospects for closer relationships real and rewarding.

Benefits emerging from these relationships already are evident. Certainly, more will follow, especially once the hydrospace community succeeds in acquiring a nationally accepted goal. Even in this, the fields share a certain commonality. As with the skeptics in aerospace of a few years ago, many people today feel that probing the sea to depths of several miles involves insurmountable obstacles. These same people however, quickly accepted men flying at 18,000 mph in orbit for periods of several weeks. Yet a hard engineering evaluation of the obstacles in the deep submergence undertakings to date shows them to be no more difficult than those involved in space flight.

† Trademark, Corning Glass Works.