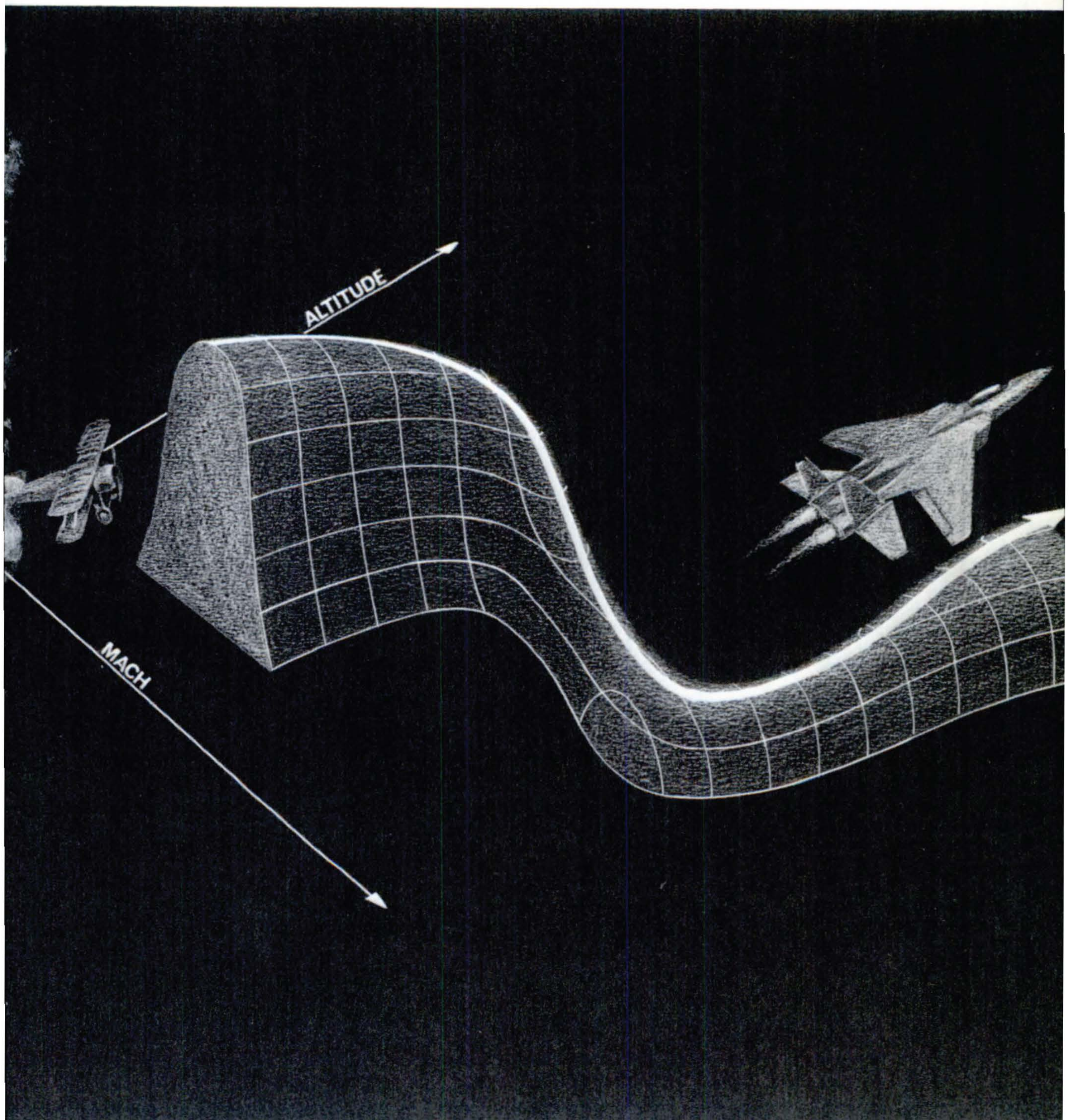
NAVAL RESEARCH

REVIEWS

JUNE 1971



PROFILE IN SCIENCE

Dr. George T. Rado is internationally known for his pioneering achievements in magnetism research, including discoveries of spin wave effects in ferromagnetic resonance, the magneto-electric effect and the origin of magnetic anisotropy in ferrites, and important contributions to electromagnetic propagation in magnetic insulators and metals. Some of these achievements have directly resulted in valuable technological developments of magnetic materials used in microwave and communications devices. Since 1955, Dr. Rado has been Head of the Magnetism Branch at the Naval Research Laboratory. He is also co-editor of the most widely known treatise on magnetism and Secretary of the Magnetism Commission of the International Union of Pure and Applied Physics. Recently Dr. Rado received the Navy Award for Distinguished Achievement in Science.

Aircraft Performance and Energy Management

O. H. Lindquist
Honeywell S&RC
Minneapolis, Minnesota

and

G. Flohil
Office of Naval Research

"Power, stability, control; these were the principal problems confronting all pioneers in the effort to achieve successful flight" (1).

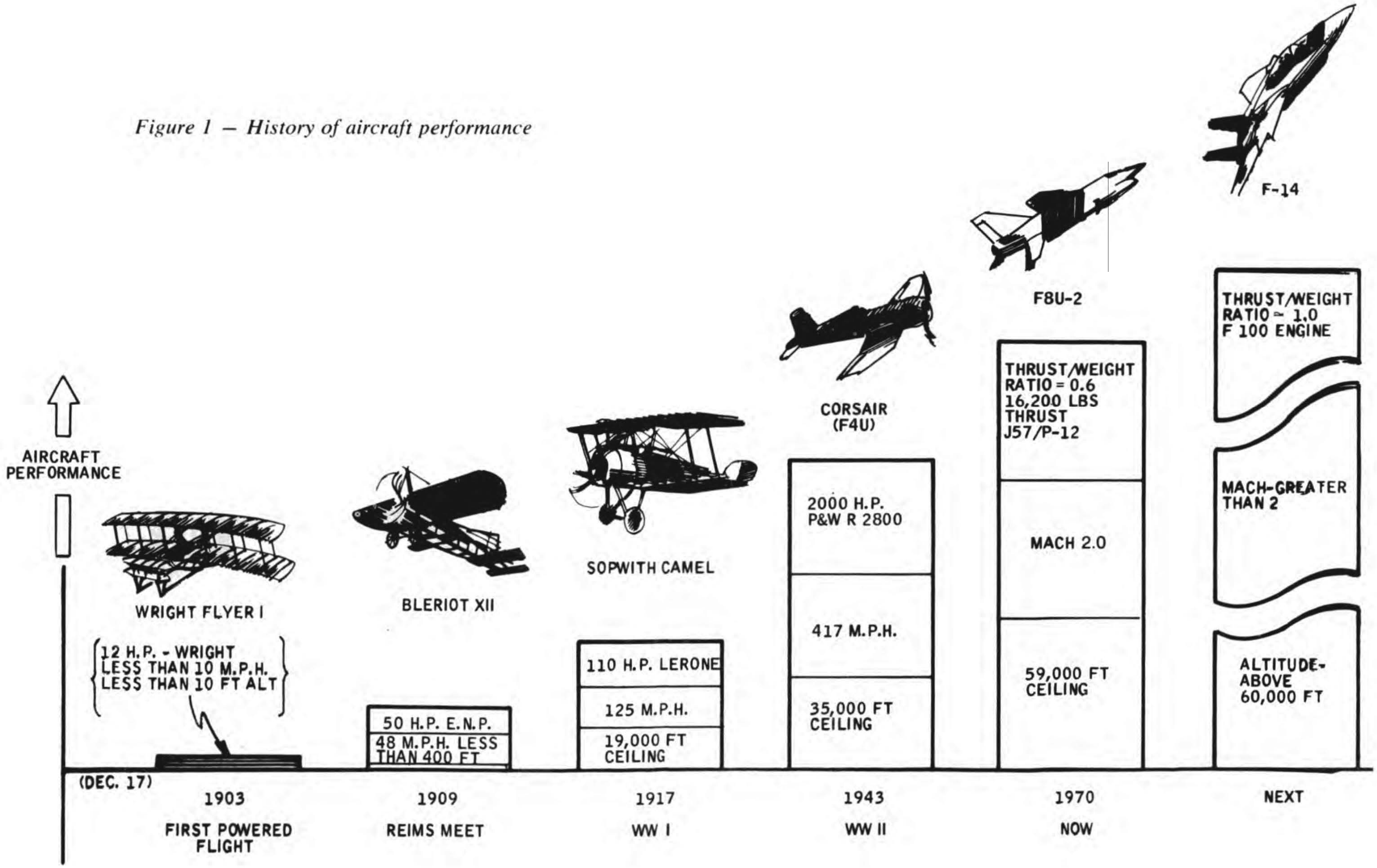
In 1903, 12 horsepower generated in four cylinders propelled "Wright Flyer I" airborne for 12 seconds. The inventor-designer-owner pilot "warped" his wings and moved his rudder to overcome the inherent instability of the vehicle. Six years later, prizes for aircraft performance were awarded for distance, speed, altitude and passenger carrying at the first great air meeting at Reims. The struggle for air superiority had begun, and revolved around two primary issues: aircraft capability and flying technique in the combat environment.

Vehicle Capability

The relative contribution of aircraft performance to air superiority has changed over the years. The first air combat occurred in World War I and caused a technological explosion. The five years following the flights of the unarmed Morane-Saulnier monoplane saw a staggering number of designs, engine retrofits, and other modifications. Spads, Camels, Albatrosses, Bristols, Nieuports (83 model numbers) came in rapid succession.

Figure 1 illustrates this in historical perspective to aircraft development. The Wright Flyer "just" flew. The Reims meet provided proof that the airplane was a practical invention, able to carry payloads for major distances at rapid speeds. The Sopwith Camel was famed for its maneuvering-performance capability and required the enemy to design a superior aircraft. Germany's answer was the Fokker DRI, a "Dreidecker" 3-wing pursuit aircraft specifically designed for maneuverability, not speed. The DRI flew rings around any machine at the front with its "fantastic turning and climbing ability" and took a heavy Allied toll (2).

Figure 1 — History of aircraft performance



The Chance-Vought-designed Corsair of World War II was introduced into Navy and Marine Corps Service in 1942. Former pilots still remember its turn capability as compared to the highly maneuverable Zero's. It was the only plane kept in production after the war and a version with improved engine supercharging was used in Korea. The last version provided surprising capability at high altitudes (service ceiling 42,500 ft) with respect to early jets. The F8U and F4 are today's Navy interceptor aircraft with the F14 representing the next generation.

Although the competition for better aircraft has continued, a change in the nature of the competition has taken place. The primary differences are in the vast aeronautical science and technology available to all nations, and the increased cost and complexity of developing a new aircraft with its associated equipment. As an illustration, the Phantom series widely used today was designed in the 1950s. Long development cycles and enormous funding requirements are typical of today's aircraft. The result is fewer new aircraft with better defined performance capabilities. The likelihood of being able to achieve an aircraft performance which is so markedly superior that the aircraft will permit significant domination of air space is now unlikely, provided that competitive parties both address the issue with their best talent and capabilities.

Flying Technique

The second issue, the use of flying skills and strategy to take advantage of available performance in the combat environment, is a more crucial issue that was envisioned a decade ago and is receiving emphasis in current Navy and Air Force studies.

Two pioneers of aerial combat strategy were Reed Chambers and Eddie Rickenbacker, of the 94th American squadron near Villeneuve, France, who in 1918 spent nights and rainy days discussing combat flying by the hour. They were convinced that in the completely new arena of aerial warfare "they could devise some new strategy, some new technique, that would mean the difference between victory and defeat" (3). Oswald Boelcke, known by some as the father of pursuit aviation, wrote the first manual for fighter pilots. The aircraft of that day were tested and tactics developed on an experimental basis. Instrumentation was meager; the barometric altimeter was a breakthrough. Tactics and procedures were being developed and pilot training began to receive greater attention.

World War II vehicles were well instrumented and top performance was obtained by adherence to procedures and techniques which were formally documented. For example, engines were operated at prescribed manifold pressures and other instrumented measurements. A well-trained pilot was required to obtain the maximum performance available in the aircraft. The complication adding to the pilot's workload was directly related to the expanded capabilities inherent in the aircraft power margin and its flight envelope.

Today's operational pilot has a difficult task if he is to obtain maximum performance from current aircraft. The "simplified" aircraft performance data recommended for typical F4 flight planning requires about 200 pages of highly compressed data. Additional F4 data occupies a shelf on every carrier and other special documentation discusses tactics with respect to competitive aircraft. Operationally, the pilots still apply the massive data relationships by rules-of-thumb and by operational procedures. Some pilots have reputations as expert fuel managers and provide their leadership to the less analytically oriented. Wide variations exist in the capabilities of individuals to obtain the maximum range, climb, and other performance from a given vehicle.

The next generation of aircraft presents a more complex picture with respect to performance capability. The F14 and F15 design capabilities will present a wider range of options and alternates than before. These aircraft of tomorrow are being designed as air-superiority aircraft with special emphasis on maneuverability (4). Major increases in maneuver-flexibility in these aircraft are due to high thrust/weight ratios, increased thrust, lower wing loading and variable wing sweep (F14). The pilot who must manage the increased capability is faced with an expanded repertoire of available tactics and increased complexity in equipment operation. The full employment of this capability by present practice would result in a complex piloting task and thus an increased training program.

The complexity needed to obtain maximum performance has led pilots, engineers and theoreticians to pursue methods of simplifying and understanding the total problems involved. Past experience has shown that alternate techniques can be used in many situations unforeseen when the weapon system was first devised, such as the case when World War II Corsairs were used in MIG alley in Korea.

There always seems to be some flight performance corner, or some distance or position relationship which makes an otherwise inferior aircraft weapon system effective. The hunt continues for that "corner" or for that tactic which provides aircraft performance superior to that of the enemy.

A part of this pursuit is in the area of "energy management" and optimal flight path control. Energy management has been defined as the total available engine/vehicle/fuel energy in accomplishing the space-time requirements of the mission. Such a definition implies that a total view of the control of the aircraft is being considered rather than the establishment of a particular local optimal condition.

A generalized mission segment for a supersonic aircraft is shown in Figure 2. The pilot has his aircraft at R_1 in a state 1 condition at the

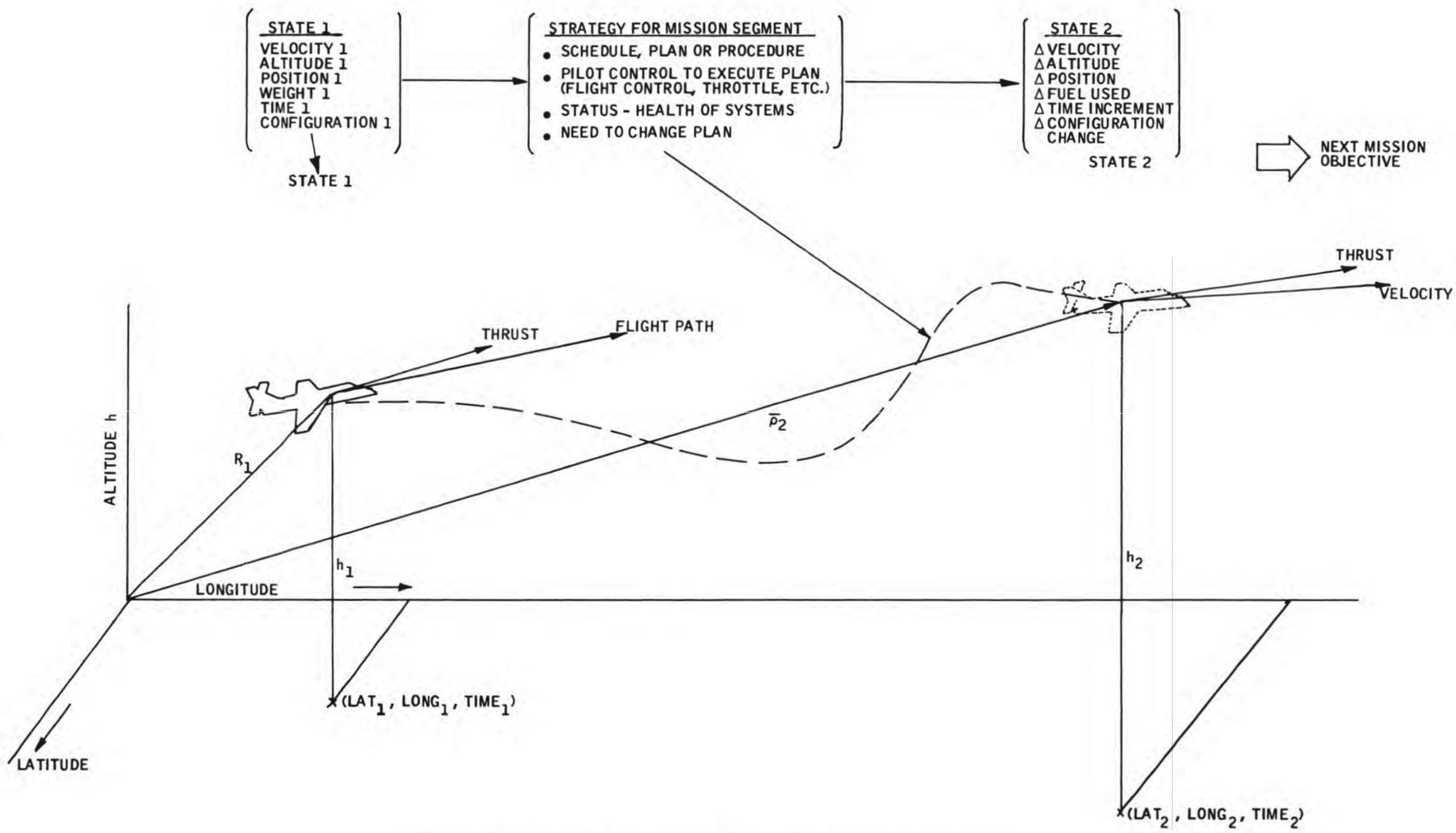


Figure 2 — Overall problem of flight path-energy management

start of a mission segment. He desires to achieve R_2, with his aircraft arriving at a state 2 condition. The state condition is the total vehicle description in terms of energy, velocity, position, fuel and aircraft weight, flight configuration and time. The particular mission segment will determine constraints, items to be optimized or controlled, and the accuracy of the desired solution. Numerous alternatives are available for going from state 1 to 2. The pilot needs to control the selection of the alternative most appropriate to his operational and combat situation.

He must select a strategy within the capability of his vehicle, his energy resources, and his ability to execute required control movements which permit him to arrive at state 2 in a desirable condition to continue his mission. Energy management is the scheme by which selecting and implementing an optimum flight takes place.

In one example of this work for an advanced aircraft, 10 percent reduction in time was predicted for obtaining supersonic speed by application of energy management principles. The nominal performance estimate consists of a constant-altitude acceleration from initial Mach to final Mach. The optimum run consists of a combination dive along the Boyd-Christie rule-of-thumb path and a climb along a path where energy is gained at a calculated maximum back to the initial altitude. These flight simulations are shown in Figure 3. This maneuver has been computed and flight tested successfully for several aircraft. Energy management considerations have indicated that many aircraft performance figures can be improved by flying optimum flight programs. The improvements become especially interesting in supersonic aircraft with high thrust-to-weight ratio, variable wing sweep and multiple modes of operation.

The theoretical approach to flight path optimization can be divided roughly into two categories which describe the mathematical techniques,

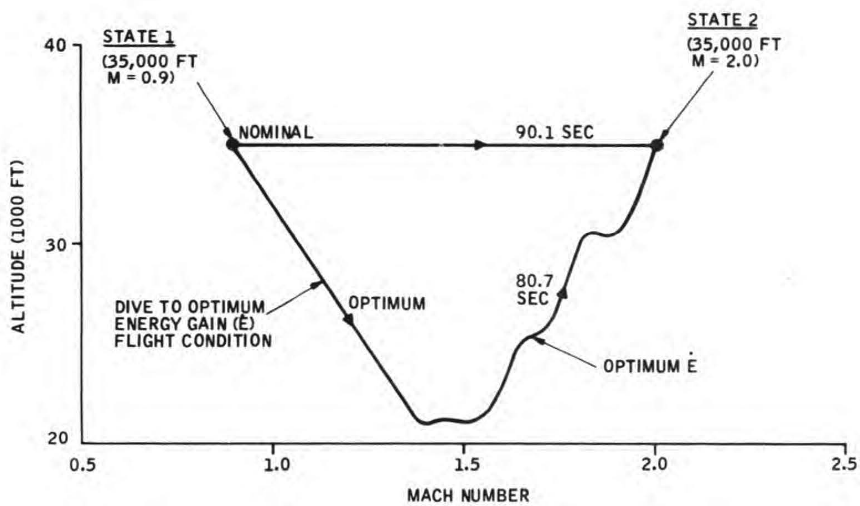


Figure 3 — Example of energy management result

classical or variational. The early efforts, whose roots were planted in predigital computer years, are often called the classical approach. Basically, this approach makes the problem tractable by neglecting the effects of acceleration, thus simplifying the equations describing flight. This technique has received much attention and has become highly developed (5,6,7). The advent of supersonic flight and high thrust-to-weight ratios has strained the capability of such classical treatments.

The second mathematical technique, which has gained popularity with the advent of high-speed digital computers, is the variational approach. It is popular to call this approach by other names such as "modern optimization techniques," "modern calculus of variations," *etc*. Classical methods have remained adequate for maximum-range, steady-state cruising. The minimum-time climb has forced the development of variational techniques. The first work seems to be that of Lippisch (8). In World War II, he applied the calculus of variations to the climb of the German ME-113 rocket powered aircraft. Lush (9) and Rutowski (10) extended his work to the degree necessary for modern application. Miele (11) has done much to generalize the application to a wide range of flight problems.

Modern optimization theory is the present-day extension of the calculus of variations. An approach to the problem of reduction to on-line practice rather than for developing handbook material is first seen in the incisive activity of Rutowski, whose pioneering paper on energy-state approximation presents the general aircraft performance problem as a balance between potential and kinetic energy changes, the drag dissipated energy, and the energy derived from the fuel.

He observed that specific energy, defined as energy per pound of aircraft, is the important factor in the flight of a high-performance aircraft. This formulation yields a basic equation for the rate of change of specific energy which replaced the altitude and velocity change equations.

Using the energy-change equation, Rutowski outlined a graphical method which permits finding either the path or minimum time or minimum fuel to fly from one combination of speed and altitude to another, providing energy changes monotonically. This formulation provides a simplified system of equations to be solved. The study of plots of energy relationships between aircraft has been the modern-day alternative for the Chambers-Rickenbacker hanger talks of 1918.

Bryson (12) studied performance optimization of supersonic aircraft using energy-state approximations. As an example, he treated maximum range by posing a two-point boundary value problem using the energy-rate equation as a constraint. The result is a climb approximating the Rutowski path at low altitudes which changes to a slowly varying cruise in Mach-altitude space at higher altitudes.

The further extension of the theory, including use of the approximate solution to the Euler-Lagrange equations, has been the subject of a study conducted by the Office of Naval Research. These studies have included thrust and wing sweep optimization in mission-constrained operations. Energy-state formulations are used to reduce the complexity of the optimization equation so that the equations can be solved without using complicated iteration techniques required by current methods. Computer capacity requirements for these solutions are low enough to permit real-time on-board solution of aircraft optimization problems. Such airborne computers are currently available. The technical approach of this study has been a search for an advanced energy-management system to take advantage of the new capability. The elements and operation of such a system have been defined in some detail in References 13 and 14, final reports of recently completed ONR studies. The energy-management system will improve the automatic and manual operation for most mission segments of air superiority, surface attack, long-range strike and reconnaissance missions. Some advantages of such energy management systems are summarized in Table 1.

TABLE 1
Predicted Advantage of Energy Management System Compared to Nominal Operational Techniques (Advanced Supersonic Aircraft)

Parameter	Results
Minimum Time to Climb	19% time saved
Minimum Fuel Climb	13% fuel saved
Minimum Fuel Trajectory (Climb and Cruise) to 435 miles	10% fuel saved 15% time saved
Maximum Acceleration from 0.9 to 2.0 Mach at 35,000 feet	10% time saved 15% range increase
Intercept Range to Mach 1.8 – 30,000 feet	+200% distance at intercept increase

These results were obtained from flying a comprehensive autopilot-controlled simulated study vehicle along commanded flight paths. Command signals for flight path control were derived from on-line energy management computation, and were compared to prescheduled "nominal" flight as typically described in operational manuals.

The sensitivity and advantages to be gained from optimizing formulation are evident in Figure 4. $\dot{E}$, specific excess power, (T-D)V*/m, is

*(Thrust-Drag)Velocity/mass

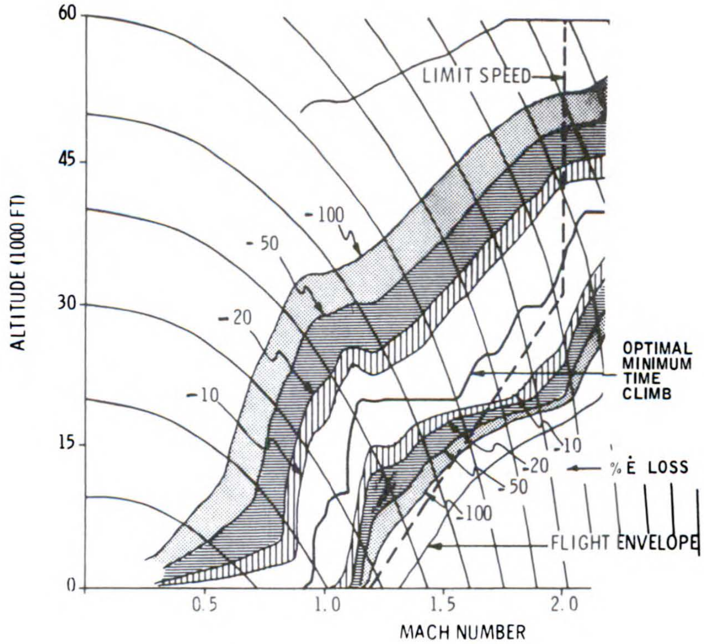


Figure 4 — Minimum time sensitivity diagram

a useful parameter in obtaining maximum energy from the airframe-vehicle combination. The optimum way of gaining an energy state (Mach, h) is to keep maximizing the value of Ė. The figure shows where the maximum value exists for each energy condition and indicates the loss in energy gain capability associated with various paths. As an example, a fiight by the IEIS* study vehicle along the optimum path will reach an intercept condition of M 1.93 and 38,000 feet about 1/2 minute quicker and 38 miles further from a carrier than by the nominal "rule of thumb" procedure of today.

This type of performance difference could be the difference between victory and defeat in many situations.

The question of the theoretical value of energy management has been established and the results can be applied to any vehicle. The question remains as to particulars in applying this theory to tomorrow's aircraft. If improved general techniques and rules of thumb are adequate, there is little need to develop new hardware, although training and practice to apply the techniques may delay full operational use. The complexity of tomorrow's aircraft indicates that better means of employing the full capability of the aircraft may be necessary. To take advantage of our areas of superiority and to avoid combat in undesirable flight regimes, it may require more specific implementation in displays, computation, and/or automatic control. This question is the primary issue in today's advanced work being conducted by ONR in coordination with the Naval

*Integrated Engine Instrumentation System

Air Systems Command. It also is an aspect of the "Integrated Engine Instrumentation System" presently under study by NASC.

Energy management studies of today will initially provide the definition of techniques and hardware which will need to be evaluated in test aircraft. Early expert use of the full performance capability of future vehicles is dependent upon how this study area progresses.

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Experimental Dives in Cold Water

A program of extensive experimental dives in cold water was conducted recently at the Navy Torpedo Station, Keyport, Washington, by Oceanautics, Inc. supported by the Office of Naval Research. Naval Special Warfare Group supported the tests in which crews of Navy divers operated a wet submersible in 42°F water for exposure durations of 4, 5 and 6 hours. Divers wore tailored wet suits with no supplemental heating and established a new record of effective performance in cold water. Eight channels of performance and physiological data were continuously recorded using a hard wire recorder in the submersible. In addition, an acoustic telemetry system was used to monitor diver core temperature and ECG from a safety boat on the surface. Technical report will be available from the sponsoring agency, Engineering Psychology Programs, Office of Naval Research.

Zimmerman Ice Island—ZIMIS

Arnold M. Hanson*
Office of Naval Research

Paul F. Twitchell*
Office of Naval Research
Boston, Massachusetts

Lloyd W. Zimmerman*
Naval Arctic Research Laboratory

On the 30th of March 1971, Mr. Zimmerman was flying with polar bear researchers. His mission was to aid Dr. A. K. Fisher of the University of Iowa to collect polar bear tissue. The flight was about 50 minutes out of Barrow when an unusual looking floe was noticed. The "floe" was ahead and to the left of course (about 035° True from Barrow). The aircraft closed to about one-half mile distance. The nearly rectangular shape and a parallel pattern of lines running the long way of the "floe" were the outstanding features observed. The color was more greyish than the surrounding ice and the long axis of the ice-cake was nearly north-sound in orientation. The east and west edges were not easily discernible because of ice ridging.

On the way home, the floe was approached from the north. This end was more or less free of pressure ridges. The freeboard was estimated to be 20 feet at the northwest corner and at the northeast corner to be 10 feet. The ridges extending the length of the "island" appeared rather flat. From the estimate of freeboard and the flatness of the entire piece of ice, it was presumed that a large glacial ice fragment had been found. The size of this fragment was estimated to be 1-1/2 by 5-1/2 miles. A radar fix was obtained from Barrow, 032° True and 60 nautical miles distance.

The proximity of the ice discovery and a lull in the routine flight activity allowed consideration of a mission to explore ZIMIS. John Schindler, Deputy Director of the Naval Arctic Research Laboratory (NARL) and Arnold Hanson of the Office of Naval Research planned a reconnaissance mission. Two Cessna 180's on skis with two men (pilot and pax) in each would constitute the total party. Ice samples would be taken for salinity analyses and surface debris, if any, would be sampled. The major dimensions would be measured and a sketch map made. Photography would be a necessary part. General observations of the character of ZIMIS would also be noted.

**Mr. Hanson* is Scientific Officer for the Arctic program for the Office of Naval Research.
Mr. Twitchell is the Meteorologist for the Boston Branch Office of ONR.
Mr. Zimmerman is staff pilot for the Naval Arctic Research Laboratory at Barrow, Alaska.

Figure 1 — The survey of ZIMIS began with oblique photography from about 3000 feet altitude

The search was rather simple since the previous fix on ZIMIS was reasonably accurate and the drift during the short interval was small (about five miles).

The survey of ZIMIS began with oblique photography from about 3000 feet altitude. A typical view is shown in Figure 1. One Cessna went down to begin close inspection and the second obtained a radar fix from Barrow.

The perimeter of the island was readily determined by the transition from the more or less flat snow covered greyish ice to angular blocks of pressure ridges or an abrupt cliff. Low level passes were made by both aircraft forward and back along the long axis and also perpendicular to the long axis (about a kilometer in from the blunt end). The passes were timed to the second and the forward and return intervals averaged. A nearly constant speed during a pass was maintained. The distances (using indicated air speeds) obtained by the two aircraft were averaged. The results were 4.5 miles for length and 1.2 miles for width. The line of the width measurement was for our purpose the widest part of the ice island.

Visual observation at low level showed the island surface to be mostly snow covered probably 95 percent or more. The snow cover was dominated by the sastrugi drift form. There was an apparent regularity of the arrangement of the bare ice patches. A low level flight up a "valley" revealed a ridge and trough system similar to Fletcher's Ice Island, however, our impression was that the individual ridges and troughs extended the full length of this ice island.

The first landing on ZIMIS was about 2140Z after several low passes and ski dragging to check snow strength and roughness. This landing was about a kilometer in from the north or blunt end of the island as seen from the air in Figure 2 and from the ice in Figure 3. The second aircraft landed about 400 meters nearer the north end.

Using a mountaineers ice ax, several mud samples were chipped from the ice. Small mud pellets were visible in this bare ice patch. These pellets were scattered and generally only a few millimeters diameter at most. The larger globes or lenses of mud were at the bottom of snow covered melt holes. The contrast of the white snow with the greyish ice made the mud pits easy to locate in the wind swept bare ice patches. No attempt was made to dig under the snow cover for mud. The snow drifts, almost without exception, were strong and hard enough to bear the weight of foot traffic.

Our ice corer, obtained without prior trial, had dull teeth and therefore was difficult to turn in the cold hard ice and, in fact, caused the ice

Figure 2 — The first landing was about a kilometer in from the north or blunt end of the island

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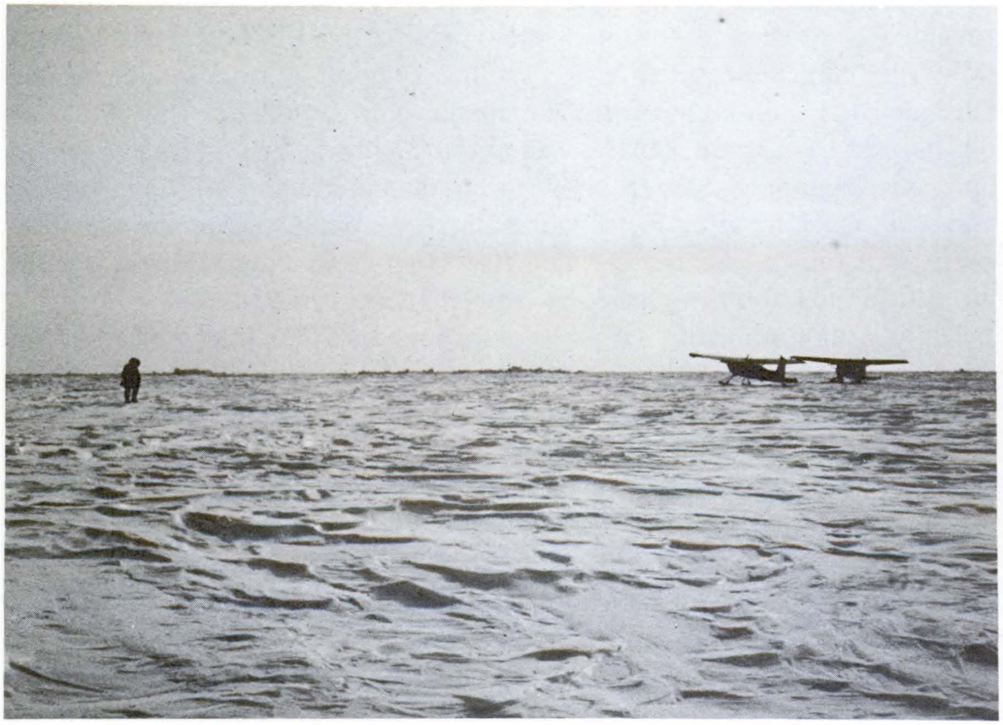

Figure 3 — The Cessna 180's landed safely

to shatter. The upper 95 cm were divided into two samples which were placed in clean plastic bags. A taste test of the cuttings revealed no detectable salt (salinity $< 1°/_{oo}$).

A black flag of trail marker type about 8 × 10 inches on a 4 foot stake was set in this hole. The time expended in coring such a short depth precluded continuing with a plan to set all stakes to similar depths.

The depth of the snow cover was sampled by plunging in an ice ax handle. The depth varied from zero to over a meter. The latter depth was found in what was probably a stream channel at the blunt end of the island. Several measurements of one-half ax handle (about 45 cm) were found, one was probably in a second small stream, others were in thicker appearing drifts. Many ax handle penetrations were in the range of 10 to 30 cm. The snow cover had the appearance of smoothing the ridges and valleys by being deeper in the valleys.

Measurements were made to estimate the free board of the north end of ZIMIS. Since we could not find open cracks near the island, measuring the island's height above the pack ice would be a conservative measure of the island's freeboard. Three estimates made were from 4 m to 5 m. Figure 4 is a view of the visible free board from the nearby pack ice.

The ice in the exposed face of the blunt end was banded as seen in Figure 5. The bands were of low contrast with each other and more or less parallel with the upper surface where examined. A thin layer of

Figure 4 – A view of the visible free board from the nearby pack ice

Figure 5 – The ice in the exposed face of the blunt end was banded

scattered mud pellets was observed at one location about a meter down from the upper surface. The pellets were of order of 1 mm in diameter.

The glazed character of the ice in the wind swept places on the upper surface of ZIMIS suggests that a freezing rain occurred at the end of the melt season. Some of the mud pits were filled with ice, which was interpreted as supporting evidence for the rain hypothesis. Nearby, several small sea ice floes appeared also to have icy windswept patches. During a melt season the upper surface is characteristically granular, bladed, or candled, most typically the former. When frozen such a granular surface does not scatter light like a glazed surface.

This observation, combined with knowledge of the Arctic Ocean surface currents and the historical track of T-3, could establish a means of positioning the island six months earlier. The ocean current information would backtrack the island in six months to a position in the Beaufort Sea west of Banks Island. The T-3 track, as shown in Figure 6, would suggest a position north of Barter Island, Alaska, or at longitude of approximately 140 to 145°W. Surface weather charts prepared by National Meteorological Center, Suitland, Maryland, were examined from the period of 1 August through 31 October 1970. From these charts, weather systems which could produce freezing rain were identified. The storm systems selected were in the periods 4-6, 11-13, 18-19 and 24-25 September. Selection of these dates was primarily based upon surface weather reports from stations marginal to the east and south coasts of the Beaufort Sea. Observations from the weather station at Barter Island were obtained for the months of August, September and October from the National Weather Records Center, Asheville, North Carolina. Hour-by-hour observations were reviewed. The sequence of weather events associated with passage of a frontal system on 12 and 13 September could have produced the surface ice conditions observed by the authors. On the morning of 12 September, the reported temperature at Barter was 34°F and by mid-afternoon the temperature had climbed to 50°F with rain. The southerly winds shifted to westerly at 16:00 hours local time and a drop in temperature to 35°F took place in approximately two hours followed by periods of very light drizzle. On 13 September, at 02:00 hours rain commenced again and the cold front passed through at 04:23 hours local time, with the temperature dropping into the twenties with a brief period of light snow. All precipitation reported for the remainder of September and October was snow. The glazed ice surface observed by the authors could well have been produced by the sequence of precipitation that occurred at Barter Island on 12 and 13 September. The weather system did not appear to produce the same sequence of precipitation at Barrow, Alaska to the west or Mould Bay N.W.T. Canada to the east. It is concluded, therefore, that the ice island surveyed on 1 April 1971 northeast by north of Barrow, Alaska, was in a position in the Beaufort Sea north of Barter Island on 12 September.

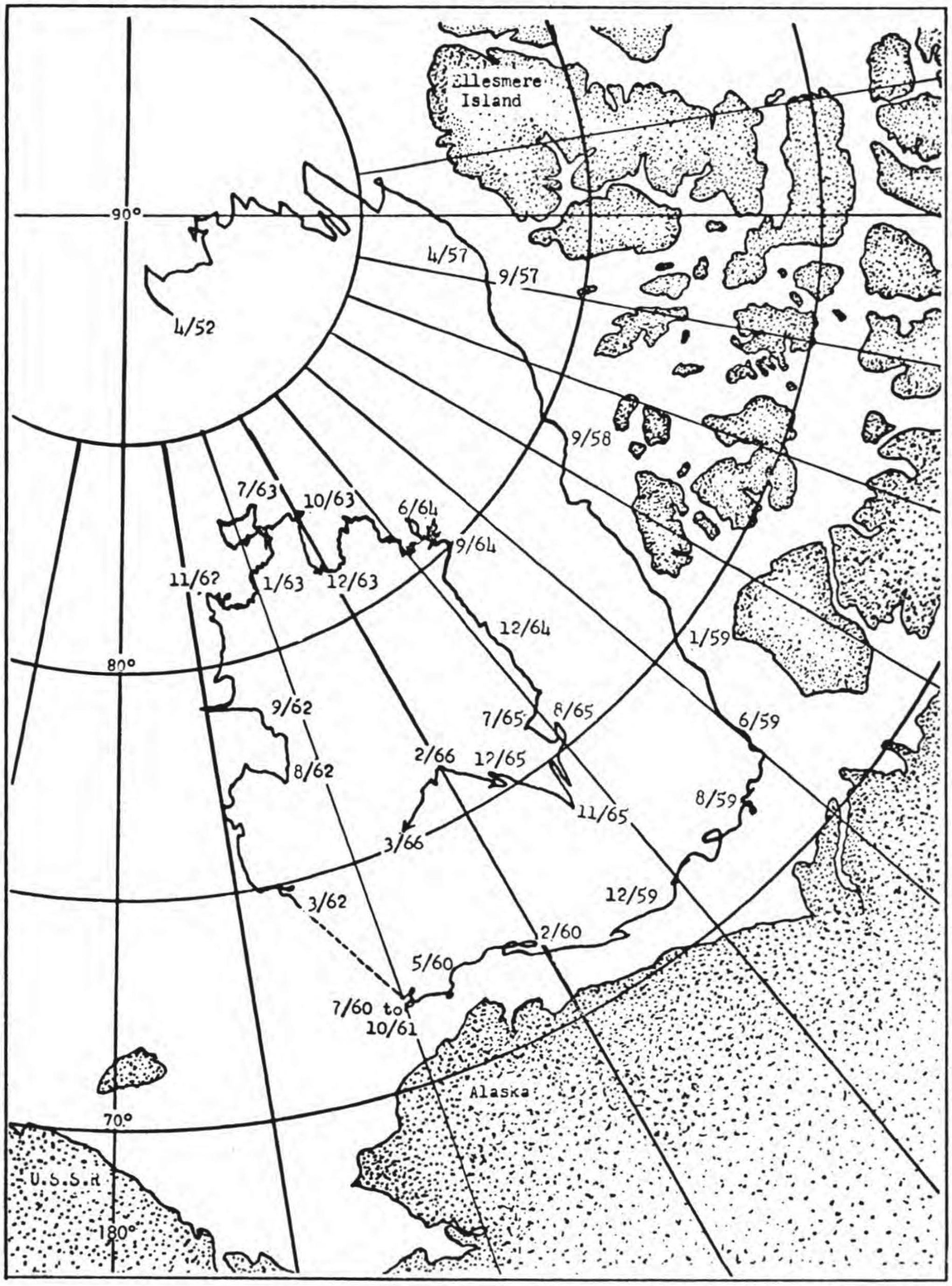

*Figure 6 – Drift track–Fletcher's Ice Island, T-3, from April 1962 to March 1966**

***The map is reprinted from the proceedings of the symposium on Arctic Drifting Stations, Warrenton, Virginia, 1966.**

Note that T-3 also traversed the same region at about the same time of year in approximately 5 months time during the winter of 1959-1960.

The density of the ice was estimated to be in the neighborhood of .85 to .92. This ice density is suggested by its appearance compared to past experience.

The pointed end of ZIMIS appeared to have less freeboard than the blunt end. After take off, a fly by was made past the blunt and pointed ends in succession. This sort of calibrated our eye ball estimate (EBE) and gave freeboard estimates on the pointed end of 2 to 3 meters. Such being the case, ZIMIS varies in thickness from 35 m to 25 m and is perhaps thinner several places along the sides.

There were no significant bays, however, the character of pressure ridges along the perimeter suggests that there had been relative ice motion at some time during the past winter at all edges. The possible use of ZIMIS as a research platform must therefore take into account the hazard of working across an active fault zone and the difficulty of working through thick ice.

The radar fixes obtained by number two aircraft were 038°54 miles at the south end of ZIMIS and 032°55 miles at the north end. The first fix was taken upon arrival at ZIMIS and the second prior to departure.

The general morphology, mud, freeboard, banding and mud layers embedded below the surface leaves no doubt as to the glacial origin of ZIMIS. A check with the Navy Oceanographic Office and with Canadian Continental Shelf scientists revealed that ZIMIS was a "new" ice island. The possibility exists that it may be a large fragment of a larger ice island. The "clean" unweathered appearance of the fracture which formed the blunt end of ZIMIS does lend support to a fragment hypothesis. From personal experience with the weathering rate on newly fractured ice islands, we suggest that fragmentation is less than a year old; however, the freezing rain possibilities and evidence cited above could change this inference on age.

The prospect of using this ice island for a new ice station, perhaps ARLIS VII, is an exciting one. The prospect is dimmed, however, by the proximity of ZIMIS to the coast. The summer of 1971 will be critical for the life of this ice island.

Unique Air Cushion Vehicle Model Testing Program Developed for Navy

A unique model testing program that simulates the operation of air cushion vehicles under severe surf conditions has been developed for the Navy and used to test two models that are candidates for the Navy's first air cushion amphibious assault landing craft (AALC).

(Continued on Page 27)

Experimental Investigation of Several Neutrally-Buoyant Bubble Generators for Aerodynamic Flow Visualization

R. W. Hale, P. Tan, and D. E. Ordway
Sage Action, Inc.
Ithaca, New York

Experimental aerodynamicists and others concerned with understanding air motion have long sought practical methods for actually *seeing* air movement. For decades now they have had to rely almost exclusively on smoke for this purpose. But, less and less, smoke is able to do the job. Most air flow patterns of current interest are very complex, usually turbulent and frequently unsteady. Subject to these conditions, smoke mixes and dissipates too rapidly. In addition, it is often difficult and noxious to use, especially in the large closed-circuit wind tunnels that are employed.

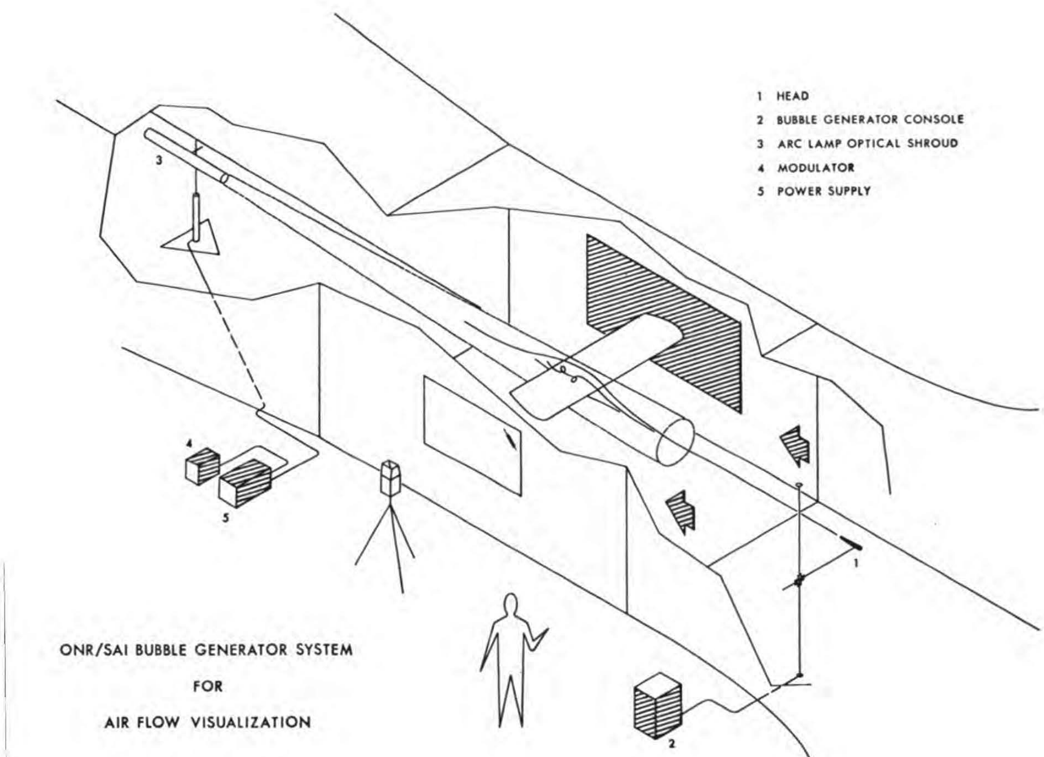

Figure 1 — ONR/SAI bubble generator system for air flow visualization

Recently, a new technique for flow visualization has emerged. Under Office of Naval Research sponsorship, Sage Action, Inc. of Ithaca, N.Y. devised a practical way of implanting small bubbles, about 1/8 inch in diameter, in an air flow and photographing their motion. The key features of this development are the unique generation scheme and neutral buoyancy of the bubbles. They are generated extremely rapidly, on the order of 15,000 per minute. Their neutral buoyancy is achieved by filling them with helium gas. This allows the bubbles to follow any air motion faithfully over an entire range of flow velocities from near 0 to more than 200 feet per second. So far, an upper limit has not been determined; it is anticipated that more advanced versions of the device will produce bubbles capable of remaining intact in transonic air flows.

To apply the technique, the necessary equipment can be set up easily in a few hours. A typical arrangement in a wind tunnel is shown in Figure 1. The "head" that generates the bubbles is a small, pencil-shaped device, approximately 4-1/2 inches long and 5/8 in diameter (Figure 2). The bubbles are first formed inside the head and then injected into the surrounding freestream. They accelerate quickly and reach the freestream velocity after traveling a short distance. The head is installed upstream of the flow pattern to be visualized, far enough to avoid any disturbing influence. A compact, high-intensity lamp to illuminate the bubbles is installed downstream of the region to be studied. The lamp has a narrow beam which is directed upstream along the bubble trajectories. This minimizes reflections and stray light.

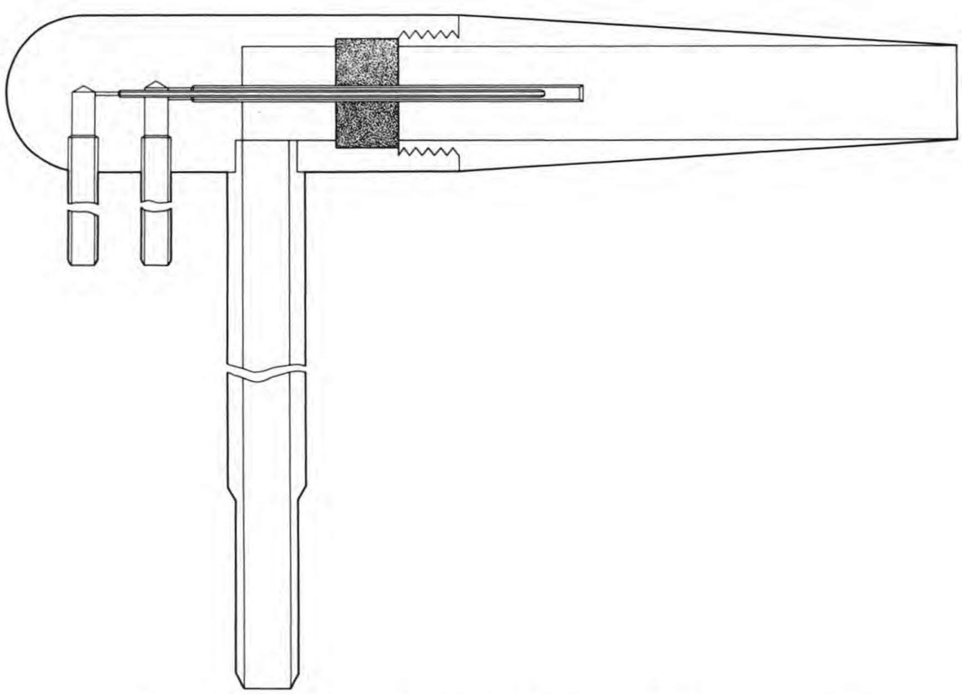

Figure 2 — Cross-section schematic of the high speed bubble generator head

The motion of the bubbles, and therefore the air, is generally viewed and photographed from the side or above. With a camera, the shutter speed is set so that a number of bubbles pass through the field of view during the exposure. Each bubble in turn leaves an image of its path, or a streak, on the film and this streak becomes a record of the air movement within this time frame. The record of a number of streaks on a single photograph then produces a remarkable history of the air motion, revealing the flow in graphic detail!

Another dimension has been provided by modulation of the lamp that illuminates the bubbles. That is, the lamp is effectively turned off and on very rapidly, from 250 to 1,000 times each second. With this modulated light, the streaks appear "dashed" or broken at precise intervals in time, whenever the lamp is turned off. From the measured length between breaks in the streak and the known time interval, the actual bubble velocity is found. This affords an instantaneous velocity map of the complete flowfield where point-by-point measurements with a conventional probe are tedious or impractical.

An integrated system of the bubble generator head, the lamp and the modulator, together with the somewhat specialized photography which is required, attained maturity in tests carried out at NSRDC in November 1970. These tests were performed in the 8 × 10 foot Subsonic North Wind Tunnel. They were piggybacked to another test program aimed at the problem of the "tip vortex" from an aircraft wing or helicopter rotor blade. This is a particularly interesting flow phenomenon to investigate. It is so common and yet, at the same time, so poorly understood. Currently, there is a great deal of interest in this problem because of the appreciable and sometimes dangerous wake turbulence behind the new jumbo jet aircraft and the rotor bang or blade slap noise of helicopters, both due to trailing vortices.

An overall view of the vortex pattern is portrayed by the bubble streaks in Figure 3. The upper surface of the blade, or wing tip, is seen in Figure 3. This blade has a 15 percent thick, symmetrical airfoil section with a constant 8 inch chord set at 10 degree angle of attack to the tunnel flow. The flow is from left to right. The core of the vortex appears as a brilliant, solid tube downstream of the blade and passes roughly through the middle of the streak pattern. Within this core, the motion is predominantly in the downstream or axial direction. Outside the core, on the other hand, there is a strong rotational motion superimposed on the axial motion. Facing downstream, the rotational motion is in the clockwise direction. It becomes larger moving radially away from the core, rises to a peak value and then decays. The rotational motion, combined with the axial motion and a small radial motion, results in helical bubble trajectories with changing pitch and radius. This creates the beautiful "basketweave" pattern that is observed.

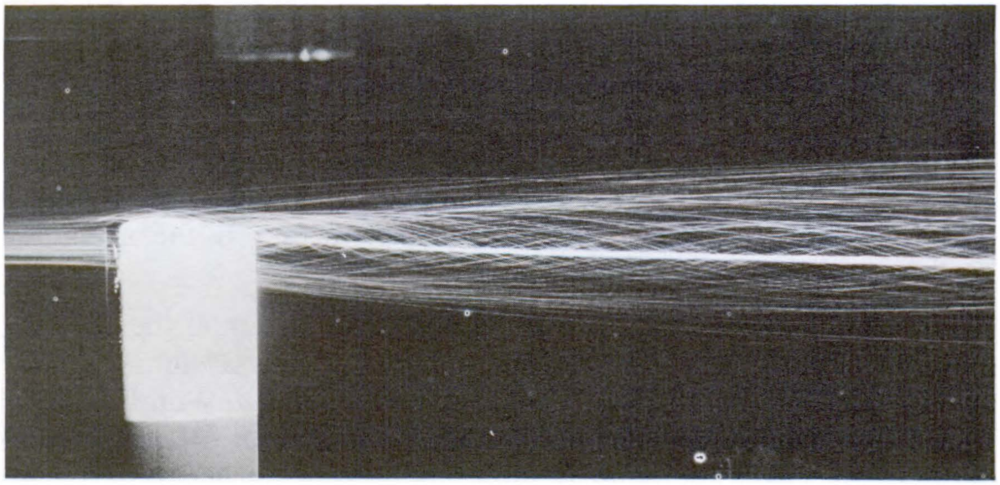

Figure 3 — An overall view of the vortex pattern is portrayed in the first bubble streak photograph. The upper surface of the blade or wing tip is seen in the photograph.

Figure 4 shows a closer view of the flow in the vicinity of the blade taken with a shorter exposure. In certain cases, a shorter exposure has a beneficial effect because fewer bubble streaks are recorded. Here it brings out several intricacies, for example, the motion over the edge of the tip and the manner in which the bubbles spiral around and into the core. The radial velocity is also clearly evident. This velocity plays a pivotal role, sustaining the vortex strength by convection of angular momentum inwards. Since the pattern is so strongly three-dimensional, it would be almost impossible to obtain such a wealth of information in any other reasonable fashion.

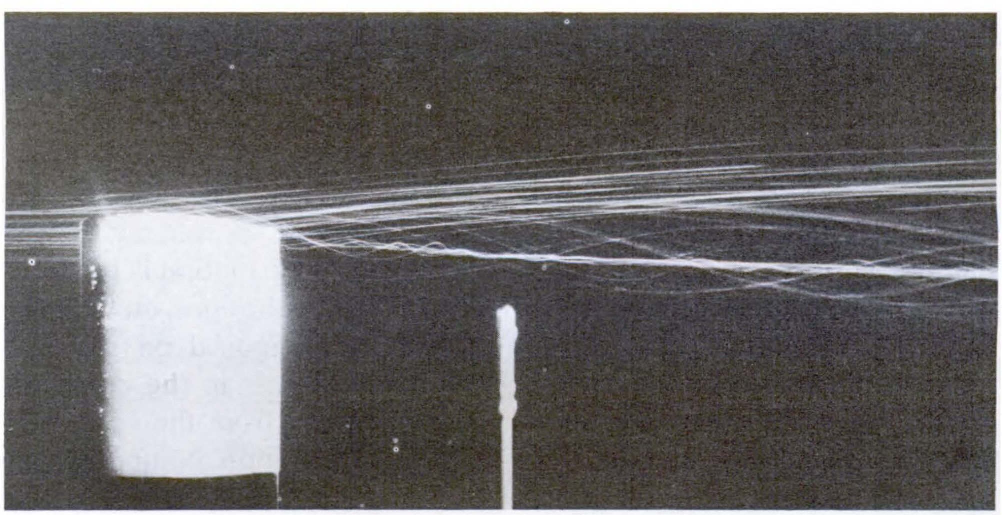

Figure 4 — A closer view of the flow near the blade taken with a shorter exposure

The flow pattern depicted in Figure 5 is established downstream twelve chord lengths or so. The streaks inboard of the core end abruptly because they pass out of the light beam. The same overall features as above reappear, but there does seem to be a difference between the helical trajectories that are inboard and outboard of the core. Inboard of the core the pitch increases, indicating that the axial velocity profile is less and not axisymmetric about the core. This must be a manifestation of the viscous wake behind the wing that arises from the boundary layer.

To understand the flow better, the same picture was shot with lamp modulation and is presented in Figure 6. The lamp was modulated at 250 cycles per second. At this frequency, a bubble moving with the free-stream velocity at 50 fps would go 0.2 foot or 2.4 inches between breaks

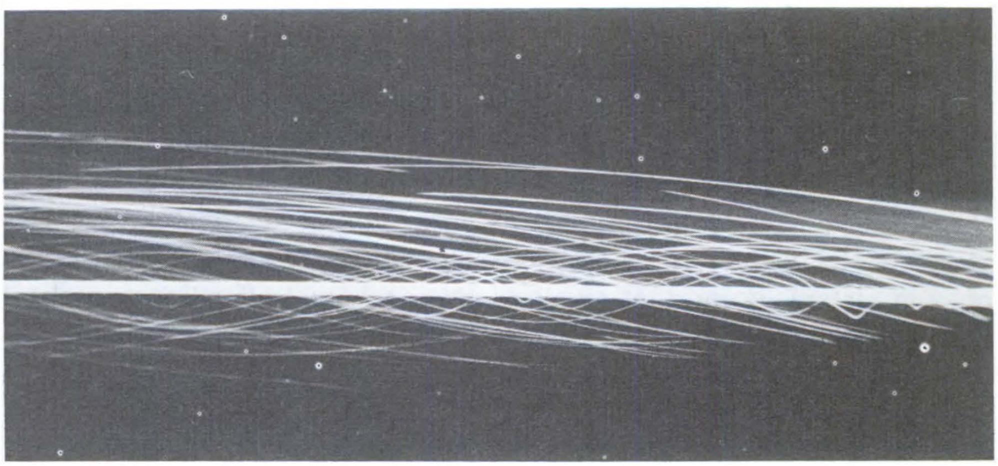

Figure 5 – The flow pattern depicted here was established about 12 cord lengths downstream

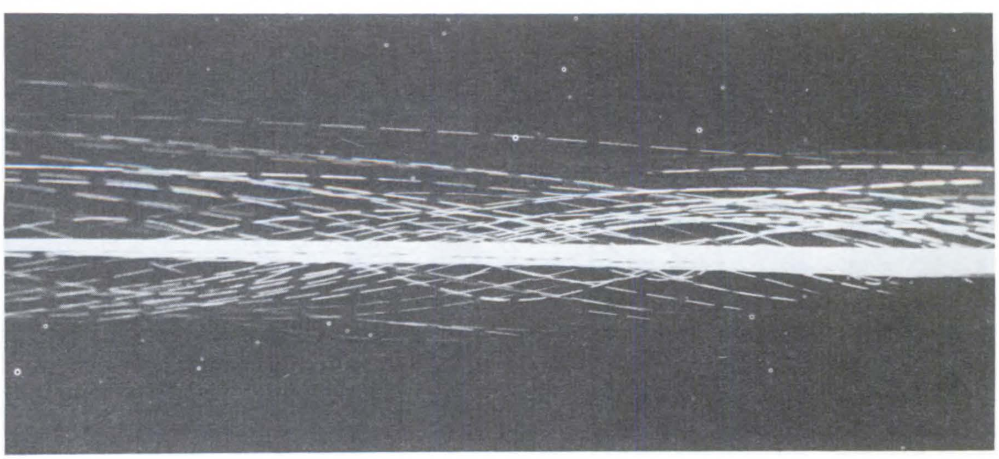

Figure 6 – Here the lamp was modulated at 250 cycles per second

in its streak. A great deal of quantitative data can be gathered from this photograph. The calculated axial velocity outboard of the core is essentially the freestream velocity, while the axial velocity inboard is appreciably lower, as suspected. Roughly, it is two-thirds of the free-stream value. Rotational and radial velocities were computed as well. The rotational velocity is on the order of 15 fps and the radial velocity 2 fps at a radius of 1.3 inch. The core itself, as defined by the solid tube of bubbles, is about 1 inch in diameter and grows slowly in the down-stream direction.

These representative photographs constitute, perhaps, the best description of a tip vortex in existence and illustrate what a powerful tool flow visualization is. Relatively speaking, complicated flow patterns are deduced in an instant, which before would have to be ferreted out by means of an extensive set of measurements. In fact, once the pattern is visualized, any measurements themselves can be made much more efficiently. The cost savings and the insight gained are hard to over-estimate.

The new technique advanced has successfully demonstrated its simplicity, reliability, accuracy and adaptability. Currently, efforts are underway at Sage Action to try to develop an even better picture of the tip vortex phenomenon and to increase the speed capability of this technique to high subsonic or transonic velocity. We may expect in the not too distant future, that many wind tunnels will offer flow visualization with bubbles as part of their overall testing equipment.

Machine Recognition of Handprinted Characters

At the University of Texas, in the Joint Services Electronics Program a strong group has developed in the field of digital and adaptive filtering, for which ONR provides the Navy support as well as pattern recognition. An important advance in the quick assimilation of Fortran-coding handprinted characters has been made by Professor Phillip S. Noe at that University. The machine recognition system translates optically-scanned alphanumeric coding symbols into the computer. Sophisticated, unambiguous measurement and decision algorithms have been evolved to accurately identify and relay the 42 characters used in Fortran coding. The research system has been perfected to the point where 95 percent recognition rate was obtained for a single-author file of 6000 characters (degraded performance when multi-authors are involved). Such variations as broken characters, effects of pencil smudge and inadvertent skewing of the handwriting, have been studied with the aim of minimizing their influences on reliability.

This work is of direct import in expediting computer-aided electronic circuit design, and in many communications studies which require programming by Fortran, Cobol and other data processing languages.

On the Naval Research Reserve

Promotion Selections

There were two thousand four hundred and eighteen officers selected for promotion to Lieutenant by the Fiscal Year 1971 Reserve Selection Board. Congratulations go to seven members of the Research Reserve Program:

	NRRC
Bullano, Gerald A.	4-7
Collins, Stephen R.	4-1
Davidson, Raymond F.	8-13
Farris, Billy B.	5-2
Giuoco, Samuel E.	8-13
Green, Arthur A., Jr.	1-3
Young, John P.	3-7

NRRC 5-8 Report

At the annual dinner meeting on June 10, the members of Naval Research Reserve Company 5-8, Washington, D.C. and their ladies honored four retiring members: CAPT Ashton F. Embry, Jr., CDR Albert E. Shively, CDR James W. Titus, and CDR Gilbert C. Tolhurst. The Company Commanding Officer, CDR Theron W. Davidson, recognized the long and devoted service of these officers. The after dinner address, "Women in the Navy," was given by CAPT Robbin Quigley, Assistant Chief of Naval Personnel for Women. The Company members have some first hand knowledge of Navy Women because their membership includes CAPT Eleanor F. Kehoe, one of the first three Reserve Wave Officers selected for CAPT.

Unmanned Arctic Research Submersible Designed

Design specifications and drawings have been completed for the Unmanned Arctic Research Submersibles (UARS) and its support system for launch, control tracking and recovery. Development and fabrication of the UARS is being undertaken by the University of Washington under an ONR contract. The UARS is a fiberglass hull, blunt nosed torpedo shaped device about nine feet long and two feet in diameter capable of excursions of 1500 ft deep at a speed of three knots for periods of ten hours. The UARS will follow a pre-programmed track, but may be remotely controlled *via* acoustic telemetry links. Primary use of the UARS will be collection of under-ice profiles in the Arctic, together with temperature and salinity samples along the tracks. It will also be a useful tool for observations in the marginal ice zone. It is planned to begin field tests in the Arctic about March 1972. Funding for this program is provided by ARPA.

Research Notes

Free-Fall Electromagnetic Current Meter

A free-fall device, capable of measuring the horizontal velocity of ocean currents at any or all depths in the sea has been developed by Dr. Thomas Sanford, Woods Hole Oceanographic Institution, under an ONR contract. The device measures the induced electric field associated with ocean currents passing through the geomagnetic field of the earth.

The instrument is a 7 foot, 6 inch ID pressure cylinder with fins. The electric field is measured as the voltage between the ends of opposite fins. The fins are pitched so the instrument will rotate as it falls through the water—allowing the magnitude of the induced orthogonal electric field to be measured and thus obtaining a signal proportional to the current vector.

The operation of the instrument at sea is relatively simple. As the instrument freely falls through the sea the information on how the horizontal velocity varies with depth is acoustically telemetered back to the ship and displayed on the Precision Depth Recorder. The signals consist of a reference time pulse and delayed pulses giving pressure, electric field magnitude and a north reference. When the instrument strikes the bottom, a weight is released and the instrument returns to the surface, repeating the measurements as a "Free-Rising" device. An accuracy of the order of 1 cm/sec is obtained.

The first set of measurements with the instrument were recently taken in the Gulf Stream. The results show that the measured electric field is in good agreement with theoretical predictions. Horizontal current velocity profiles, with a measurement every eight months, were made to the bottom (4400m). It took approximately one hour to make a profile. The profiles showed a "fine structure" in the velocity reminiscent of the "fine structure" or "layering" now seen in temperature with the Salinity, Temperature, Depth probes. Future plans call for incorporating temperature in the free-fall current meter. In addition to measuring current structure these electromagnetic measurements may provide a very useful means of studying the motion of internal waves.

Alvin's Back at Work

The scientific submarine *Alvin* will return to the site of its sinking 120 miles south of Cape Cod for its first research dive since reconstruction at the Woods Hole Oceanographic Institution.

The *Alvin,* owned by the Office of Naval Research but operated by the Oceanographic Institution, sank in 5,051 feet of water in October 1968, when a retaining cable snapped during launch operations. It was recovered the following August, rebuilt at Woods Hole, and conducted its first dive in more than two and one-half years in shallow water testing. Since that time, the *Alvin* has undergone a series of test, orientation, and certification dives off Woods Hole.

The *Alvin* is currently aboard its mother ship, the catamaran *Lulu,* tied up at the New England Aquarium in Boston. The vessels are participating in the Boston Sea Rovers 17th Annual Underwater Clinic and the Marine Careers Conference at Boston University sponsored by the Sea Rovers, B.U. and the Aquarium.

After the Boston visit, the vessels are scheduled for *Alvin's* first research dive series since reconstruction, to last from June 2 to June 12th. Besides returning to the site of the sinking for possible location and recovery of equipment lost in the recovery of the submarine, *Alvin* and *Lulu*, escorted by another Oceanographic Institution vessel, the *Gosnold,* will go to a second site, some 120 miles due south of Martha's Vineyard. At that location, *Alvin* will make three dives to a depth of approximately 6,000 feet and will set up the first permanent bottom station to be established by a submersible. Instruments will be placed in a specific location on the sea floor for the Oceanographic Institution's departments of biology, geology and geophysics, physical oceanography, and ocean engineering, for purposes of monitoring bottom environmental processes. The experiments will last for periods of six days, three months, and a year, with *Alvin* returning to the site to retrieve the instrumentation. Samples of solid waste may also be fixed at the sea floor station for purposes of experiments on decomposition in the deep sea.

Alvin's anticipated operating schedule for the balance of the year calls for research dives funded by ONR (Office of Naval Research), NSF (National Science Foundation), NOAA (National Oceanic and Atmospheric Administration), and ARPA (Advanced Research Projects Agency). The sub will operate out of Woods Hole until August and then move south, for dives off Cape Hatteras, Fort Pierce, Miami, Key West, and Nassau, accompanied by both *Lulu* and *Gosnold*. *Alvin* will return to Woods Hole in late December for additional reconstruction calling for the sub to be refitted with a titanium hull, increasing its operational capability from a 6,000 to a 10,000 foot depth.

The *Alvin* is one of six ocean-going vessels operated by the Oceanographic Institution for scientfic research around the world. A resident staff of more than 600 scientists and support personnel functions at the Woods Hole facilities for a wide range of studies in physics, chemistry, biology, meteorology and geology.

Stable Floating Platform Model Tested

Preliminary results of 1:8 scale model tests of a stable floating platform (SFP) utilizing a four-legged FLIP concept have been very promising, and a decision has been made to proceed with plans for fabricating a full scale model. This work is being performed by the Advanced Ocean Engineering Laboratory (AOEL) of Scripps Institution of Oceanography under an ONR contract. This SFP design concept involves the attachment of a 100 ft square deck through pivot points between the extreme ends of a rigidly connected pair of 25 ft diameter cylinders of about 300 ft length to form one module, and the hinging together of two such modules to form a stable floating platform offering some 35,000 sq ft of work area with a dynamic payload of about 500 long tons. New technology under development includes: use of post-tensioned concrete for the cylindrical legs; design of the deck-to-legs pivot connections; and design of couplings between two independent modules to form a larger platform. It is anticipated that actual full scale construction will begin about October 1971 with completion of the first module about December 1972. Funding for this program is provided by ARPA.

(Continued from Page 18)

A critical element in the performance of any amphibious vehicles is the transition from water to land and back to water while operating in a plunging surf. Previous testing of amphibious vehicle models simulating such conditions has been confined to measuring the forces on the models with a significant lack of freedom in the various degrees of motion. Full scale trials of prototype are necessarily difficult to schedule, expensive, lengthy and even hazardous to personnel and the vehicles.

Hydronautics, Inc., Laurel, Md., using its recently completed 308-foot long ship model basin facility, developed under an Office of Naval Research contract model test techniques that overcome this problem. Special instrumentation includes a surf-generating beach system and a towing rig that allows the model to surge, heave, pitch and roll.

The two six-foot models that were tested are designs that are under consideration for the prototype AALC, a program that is under the technical management of the Naval Ship Research and Development Center, Carderock, Md. and the Naval Ship Systems

Command. One model was provided by the Aerojet General Corporation and the other by the Bell Aerosystems Company.

Tests of the two models demonstrated that both can run up on the beach through surf up to and including 12-foot breakers and retract or return to the water through 12-foot breakers. The test data has been used by Aerojet General and Bell Aerosystems to optimize their designs.

Each company is now constructing two full-scale test craft under Navy contract to be considered in the final selection. All four test craft are 165 tons and approximately 100 feet in length, 50 feet wide and 23 feet high.

The six-foot models are also being modified to match design changes, and they will be tested further for surf performance at Hydronautics. In this way major problem areas in regard to the performance of the air cushion AALC in heavy surf will have been corrected by the time construction is completed. It is believed that this will lead to the production of amphibious vehicle prototypes that will be much closer to operational standards than has been previously possible.

Twenty-Four Million Dollar Gamble Pays Off

The concept of a Multiplexed Information and Computing Service (MULTICS), which would provide a continuous, reliable, 7-days-a-week, 24-hours-a-day, time-shared computer system capable of meeting nearly all present and near future computer requirements, grew out of and is an extension of the basic concepts and philosophy of the Compatible Time-Sharing System (CTSS) developed at MIT during the late 50's and early 60's.

Many diverse objectives were incorporated into the plans for MULTICS, including the ability to alter the number of central processors and the amount of core and secondary storage in response to system needs even while users are logged in, and the development of a paging type virtual memory capable of accommodating extremely large and complex problems, thereby permitting problems that were too cumbersome to be tackled in the past to be successfully pursued, while at the same time retaining a sufficiently small overhead to permit the small user to operate efficiently and cost-effectively. Other features, including the ability for two or more users to share a single copy of a file as data in core memory and to obtain controlled access to other users' file directories, were to be incorporated into the system.

In 1963, the Office of Naval Research with Advanced Research Projects Agency support, initiated funding of this ambitious project. In order to achieve the goals outlined above, an entirely new set of computer hardware had to be designed. This was undertaken by the General Electric Co., which made numerous modifications to its 635 series machine. The most gargantuan task was, however, the programming effort. At times, substantially over 100 programmers were working on various aspects of the system. Complexity grew to such a point that coordination of the effort became a superhuman task, and a point was ultimately reached where the possibility of salvaging even a marginally useful system was in doubt. Some observers had written the project off as a daring but unsuccessful experiment. Slowly the system programming came under control and was gotten on the air with a single terminal which was later stepwise expanded to a point where over 40 users can be simultaneously and effectively serviced. Many programs had to be revised and refined as many as a dozen times before efficient operation was achieved.

Today a practical system is available which is so much in demand at MIT that expansion of the facility cannot keep up with requests for service. Although the system is now cost competitive, further refinements are almost daily being made, many of which result from experience gained by observation of the MIT user groups. The real significance of MULTICS is, of course, the impact which its development is having on the planning of new computer systems. While the total investment in this effort has been substantial, it

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is already apparent that the money has been well spent and the future will see a handsome return on this investiment.

Concepts of library search are not yet good enough to satisfy some users, and telephone lines still limit the system's input-output capabilities. These limitations must be overcome before large systems can be efficiently linked on the network. MULTICS will also have to explore ways of organizing the simultaneous use of large numbers of processing units.

As these problems are solved the MULTICS approach offers great promise for the improvement of command and control and logistics systems as well as the management of large, complex programs.

Cover Caption

In the illustration, the vertical segments denote increments of altitude and the horizontal indicate levels of energy rate. The high-performance aircraft begins its climb at a low altitude and at a subsonic speed chosen to have a high energy rate. After passing the transonic region, some potential energy (altitude) is bled-off in a shallow dive while kinetic energy (speed) is rapidly increased. This process is then reversed to exchange speed for altitude. Throttle is maintained at a maximum setting throughout the transit. In performing a minimum-time climb, maximum energy rates, dE/dt, can be maintained only by flying a Mach versus altitude schedule as shown by the ridgeline. An aircraft's flight characteristics determine its particular energy rate contour; the one illustrated is typical of a high-performance aircraft, e.g., an F-14 or F-15. Such contours can be developed for subsonic aircraft as well. An energy rate contour for the Sopwith Camel can be determined but is not shown. Its maximum energy state, indicated in terms of terminal speed (Mach) and altitude, is greatly surpassed by modern military aircraft. (Provided by courtesy of Honeywell, Inc., Systems and Research Division)

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