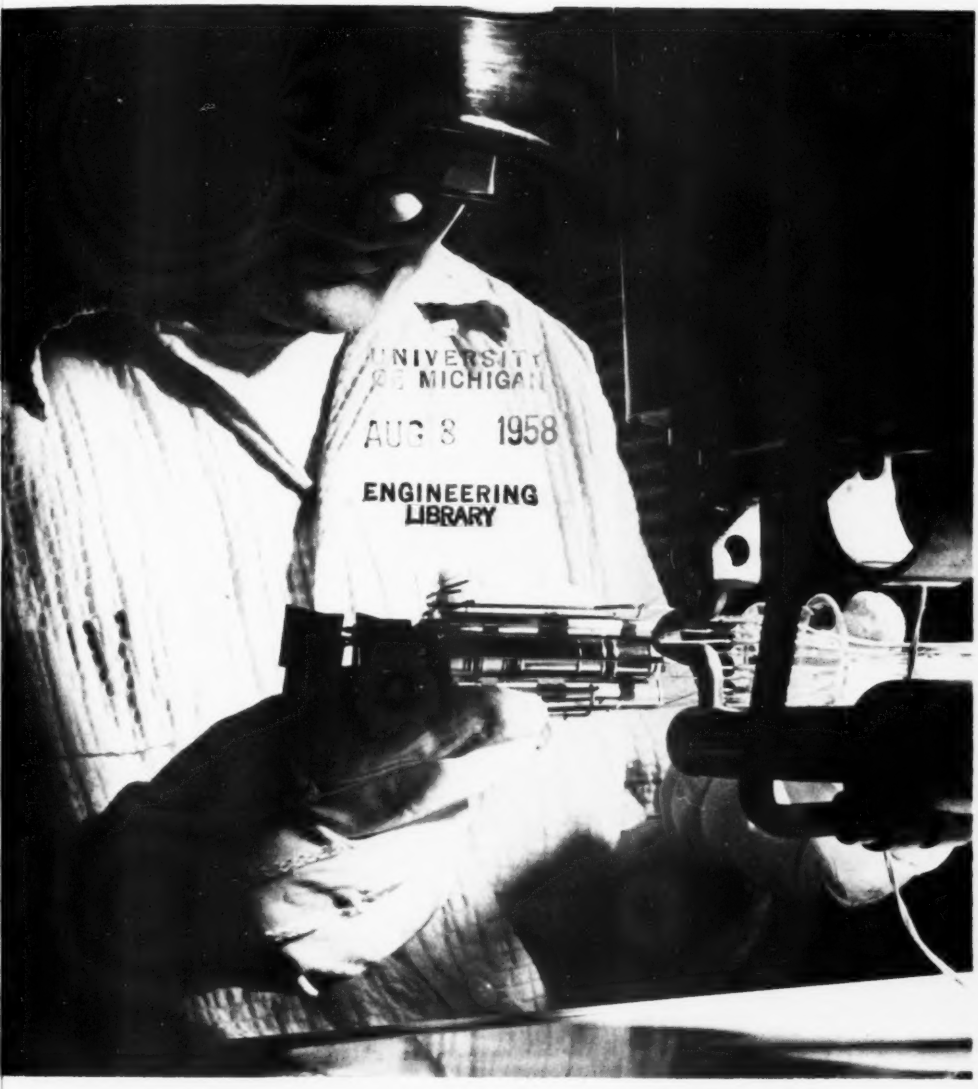
OFFICE OF NAVAL RESEARCH JULY 1958

RESEARCH REVIEWS



DEPARTMENT OF THE NAVY
WASHINGTON, D. C.

NAVEXOS P-510

Inflatoplane Takes to Water

The suitability of the Inflatoplane, an inflatable rubber aircraft built by the Goodyear Aircraft Corporation for the Office of Naval Research, was tested recently for water operations. For this purpose, it was outfitted with a hydro-ski fabricated of lightweight aluminum alloy and given a series of trial flights from Wingfoot Lake, Akron, Ohio, as illustrated on this page. As a result of the plane's successful performance on its new "feet," Goodyear engineers believe it can operate as well from snow, mud, and other slick surfaces as it can from water.

ONR began sponsoring research on the Inflatoplane back in 1956. Since then the Army has entered the program. Now Goodyear is building ten of the planes for the two Services.

The wing, tail, and cockpit of the unusual aircraft are made of two walls of rubberized fabric joined by nylon thread. To make this material rigid, less air pressure is required than to inflate an automobile tire. The new hydro-ski can be attached to the main landing gear in a matter of minutes.

The Logic of Computers and Neural Mechanisms*

Can the process of designing machines be mechanized? Are there some things that machines, for logical reasons, will never be able to do? To what extent can machines imitate human thought processes? Can machines grow? Can machines "reproduce" themselves?

A research group at the University of Michigan Research Institute has for some time been seeking answers to such questions as part of an investigation of the theoretical capabilities and limitations of machines. The investigation, sponsored in part by the Information Systems Branch of the Office of Naval Research, is headed by Arthur W. Burks, Professor of Philosophy. Dr. Burks worked with the late John von Neumann in the design of the computing machine of the Institute for Advanced Study at Princeton, New Jersey.

When speaking of machines, the group often prefers the expression "automata" because this word indicates that the machines may be capable of acting independently of immediate human direction. That is, in a rudimentary fashion they remember instructions and can act even though a human is not present. Probably the most "sophisticated" existing representatives of the sort of machines studied are the large automatic digital computers such as Univac, Maniac, and the IBM data-handling machines.

These modern machines are physically constructed of vacuum tubes, crystal diodes, transistors, and other electronic components. Earlier machines were constructed of electromagnetic relays, or notched cogs and gears. Earlier yet was the abacus with its beads strung on wires. The physical embodiments of computing devices may vary greatly; yet to some extent all these machines have similar underlying logical structures. The research group is interested in these underlying logical properties that persist regardless of the new "hardware" engineers may decide to employ.

Instead of working with hardware or direct schematics of hardware, the group works with various "languages" for describing the structure and behavior of machines. One such language is English, but because descriptions in English are often unwieldly, imprecise, or ambiguous, mathematical and symbolic-logic shorthand notations are preferred. Although mathematical and logical languages are rather stylized in "grammar" and restricted in "vocabulary," the precision gained makes up for these deficiencies.

A relatively simple "language" which is often employed to express the behavior of automata is the propositional calculus. A desired behavior expressed somewhat awkwardly and inefficiently in English might be "let junction C be active only if junction A is not active or B is not

*Adapted from an article published in Engineering Research Institute News, University of Michigan, April 1958.

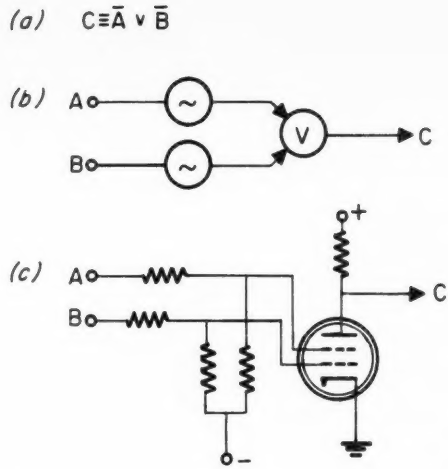


Figure 1

active." This can be expressed in the symbolic notation of propositional calculus as $C \equiv \bar{A} \vee \bar{B}$. Figure 1 shows several ways of expressing this relationship. In 1(a) we again have the expression in the notation of propositional calculus. In 1(b) we have a diagrammatic representation of a logical structure producing the desired behavior, whereas 1(c) gives the electronic schematic diagram an engineer might use in physically realizing the relationship. Each of these may be looked upon as expressing the relationship in a different language. These examples exhaust by no means the possible ways of expressing the relationship.

Many of the problems of the group have to do with the connections between these different ways of expressing relationships. There is a method for converting from expressions like those of 1(a) to those of 1(b). Unfortunately, there is no known general mechanical procedure, no algorithm, for converting from behavioral conditions to structural diagrams. The designing of machines would be much simpler if such a generally applicable algorithm could be discovered. If such an algorithm did exist, much of the problem of designing machines could be turned over to other machines. The designer would express the behavior he wanted the automaton to have, and then present this to a computing machine which would apply the algorithm and produce the structural specifications for the new automaton. The structural specifications could then be given to the engineer who would decide on the physical properties of the machine.

Just because a certain behavior can be expressed does not mean that a device could be built to act in that fashion. For this reason it would be advantageous to have another algorithm which would tell you whether or not it could be.

Automata may have different structures and yet behave exactly alike. It would be convenient to have a procedure which tells you when two automata are behaviorally equivalent, regardless of structural differences. If the structure of two machines is identical, then the machines will behave in the same manner for the same inputs. Often, however, there is no way of telling what the precise structure is. The machine may be a "black box." The investigator does not know the complete structure of the device inside the "black box," but he does have access to certain junctions of the device. Knowing the output that is produced when certain junctions are fed signals, the investigator can often infer a structure diagram which describes an automaton that has that behavior. The structure diagram might or might not be a true "picture" of the real structure of the device, but the behavior of the two automata would be identical.

A behavioral psychologist is frequently confronted with a similar problem. He does not know the precise structure of the human neural system. It is like a "black box" and is virtually sealed off from investigation. The psychologist does, however, have access to some of the "input and output terminals"—the sensor and effector organs of the human organism. He tries to determine the inputs that are correlated with certain outputs even though he does not know the precise nature of the "device" which transforms the input patterns into certain output patterns.

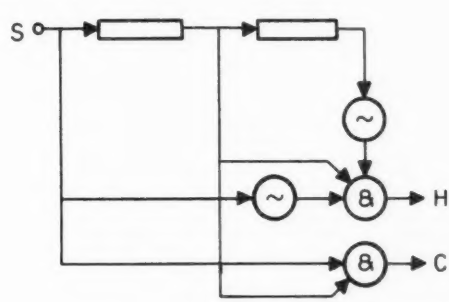
"Memory," cycles, and other timed action greatly complicate the analysis of human and machine behavior. Figure 2 indicates the relative complexity which results when even rather simple timed action must be expressed. The rectangles in the logical network diagrams represent unit time delays.

The behavior statement of Figure 2 may be read: "junction H will be active at time t + 2 only if junction S is not active at time t + 2, S is

(a) Behavior Conditions

1. $H(t+2) \equiv \overline{S(t)} \cdot S(t+1) \cdot \overline{S(t+2)}$
2. $C(t+1) \equiv S(t) \cdot S(t+1)$

(b) Logical Networks Structure



(c) Typical Pulse Representations

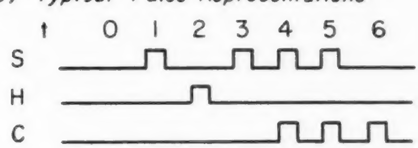


Figure 2

active at t + 1, and S is not active at time t. Junction C, on the other hand, will be active at time t + 1 if and only if junction S is active at time t + 1 and has been also active at the moment of time preceding (i.e., at time t).

This logical circuit behaves something like a certain small portion of the human nervous system. It imitates the familiar phenomenon which takes place when a cold object (a small piece of ice, for instance) is pressed against the skin. If the cold object is held against the skin for only a moment, the object feels as if it were hot. If, however, the cold object remains in contact with the skin for more than an instant, the nervous system registers correctly that the object is cold. In the diagram, "S" indicates the stimulus received from the cold object and "H" and "C" indicate, respectively, the hot and cold signals registered in the central nervous system. The pulse stimulus patterns which will result in "hot" or "cold" reactions are indicated in 2(c). Note that the reactions do not occur at the instant of stimulation but only after an interval of time.

The operation of the neurons of the nervous system can be modeled using combinations of the elements employed in logical design. The precise functioning of the central nervous system is not completely

(a) Behavior Conditions

$$E(t+1) \equiv A(t)\cdot B(t)\cdot \overline{D(t)} \vee A(t)\cdot C(t)\cdot \overline{D(t)} \vee B(t)\cdot C(t)\cdot \overline{D(t)} \vee A(t)\cdot B(t)\cdot C(t)\cdot \overline{D(t)}$$

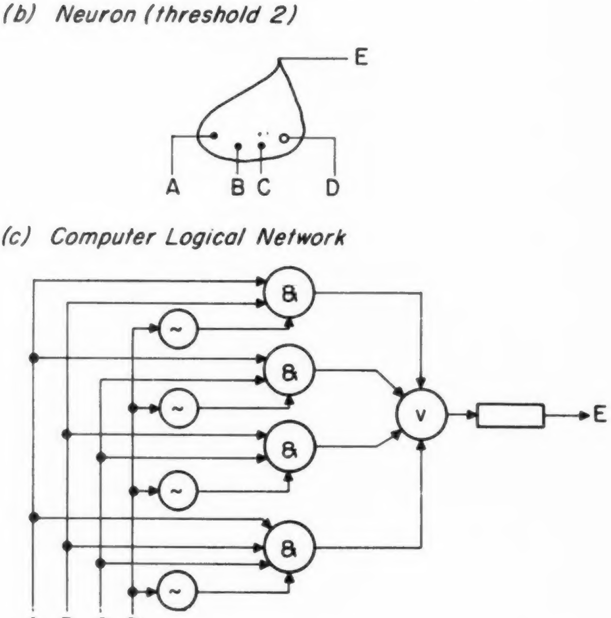


Figure 3

known, but physiologists have been able to determine that some elements of the system behave somewhat like electrical switches. These "switch" elements are called neurons. A neuron consists of a cell body upon which one or more nerve fiber "end-bulbs" impinge. (See Neuron, Figure 3.) The end-bulbs can be of two sorts: excitatory (A, B, C) or inhibitory (D). In general, a neuron will "fire" (discharge a small electrical pulse) if a certain critical minimum number of excitatory end-bulbs are activated. This critical minimum number of activated excitatory end-bulbs is called the "threshold" of the neuron. If, however, any inhibitory end-bulb is activated, the neuron will not fire even though the threshold value of excitatory end-bulbs has been reached. In Figure 3 there is also a representation of a computer logical network equivalent to the neuron.

It is apparent that more extensive logical networks can be used to model larger portions of the behavior of the human nervous system. It is hoped that, by increasing the scope and complexity of the modeling, more information as to the nature of physiological and psychological behavior may be obtained. The research group is conducting an investigation in this area and is beginning by considering how a logical-networks model of the nervous system could "learn." In particular, studies are being made, by computer simulation, on the ways in which the preferred pathways for a signal through a net may be altered by use. The precise paths over which nervous impulses pass in the human cortex may vary considerably as time goes on and "learning" takes place. The "connections" seem to change because the thresholds of triggering change. A path once used tends under most circumstances to be used again. This change which occurs may itself be called "learning." This sort of learning is also possible for a machine.

In addition to these rather simple human-like behaviors, there are many possible automata behaviors that would seem at first notice quite unlikely to be attained by a machine. For instance, in certain respects the machine can be thought of as "growing." One very simple way in which a machine "grows" is by addition to its information storage capacity, its "memory." Many existing computing machines possess this ability to enlarge their storage. This is accomplished by various means, but most commonly by allowing the connection of additional reels of magnetic tape, upon which data can be recorded. Machines can also be said to "grow" when new units are added to them to enable them to perform new operations. Logical theory can take such growth into account.

The problem of machines changing in size can be considered quite apart from the ways in which this increase in size is accomplished at present. The theory, for instance, need not apply merely to instances in which a human technician adds new tape-reel memory capacity or connects new control units; it can also apply to possible future situations in which machines control more fully their own changes in size.

Logical theory can also take into account a special sort of growth, the construction by a machine of a duplicate of itself. It is possible to describe a machine which would perform work useful to humans and then proceed to make an image of itself complete with the instructions to do useful work. This "offspring" would, in turn, make an image of itself. Even if this solution is acceptable on the level of mathematics and logic, one may find it difficult to visualize physical entities that might embody this process. However, as the late John von Neumann suggested, one might be able to visualize the "parent" machine paddling about in a sort of thick soup of spare parts. The machine scoops up a part at random, tests to see if it is the one it needs next, and, if so, fits it into place in the copy it is making of itself. As it completes the copy, the parent machine would insert a duplicate of its own instructions, and detach the new machine to begin its working life and then to forage for itself among the available spare parts to construct a copy of itself.

Army R&D Chief Visits NTDC

A prototype of the Corporal guided missile model was one of the many training devices viewed by LT GEN Arthur G. Trudeau, Chief of Army Research and Development, during his recent visit to the U. S. Naval Training Device Center, Port Washington, New York. COL K. H. Hunter, USA, Associate Director (Army) of NTDC, escorted GEN Trudeau on a tour of the Center. COL Hunter discussed the philosophy of synthetic training equipment and described the many Army training devices produced at NTDC through the cooperation of the Army and Navy training specialists working there.

LT GEN Trudeau (right) and COL Hunter discuss a model of the Corporal missile. The model can be taken apart to familiarize students with its various components and the location of each within the missile shell.

Skypaths

Flying many of today's military aircraft efficiently under all conditions requires superhuman capabilities. Pilots must now keep control of planes that move more than four times as fast as Lindbergh's "Spirit of Saint Louis" and more than twice as fast as the fastest planes of World War II. This means that they must respond to changing situations much more quickly than they have had to before. In addition, mission requirements have become increasingly complex, requiring that the pilot assimilate more and more data to function adequately. Furthermore, one of the pilot's information sources—the surrounding sky and terrain—is often obscured by weather or night. And the other—his instrument panel—is made up of such a bewildering array of dials, knobs, and switches that he cannot readily calculate what his next maneuver should be. Add to these limitations one other—that which exists because pilots are human beings (not supermen)—and you have the makings of an impossible situation.

These are the conditions under which military aircraft are now being flown. Fortunately, however, an entirely new system of providing information to the pilot, one enabling him to judge instantaneously what he should do in almost any situation—is now being developed and will soon be placed in both military and civilian aircraft. By means of the new instrumentation, pilots will be able to guide their planes from take-off to landing even more safely and surely than they drive their cars along the nation's superhighways. The development was begun by the Office of Naval Research and the Bureau of Aeronautics more than five years ago. Later, the Army Signal Corps joined in supporting the work, which is now called the Army-Navy Instrumentation Program (ANIP).

The new system consists in part of two transparent flat-plate television screens, one set vertically into the windshield of the plane's cockpit and the other horizontally in front of the pilot. On the vertical screen, a path-like representation of the course the plane's instruments indicate it should follow toward its destination is made to appear. With the plane exactly on course, this "pathway in the sky" stretches ribbon-like in front of the pilot, just as a road appears when driving a car. The background is a dynamic three-dimensional presentation of the sky and the ground. When the pilot is off course, the pathway appears at one side or below or above him.

On the horizontal screen is displayed a map of the area, showing the plane's navigational position. A controlled constantly contracting circle on the map indicates how far the plane will be able to fly at its current rate of fuel consumption.

The position of the pathway on the vertical screen provides the answer to one of the three primary questions the pilot is constantly thinking about—What should I be doing?" Answers to the other vital questions—"How am I doing?" and "What am I doing?"—are provided by additional information that is made to appear on both screens.

The pathway and other pictures displayed on the screens are artificially generated on board the aircraft from the same information sources that feed data to the dials on today's instrument panels. The bulk of the work required to convert this raw data to simple television pictures is done by a computer. This machine is capable of making 15,000 computations a second while processing data on flight conditions, yet is smaller than a breadbox and weighs less than 40 pounds. Thirty times a second it calculates the aircraft's exact location and tells the pilot the distance to his destination and the time required to reach it. At the same time, the machine figures out from the aircraft's performance and flight data the best possible speed and altitude to fly in order to use the least amount of fuel.

Navigation and fuel management now take a large share of a pilot's time and attention while flying supersonic aircraft. The "fuel mileage" of a jet plane changes greatly with the speed, altitude, weight, and settings of the engine controls. If the pilot wants to fly as far as possible with the fuel available, he must repeatedly calculate the best combinations of these factors, since the plane's gross weight changes as fuel is used up. Should bad weather or winds affect the plane's course or fuel consumption, and the pilot not be able to calculate their effects accurately, he runs the risk of venturing beyond a "point of no return."

With the new computer, however, accurate calculating and navigating are done automatically for the pilot. Should it become necessary for him to change his mission in mid-flight, he simply sets in the position of the new destination, and the computer immediately tells him whether or not he has enough fuel to reach it.

The key figure in the development of the ANIP instrumentation is CDR George W. Hoover of ONR's Air Branch. CDR Hoover has personally coordinated the work of more than 600 industrial firms, which, one way or another, have had a hand in the program since it was first undertaken. It has been largely through his efforts that the program has rolled so smoothly toward a successful completion.

The Douglas Aircraft Company, Inc., El Segundo Division, El Segundo, Calif., is the prime contractor for developing the new system for fixed-wing aircraft. Similar instrumentation for helicopters is being designed by the Bell Helicopter Corporation, Fort Worth, Texas.

Where do we go from here? Within a few years the first models of the new display will be installed in military and civilian aircraft. But improvements will continue to be made, leading to better models which will be placed in our aircraft many years hence. In addition, other applications will be made. Under ONR sponsorship, an investigation called Project SUBIC is now underway at the Electric Boat Company, Groton, Conn., to adapt the system to submarine control. A program for applying the instrumentation to surface ships is being planned, too. The display can also be used in tanks and in missiles and other vehicles guided by remote control. Looking still farther into the future, the "pathway in the sky" may well prove to be the guide our space ships will follow in flights between the earth and moon and the other planets.

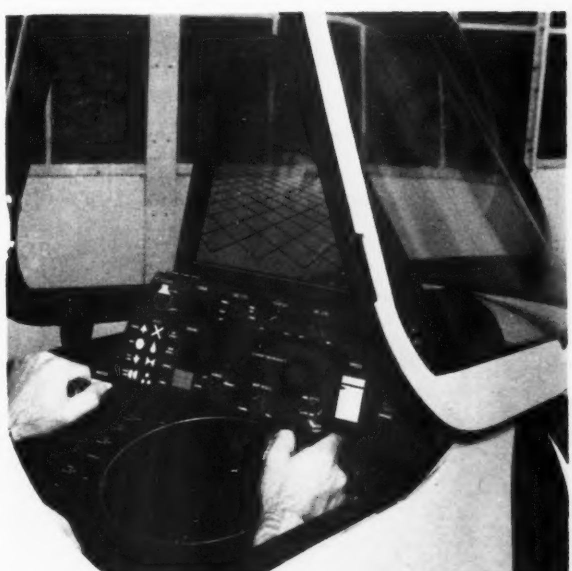
A pictorial description of the ANIP system appears on the following three pages.

The instrument panels in today's aircraft are characterized by a complex array of knobs, meters, dials, lights, and switches.

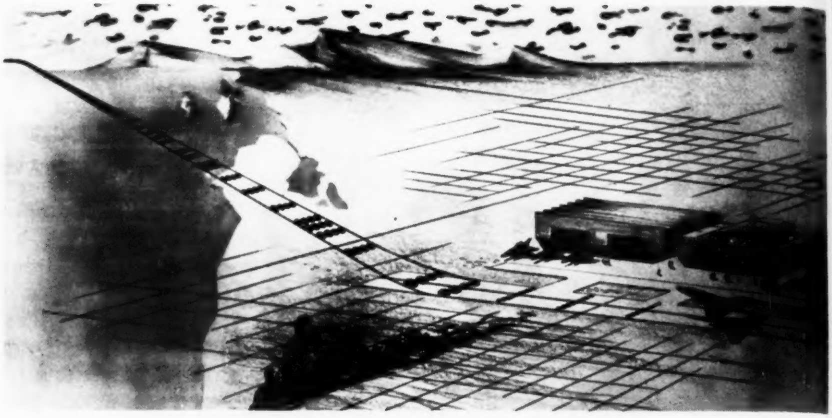
The Old and the New

Through the ANIP approach to cockpit instrumentation, flying "blind" will become a thing of the past. All the information the pilot needs to control his plane will appear on the new, simplified panels, much of it pictorially, regardless of the weather or time of day. The contrast in appearance of the old and new systems is as striking as the difference in capabilities between them.

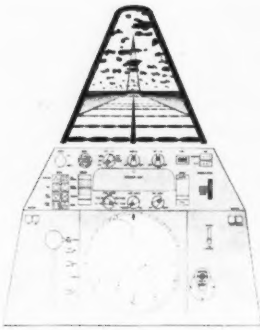
The ANIP panels are so "clean" they make flying look easy. Note the new locations of short control stick (in right hand) and throttle (in left hand).



Artist's Concept of the Plane and Pathway

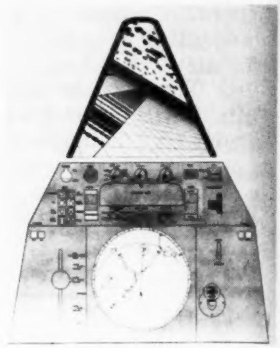


The takeoff. If the pathway were actually visible from this point of view, it would appear as it does here, stretching far ahead of the plane.

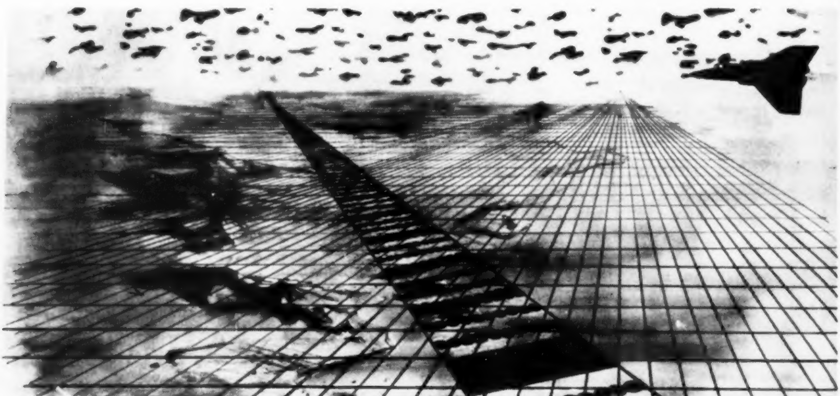


To the pilot taking off, the pathway looks like this. . . .

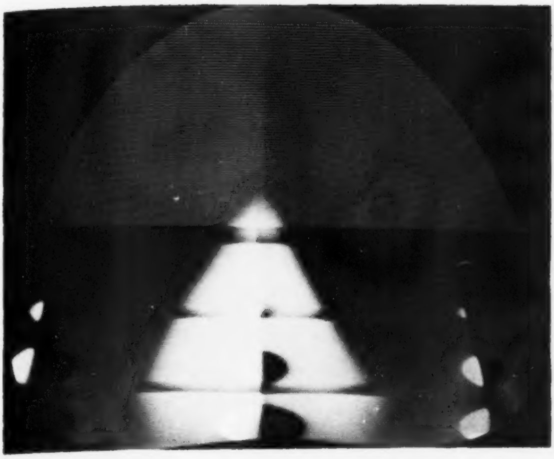
. . . .and when airborne, like this.



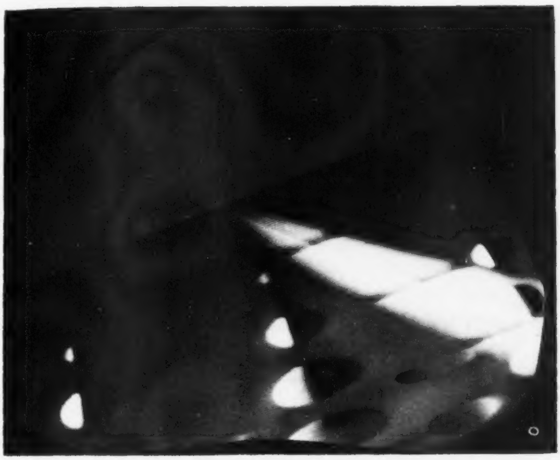
The plane maneuvers to get back on course. In this situation, the display panels would appear as they do at right above.



As the Pilot Sees the Pathway

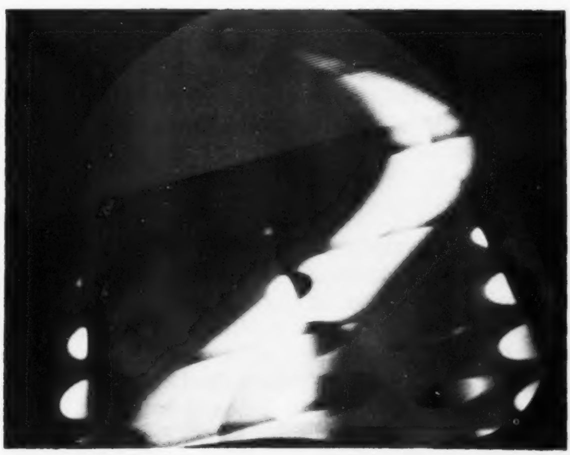


Here, the plane is directly on course, and the pathway extends straight ahead.

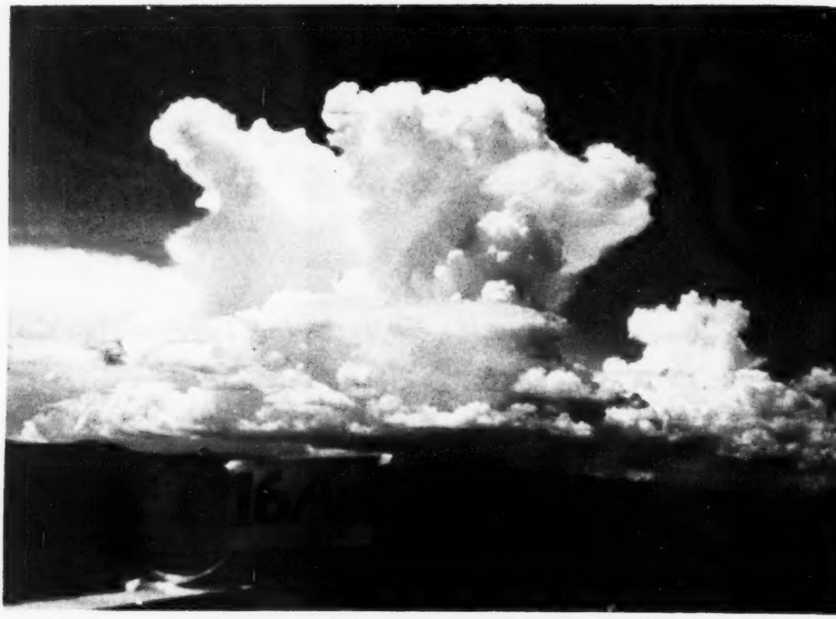


The photographs on this page were taken of the screen of a standard cathode-ray television tube. The image on the screen is identical to that seen by the pilot flying a plane equipped with the ANIP instrumentation.

Here, the pilot can see he is off course. He can easily make the proper adjustments of his controls to get back on the pathway again.



Here, the curving pathway tells the pilot that he must turn.



A cumulo-nimbus cloud over Mt. Withington, New Mexico. This storm is typical of the simple air-mass storms studied by the author. The first electrification appeared at 11:14 A.M. and the first precipitation at 11:16.

Relationships Between Thunderstorm and Fair Weather Electricity

Bernard Vonnegut
Arthur D. Little, Inc.

Students of atmospheric electricity generally subscribe to British physicist C. T. R. Wilson's theory that the fair-weather atmospheric electrical field is caused by thunderstorm electrification. There is good evidence for believing his idea that the thunderstorms continuously occurring on the earth are the electrical generators that maintain the ionosphere at a positive potential of about 300 kv with respect to the earth. Under the influence of this potential difference, a continuous current flows from the ionosphere to the earth giving rise to fair-weather space charge and electric fields.

Although there is general agreement that fair-weather electricity is caused by thunderstorms, there is a divergence of opinion on the question of whether or not the charge-generation process in thunderstorms is caused by fair-weather atmospheric electricity. At the present time there are perhaps half a dozen or more theories to explain how thunderstorms become electrified. Some of these theories are based on the idea that the electrification is initiated by the fair-weather field or space charge. For example, C. T. R. Wilson has proposed that electrification could be caused by the selective capture of negative charge by falling raindrops polarized by the fair-weather field. And G. Grenet, a French physicist, has suggested that electrification could be initiated by the convection of fair-weather space charge into growing cumulus clouds.

On the other hand there are theories of thunderstorm charge generation that do not involve fair-weather electricity. As examples of these we have the theory of G. C. Simpson that the charge is generated by the breaking of water drops in vertical air currents, and that of S. E. Reynold that it is caused by collisions between graupel particles (soft hail) and small ice crystals.

Which of these two classes of mechanisms is correct is of some consequence. Both the fair-weather electric field and space charge are subject to considerable variation with time and location and are strongly influenced by aerosols in the atmosphere and by natural and artificial ionization. If the electrification of thunderstorms is initiated by fair-weather electrification, we might expect that the development and nature of these storms would be subject to considerable variation from this cause. On the other hand, if thunderstorm electrification proceeds from other mechanisms that do not involve the fair-weather field, we would expect to find no correlation between the thunderstorm's behavior and the preceding fair-weather electrical variables.

There is a good chance that it may be possible to control the beginning of the charge-generating mechanism in thunderstorms if it is initiated by fair-weather atmospheric electricity. The power involved in maintaining fair-weather electric fields is not large, amounting to only about one watt per square mile. It appears that the fair-weather field could be modified over considerable areas with a moderate expenditure of energy.

The nature of the earth's atmospheric electrical process will be quite different depending on which of the two types of thunderstorm charge generation mechanisms is correct. If thunderstorm electrification depends on the fair-weather atmospheric field and space charge, then the atmospheric electrical process would have a positive feedback. It would be quite similar to self-exciting electrical apparatus, such as the Wimshurst machine and generators of the sort that do not generate current until they have a field and do not have a field until they generate current. If this is the case, the earth's electrical process could operate with either polarity or be in an unexcited state with no activity at all.

However, if thunderstorm electrification is independent of fair-weather electricity there is no feedback in the earth's electrical process. If this is the case, the electrification of storms and the currents they cause to flow to the ionosphere would be quite independent of the ionospheric potential.

There are several ways that one might determine whether or not the electrification in thunderstorms is related to the fair-weather space charge and the fair-weather field. One is to see whether the electrical behavior of storms can be related to the fair-weather electrical variables prior to their formation. Another way is to see if the electrification of storms can be influenced by artificially controlling the electrification of the air from which they form.

As part of the research program on atmospheric electricity that we have been carrying out under the sponsorship of the Office of Naval

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Research and the Bureau of Aeronautics, we have endeavored to determine in both of these ways whether or not storm electrification is influenced by fair-weather electricity. Our results are still far from conclusive, yet they appear to be consistent with the idea that fair-weather electric charge may play a part in the initiation of thunderstorm electrification.

In observations made from an airplane of fair-weather cumulus clouds, both in New England and in the Middle West, we observed weak electric fields, indicating that some clouds had positive and others negative tops. In general, the distribution of space charge in the air from which these clouds were growing was quite complex and consisted of layers of both positive and negative charge. It was difficult, therefore, to know just what net charge the growing cloud was "inhaling" and to be sure whether the observed polarity was that predicted from theory. We were never lucky enough to observe one of these clouds changing into a thunderstorm to see whether the polarity of its electrification was the same as that of the initial cumulus cloud. In several cases wherein fairly large, vigorous cumulus clouds were observed growing from substantially neutral air, no electric fields associated with the cloud could be detected.

During the past summer we conducted experiments from the summit of Mt. Withington, New Mexico, to measure the electrification of the thunderstorms that form over it almost daily (Re[illegible]views, September 1957). We found that under fair-weather co[illegible]ns on the summit, the space charge in the air that presumably is rising to form these clouds contains quite a high concentration of positive charge. Our observations of the early stages of the electrification process, made with field meters carried on tethered balloons and with an airplane above the cloud, show that these clouds have positive charge in their tops and negative charge in their bottoms (before any precipitation could be detected by radar). This polarity appears consistent with the idea that the electrification is caused by the fair-weather space charge.

Last summer in preliminary experiments carried out at Jacksboro, Texas, we attempted to influence cloud electrification by introducing rather concentrated negative charge into the atmosphere. This was done with a wire about 4 miles long and 30 feet high that was maintained at a high D.C. potential. In these experiments we found that the negative space charge we were introducing reversed the normal fair-weather field for 4 or 5 miles downwind. On occasions when low cumulus clouds were growing from this region of artificially electrified air, we found that the electric fields beneath the clouds were far more strongly reversed than elsewhere. There appears little doubt on the basis of these observations that our artificially produced charge was entering these small clouds. Unfortunately, because of inadequate instrumentation, we do not know whether or not the clouds receiving the charge finally developed into thunderstorms downwind and whether or not the charge modified their subsequent electrical development.

We are hopeful that further experiments will eventually lead to a clearer understanding of the relationships between fair-weather and thunderstorm electricity. Furthermore, we hope to learn to what extent cloud electrification can be influenced by the artificial introduction of electric charge and what effect, if any, electrification has on cloud behavior.

Is it Reliable?

Operations Evaluation Group
Office of the Chief of Naval Operations

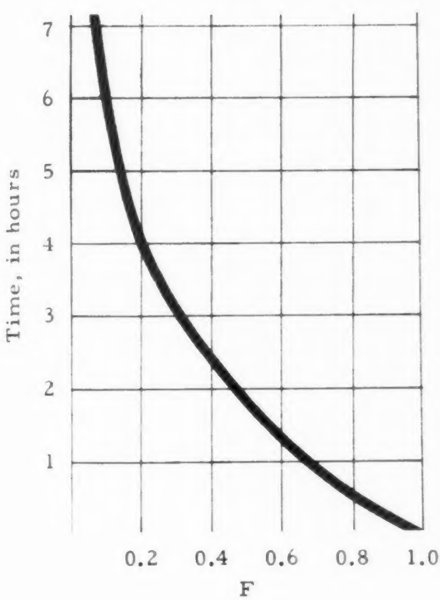
Improved performance = complexity = more parts = more parts to fail.

It is a sad fact that as our advancing technology increases the range, speed, and accuracy of military devices, the less likely they are to operate when needed. Several basic questions are related to this problem.

- How is reliability measured?
- What is the effect of unreliability on military operations?
- Basically, what causes unreliability?
- When do failures occur?
- What is being done to improve the situation?

MEASURING RELIABILITY

To answer the first question, let's consider the reliability of an imaginary airborne intercept radar which we have placed in each aircraft of a squadron. If we keep a record of the length of time each instrument operates properly before failing, we can construct a curve of its "probability of survival." A sample curve appears below.



Probability of survival of an imaginary airborne intercept radar. The curve shows the lengths of time the radar functioned before failing for various fractions (F) of all of its operating periods.

It is evident that a large fraction of these operating periods lasted one hour or more, but that only a small fraction lasted longer than three hours.

The reliability of the radar can now be defined in terms of the mission time of the aircraft. For example, the probability that the radar will operate satisfactorily throughout a two-hour patrol is 0.45, or 45 percent. If the mission time is four hours, more aircraft should be sent, because the probability that any one radar would function throughout the mission would be only 20 percent. A decrease in reliability may thereby raise force requirements considerably, making it necessary to send more aircraft on each mission or, preferably, more aircraft on staggered short flights.

Survival curves for most complex equipment approximate the one shown. Scientists describe such curves in terms of "mean life"—the average time a set functions before failing, taking into account the frequency of occurrence of different times to failure. By bisecting the curve we have drawn, the mean life is found to be 2.5 hours.

WHAT IS THE EFFECT OF UNRELIABILITY ON MILITARY OPERATIONS

From this example it is easy to see that attempts to improve the performance of a military tool or weapon may call for an increase in force requirements—to keep enough pieces of equipment in operation to carry out assigned missions. Just as clearly, the size and composition of manpower forces may be changed, too. As technology extends man's senses and his reach to such an extent that he seldom sees his adversaries, more and more men will be required to nurse and repair the aids which make this possible. Men capable of performing these functions are not necessarily better or worse than those proficient in combat, but they probably are rarer. If standard equipment is not reliable, there simply may not be enough men available to repair it.

Low reliability costs money as well as manpower. Repairs made on electronic equipment during its lifetime are estimated to cost between 10 and 100 times the initial cost. This obviously makes it desirable to spend more initially, if doing so will reduce the need for upkeep. But today there is no easy way to purchase such a return.

WHAT CAUSES UNRELIABILITY

Obviously, a complex device fails because some component fails. But what leads to the breakdown? In general, there are two major causes of failure—stresses set up by physical factors and stresses set up by the activities of human operators.

Physical stresses.—The physical stresses which cause components to break down present a sliding scale of complexity. At one end of the scale are mechanical and hydraulic components, which are well understood; their failures are predictable and therefore, with proper design, can be avoided. At the other end are certain electrical and electronic components that never were adequate to begin with, and thus fail quickly. Some of these troublesome failures occur after known times, while others simply happen at random. Random failure is typical of vacuum tubes, for example, especially when exposed to shock or vibration.

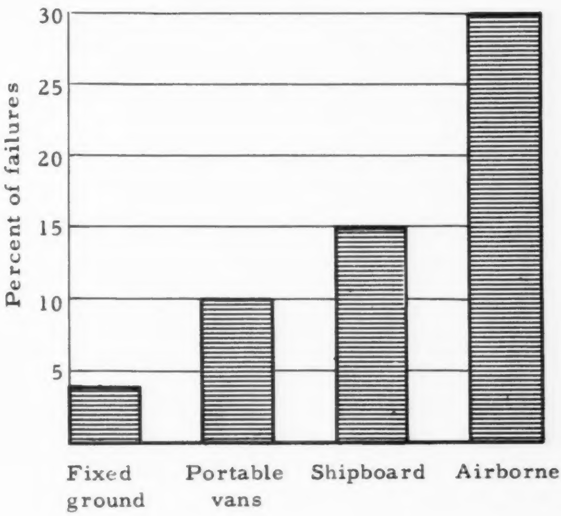
What factors give rise to physical stresses? Mechanical stresses, such as shock and vibration, are caused by the motions of the ship, aircraft, or other vehicle. Electrical stresses include the effects of voltage transients or intermittent shorts. Thermal stresses are brought about by high ambient temperature and thermal gradients. Chemical stresses are set up by water vapor and chemicals borne by the atmosphere. In aircraft equipment, pressure changes which occur when a plane ascends or descends act as a stress by allowing the discharge of electricity on the surface and by making sealed units breathe in chemicals.

But even when the magnitudes of the stresses are known, the time a component will operate before failing is difficult to predict. In fact, if identical components are subjected to the same stresses for the same period, they probably will not fail at the same time. In other words, "identical" components are not identical but have different stress resistance due to variations in the material used in their construction, to variations in handling when assembled, and to other factors. It is possible to account for chance failures of components by combining the effects of variations in stress resistance and random variations in applied stress.

As was previously indicated, most failures occur in the electronic portions of complex systems. Such systems are of two general types: reusable equipment, such as radar and communication sets, and expendable equipment, such as proximity fuzed AA shells and guided missiles. Expendable equipment has a higher failure rate than reusable equipment for several reasons. First, the stresses in guided missiles or in AA shells, particularly during boost, are greater than those in conventional equipment, with the result that temperatures become too high.

Even in reusable electronic equipments a wide range of stresses exist. This is well illustrated by the mortality rate for vacuum tubes during the first 1,000 hours of operation in the following situations:

Mortality rates for vacuum tubes during the first 1,000 hours of operation in several different situations.



How useful it would be if we could discover what stresses exist in a given situation, for it would then be possible either to manufacture components capable of withstanding those stresses or to modify the environment so that available components would survive. Components of reusable electronic equipment are being developed which withstand the measured stresses fairly successfully. For expendable equipment, however, this cannot always be done, because it is so difficult to obtain information about the environment in which the components are to operate. In most cases of missile-flight failure, it is even impossible to determine which component failed, let alone the cause of failure, since the majority of missiles recovered are those which did not fail.

Most of the present effort to improve missile reliability has centered on determining, by tests made before flight, which components fail. In other words, we are making these missiles able to survive test-bench operation, but clearly we have much to learn of the magnitude of stresses created during actual flight.

Operator stresses.—Both the components and entire systems are subject to another class of stresses: those produced by the users. The equipment is linked to an operator through a set of controls. The controls must be designed so that random twiddling cannot result in internal stresses which cause failure. Furthermore, the operator must be presented with information that tells him whether the equipment is functioning properly.

Recognizing whether a complex device is functioning as it should, or at all, is sometimes very difficult. This can be seen from the fact that of all parts replaced when military equipment is repaired, roughly one third have no defect whatever. In a certain sense, the diagnosis problem is insoluble, since ambiguity can usually be reduced only by making the test equipment more complex. If this is done, the test equipment itself is then more likely to fail. And so on.

During the diagnosis of failure of a complex equipment, one or more parts usually are removed and individually tested. Tubes are more easily removed than most other components, which are generally soldered in, and consequently they are most often suspect. In fact, roughly two thirds of all defects in typical electronic devices are ascribed to tube failures by electronic technicians. When the same equipment is maintained by factory engineers, only one third or so of all defects are ascribed to tubes. In other words, with individual components as well as with complex equipment, there is room for error in determining whether the device is functioning properly.

One way to reduce indiscriminate tube-pulling is to design each equipment as a set of "black boxes." Test apparatus could then be designed to tell which black box should be replaced. One difficulty with this scheme is that black boxes would soon be replaced as casually and as hopefully as tubes now are. And black boxes are much more expensive.

Unnecessary repairs are costly and also have an indirect effect on reliability; every repair effort has some chance of planting the seeds of future failures. In fact, roughly one fifth of all failures can be traced to damage started when previous repairs were made. This accounts in part for the lack of success of so-called "preventive maintenance," the practice of replacing components periodically so that only "young" ones will be present. The act of replacement is destructive and the "young" components have the same probability of failing in the next operating cycle as have the older ones.

WHEN FAILURES OCCUR

Failures occur most frequently shortly after equipment is turned on. Many ships, for example, find that failures are more numerous just after an in-port period than they are after a few days at sea. As a consequence, some operators never turn the equipment off. It is too early to say whether this scheme really improves reliability. One penalty of continuous operation is that power must be supplied at all times. This is not easily managed for aircraft that are not in operation, because their generators are not functioning. Therefore, the equipment must be hooked up to a power source at the ground station. At least one aircraft fire has resulted from this arrangement. Another penalty is that tubes eventually deteriorate due to the migration of chemicals in the metal and glass parts kept at high temperature. This latter effect has been a serious problem in large electronic computers, which are seldom shut down.

IMPROVING RELIABILITY

In which directions must effort be applied to improve reliability in the future, and what are the prospects for improvement? The mortality rate of the best vacuum tubes (in giant computers, for example) is about 0.1 percent failures per 1,000 hours of operation. This compares with 30 percent per 1,000 hours for similar tubes used in airborne electronic devices. Obviously, even the best tubes are not constructed to withstand airborne use. The upper limit on tube mean life in "easy" environments is set by the cost of best materials plus best labor and good inspection teams. If tube life in severe environments is to improve, the cost must increase to pay for studies of the environment, the engineering design, and greater care in assembly and inspection.

Of course, work also needs to be done to improve components other than tubes. All components, but fixed resistors in particular, must be better designed mechanically to withstand severe vibration. They can be protected from shock, but this does not solve the vibration problem because a good shock absorber is a good vibration transmitter. Since it is easier to build a good shock-absorbing mount than to build a vibration isolator, components must be built to take vibration.

Improvements of isolated components must be matched with careful circuit and system design studies, if equipment reliability is to improve also. The designer must match component capabilities with the desired functions. For example, increased reliability may result from the use of more components, if the addition means less workload on each. Also, components of low reliability can be duplicated to provide spares when needed. Complicated equipment must be designed as a unit, so that all interactions may be accounted for. Guided missiles, for example, should be designed by a single team, not be separate teams for power plant, airframe, hydraulics, electronics, warhead, and so forth.

At present it would be difficult, but not impossible, for equipment designers to prepare estimates of the trade-offs between reliability and performance and between reliability and cost. Such estimates should be requested in the future, for they will enable the military planner to decide with greater assurance whether or not to push for more performance and when a higher price would be worth paying.

Often in the process of achieving better performance an upper limit of equipment complexity is reached, beyond which the equipment becomes less and less reliable. This may more than offset the improved performance. Designers should be asked to estimate this limit for their equipment when used in a specific environment.

There probably always will be some equipments which, because they push available components to new limits or because they are too complicated, cannot be made sufficiently reliable. In such cases, the design must emphasize rapid and, eventually, automatic diagnosis and easy accessibility for repairs. However, care must be taken to avoid designing an equally complicated equipment to perform the diagnosis. In order for an equipment so designed to be used effectively, special command attention may be necessary. For example, effective use of radar having a magnetron of low mean life might require a man to stand by with an extra magnetron to plug in immediately.

IN SUMMARY....

The price paid by the military services for equipment that is unreliable is high, no matter how measured, whether in dollars, in force requirements, or in engagements lost. Considerable effort is now going into determining when and why components and equipments fail; this research should continue. Basic research on components should also be subsidized further, and contractors should be encouraged to design future complex systems with a unified approach, keeping in mind the problems of both operator and maintenance crews. In addition, analyses are needed of the trade-offs between cost, performance, and reliability for future systems. When technical improvements cannot be made, new policies of operation and maintenance should be adopted.

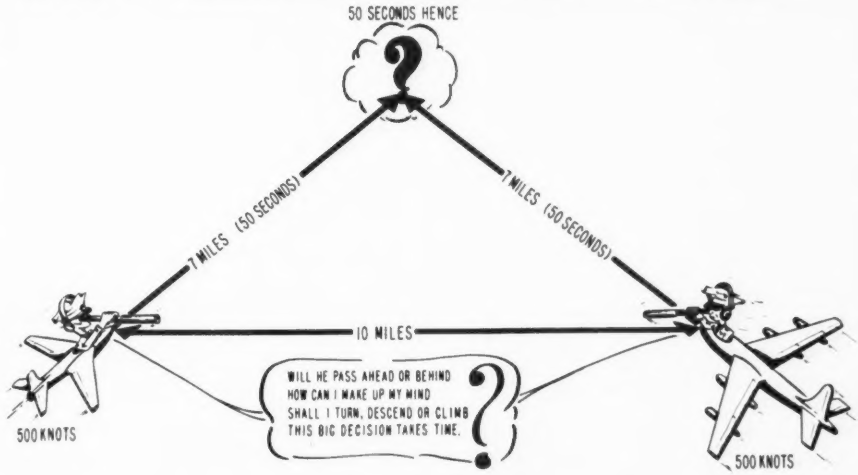
Navy to Build Radio Research Observatory

Late this summer, construction of a $60 million radio astronomy facility, to be known as the Naval Radio Research Observatory, will begin in the mountains near Sugar Grove, West Virginia.

NRRO will be one of the foremost scientific tools available for studies of outer space, for advanced research on characteristics of the earth's atmosphere, and for obtaining geodetic and geomagnetic data on the earth itself.

Research Notes

Toward a Solution of the Aircraft Collision Problem



What is the likelihood of your becoming a collision casualty during your next airplane trip? A Civil Aeronautics Board report for the period September 1, 1956 through June 1, 1957 lists 1,080 near collisions. This amounts to about four near misses per day. A study of these incidents indicates that often only one of the pilots of the planes involved in near collisions was aware of his danger, and that often the pilots of the converging aircraft barely had enough time to correct their potentially dangerous flight paths.

Mid-air collisions are occurring more frequently these days because of the higher speeds at which aircraft now fly and because of the increasing density of air traffic. Furthermore, a sharp rise in the rate at which these accidents occur can be expected in the next few years as the amount of jet traffic increases.

Recently, many proposals have been made for solving this problem. The equipment ranges from proximity warning devices to complex trackers, both infrared and radar. Although the techniques are based on the sound principle that each aircraft should carry its own equipment for gathering data on potential collisions, rather than relying on information transmitted from ground stations, the schemes are not foolproof. The mere detection by one aircraft of the relative position of another aircraft in the same general airspace is not enough to provide a basis for calculating potential collision risk, let along for determining a collision-escape maneuver.

What, then, can be done to avert collisions? One possible solution has been offered by a group of investigators at the Naval Research Laboratory. Their plan calls for a collision-avoidance system utilizing radio-communication and computer techniques. The system would function in this way:

First, the equipment in each plane occupying the same general air space would automatically interrogate information sources in the other plane. The data sought would include relative position, flight direction, altitude, and speed. In response, the equipment in the second plane would automatically transmit the data. On the basis of this intelligence, which would also be transmitted from the first plane to the second plane, computers in each plane would calculate the collision risk which existed. If the planes were converging, the equipment would automatically steer each plane on a course that would insure safe clearance.

Such a system could include a radar for measuring relative position, an interrogator-transponder to allow private communication, and computer elements to solve necessary equations. As a substitute for radar, which would probably be too expensive to install in all aircraft, a combination of radio position-measuring equipment and inertial velocity-sensing equipment could be used. The only new instrumentation required for the system would be the computing elements, communication coding elements, and the output-alarm circuits.

The NRL investigators are continuing their study of the aircraft-collision problem. Their aim is to specify the minimum requirements of an absolutely reliable system. This will enable them to better evaluate the devices proposed for application to military and civilian air-traffic control problems.

A-Subs Set New Submergence Record

New endurance marks for continuous submerged operations have been set by the nuclear-powered submarines SEAWOLF and SKATE. When the two craft surfaced recently off Long Island Sound, they had spent more than 30 consecutive days underwater and had steamed more than 8,000 statute miles. During the period, the air in the submarines was constantly replenished by the ship's machinery. This is the longest known time man has been exposed to an artificial atmosphere under actual rather than laboratory-controlled conditions.

The achievement was made possible in large part through research done by the Chemistry Division at NRL on equipment and systems needed to make the submarine atmosphere habitable during long periods of submergence. This has resulted in the development of methods for analyzing the air, for revivifying the air by adding oxygen to it, and for eliminating contaminants.

ADM Arleigh A. Burke, USN, Chief of Naval Operations, described the cruise as "a real test under actual operating conditions upon which the very lives of the personnel involved depended." He said, "The men who established the new mark dramatically proved the ability of the Navy's submarine service to conduct unrestricted operations under artificial atmospheric conditions with no adverse effects. This is a major breakthrough of the first magnitude with implications extending far beyond the realm of underseas warfare." (For a discussion of the similarities of submarine and space-ship atmospheres, see "Accommodating the Space Man," Research Reviews, June 1958.)

Poisonous Fishes

In a report issued recently by the U. S. Public Health Service, LCDR B.W. Halstead, MC, USNR, says that poisonous fishes are causing mass intoxications in the western Pacific. These outbreaks began about 1952, became increasingly severe during 1955, and have continued until the present time. According to estimates, more than 40,000 persons have been poisoned. Most of the poisoning has occurred in Japan, the Philippine Islands, and more recently, in Viet Nam. The fishes causing the outbreaks are octopus (Octopus vulgaris and O, dofleini), squid (Omnastrephes sloani pacificus), Japanese horse mackerel (Trachurus japonicus), common Japanese mackerel (Scombar japonicus), flying fish (Prognichthys agoo), and oceanic bonito (Katsuwonus pelamis). All of the outbreaks have been seasonal, taking place from June to the middle of September.

A similar outbreak occurred between 1943 and 1946 at Midway, Johnston, and the Line Islands. Before that time fish poisoning was sporadic and unpredictable, generally affecting only a small number of people at any one time. It did not, therefore, attract a great deal of attention in medical circles.

Apparently, any marine fish can under certain conditions become poisonous as a result of its food habits—feeding on marine algae. This is indicated by the fact that more than 300 species have been incriminated as the cause of only one of the eight types of poisoning that have been identified. Bacteriological tests have been negative, and the degree of freshness of the organisms seems to have no bearing on the poisoning. There is no evidence that plankton or radioactive substances are factors in the production of poisons.

Poisonous fishes are largely circumtropical in distribution, but on occasion, occur in temperate waters. With the exception of two or three boreal species, they are now believed to range between 45° N. and 45° S. Particularly large populations occur in the central Indo-Pacific area and in the West Indies.

Within these general areas, poisonous fishes seem to be limited in distribution. For example, they are more common near islands than they are along continental shores. And they may vary considerably in their distribution about a single island. In fact, a single species may be toxic in one part of an island, but edible in another. As a rule, lagoon fishes are more likely to be poisonous than those living on seaward reefs. Fishes captured in deep waters far from shore are generally safe to eat.

If a fish is toxic, the muscle tissue will be found to be poisonous in about 50 percent of the specimens, and the viscera, in about 90 percent or more. However, the distribution of the poison in the body of the fish will vary from one individual to the next. No consistent pattern has been observed as to the relationship between the size of a fish and its toxicity.

As far as is known, one cannot detect a poisonous fish by its appearance. The most reliable field method is to feed a small sample of the fish to a kitten or a dog. If the animal remains asymptomatic for 12 hours, the fish is generally safe to eat. Investigations are now in progress at the School of Tropical and Preventive Medicine, Loma Linda, Calif., aimed at developing a reliable, rapid chemical field test.

The treatment of fish poisoning is largely symptomatic. There are no specific antidotes, and an attack does not impart immunity.

The HSS-1N

A new helicopter capable of day and night flight under instrument flight conditions is now in production at Sikorsky Aircraft Division of United Aircraft Corporation. The single-engine craft, labeled the HSS-1N, is the latest Navy version of the familiar Sikorsky S-58, which is widely used both for military and commercial operations. Seven years of research and development by Sikorsky engineers and the U.S. Navy have gone into its development.

The instrument flight capability of the HSS-1N gives the aircraft an unprecedented potential, particularly for anti-submarine warfare work.

A major step toward instrument flight for helicopters was the development of automatic stabilization equipment (ASE) (Research Reviews, April 1957). In simplest terms, ASE is an electronic system which unburdens the pilot of the necessity of making constant adjustments to control the helicopter. It is similar to the auto-pilot of fixed-wing aircraft, except that it operates during all flight conditions to improve the helicopter's handling qualities. Expressed in another way, ASE allows the pilot to monitor the helicopter's performance in a comparatively relaxed manner.

ONR Branch Office Representative Honored

At a ceremony held recently at the Harvard Club of Boston, eleven emeritus members of the faculty of the Harvard School of Public Health were honored by Harvard's president, N. M. Pusey. Among this group was Professor E. B. Wilson of the Boston branch office of the Office of Naval Research. An appreciative citation prepared for the occasion traced the main features of Dr. Wilson's career. These included receipt of a Ph. D. degree in mathematics at Yale, headship of the Department of Physics at the Massachusetts Institute of Technology, and professorship of vital statistics at the Harvard School of Public Health. He gave the Lowell Lecture at Boston on aeronautics and the Stevenson Lectures on social sciences at Glasgow. He has been president of the American Academy of Arts and Sciences, the American Statistical Association, the Social Sciences Research Council, and vice president of the National Academy of Sciences. He has also been a member of numerous important committees and has served as a consultant for the National Committee on Aeronautics of the National Academy of Sciences.

On the Naval Research Reserve

Medical College of Virginia Honored

The role played by the Medical College of Virginia, Richmond, Virginia, in support of national defense was recognized recently at a ceremony held in the office of Dr. R. Blackwell Smith, Jr., president of the institution. The recognition was given through the Department of Defense Reserve Award, which was presented to Dr. Smith on behalf of the Secretary of Defense by RADM French R. Moore, MC, USN, representing the Commandant, Fifth Naval District.

Also present at the function was CAPT Roscoe D. Hughes, USNR, Commanding Officer, NRRC 5-5, Richmond, Virginia, who initiated the nomination for the award. In his civilian capacity, Dr. Hughes is head of the Department of Biology and Genetics of the college. Others who attended the event included members of the college and local representatives of the Army, Navy, Air Force, and Marine Corps.

In making the presentation, RADM Moore said in part, "There was a time in the not too distant past when the task of providing for the national security was left primarily to the regular components of the Armed Forces. Today, this task must be shared by all of us—the regular components of the Armed Forces; you in medicine and dentistry and the allied sciences; and the large group of civilian sailors, marines, soldiers, and airmen who make up our trained reserve force. Without a properly constituted and trained reserve force, this country would not possess the strength in depth that it now has. The Secretary of Defense and the Secretary of the Navy are most appreciative and grateful that you have taken it upon yourselves voluntarily to assist in strengthening the reserve training program of our Armed Forces."

Dr. R. Blackwell Smith, Jr., President of the Medical College of Virginia, receives the Reserve Award pennant from RADM French R. Moore, MC, USN. Pictured also are LCDR L. D. Abbott, Jr., USNR, and CAPT R. D. Hughes, USNR.

Seminar in Aviation Medicine

The third annual Reserve Research Seminar in Aviation Medicine was held at the U. S. Naval School of Aviation Medicine in Pensacola, Florida, from May 12 to 25, 1958. Among the 33 reservists of the Army, Navy, and Air Force who attended were physicians, psychologists, basic medical scientists, engineers, and representatives of the professions of psychiatry, ophthalmology, dentistry, optometry, radiology, pathology, and electronics.

The purpose of these seminars is to provide reservists with a broad understanding of the role of naval aviation in the conduct of modern warfare and of the personnel and operational problems this gives rise to.

At the beginning of the seminar, the Chief of Naval Air Training and his staff discussed the logistics and training problems involved in the procurement, selection, training, and retention of naval aviators capable of handling the complex, expensive, and "hot" aircraft now being delivered to the Fleet.

Among the other subjects dealt with was the physics of the upper atmosphere, outer space, and satellite launching. These talks were followed by discussions of the biological, physiological, and psychological problems which confront man in high speed, high altitude flight under all-weather and combat conditions. In addition, special presentations were made on the biological and psychological problems involved in the explorations of outer space.

Visits and informal discussions were held with small groups in the various research laboratories. These included physiology, biochemistry, low pressure, acoustics, radiation, electron microscopy, ophthalmology, and psychology.

The crash circuit is explained to reservists.

Special tours were conducted to outlying flying fields. There the reservists observed various phases of training, such as pre-flight, primary and basic flight training, navigation, instrument flight operations, communications, escape and rescue, and helicopter and jet operations.

One day was devoted to a trip to Eglin Air Force Base for a demonstration of fire power and long-range high-altitude aircraft.

The use of pressure suits to protect the pilot against gravitational forces in high-speed maneuvers as well as in escape from aircraft at high altitudes was demonstrated. At the USAF Air Proving Ground Command, tests of planes and ordnance under climatic conditions simulating the tropics and arctic regions of the earth were observed. Donning arctic clothing, hoods, and masks, small groups were led through the test hanger where six planes were undergoing tests at -65° F. The change from the 86° F outdoor temperature to this frigid atmosphere in less than a minute was indeed impressive.

Especially interesting presentations were made by CAPT Charles F. Gell of the Aeronautical Medical Equipment Laboratory, Philadelphia, and CDR George W. Hoover of ONR.

CAPT Gell described and showed movies of the confinement of six volunteers for seven days in a small cabin simulating conditions of space flight. Around the clock observations were made of the physiological conditions of the men, and their performance on psychological tests and problems of learning was measured.

CDR Hoover discussed the ONR development program for a new electronic cockpit instrumentation and control system (see article beginning on page 7). This system provides the pilot with information permitting him to maneuver an aircraft under all weather conditions as if he were flying by visual contact on a clear, sunny day.

A demonstration of the "wheel and flap" trainer.

The seminar was planned and conducted by CDR Henry A. Imus, MSC, USNR, a member of NRRC 5-10, Naval Medical Research Institute, Bethesda, Maryland. The Office of Naval Research, in conjunction with the Naval Air Training Command and the Naval School of Aviation Medicine sponsored the seminar with the approval of the Bureau of Naval Personnel, the Bureau of Medicine and Surgery, and the Bureau of Aeronautics.

Improving Reading Speed and Comprehension

A research study entitled "Improving the Reading Speed and Comprehension of Naval Reserve Personnel" was recently completed as a company project by NRRC 9-7, Lafayette, Indiana. Carried out under the general direction of the company's commanding officer, LCDR A. E. Bell, USNR, the study was brought to a successful conclusion with the technical guidance and assistance of CDR G. B. Schick, USNR, and CDR B. Schmidt, USNR, both on the staff of Purdue University's Developmental Reading Laboratory.

The objectives of the investigation were threefold: (1) to determine the effectiveness of a prescribed developmental reading program for improving the reading speed and comprehension of Naval Research Reservists, (2) to compare the effectiveness of training periods spaced at weekly or less frequent intervals with the normal schedule of biweekly training periods, (3) to determine, after a lapse of one year, any increases in reading speed or comprehension effected through the reading program.

All members of NRRC 9-7 participated in the study. The conclusions reached confirm other survey findings which show that substantial gains in reading speed and comprehension can be attained by certain techniques when used with properly motivated groups.

Seminar Schedule for Fiscal Year 1959

Eight Research Reserve seminars have been planned for fiscal year 1959. Their titles and the places and dates they will be held are listed below:

Research Methods, Columbus, Ohio	July 7, 1958
Nuclear Science, Idaho Falls, Idaho	July 21, 1958
West Coast, Pasadena, California	August 4, 1958
Naval Research Laboratory, Washington, D. C.	August 18, 1958
Submarine and Diving Medicine, Naval Medical Research Laboratory, New London, Conn.	October 27, 1958
Nuclear Science, Oak Ridge, Tennessee	December 1, 1958
Aviation Medicine, Pensacola, Florida	March 9, 1959
Research Reserve Seminar, ONR, Washington, D. C.	June 1, 1959

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LAST MONTH WITH "VANGUARD"

One minute after midnight EST on June 26, a 72-foot VANGUARD rocket carrying a 20-inch satellite was launched from the Missile Test Center, Cape Canaveral, Florida. After attaining an altitude of about 35 miles, burnout of the first-stage engine occurred at the proper point. But second stage ignition did not occur. As a result, the vehicle, together with the third-stage and satellite, did not achieve the desired altitude and velocity. As we go to press, the flight records are being examined to determine the cause of the malfunction.

The satellite carried by the rocket contained instruments that were to measure the solar X-radiation, erosion of the satellite's surface, and the impact of meteors striking the sphere.

Its first-stage engine going full blast, a VANGUARD rocket lifts off its launching pad at Cape Canaveral, Florida, and gathers speed for a flight high above the earth.

In This Issue

COVER PHOTO: An electron gun for a cathode ray tube is spot welded before being installed in a research rocket. For a discussion of the reliability of such complex equipment see article beginning on page 15.

RESEARCH REVIEWS endeavors to report briefly highlights of technical progress in research by Navy laboratories and contractors and the development of important naval research facilities. Articles which meet these broad criteria and possess a good degree of readability are welcomed. Manuscripts and changes of address should be sent to Code 740, Office of Naval Research, Washington, D. C. . . . Research Reviews is listed for sale by the Superintendent of Documents, U. S. Government Printing Office, Washington, D. C. Subscription price: $1.50 per year in U. S. and Canada; $2.00 per year, foreign; $0.15 per individual copy. Use of funds for printing this publication was approved by the Director of the Bureau of the Budget, February 12, 1958.