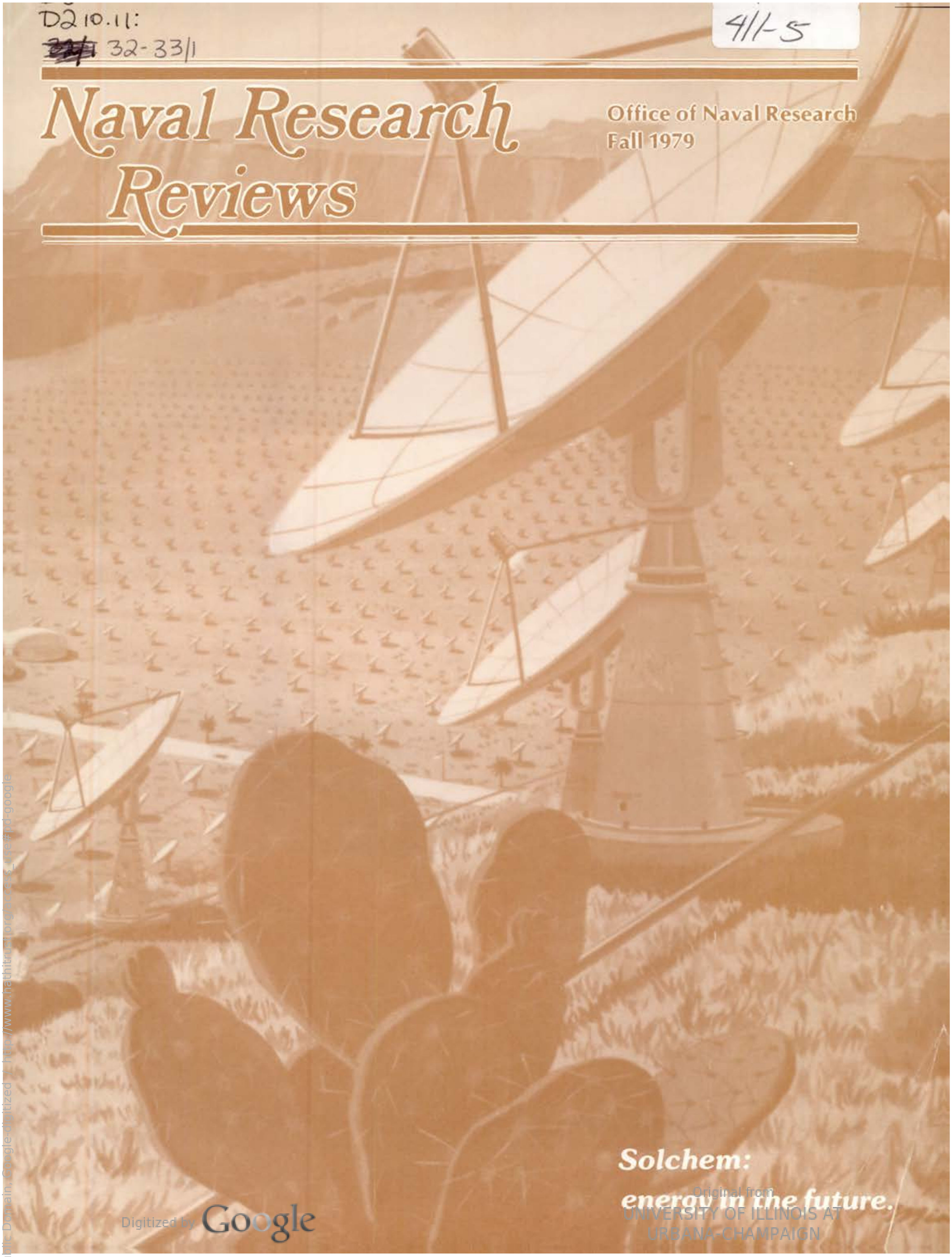
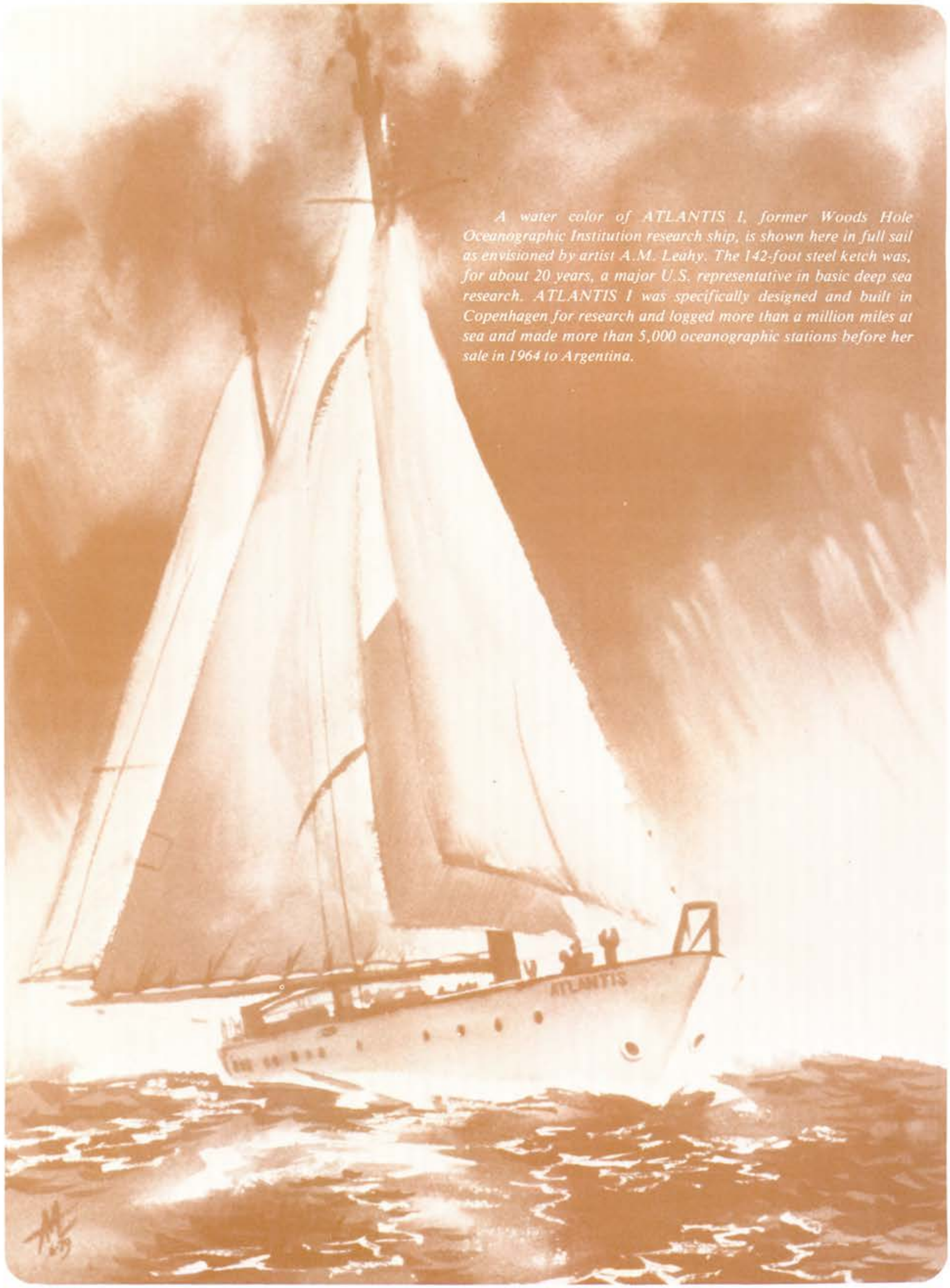
Naval Research Reviews

Office of Naval Research
Fall 1979



Solchem:

energy in the future.



A water color of ATLANTIS I, former Woods Hole Oceanographic Institution research ship, is shown here in full sail as envisioned by artist A.M. Leahy. The 142-foot steel ketch was, for about 20 years, a major U.S. representative in basic deep sea research. ATLANTIS I was specifically designed and built in Copenhagen for research and logged more than a million miles at sea and made more than 5,000 oceanographic stations before her sale in 1964 to Argentina.

NAVSO P-510

Naval Research Reviews

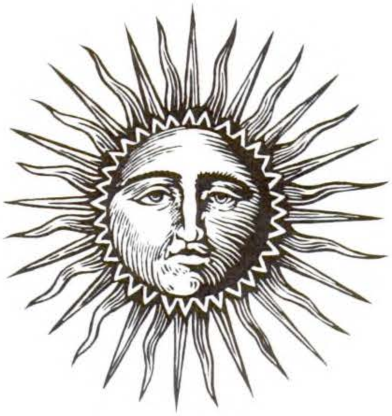
Office of Naval Research
Fall 1979
Vol. XXXII No. 1

ARTICLES

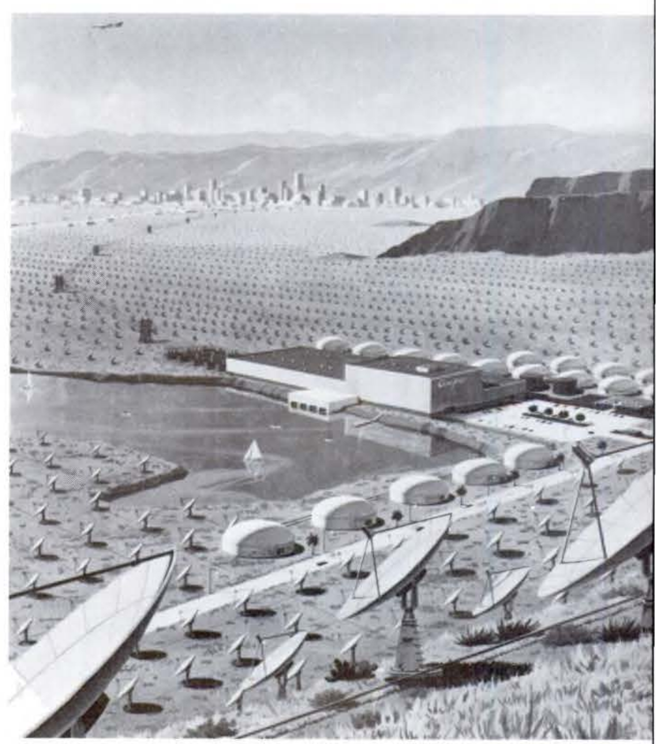
DEPARTMENTS

About Our Cover *A new approach to large-scale solar power is illustrated by Pierre Mion in the orchard-like collection system, based on chemistry, called SOLCHEM. See page 2, and report on recent experiment in Research Notes, page 42.*

Naval Research Reviews publishes highlights of research conducted by Navy laboratories and contractors and describes important naval experimental facilities. Manuscripts submitted for publication, correspondence concerning prospective articles, and changes of address, should be directed to Code 733, Office of Naval Research, Arlington, Va. 22217. Requests for subscriptions should be directed to the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402. The issuance of this periodical approved in accordance with Department of the Navy publications and printing regulations.



SOLCHEM: A Design for Day/Night Sola



The cover picture illustrates a new approach to large-scale solar power. It is based on chemistry and is called *Solchem*. Each of the many individual collector dishes, which track the sun, reflects intense sunlight onto a chemical converter at the focal point. In the process, solar heat is turned into chemical energy. Energy accumulated during the daylight is stored in large tanks so as to be continously available, 24 hours a day, no matter what the weather.

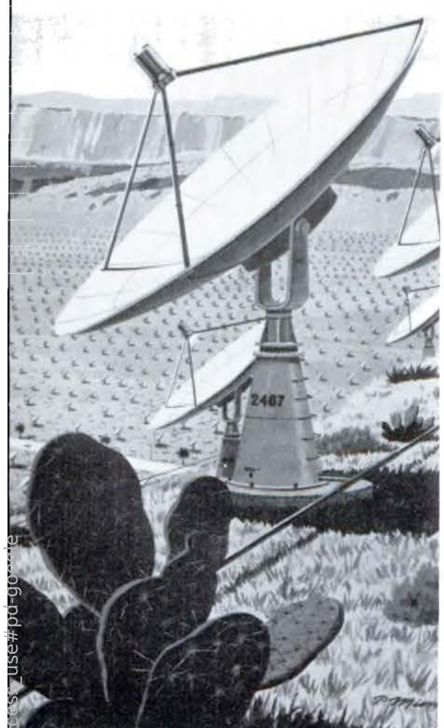
The collector-converters, each one really a small factory, produce energy-rich gases for delivery to a central station. Each converter, as shown in Figure 1, receives SO_3 at 90°C from a piping network. The gas enters a heat exchange section made up of corrugated plates of whiteware ceramic formed into spiral passages. In half of these, cold gas moves inward, while at alternating levels hot gases spiral outward. The SO_3 enters from the perimenter, and as it spirals inward, is heated to 700°C. It then flows downward into the reaction chamber, where it is further heated by concentrated sunlight to 800ºC. Next, it passes over a catalyst and dissociates, with absorption of heat.

The gases produced by this process enter the central core, and as they move outward at alternating levels, are cooled to about 100ºC. At this relatively low temperature they are drawn off in low-pressure pipe lines and delivered, with minimum energy loss, to the central power station. Here they recombine and in the process release the solar heat that has been collected. The combined gas is returned to the collectors through piping that completes a closed circuit. The SO_3 is now ready for another cycle of heating, dissociation, heat exchnage, and transport.

Energy storage is provided by the tank shown in Figure 2, which contains cans of salt, heat-pipe fluid, and steam pipes. When the gases are recombined at the bottom of the tank, the resulting heat causes the heat-pipe fluid to boil.

As a result, condensation forms on the surface of cans filled with a salt eutectic that melts at 385°C. These cans, which occupy the bulk of the interior of the tank, are a heat-of-fusion energy-storage medium. The stored energy is readily available for various uses through heat-pipe techniques.

ower



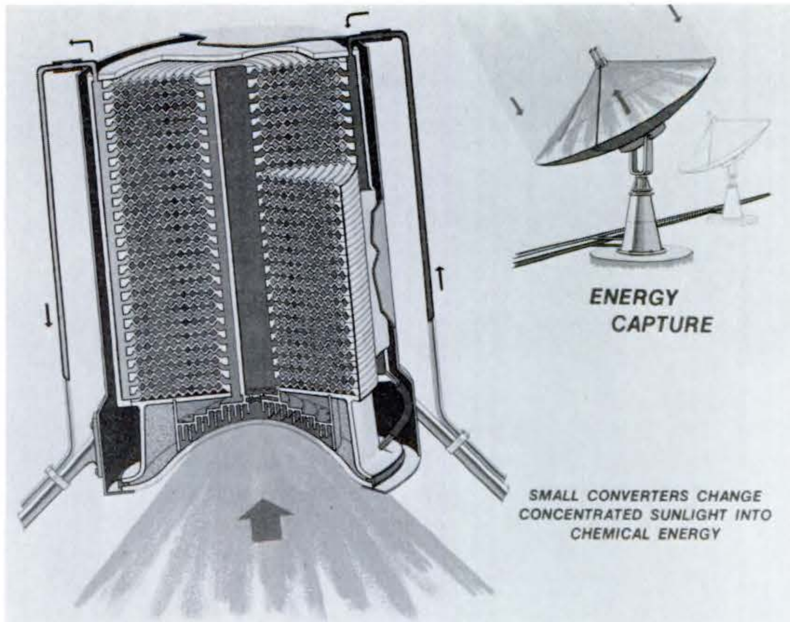
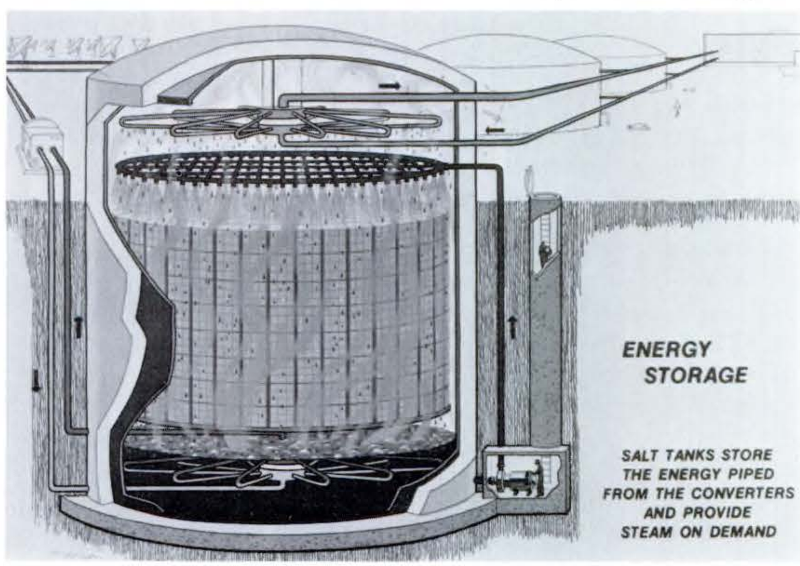


Figure 1.

Figure 2.



The tank shown is designed to produce steam, which drives conventional high- performance steam turbines to generate electricity. When steam is desired, water is fed into pipes at the top of the tank. The heat-pipe fluid condenses on these pipes, releasing heat that boils the water inside and superheats the resulting steam. At night it is necessary to pump heat-pipe fluid over the salt cans in order to keep them wet and maintain the vapor pressure in the tank. During the night and periods of net energy drain, freezing of the molten salt releases heat to replace the energy which is being used.

Over three years ago Naval Research Laboratory scientists initiated *Solchem* as a new approach to harnessing the free and inexhaustible energy of the sun. The design concept is applicable to both the generating of electricity and the production of liquid and gas fuels by steam treatment of waste solids. Experimental work is now concentrating on the energy storage system. ■

Can a Solid be Amorphous and Yet be Ferromagnetic?*

by F. E. Luborsky

* *ACKNOWLEDGEMENTS*

This work was carried out with the partial support of the Office of Naval Research and monitored by Bruce A. MacDonald of the Metallurgy and Ceramics Program Office and by Frank S. Gardner of the Boston Scientific Department of the Office of Naval Research.

Introduction

Can a solid be amorphous and yet be ferromagnetic? Up until 1960 it was thought that only crystalline solids could be ferromagnetic, that is, that the crystal lattice and the resultant magnetic exchange forces between atoms were necessary. In 1960 Gubanov predicted from theoretical considerations that amorphous solids could be ferromagnetic. This was based on the evidence that the electronic band structure of crystalline solids did not change in any fundamental way on transition to the liquid state. This implied that the band structure is dependent principally on short range atomic order, rather than long range order. Thus ferromagnetism, which depends on short range effects, should not be destroyed in the corresponding amorphous solid.

It took just five years before the theoretically expected ferromagnetic behavior of amorphous solids was experimentally demonstrated in work on cobalt-gold alloys. However the first alloy with substantial magnetization to be prepared in the amorphous state was an alloy containing 75 atomic percent iron, the remainder being phosphorus and carbon. This appeared to be a

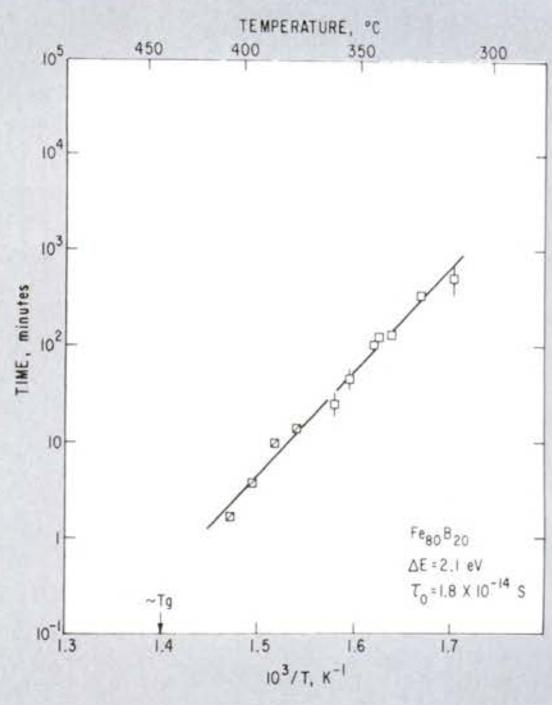


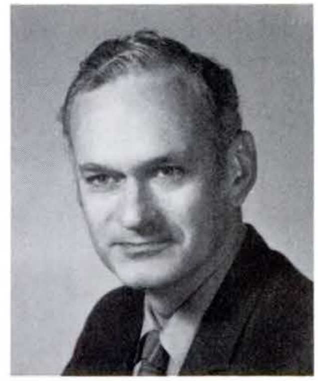
Fig. 1 Typical curve of time for the start of crystallization vs the reciprocal of the absolute temperature for amorphous $Fe_{80}B_{20}$.

typical soft magnetic alloy with the relatively low coercive field of 3 0e /240A/m/ and the high saturation magnetization of 7kG.

In 1971 it was pointed out by scientists in England that amorphous ferromagnets should have extremely low coercive forces because, lacking a crystal lattice, there is no magnetocrystalline anisotropy. However, the 3 Oe obtained for the $Fe_{75}P_{15}C_{10}$ amorphous alloy was orders of magnitude higher than commercially available Fe-Ni crystalline alloys. It has now become clear that this high coercive field was the result of the large strain introduced by the rapid quenching used to prepare the amorphous alloy. This strain interacts with the magnetostriction of the alloy to produce a strain-magnetostriction anisotropy. In our laboratory we were the first to demonstrate the reduction of coercivity by suitable stress-relief anneals. Coercive fields of iron-nickel-phosphous-boron amorphous alloys were reduced from ~0.1 0e to 0.01 0e. Annealing under the influence of an applied stress further reduced the coercive fields down to ~0.003 0e. These coercivities of 0.003 to 0.01 0e make these amorphous alloys competitive in properties with the best available, but expensive, Ni-Fe (Permalloy) alloys and far superior to the Fe-3.2% Si sheet steels used in motors and transformers.

Alloy Preparation and Crystallization

How are these alloys prepared? Amorphous alloys may be prepared by a variety of techniques; techniques in which the individual atoms in the alloy are quenched so rapidly that the liquid-like structure is frozen into the solid. Thus electrodeposition, electroless deposition, vacuum deposition, sputtering, plasma spraying and many forms of quenching the molten alloy at high rates, have all been used. In fact the first report of what now appears to have been an amorphous alloy was made by Bremer in 1950. In this work he prepared Ni-P alloys by electrodeposition for use as hard, wear-resistant coatings. The first method used for intentionally preparing amorphous



Dr. Luborsky is on the staff of General Electric's Research and Development Center Schenectady, New York, 12345. Twelve patents and 110 publications pertaining to the magnetic, metallurgical, and electrochemical aspects of soft materials, hard materials, and thin films have made him an authority in the field.

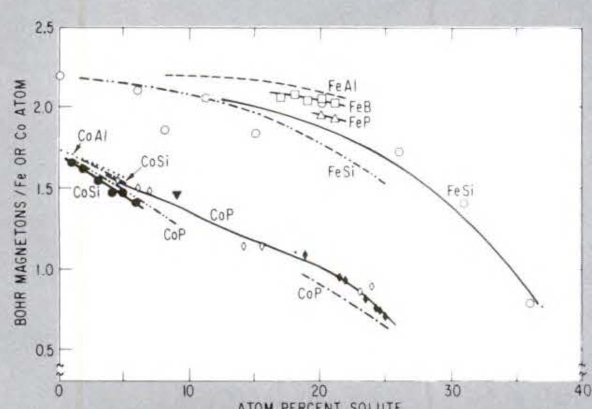


Fig. 2 **Magnetic moments at O K as a function of solute concentration. Crystalline alloys shown by broken curves with no data points; amorphous alloys shown by solid curves with data points.**

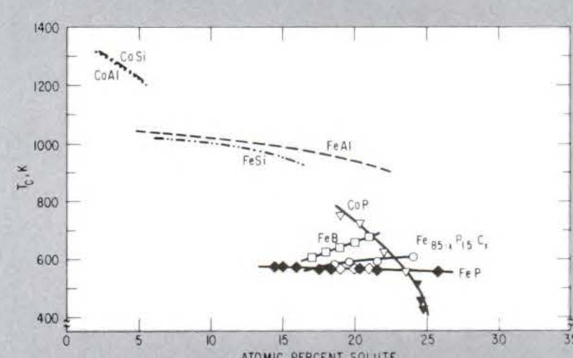


Fig. 3 **Curie temperature as a function of solute concentration. Crystalline alloys shown by broken curves with no data points; amorphous alloys shown by solid curves with data points.**

alloys, reported by Duwez, propelled a liquid alloy droplet onto a cold substrate where the droplet spread out into a thin layer and thus was quenched rapidly enough to bypass crystallization. Soon after this first technique was reported, a modification was developed whereby the alloy spread as a thin layer between two mutually approaching pistons. These and other variations are generally referred to by the onomatopoetic term "splat" quenching. A real technological interest developed after Pond and Maddin, in 1969, reported on the preparation of continous ribbons of amorphous alloys. This method consisted of directing a stream of molten alloy onto the surface of a rapidly rotating drum. Under the proper operating conditions a solid, well-defined ribbon is continuously thrown off of the wheel. This simple method now forms the basis for present day preparation of wide amorphous metal sheets, using a fine slotted orifice instead of a fine circular orifice to eject the molten stream.

Why is it that amorphous metals were not discovered until the 1960's? Pure metals cannot be quenched rapidly enough even by "splat" quenching techniques to form the amorphous phase because of their high melting temperatures, T_m, and relatively low glass temperature, T_g, i.e., T_m-T_g is too large. It has been found however that additions of metalloid atoms such as boron, carbon, phosphorus, silicon, aluminum, etc., greatly facilitates the formation of amorphous phases. The compositions of metal and metalloid atoms most favorable for the formation of amorphous phases lie at, or near, the eutectic composition, i.e., at the minimum melting temperature.

Once the amorphous phase has been formed the question remaining is, how stable is it; i.e., what is the resistance to rearrangement of its atoms to form a regular crystal lattice? To answer this we will first discuss the atomic structure of amorphous alloys. The model for amorphous alloys is based on the densest random packing of hard spheres. In this model the metal atoms are assumed to form a random network of close-packed hard spheres with the smaller metalloid atoms filling the holes inherent in such a structure. The most stable configuration is the situation when all of the holes are filled, corresponding to about 20 a/o metalloid. This is near the eutectic composition of many of the alloys and is in the range of the stable glass composition. Coupled with this simple geometric picture of stability must be added the effect of interatomic interactions, i.e., chemical bonding and the influence of the electronic structure of the alloy.

The crystallization behavior of amorphous alloys is a thermally activated process and thus depends on time and temperature. An example of the results obtained for the crystallization of one alloy is shown in Figure 1 on an Arrhenius plot of time for the start of crystallization vs. the reciprocal of the absolute temperature. This straight line relation may be extrapolated to the lower operating temperatures characteristic of equipment exposures. Thus, from this curve we predict that it will take 500 years at 175°C before crystallization starts. All of our experience to date shows that the magnetic properties remain constant until crystallization starts. Thus the start of crystallization represents the end-of-life for these amorphous alloys.

Magnetic Properties

What are the magnetic characteristics which make the amorphous alloys interesting for applications? To answer this question we will review the properties available in amorphous alloys.

The local environment around each atom in an amorphous solid differs from site to site, in contrast to its regular nature in a crystalline solid. Therefore the magnetic moment of an atom is not expected to be identical on every atom. Thus the atomic hyperfine interactions will show a distribution of values which show up as a broadening of the lines in the Mössbauer spectra and in nuclear magnetic resonance. However, the effect of this distribution of hyperfine interactions is not usually seen in the magnetic moments, Curie temperatures or in the various anisotropies. The major change in these magnetic properties comes from the change in the electronic environment caused by the necessary presence of the metalloid atoms. Some typical effects of the metalloid atoms on the magnetic moments and Curie temperatures of amorphous iron and cobalt alloys are shown in Figures 2 and 3.

High Magnetization Alloys

One of the major advantages of the high magnetization alloy Fe_{80} B_{20} is its extremely low losses compared to conventional Fe-3.2% Si-grain-oriented sheet steel. Losses are down by a factor of three to four, as illustrated in Figure 4.

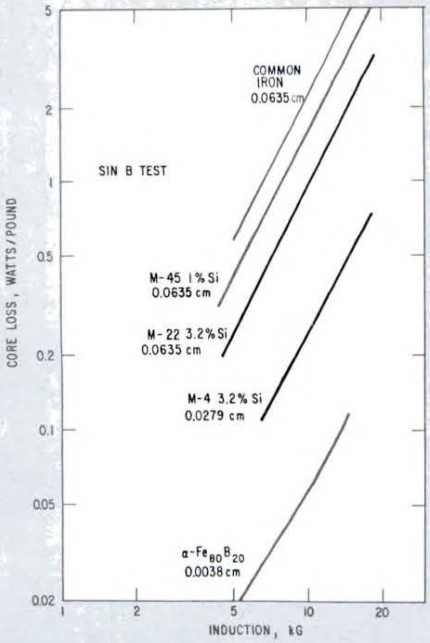


Fig. 4 **Total magnetic loss as a function of induction for some commonly used iron-based magnetic alloys and for amorphous $Fe_{80}B_{20}$ M-4 is grain oriented, the other alloys are not grain oriented. M-4, M-22 and M-45 are American Iron and Steel Institute standard designations.**

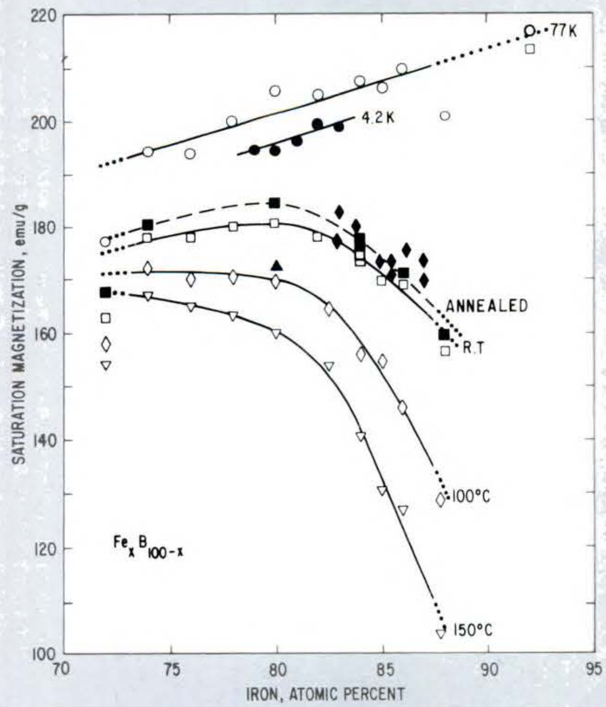


Fig. 5 **Saturation magnetization at various temperatures for Fe-B amorphious alloys. Dotted lines indicate alloys with a small percentage of crystalline phase. Dashed line indicates the results of annealing on room temperature magnetization.**

Thus the power losses in any device will be substantially reduced. This will contribute to savings over the lifetime of the device. For example, it has been calculated that, if all of the distribution transformers were made frcm amorphous alloys, the savings would amount to at least 200 million dollars per year. This is based on a reduction in losses from 0.7 down to 0.2 watts/pound in the present day transformers. The iron losses in these transformers amounts to 0.5% and they generate 2×10^{12} Kwh of electricity.

One of the drawbacks to the use of amorphous alloys is their generally lower saturation magnetizations compared to corresponding crystalline alloys because of the necessary presence of about 20 a/o metalloids. This reduces the magnetization, as shown in Figure 2. One of the highest magnetization alloys known today, containing iron and boron, is $Fe_{80}B_{20}$ with $4\pi M_S \sim 16.5$ kG. This is to be compared to the Fe-3.2% sheet steel with $4\pi M_S = 20$G. The 20% lower magnetization of the best available amorphous alloy, compared to the conventional sheet steel, is a real drawback in the fabrication of motors and transformers. Basically it means that 20% more amorphous alloy is required to produce the same number of flux lines. This increases the size of the equipment and thus the amount of the copper windings and insulation, all of which contribute to the total cost.

The question now is, can we find other amorphous alloy compositions with higher values of saturation magnetization? This is the phase of the work we are now engaged in. To see the direction of this work we must ask how the Fe-B alloy system behaves as the concentration of boron varies; i.e., can we simply increase the iron content sufficiently to increase $4\pi M_S$? The results of this approach are shown in Figure 5. At the low measuring temperature of 77K the magnetization does indeed increase with increase in iron content. However, at room temperature the magnetization goes through a peak value at 80 a/o iron. The subsequent drop is caused by the decrease in magnetization as the Curie temperature, T_c, decreases. This rapid decrease in Curie temperature is shown in Figure 6.

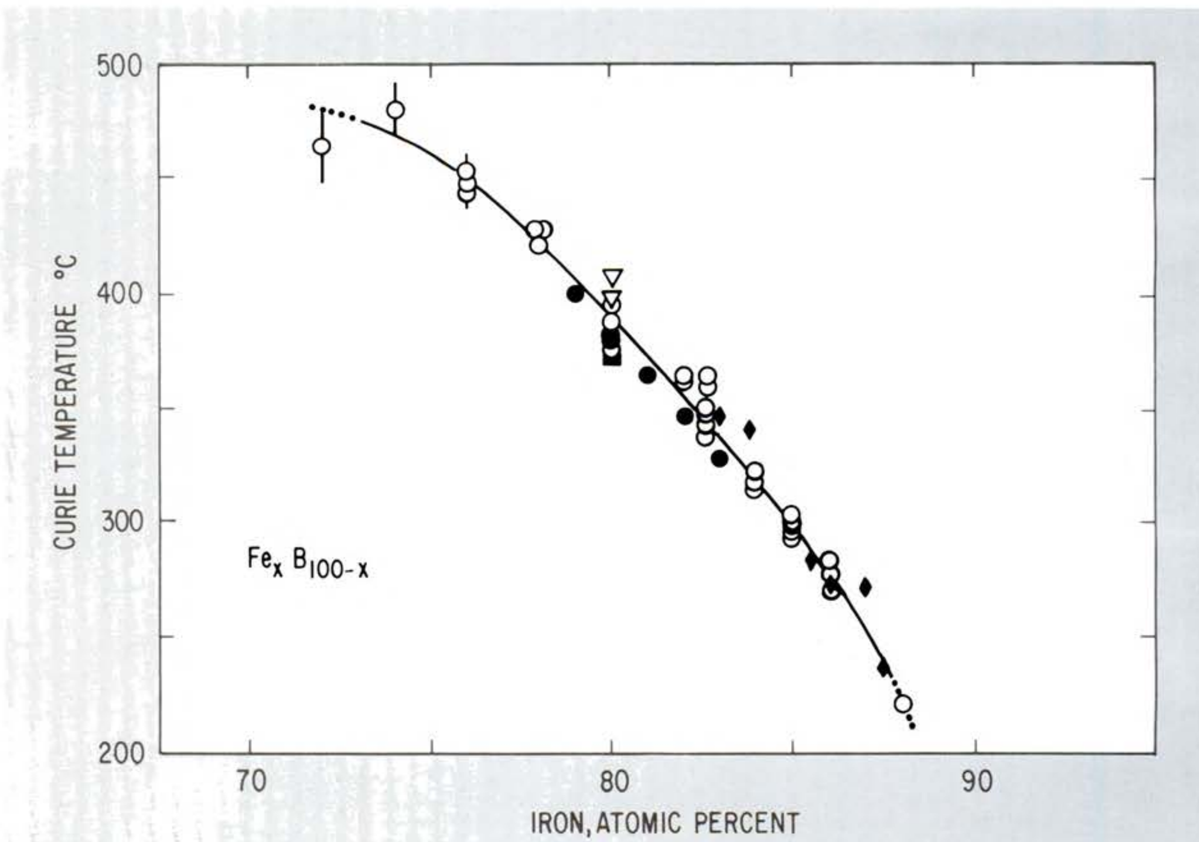
Thus one approach to raising $4\pi M_S$ is to find alloying additions to the Fe-B basic alloy which will raise T_c. It is expected that boron will be the most effective metalloid from the standpoint of being the poorest electron donor. However C and Si are expected to be the next most effective additives. Results for both carbon and silicon have been reported, showing that both raise T_c by small amounts. Silicon additions raise the iron content at which the peak in (σ_s) is obtained. However, because of the decrease $4\pi M_s$ (due to silicon's greater electron donor character), the peak σ_s remains unchanged. Furthermore, the ease of formation of the amorphous phase improves with the addition of silicon and the coercivity decreases, both beneficial trends. Carbon additions also increase the Curie temperature but there is some disagreement in the reported results as to whether the carbon additions actually increase the peak σ_s. Values close to 190 emu/g corresponding to 18 kG have been reported. However, the coercivity of Fe-B-C alloys increases markedly as carbon is added. This suggests that the losses will also increase, leading to undesirable properties.

Future work will explore the effect of other metalloids such as Al, Ge, and As as well as the effect of quaternary alloys on the properties. It is hoped that better combinations of properties at 17.5-18 kG can be obtained and that $4\pi M_S$ values above 18 kG can be achieved. However even with the presently available properties the anticipated costs of distribution transformers are competitive with conventional Fe-3.25% Si alloys and the performance is certainly superior.

Costs

An obvious question of concern is what the projected costs are of these high magnetization amorphous alloys? Will they be expensive, specialty alloys and therefore able to compete only with the NiFe alloys, or will they be inexpensive enough to compete with the Fe-3.2% Si alloys? A

Fig. 6 **Curie temperature of Fe-B amorphosu alloys. Dotted lines indicate alloys with a small percentage of crystalline phase.**



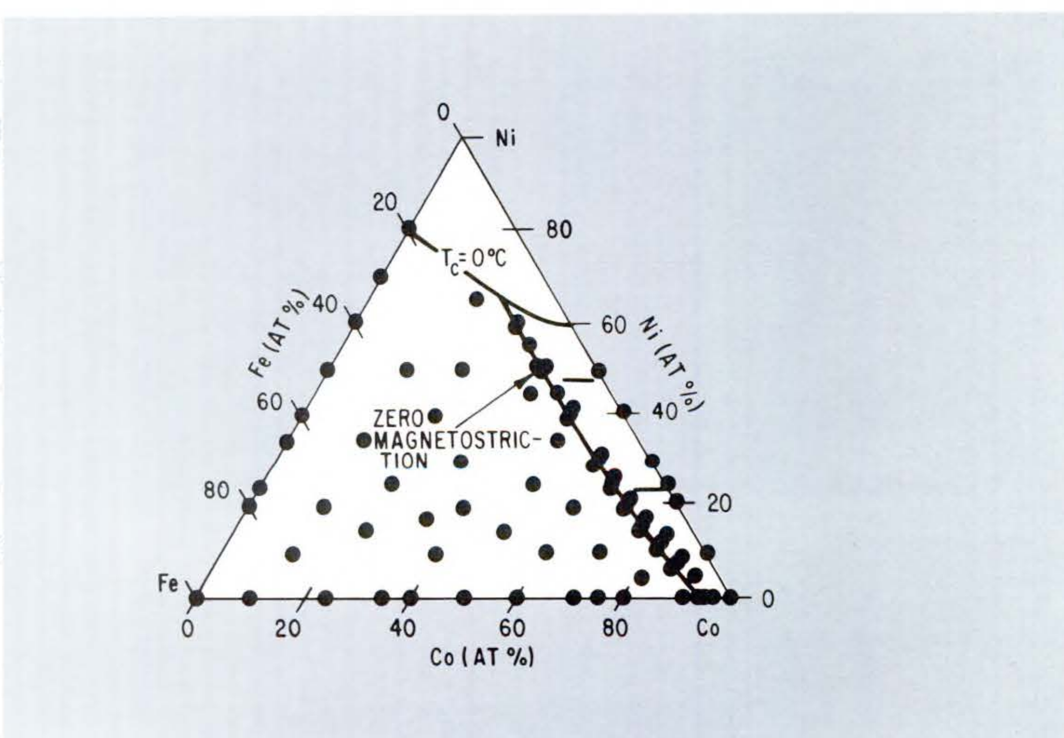
prediction of costs under conditions of mass production is difficult to make with any certainty because there is, as yet, only one commercial supplier of amorphous alloys, Allied Chemical Company. To date they have supplied small sample quantities and no cost figures are available from them. Through our own experience in making amorphous alloys, we can discuss a first estimate of costs associated with mass-produced ribbons. First, the cost of the raw materials for the alloy $Fe_{81}B_{17}Si_2$ can be based on iron scrap at \$0.04/lb, ferroboron master alloy at \$0.60/lb, and ferrosilicon at \$0.17/lb to give the cost of the materials at \$0.16/lb. In view of the rather simple manufacturing procedure in obtaining the tape from the melt and low temperatures used for the final anneal it is unlikely that the processing costs will run more than \$.16-.32/lb to give a total cost of \$.32-.48/lb. This may be compared to the cost of oriented Fe-3.2 % Si sheet steel of \$50.-.60/lb. This higher cost for sheet steels is due to the complex processing necessary to produce the final sheet thickness and the oriented crystallographic texture.

Electronic Applications

For applications in electroncis the high saturation is not usually required and thus additions of nickel and cobalt are desired as a means of reducing magnetostriction to improve the coercivity and reduce the losses. In fact, there are a series of alloys reported which contain 5-10 a/o iron which are zero magnetostrictive as shown in Figure 7. With these and other low loss alloys the magnetic properties of the best available, but expensive, Permalloy alloys can be equaled. In addition they are exceedingly tough physically. This has resulted in some interesting applications.

Until 1976 there were no devices described in the literature using amorphous alloys. In 1976 two different applications of amorphous metals were reported. The first of these was the use of the ribbon for shielding. Large sheets were made by simple weaving and then these were coated with a polymer. Cylindrical shields made from these woven fabrics were measured at 60 Hz and compared to an equal weight shield wrapped from polycrystalline 80Ni20Fe foil. Neither was annealed. Shielding ratios of the woven glass

Fig. 7 Magnetostriction of amorphous $(Fe\text{-}Ni\text{-}Co)_{78}B_{14}Si_8$ alloys.



compared favorably with the polycrystalline foils. The woven glass however has the advantage of flexibility without altering shielding performance and it is less sensitive to mechanical strain.

The second application reported in 1976 was for delay lines. Electronically controllable acoustic delay lines were built and tested. These made use of a "ΔE effect," i.e., the change in Youngs modulus E with applied field H, where E is directly related to the sound velocity. The ΔE effect was extremely large in a variety of amorphous alloys tested for the delay lines. ($Fe_{80}P_{13}C_7$ had a peak ΔE of 0.8 at 5 Oe, $Fe_{78}Si_{10}B_{12}$ had a peak of value of 1.9, the largest ever reported.) In these programs the magnetomechanical coupling factor k was also measured. The value of k is the most important dynamic transducer parameter and gives a measure of the elastic energy generated by magnetic excitation. The very large value of 0.53 was found for annealed $Fe_{80}P_{13}C_7$ and 0.75 for $Fe_{78}Si_{10}B_{12}$. Delay times of ~2 μs/cm were obtained in zero field; maximum changes of ~12% were obtained in a field of 8 Oe at 100 kHz.

Other applications were reported in 1977. An electronic current transformer was described which used an amorphous metal tape core made from $Fe_{40}Ni_{40}P_{14}B_6$ operating into a virtually zero ohm load by using feedback from an operational amplifier. Due to the very low flux density created by virtually short-circuiting the transformer, the non-linear effects and core losses are reduced substantially. A transformer core of reduced size may be made by using such an electronic transformer. In a current transformer of this kind precise linear response is required. Deviations from linearity are caused both by errors in magnitude and in phase shift of the output as a function of input drive current. Test results have shown that the amorphous metal core using the active load has performance equal to $_{80}Ni_{20}Fe$ with respect to magnitude error. However, the phase shift is somewhat poorer than for NiFe of the same size. The amorphous core is significantly superior to the FeSi core in both magnitude and phase shift error. The results demonstrated the suitability of this amorphous core material for use as a current transformer with the active load.

Another application reported in 1977 was the use of amorphous cores as tensile-stress transducers in a multivibrator configuration. This makes use of the remarkable sensitivity in magnetic properties with tensile stress of amorphous alloys. A differential type of multivibrator was constructed using two cores wound from $Fe_{40}Ni_{40}P_{14}B_6$. Tension or compression could be applied to the windings of one of the cores. It was made with two types of transducing behavior: (1) an analog type, with no zero output but good linearity and sensitivity and no hysteresis and (2) a threshold type, with zero output for tensile stress under a critical value and maximum output for stress over this critical value. Conventional crystalline permalloy would be very poor for use in this application because of its soft mechanical behavior.

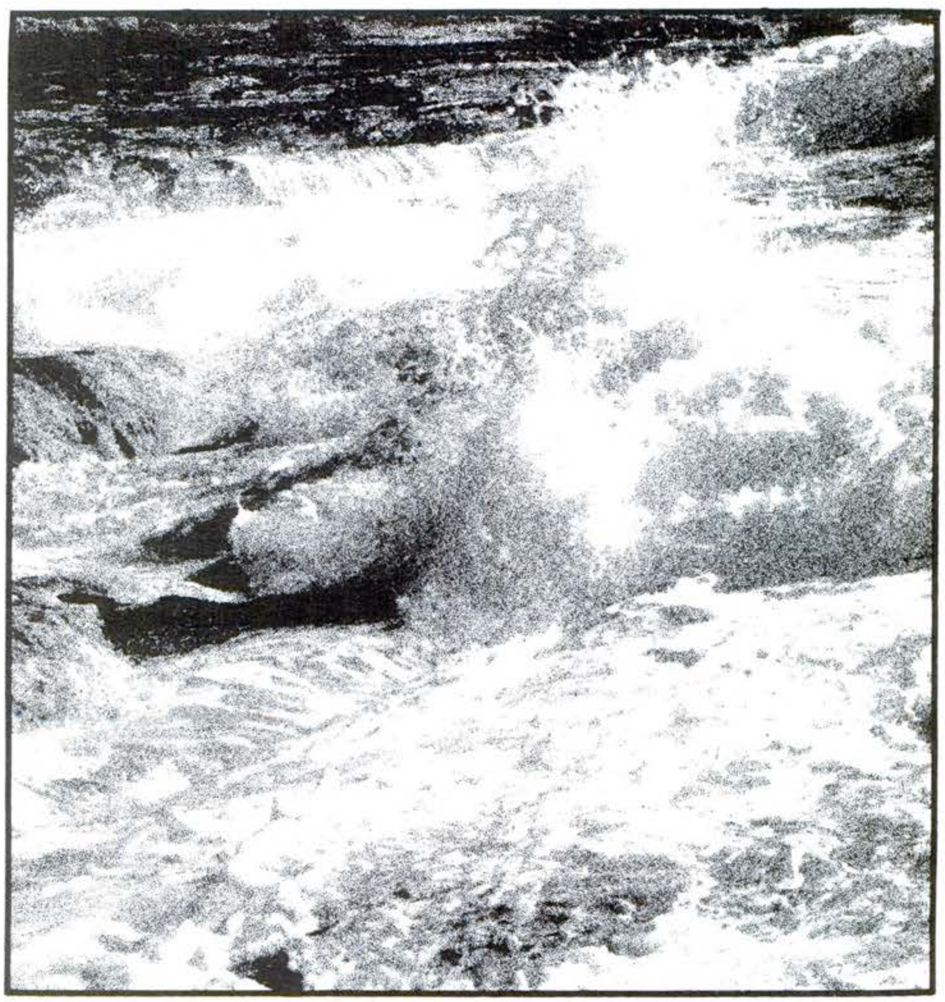
The final application reported in 1977 was for the use of amorphous ribbons in transverse filters. These made use of the magnetostrictive waves on the amorphous ribbon. Arbitrary transfer functions were easily realized by adjusting voltages and polarities.

Summing-Up

Amorphous magnetic alloys are a new class of soft magnetic materials, the first new class since the discovery of the soft ferrites during the 1940's. Some of these alloys have losses which are one-third to one-quarter the losses of Fe-Si sheet material although their saturation magnetization is 10-15% lower. They are in direct competition with Fe-Si for applications in motors and transformers. Other amophorous metals, alloys containing cobalt and nickel, have exceedingly high permeabilities and low losses, making them competitive in properties with the nickel-iron alloys. These excellent magnetic properties coupled with excellent physical strengths have generated descriptions in the literature of potential applications. This new class of alloys is likely to become an important factor in new magnetic designs. ■

Spatial Variability in the Upper Ocean

by John P. Dugan



Over the last decade, the oceanographic research community has become increasingly interested in the variability of physical properties in the upper ocean layers. The research activity has been concentrated heavily in studies of the spatial and temporal fluctuations in and above the permanent thermocline. There are many causes for the variability in the water temperature, salinity, and current velocity, some of which are well known and well understood, and others of which are not understood. In this paper, we discuss some of the phenomena that occur in the upper layers, show some examples of the spatial structure, and point out some of the prominent features that are particularly of interest to the operational forces because of their implications to ocean acoustics. We conclude by discussing some of the limitations to further progress imposed by lack of appropriate data and the instrumentation to get it. The findings resulted from research conducted by the Naval Research Laboratory.

Scales of fluctuations in the ocean

The ocean exhibits fluctuations on many scales and frequencies. The spatial scales extend from the basic scale of fluctuations in the general circulation all the way down to the centimeter scale of the microstructure, while the time scales extend from years for the former to seconds for the latter. The types of motions in the ocean can be roughly grouped into the general circulation, the mesoscale, the internal wave regime, and the fine- and microstructure.

The structure of the general circulation is reasonably well known for the purposes of ocean acoustics. The space scales are determined by large scale wind stress patterns, the large scale of the solar heating and cooling cycle, and the bathymetry of the ocean basin. On this scale, the sound velocity structure is almost temporally invariant in the deep water and it varies only seasonally in the near-surface waters. In a very real sense, this scale is similar to the atmospheric "climate." The sound velocity structure can be estimated from historical data, and certain limited abstracts of the history are available in atlases.

The mesoscale fluctuations are much more energetic than the general circulation. The magnitude of the variations in the surface waters can be a healthy percentage of the seasonal variations, and the magnitude of the variations in the permanent thermocline is much greater than the seasonal cycle in many ocean areas. This scale of fluctuations includes eddies and fronts as the dominant features. The horizontal space scale is from many tens to several hundred kilometers, the vertical scale is from hundreds of meters to the ocean depth, and the time scale is from many days to several months. In a sense. this scale is similar to atmospheric "weather."

Going down in scale again, the internal/inertial wave regime represents space scales of hundreds of meters to several kilometers in the horizontal, meters to many tens of meters in the vertical, and time scales of minutes (the local buoyancy period) to order one day (the local inertial period). These motions appear to be ubiquitous, although they can be somewhat intermittent in space and time in the upper layers, and they are more energetic in the thermocline than in the deep ocean. A good statistical model of the kinematics for this class of motions has been developed by Garrett and Munk in the last few years, and Wunsch has eloquently reviewed the state-of-the-art in *Naval Research Reviews* (1). Precise explanations of the dynamics of internal wave generation, interaction and dissipation mechanisms have yet to be worked out but, for the present, the Garrett and Munk model is adequate to provide the framework for the design of oceanographic internal wave experiments and to test acoustic scattering models.

Finally, the fine- and microscale fluctuations occupy horizontal space scales of meters to hundreds of meters and time scales of seconds to tens of minutes. The most common feature on this scale is the "staircase" vertical temperature or density profile with its sheets and layers. The sheets often contain most of the vertical temperature gradient, and they can have the horizontal scale given above while having a vertical scale of only several centimeters. It is not presently clear which of several mechanisms dominates the generation and maintenance of these structures and, in particular, what the precise relationship is to the internal wave regime. The magnitude of these fluctuations is quite small, but the effects on acoustic propagation possibly are not. The state-of-the-art has been reviewed by Gregg in *Naval Research Reviews* (2).

The presentation of these different scales in the form of a frequency spectrum is useful for separating the different physical mechanisms in the time domain. The frequency spectrum of a time series measurement yields the amount of energy (variance) in each frequency interval. Figure 1, borrowed from Rhines (3) is a rendition of the spectrum of horizontal velocity fluctuations in the deep ocean. Note that both axes are on logarithmic scales, and that estimates of the actual energy levels are obtained by integrating over frequency intervals, so that most of the energy is in time periods longer than one week. These long periods comprise the mesoscale, while the peaks at the shorter periods are internal waves. The peak having a period near one day is the inertial period which is the lower frequency limit for internal/inertial waves, while the one near twelve hours is the major constituent of the internal tide. This record is from Woods Hole Site D which is near the continental shelf, a known generator of internal tides, while other records obtained away from the continental margins do not exhibit this distinct a tidal peak. The energy in the higher frequency fluctuations falls off rapidly to the buoyancy period, which corresponds to the local natural frequency of oscillation of internal gravity waves.

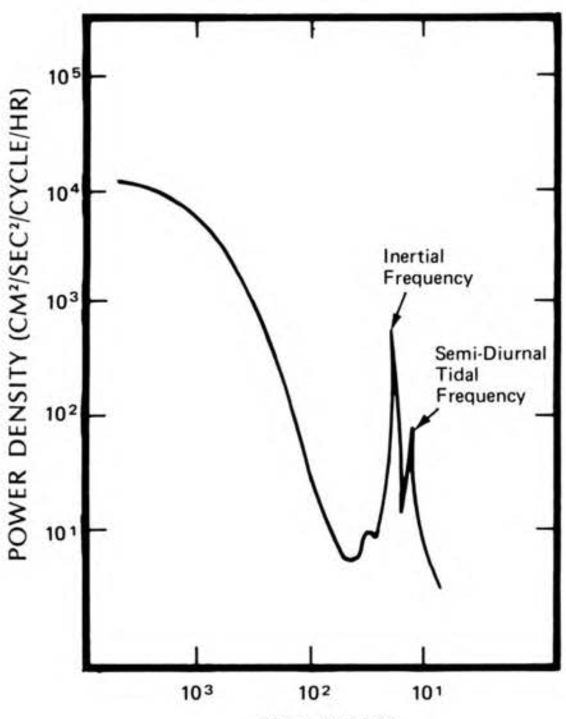


Figure 1— Power spectrum of horizontal water velocity fluctuations at 500 m depth, Woods Hole Site D (Rhines, 1971).

Dr. John Dugan is a Research Physicist in theoretic oceanography at the Naval Research Laboratory working in the fields of fluid mechanics and applied mathematics. He is director of two important programs at NRL; Special variability in the ocean and a survey of Ocean eddies. His address is code 8340, Naval Resarch Laboratory, Washington, D.C. 20375.

Figure 2 is a synopsis of spectra of time series of temperature fluctuations at a given point near Bermuda (4). As in the velocity records shown in Figure 1, these data also exhibit the strongest fluctuations at the longer periods. The gap in spectral amplitude between the mesoscale and internal wave regimes is not as pronounced in the case of temperature as it was for current velocity. This is due to the fact that inertial wave motions are nearly horizontal, so that they are more apparent as velocity fluctuations than as temperature fluctuations. There still remain,

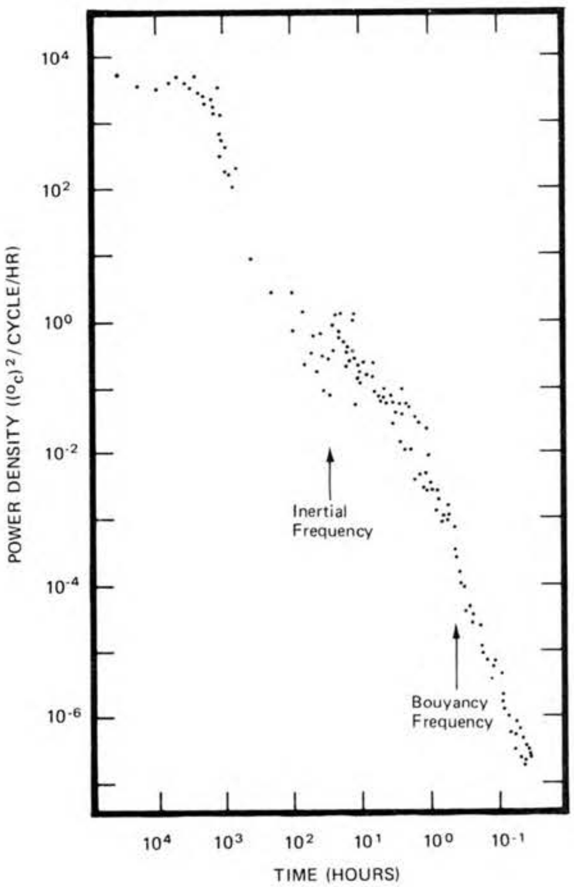


Figure 2— Power spectrum of temperature fluctuations in the main thermocline near Bermuda (Wunsch and Dahlen, 1970).

however, the obvious mesoscale and internal wave regimes. Fluctuations in the general circulation cannot be resolved in the limited lengths of data that are available. Meanwhile, on the high frequency end of the spectrum, the fluctuation energy falls precipitously for frequencies higher than the buoyancy frequency.

It would be enlightening to have a similar description of the energy levels across the length scales. Such wavenumber spectra are only available for temperature or density fluctuations and they have to be patched together from surveys on the different scales. The results are similar in the sense that the longer scales are the most energetic and the energy level falls uniformly toward the shorter scales. In the small amount of data that is available, there is no obvious gap in the spectrum of length scales between the mesoscale and internal wave scale as there was in the frequency domain. It would be interesting to know whether the behavior of fluid velocity wavenumber spectra are similar.

The Mesoscale

A sizeable portion of the research effort in physical oceanography in the last two decades has focussed upon the mesoscale. Several comprehensive programs have been aimed directly at this scale. Wyrtki had a previous article in *Naval Research Reviews* (5) about one such program.

Prior to the present decade, most of the studies of mesoscale fluctuations should be described as feature analyses. That is, the data collection, analyses, and reporting were dominated by attempts to describe the major features that were present. These features that cause the high energy levels on this scale commonly are called fronts and eddies. A front is a zone between two regions having water of different characteristics. If, for example, the front separates water of different densities, the pressure gradient across the front due to the force of gravity on the density difference may be balanced by a significant current flowing in a direction parallel to the front. The great western boundary currents like the Gulf Stream in the North Atlantic and the Kuroshio in the North Pacific involve fronts of this type (more on this later). On the other hand, there often exist fronts in the upper layers which are density compensated so that they do not involve significant currents.

An eddy in a sense is a circular front which encloses a bounded region of water of characteristics different from the surrounding area. Strong eddies like the Gulf Stream rings are generated by instabilities in a front. That is, small perturbations of the front have a tendency sometimes to grow larger until a significant meander occurs. This meander may pinch off and form a ring while the front realigns itself more or less in its original position. The ring quickly assumes a circular shape with local water surrounding water from the opposite side of the front. These rings usually are found in the vicinity of the front that spawned them. On the other hand, less energetic eddies appear to be ubiquitous and are not obviously related to the boundary current systems.

The proper description of the generation mechanisms, the evolution, and the dissipation of these features is the objective of a large number of oceanographic programs of which several were named above. Because the features move about, it has been difficult in the past to obtain a true spatial picture or a temporal history of the evolution of a particular feature. This especially was the case before the 1960's when most deep water oceanography was done from research vessels. Deep hydrographic casts were very time consuming, mechanical bathythermographs did not go deep enough, and hydrographic mooring strings in deep water practically were nonexistent.

We will return to the subject of instrumentation, but at this juncture it is more appropriate to show an example of the types of mesoscale structure which we are discussing. The example we choose to exhibit is an especially striking case that illustrates some of the current outstanding problems. The data come from one of a series of multi-ship surveys that have been completed with the cooperation of many naval activities, including the Office of the Oceanographer of the Navy, the Fleet Weather Centrals, the Mobile Environmental Groups, and the amphibious forces. Since the mesoscale features are embedded in a continuum of variability, and since they are not stationary, it is necessary to survey a large area of the ocean as quickly as possible if one hopes to obtain a "snapshot" of the area. This has been accomplished on six occasions by utlizing the services of amphibious squadrons as they return from overseas deployment. The ships were supplied with XBT (expendable bathythermograph) systems that obtain temperature profiles from the surface to a depth of 800 m while underway, with satellite navigation systems for accurate fixes of XBT casts, and with oceanographic observers. The ships spread out in

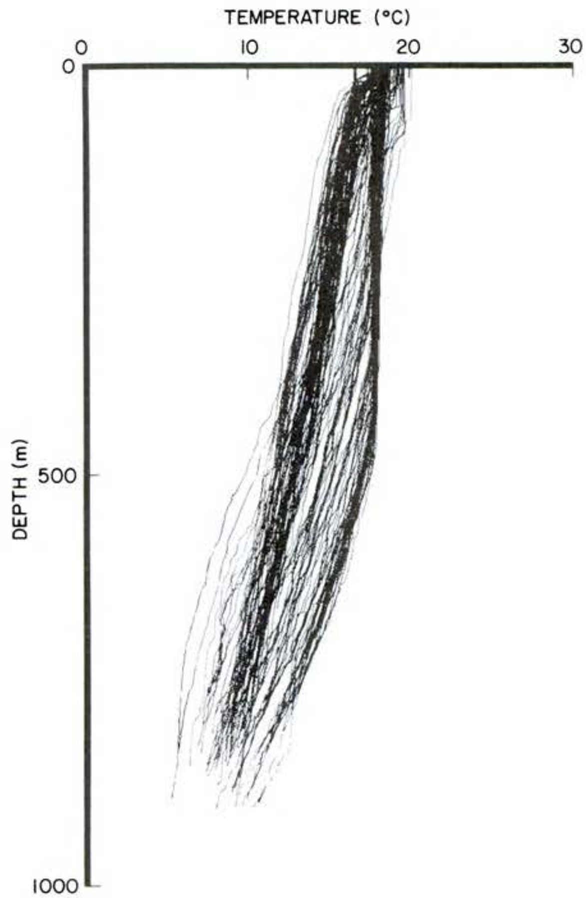


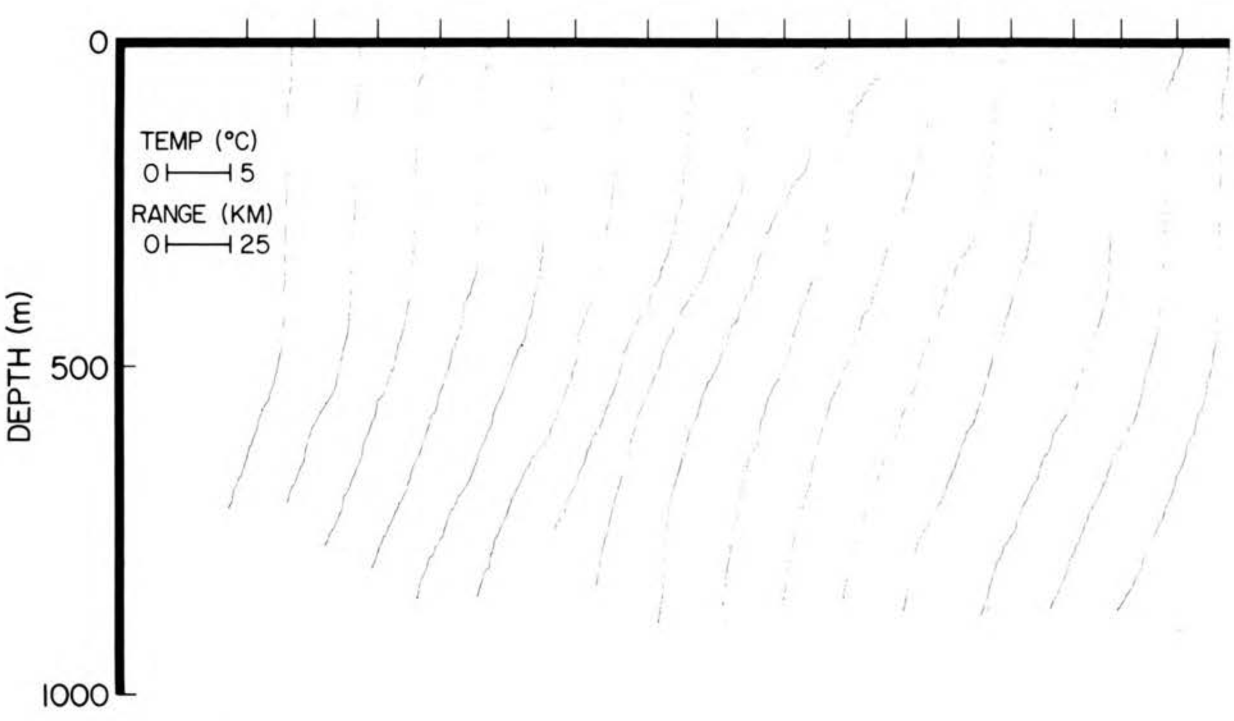
Figure 3— Temperature profiles from the surface to 900 m depth in mid-North Atlantic Ocean in May 1977.

a loose line abreast at intership spacing of from 35 to 70 km, and they survey a large rectangular swath of ocean.

Figure 3 shows some temperature profiles that were acquired in the North Atlantic by the following ships: USS Guam, Trenton, El Paso, Fort Snelling, and Harlan County. The survey region was occupied on 2-5 May 1977, and it roughly was bounded by 30-60°W and 36-38°N. The temperature profiles show a remarkable amount of variability for essentially a snapshot in time. The range of temperature in the surface layer is about 3°C, the range near 500 m depth is over 8°C, and the range at 900 m is over 5°C. The change in sound velocity that accompanies these temperature changes is over 25 m/s in the thermocline. This particular presentation brings out several notable points. Since the variability at the surface is reduced from that at depth, and since the profiles in Figure 3 often have a tendency to cross over each other in the upper hundred meters, these data bring out an apparent difficulty in any attempts to utilize remotely sensed surface temperature changes to indicate temperature changes at depth. In addition to this, there obviously are several classes of profiles present in the data. Some of the profiles exhibit a uniform thermocline with relatively constant temperature gradient from the surface to 800 m, while others have a very deep isothermal surface layer overlying a depressed permanent thermocline.

Although Figure 3 shows a large amount of variability, some of it seemingly random, there is a considerable amount of coherence between successive profiles taken about 25 km apart. As

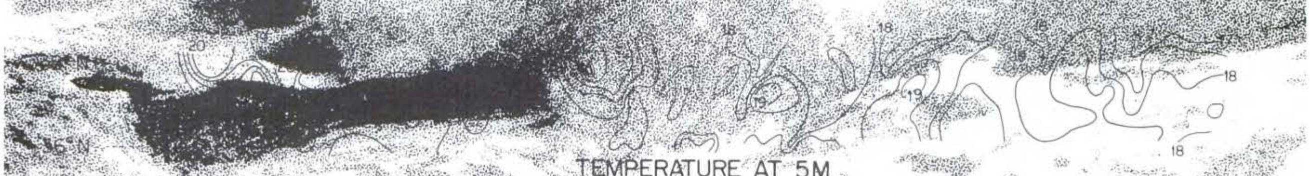
Figure 4— Sequential temperature profiles taken from previous figure. Each profile is displaced to illustrate the presence of a cold eddy.



shown in Figure 4, which is a sequence of successive profiles from one ship, there is an orderly transition from one type of thermocline structure to another. The relative temperatures are given by the scale in the figure inset, while the tic marks at the top of each profile indicate both the absolute temperature of 15°C and the position of each XBT station as indicated on the range scale. It is apparent that, near the middle of the figure, the deep isothermal water having temperature near 18°C is displaced by colder water.

A further refinement of graphical evidence of the changes in the temperature structure along a ship's track is given in Figure 5. This figure is an isotherm section from the center ship in the survey. The lines connect points of common temperature on successive profiles, and upraised lines are regions of colder water. There are four such regions west of about 42°W, while most of the area west of 42°W is warmer than that to the east. The four regions are cold eddies, and a frontal zone separates the region to the east of 42°W from the region to the west. The deep

Figure 6B— **Map of the near-surface temperature. Only the eddy near 48°W shows good correspondence between this map and the previous figure. Units are degrees Celsius.**



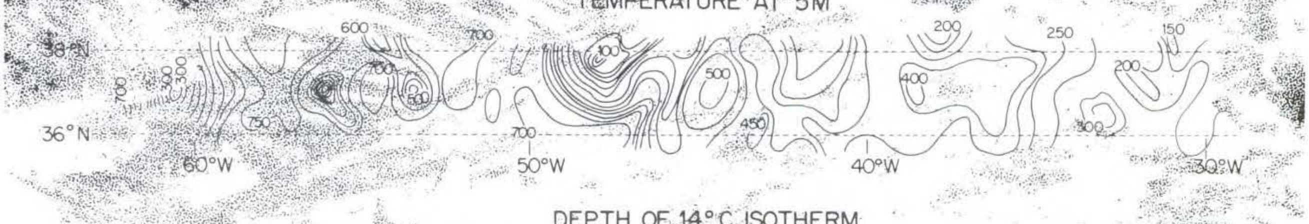
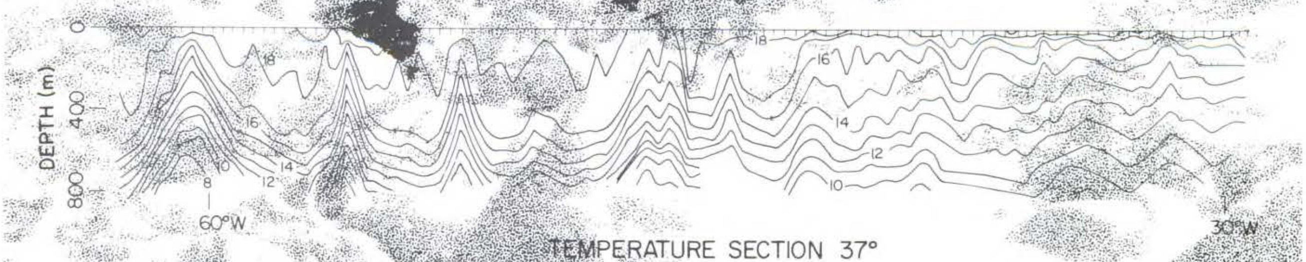


Figure 6A— **Map of the depth of the 14°C isotherm. Previous temperature section corresponds to a ship track across the center of this map. Units are in meters.**

Figure 5— **Temperature section near 37°N from 30°W to 62°W in the North Atlantic. The lines are isotherms that are obtained by connecting points of equal temperature on successive temperature profiles. Units are degrees Celsius.**



isothermal water mass near 18°C to the west of the front is the "18° water" of the Sargasso Sea, and a large amount of it apparently was formed in the winter of 1977. The changes in acoustic propagation conditions which correspond to the changes at different longitudes in this temperature section have significant impact on the prosecution of undersea warfare in the different areas. For example, the near-surface mixed layer changes markedly on the mesoscale. It is over 450 m deep near 51°W, yet it is only 100 m deep 50 km to the west of this position.

Since there were five ships engaged in this survey, we also can analyze temperature variability in the third, or North-South, direction. It is not easy to display three-dimensional data, so Figure 6 shows simply an interpretation of horizontal cuts through the data. Figure 6a is a map of the depth of the 14°C isotherm in the survey region. As may be seen in Figure 5, this isotherm is embedded in the permanent thermocline, so the map can be interpreted as representing spatial variability in the depth of the thermocline. This figure confirms that the four cold features west of 42°W in Figure 5 are eddies because of their nearly round shapes.

Figure 6b is a map of the near-surface temperature as indicated by the XBTs. It is important to understand the nature of the relation between the surface temperature and the thermocline structure if one is to use satellite infrared imagery in the future to monitor the subsurface ocean structure. Thus, a close relationship between the two maps is a matter of importance for successful remote sensing of mesoscale features. In the data, there is a cold surface region which correlates with the cold eddy near 48°W, but there is little surface expression of the eddy near 52°W. Also, the surface temperature over the two westernmost eddies actually is warmer than the surrounding area. Finally, there is no indication in the surface temperature of the drastic change in the thermocline structure across the frontal zone near 42°W. Thus, we conclude from this limited data set that the surface temperature is not a reliable indicator of subsurface variability. If surface temperature images are to be useful for prediction of thermocline structure in the future, we obviously need to know more about mixed layer dynamics.

Because of this difficulty in uniquely relating the surface temperature fluctuations to thermocline variability, it is worthwhile exploring other remote sensing methods for the purpose of monitoring the thermocline. Eddies and fronts in many cases do have significant currents that are appreciable at the surface, sometimes reaching a speed of one knot or more. Due to the coriolis force of the rotating earth, the current in the upper layers provides a balance (in oceanographic jargon it is called a geostrophic balance) which supports the horizontal density gradient across the front or the edge of the eddy. This current is analogous to the wind around atmospheric high and low pressure systems. It appears to be possible to remotely sense the surface expression of these currents by the appropriate processing of active radar signals, but there surely will be problems interpreting the resulting images. The surface layer is closely coupled with the wind stresses, and, just as in the case of surface temperature, the accompanying noise will compete with the required signal. Besides the wind drift, these sources of noise are known to include local convergences and divergences and inertial waves, all of which occur in unknown patterns at the surface.

Another technique for monitoring the mesoscale variability in the thermocline that might be viable in the future involves masses of water having differing density, and the difference can cause a deflection of the sea surface from the local geopotential surface. This deflection is estimated to be in the range of several tens of centimeters up to about a meter, with the strong western boundary currents with their associated fronts causing the largest deflections. The relation between the surface deflection and the underlying density profiles is straightforward, and it is not as closely coupled to the atmosphere as the other variables. However, the proper interpretation of the surface deflection again is subject to several noise sources, including atmospheric high and low pressure systems and surface tides.

Finally, since the mesoscale structure affects acoustic wave propagation, it would appear to be possible to invert the problem and to use underwater acoustics as a remote sensor of ocean variability. Time of travel of a pulse along several paths between a source(s) and receiver(s) is a function of the transmission medium, and theoretical arguments recently have been used to design a conceptual acoustic experiment to do oceanography in this way.

The detailed study of these several possible methods for monitoring the mesoscale structure has barely begun, and it is too early to predict a sure winner. It is, however, safe to predict that the coupled use of several methods will provide more information than any one method alone. Certainly, research on these methods of remote sensing of the ocean should receive high priority by oceanographers because they represent the only way it will be possible to measure mesoscale variability over large ocean areas on a regular basis in the near future.

The Future

The prosecution of research in mesoscale variability and in particular in the various remote sensing techniques involves fundamental problems in the physics of the sea. Reliable models need to be built which are capable of predicting the three-dimensional subsurface structure from a limited amount of information measured at or near the boundaries. In order to accomplish this, a significant amount of synoptic data like that shown in Figures 3-6 will need to be acquired. These data are required for complete understanding of the physicl processes that occur and for evaluation of the resulting models.

This requirement presents a problem, since present oceanographic instrumentation is not up to the task. Great strides have been made in the past decade, as sophisticated oceanographic instrumentation has proliferated to the point where, for the first time, it has been possible to obtain information on the dynamics of the deep ocean. Satellite navigation equipment has provided accurate station keeping for ships at sea. Mooring technology has advanced to the stage where deep currents can be measured at particular points continuously for a year or more. Floats or drifters have been deployed that track water movements at particular depths for extended periods. For near-surface currents, the drifters are tracked by satellite while, for deeper currents, they are tracked by basin-scale acoustic ranges. Even current velocity profilers are used to obtain surface to bottom profiles of the nearly horizontal water motions. For accurate measurements of vertical profiles of water properties, CTD (conductivity-temperature-depth) profilers have routinely replaced the time-honored hydrographic methods that required bringing water samples to the surface for analysis. The measurement of conductivity, temperature, and depth (actually pressure) is sufficient to determine the water density profile which is so important to ocean dynamics, and the sound velocity profile which is so important to underwater acoustics.

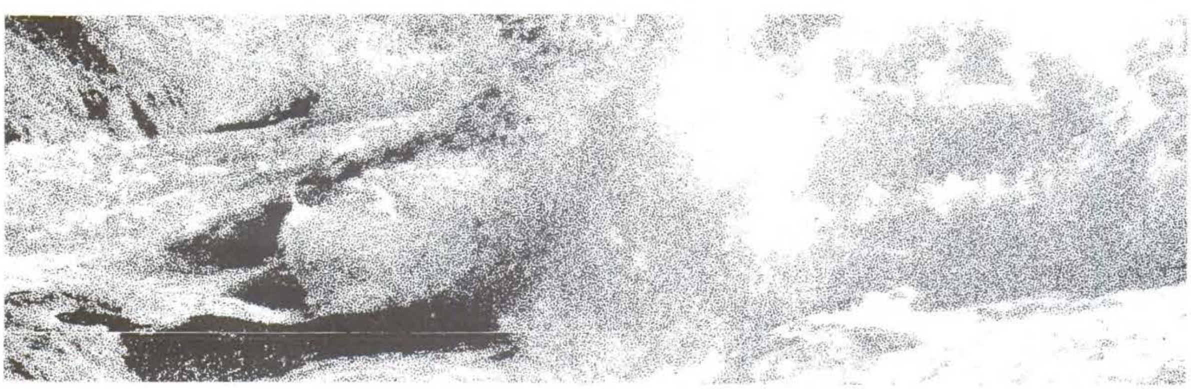
These instruments are quite accurate, and they provide the user with powerful tools. However, they fall short of the task of providing the oceanographer with synoptic data so that he can "watch" the mesoscale features evolve, much like the meteorologist watches the weather evolve. What is needed is a suite of instruments that can be deployed across large areas of ocean at rapid speed.

Many decades ago, the mechanical bathythermograph provided such a capability. It was a device that gave a continous temperature profile from the ocean surface to a depth of several hundred meters from a ship while underway. These instruments were not particularly accurate unless in the hands of an

expert, but they were reliable enough to be deployed on all Fleet ASW units for many years for tactical undersea warfare purposes. This system was replaced in the late 1960's by expendable systems that could be deployed from surface ships and aircraft. The surface ship system, the expendable bathythermograph or XBT, has an expendable drop body that sends temperature information back to the ship through a fine connecting wire. The airborne unit, or AXBT, is deployed like a sonobuoy. The temperature sensor descends from the buoy and sends its information by wire to the buoy which then transmits it by radio to the aircraft.

The XBT provides sufficiently accurate data for surveys of mesoscale thermal variability, but it is of limited utility. It only measures temperature, and its deployment is limited by the significant constraints of ships as launching platforms. The AXBT has the advantage of the mobility of the Navy P-3 aircraft, but it has limited accuracy and depth range. The maximum depth of measurement is 300 m, and this is not deep enough to acquire data on the thermocline structure in many areas and seasons. For example, much of the information in the thermal data in Figures 3-5 would be lost if all data below 300 m were not available. In fact, the depth of the near-surface mixed layer would not even be ascertained in many places. This problem occurs in large areas of the ocean north of about 35°N in the winter and spring seasons. It could be solved by having an AXBT which has the shipborne XBT capability, and such an instrument would provide a much needed mesoscale surveying tool for both the research and the operational communities.

A complete suite of expendable instrumentation which is capable of measuring the required parameter profiles from ships or aircraft will be provided only by those dedicated to the largely thankless task of developing it. Even if a concerted program were undertaken to provide the instrumentation, it would not be available on a routine basis for years. C. O'D. Iselin, in an ONR-funded symposium way back in 1956, had some insightful comments on the progress of instrumentation even before the breakthroughs of the last two decades (6). Some of these are worth recalling now. We find that "convenient, long-range, precise navigation remains the number one need in physical oceanography," or at least it still remains high on the list, and that "to be able to measure, from a moving ship, the change of speed and direction of flow as a function of depth would constitute a major advance in oceanography." We now can add the additional requirements of obtaining either salinity or sound velocity profiles as well as the temperature and water velocity profiles while underway. Iselin's third far-seeing comment had to do with utilizing aircraft for efficient coverage of the ocean. Two decades later, we have a platform that he could only have



dreamed about—the P-3—but we still do not take full advantage of this tool because of our limited-capability expendable. In addition, we find ourselves relying on the efforts of other programs to make available the next generation navigation system, the NAVSTAR Global Positioning System. The high-accuracy data stream from the GPS will yield position fixes accurate to about 5 meters, and, coupled with improved instrumentation for measuring water velocities relative to ships, it will allow precise measurement of absolute water motions in the upper ocean on horizontal scales of tens of meters to tens of kilometers.

We look forward to this next generation of ocean instrumentation development with the expectation that it will help us unravel some of the secrets of the dynamics of variability in the upper ocean. ■

References

1. Wunsch, C. "Internal Waves in the Sea," *Naval Research Reviews,* Vol. 29, No. 3, 1976.

2. Gregg, M.C. "Microstructure: Signature of Mixing in the Ocean," *Naval Research Reviews,* Col. 29, No. 11, 1976.

3. Rhines, P. A. "A Note On Long-period Motions at Site D." *"Deep-Sea Research,* Vol. 18, 1971, p. 21.

4. Wunsch, C. and J. Dahlen. "Preliminary Results of Internal Wave Measurements in the Main Thermocline at Bermuda," *Journal of Geophysical Research,* Vol. 75, 1970, 5899-5908.

5. Wyrtki, K. "NORPAX and the Upper Ocean," *Naval Research Reviews,* Vol. 29, No. 9, 1976.

6. Iselin, C. O'D. "Along What Paths is Physical Oceanography Likely to Proceed." Proceedings of the Symposium, *Aspects of Deep-Sea Research,* W. S. vonArx, Ed., Washington, D.C., Feb 29-Mar 1, 1956.

profiles in science

Professor Herbert A. Simon, Nobel Laureate for 1978 in Econimics, is Richard King Mellon University Professor of Computer Science and Psychology at Carnegie-Mellon University, where he has taught since 1949. During the past twenty years he has been studying decision-making and problem-solving processes, using computers to simulate human thinking. He has published over 400 papers and 20 books among which are "Administrative Behavior," "Human Problem Solving," and "The Science of the Artificial," renown texts in their fields. Currently Professor Simon's computer research is partially funded by the Office of Naval Research.

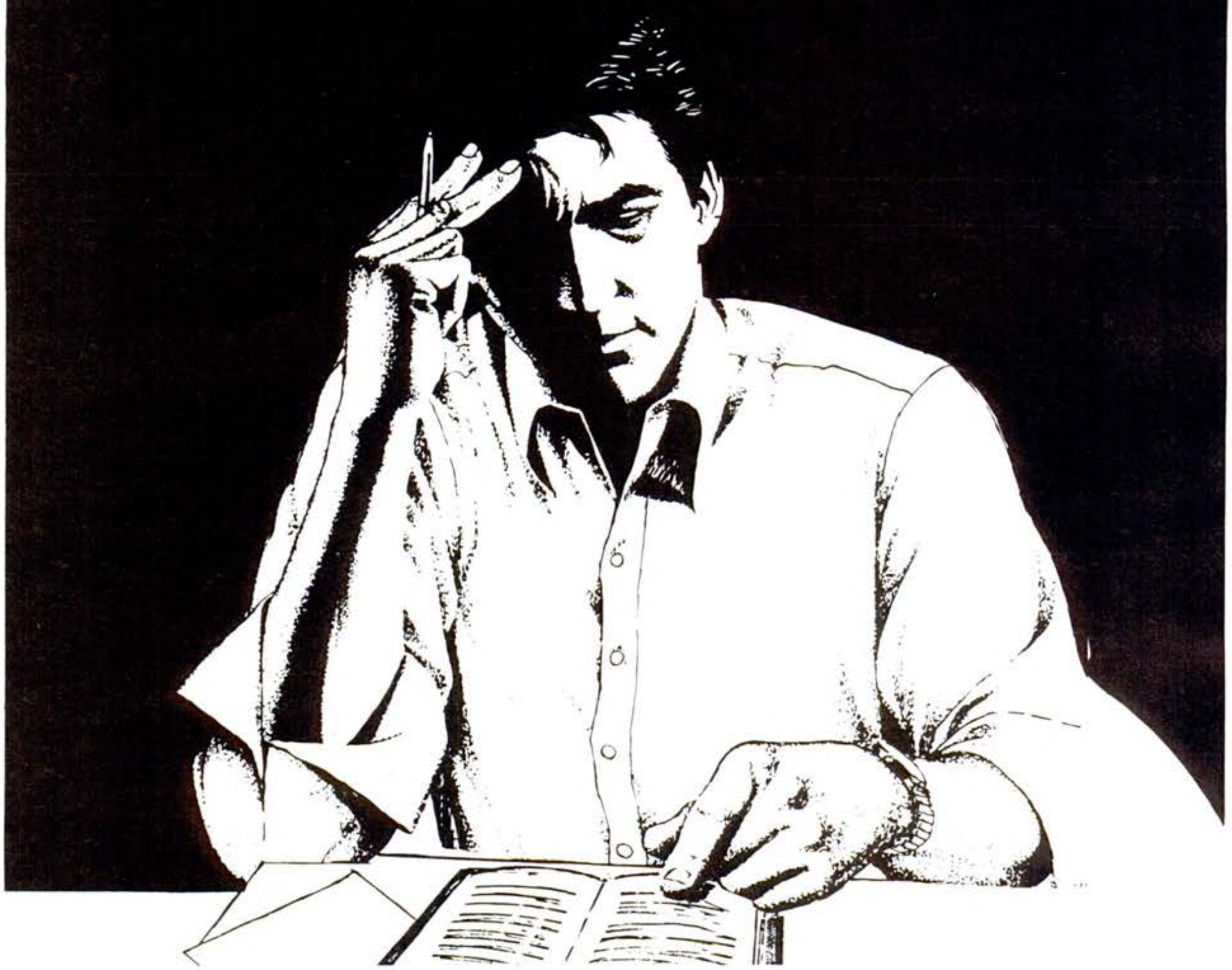
Professor Simon believes that computers will be able in our time to do anything a man can do: read, think, learn, and create. However, he contends man will not find the automated world greatly different from what it was in the past. His opinions on what automation may mean for the future of business and economy have become important guidelines for the economic theorists.

In 1967 Professor Simon was elected to the National Academy of Sciences. He received the Distinguished Scientific Contribution Award of the American Psychological Association, the A. M. Turing Award of the Association for Computing Machinery, and was elected Distinguished Fellow of the American Economic Association.

He has been Chairman of the Board of Directors of the Social Science Research Council, and of the Behavioral Sciences Division of the National Research Council, and was a member of the President's Science Advisory Committee from 1968-72.

Component Skills in Reading – Identifying Sources of Reading Disability in Young Adults

by John R. Frederiksen



The Navy is, in the late 1970's, faced with a serious dilemma: as the technical sophistication of ships, planes, and missiles has grown at a rapid pace, the skills of the average Naval recruit who must be trained to operate such equipment have declined (*Science,* 1978). (1) The problem is of such magnitude that it has reached the national media. For instance, a UPI release printed in the *Boston Sunday Globe* reports a speech by Vice Admiral J. D. Watkins, Chief of Naval Personnel, in which he related the following incident:

"Recently, on one of our ships, an engineman was rebuilding a diesel engine as part of a routine maintenance schedule. He could not read well. So he went about accomplishing the process by looking at the pictures in a technical manual. When he tried to install the cylinder liners, there was no picture. So he installed them the way he thought they should be. The result was that he installed them upside down. It cost $250,000 to repair the engine."

Admiral Watkins went on to say that "A well meaning individual who cannot read can cause unnecessary and unwanted problems, to say nothing of the danger to his life and the life of his shipmates." (2)

With simultaneous declines in the size of the recruit population and the reading skills of the prospective recruit, Naval Personnel and Training Research has been faced with an important challenge: Can it be determined how and why people read the way they do? And, how can the reading proficiency of young adults who are reading-disabled be improved?

Component Skill Deficits in Reading

The answer to the first of these questions is of fundamental importance. If there are a number of component skills involved in reading, then the sources of reading disability may vary from one individual to another, and so might the appropriate forms of remediation that should be applied in a training program. To this end, our initial task has been to develop measures that are diagnostic of the sources of reading difficulty among prospective naval recruits. (3) (4) (5) The goal of our work has been to develop a set of measures that represent the particular information-handling processes used in reading, as they are conceptualized in current theories, of the reading process.

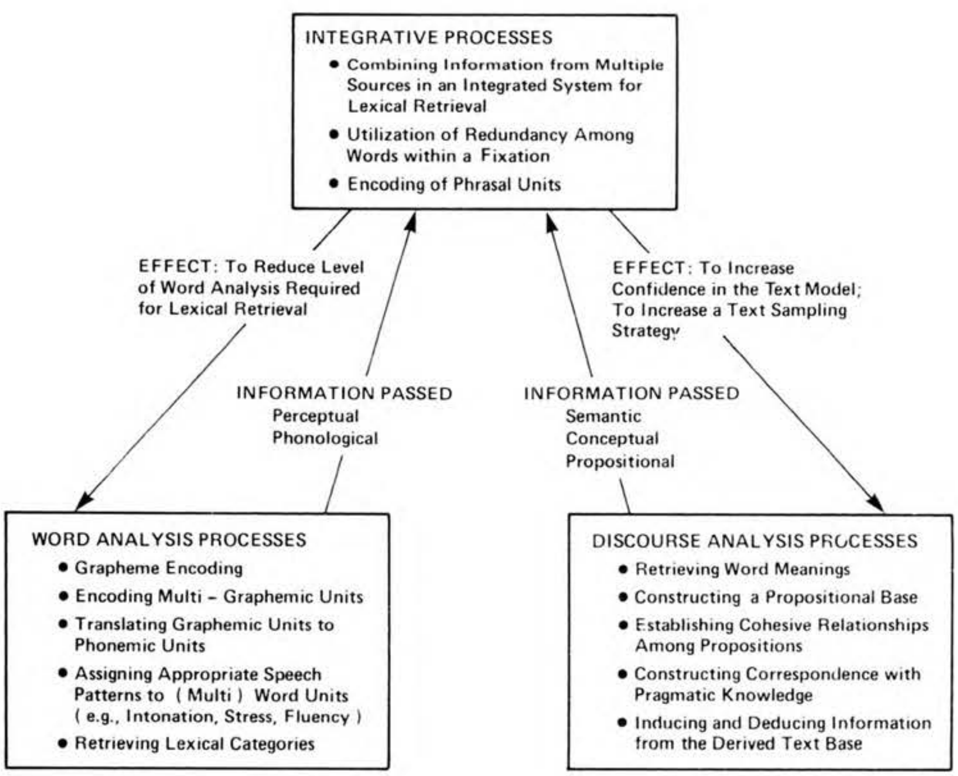
In our work we frequently measure the *times* needed by subjects to complete particular reading tasks. There are a number of reasons why the measurements of subjects' processing times has proved to be a useful tool for the assessment of skills in young adults. First, it is difficult to generate errors in such basic skills as letter identification, phonic analysis, and the like in mature subjects; nevertheless, individual differences in skill are still apparent in their processing efficiencies. Second, studies of reaction times in human information-processing tasks have served experimental psychologists well in their efforts to build precise, multi-component models for reading. In particular, the subtractive method for analyzing reaction times (RTs) has proven its value as a technique for deriving measurements that reflect a single locus of information processing. In the subtractive method, a difference in RTs is calculated for experimental conditions that vary in the processing load they place on some single processing subsystem. RT differences (or contrasts) then provide a measure of the relative difficulty of processing under the contrasted conditions. These differences in processing times—measured in 10's of milliseconds—we have found to be reliable indicators of processing efficiency in assessing individual differences in component skills.

Dr. Frederiksen is a Senior Scientist in the Information Science Division, at Bolt Beranek and Newman, 50 Moulton St., Cambridge, MA 02183. He has been Assistant Professor at Brandeis University and is an Associate in Education at the Harvard Graduate School of Education. Fredericksen's research interests are in the analysis of human information processing systems, the formulation of models for the utilization of basic cognitive skills in reading, and the measurement of individual differences in skilled human performance.

But there is also a theoretical basis for our concern with readers' processing efficiencies. The general view of reading ability we espouse is a pluralistic one; skilled reading is, we believe, a result of the successful acquisition of a number of highly automatic, component processes that operate together in an integrated and mutually facilitory manner. If the human central nervous system has any one salient characteristic, it is an extremely large capactiy for storing information—and procedures for processing information. Yet a second all-too-familiar characteristic of human cognition is the limitation in processing capacity that is revealed whenever one is required to perform two or more information-processing tasks simultaneously. Studies of dual-task performance have shown, however, that with practice, a controlled, resource-limited process can become in effect an automatic, data-limited process. (6) Moreover, such an automatic process does not degrade performance on some other task with which it is performed concurrently. Given the large storage capacity available, there is clearly great potential for a learner to develop automatic skills for handling a variety of information-processing tasks, and these automated skills will enable the learner to meet the simultaneous processing demands of any complex task that draws upon those skills, such as that of reading. Skilled reading may, in effect, represent the culmination point in the development of a powerful multiprocessor that can simultaneously analyze word structure, make lexical identifications, and process discourse structures, and do all this in an integrated fashion.

This research project supported by the Office of Naval Research, represents our attempt to identify component skills involved in reading. The domain of our inquiry includes information-processing that takes place (a) in decoding the printed word, (b) in analyzing and comprehending text (or discourse), and (c) in integrating contextual and perceptual information in encoding words and phrases (see Figure 1). Within these three general domains of processing, sets of component processes are distingiushed. *Word analysis processes* deal with the perception of multi-letter "chunks" (such as SH, OU, ABLE, ING, etc.), with the translation of graphemic units to the phonological units of speech, and with the retrieval of appropriate lexical categories. *Discourse analysis processes* are those employed in retrieving and integrating word

Fig. 1. **Categories of reading processes and the nature of their interactions.**



meanings, in comprehending the basic propositions underlying sentences, in tying together concepts in a given sentence with those in previous sentences, and in inferring additional facts or events that are not explicitly presented in a text but which are nonetheless a part of the underlying meaning to be comprehended. *Integrative processes* are those that permit a reader to use information from perceptual sources in conjunction with information derived from comprehension of prior text to efficiently encode subsequent words and phrases.

The remainder of this text describes some of the results of this research, both theoretical and empirical, centering on each of the three domains described followed briefly by some of the directions that will be taken in future work.

Word Analysis Processes

Four experiments were carried out in the course of building and testing a conceptual model for processing involved in the analysis of orthographic characteristics of English words. The experiments used a variety of tasks and designs to measure component processes; these components, along with the tasks used in their measurement, are listed in Table 1.

Table 1. Experimental tasks used to measure word analysis skills.

Component Skill	Task		Measures*
I. Efficiency of grapheme encoding	Letter matching	1	Speed in letter encoding: RT(Aa) - RT(AA)
	Bigram identification	2	Scanning rate in reporting bigrams within 4-item arrays
II. Efficiency in perceptual parsing, encoding orthographically regular multi-letter units	Letter matching	3	Facilitation in encoding jointly occurring letters: RT(Ad) - RT(Aa).
	Bigram	4	Increase in RT for reporting low-frequency compared with high-frequency bigrams
			Increase in pseudoword vocalization latency for:
III. Efficiency in phonemic translation	Pseudoword decoding	5	Increase in array length
		6	Two syllables compared with one syllable
		7	Digraph vowels compared with simple vowels
IV. Automatacity in articulation: syllabication, assignment of stress and prosodic features	Pseudoword decoding		Increase in pseudoword vocalization duration for:
		8	Two syllables compared with one syllable
		9	Digraph vowels compared with simple vowels
V. Depth of processing in word recognition:	Word naming		Comparison of decoding indicators for:
Use of visual/holistic cues versus analysis of orthography		10	Pseudowords and high-frequency words
		11	Low-frequency and high-frequency words

*Measures are defined so that high values represent inefficiencies in processing and low values represent highly efficient, automatic processes.

The Letter Matching Task

The first of these tasks permits us to measure a reader's speed in recognizing or encoding letters, and his ability to encode rapidly pairs of letters that are related to one another.

In the letter matching task, the subject is shown a brief (50 msec) display containing a pair of letters that (a) have the same name and form (AA, aa), (b) have similar names but differ in form (Aa), or (c) are totally different in name and form (Ad, ad, AD). (7) The subject's task is to indicate whether the names of the letters are the same or different, by pressing an appropriate response key marked "same" or "different." The subjects who were tested, in this and in the subsequent experiments to be described, were 20 high school students chosen to represent high and low reading abilities on the basis of scores on a standard test of reading comprehension. They ranged from exceptionally strong readers scoring at the 99th percentile, to extremely poor readers who scored as low as the 16th percentile.

Results concerning our readers' letter-encoding abilities are shown in Figure 2. We found, first, that good and poor readers differed from one another in the speed with which they encode letters. This was measured by taking the difference in RT for letters that are matched by name (e.g., Aa) and that for letters that are matched by physical pattern (AA, aa). Good readers appeared to encode letters more rapidly than did poor readers. Second, we found that there were differences among readers in the amount of savings in processing time when nominally similar letters were presented (e.g., Aa) instead of unrelated letters (Ad). It was the good readers who appeared to profit most from categorical identities among letters that were presented together. These two measures we have derived from the letter-matching task have been termed *Speed in Letter Encoding and Facilitation in Encoding Jointly Occurring Letters.* We believe that these measures refer respectively to the two aspects of Perceptual Encoding we have alluded to—encoding of individual graphemes, and encoding of multi-grapheme units.

Bigram Identification

The second task we employed was used to measure the relative processing times a reader requires in encoding common letter pairs (such as SH) and uncommon letter pairs (such as LK), all of which actually occur within English words. The task also allowed us to measure a reader's speed in scanning a multi-letter display.

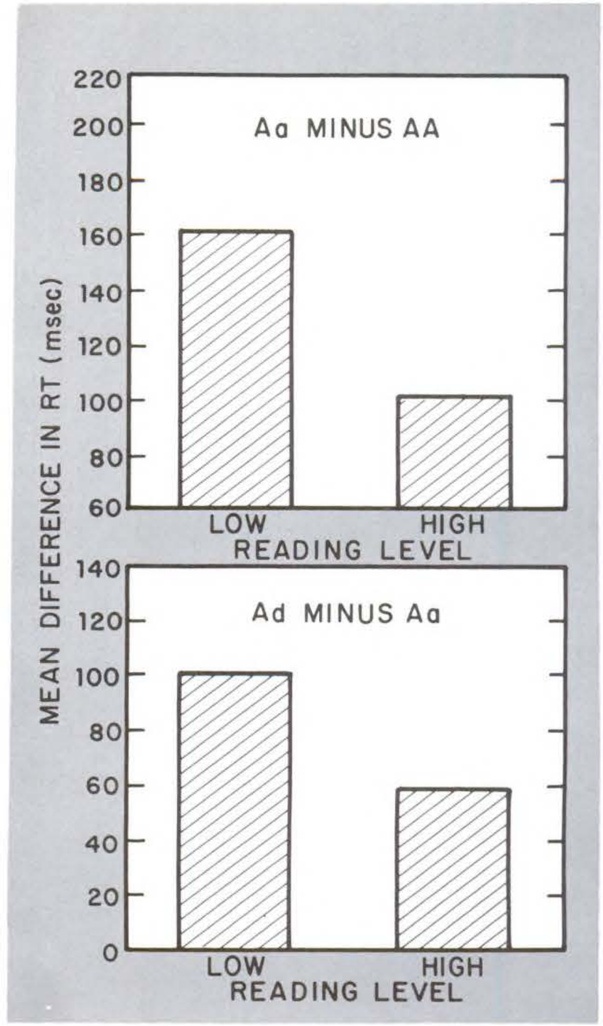


Fig. 2. Differences in reaction times for letter matching of nominally similar and physically similar letters (at the top) and for dissimilar and nominally similar letters (at the bottom).

In the bigram identification task, the subject is shown a 4-letter array that is preceeded and followed by a 4-character masking pattern (e.g., #### is presented, followed by SHOT, and that followed by ####). The actual stimulus array varies from trial to trial. On a third of the trials, the stimulus items are familiar English words, while on the remaining trials the items are presented with two letters masked so that only a single pair of adjacent letters (a bigram) is visible (e.g., SH##, #AB#, or ##TH). Further, the bigrams are chosen so as to differ in location within the item (positions 1-2,2-3, or 3-4), and in their frequency of occurrence in English prose (e.g., TH [high], GA [middle], and LK [low]. (8) In all cases, the subject's task is to report all the letters that he can see, as quickly and accurately as possible. This task is a perceptually difficult one, since the stimulus exposure allowed only 90-100 msec prior to the onset

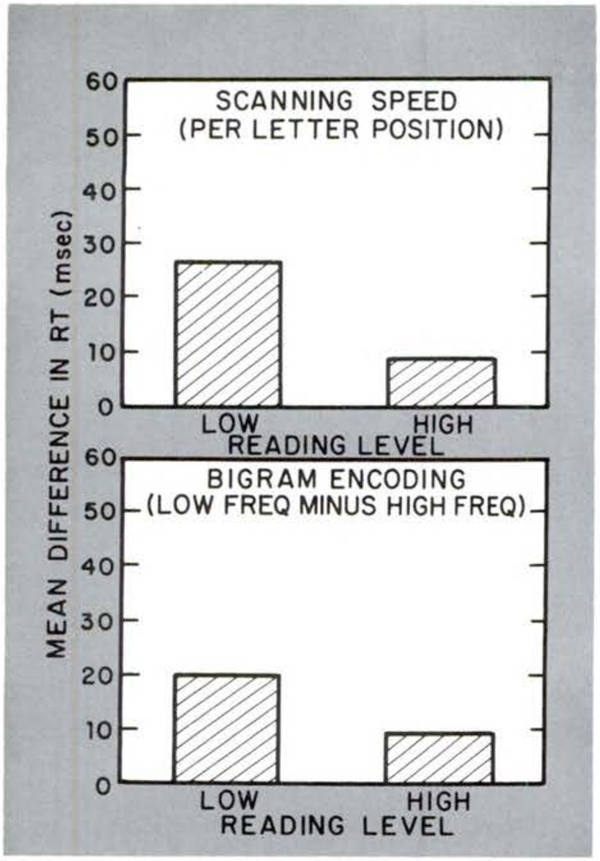


Fig. 3. Differences in mean reaction times for reporting bigrams associated with a shift in position (at the top) or with a change in bigram frequency (at the bottom).

of the masking stimulus.

The results show us that subjects of high and low reading ability differ both in their *rate of scanning* a perceptual array, and in their *sensitivity to redundancy* built into the stimulus. In Figure 3 we have plotted the increase in reaction time required for each shift in the position of the unmasked bigram, from the left to the right. As can be seen, this measure of scanning time *decreases* as reading ability increases. Put another way, there is a higher *rate* of scanning shown by high ability readers than by low ability readers.

Differences in subjects' response times in encoding low and high frequency bigrams are also shown in Figure 3. The magnitude of this RT difference is greater for poor readers than for proficient readers. Thus, while high ability readers are capable of efficiently processing letters that occur together in English over a broad frequency band, low ability readers' efficiency in identifying letter groups is limited to letter pairs that typically occur together, with high regularity.

These findings led us to consider two measures derived from this experiment: the subject's *Scanning Speed* and his *Efficiency in Encoding Bigrams.* Our second variable provides a measure of a subject's ability to encode multi-letter units that are orthographically regular, while the first is thought to provide a more general measure of Perceptual Encoding which reflects both the single grapheme and multi-grapheme subprocesses.

Pseudoword Decoding

This task was designed to measure the ability of a reader to derive the pronunciation of an orthographically regular nonword (e.g., BAUTS) and to see how his performance varied as simple orthographic forms (e.g., TULL) were replaced by more complex forms (e.g., TAUL, TISTE, TAIGHT, and the like).

Subjects were asked to pronounce pseudoword items that were derived from actual English words by changing a single vowel (e.g., BRENCH, derived from BRANCH). The set of pseudowords includes a number of orthographic forms, representing variations in length, number of syllables, and type of vowel. We measured the RT from the presentation of the display to the onset of the subject's vocalization (this period is called the latency of the response), as well as the duration of his vocal response.

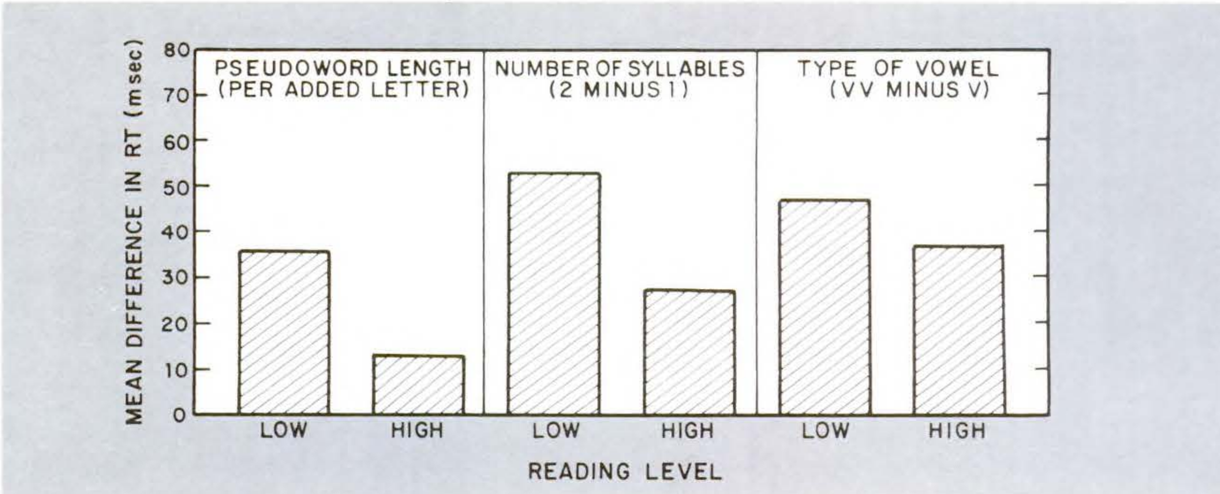


Fig. 4. Differences in onset latencies for pronouncing pseudowords that vary in their difficulty of decoding.

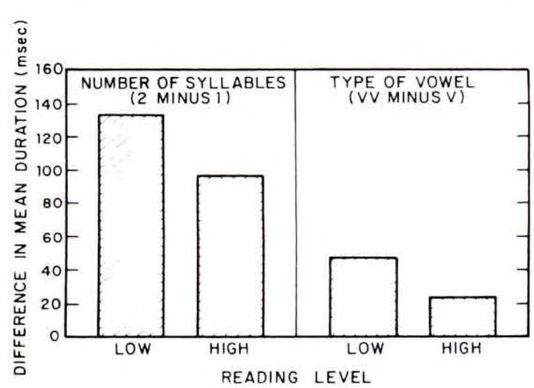
We found differences between good and poor readers in both vocalization latencies and vocalization durations for pseudowords varying in length, vowel complexity, and syllabic structure. These findings are shown in Figure 4. The low ability readers required more additional processing time to handle each added letter than did high ability readers. They also paid a greater price in processing time when a simple vowel (e.g., A) was replaced by digraph vowel (AU, AI), and when a one-syllable item was replaced by a two-syllable item. Our good and poor readers also differed in their vocalization durations, and these results are shown in Figure 5. We found that there were increases in vocalization durations for digraph vowels and two-syllable items, compared with simple vowels and single syllable items, and that these increments were greater for the poorer group of readers.

Together, these findings allowed us to define five indicators of decoding skill: The *Array Length Contrast* is the increase in mean RT for each added letter, the *Syllable Contrast* is the difference in RT for two- and one-syllable items, and the *Vowel Complexity Contrast* is the difference in RT for items having digraph vowels and single vowels. Finally, the syllable and vowel complexity contrasts were calculated again using vocalization *durations.* Each of these contrasts reflects the growth in processing difficulty occasioned by increasing the orthographic complexity of a stimulus item in a designated manner. Measures based upon RT to onset of vocalization are thought to tap earlier decoding processes of parsing and phonemic translation, while measures based upon vocalization durations tap later processes of articulatory programming, stress assignment, and the establishment of prosodic features.

Word Naming

This task allowed us to investigate the degree to which readers employ processes of orthographic analysis we have termed Decoding in recognizing common English words. The word naming task is in every respect similar to the Pseudoword Decoding task, except for the use of English words in place of pseudowords. The stimulus words were chosen to

Fig. 5. Differences in vocalization durations for pronouncing pseudowords that vary in their difficulty of decoding.



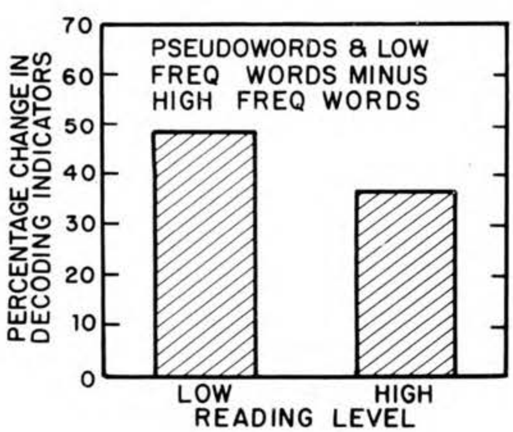
reflect, in addition to variations in orthographic form we have described above, two rates of occurrence: common words (e.g., TIME and CATCH) and rare (e.g., TINE and CONCH). Thus, each of the five contrasts described above for the Pseudoword Decoding task could also be calculated for both high frequency words (HFWs) and low frequency words (LFWs). In general, we found that there was a *drop* in the magnitude of these five indicators of decoding activity when high frequency words were substituted for pseudowords or low frequency words. Readers appear to employ Decoding processes in recognizing uncommon words, but rely on more holistic visual recognition processes when recognizing the more common words in the language.

With these observations in mind, we have constructed two measures for comparing the extent of use of Decoding in processing high frequency words with that for low frequency words and pseudowords. We calculated the *Percent Drop in Decoding Indicators for HFWs and Pseudowords* by adding together the values of our five decoding indicators for both HFWs and Psuedowords, and then calculating the percent drop using the formula:

% Drop = (Sum(Pseudowords) - Sum (HFWs))

In a like manner, we calculated the *Percent Drop in Decoding Indicators for HFWs and LFWs* by substituting LFWs for pseudowords in the above formula. By studying the values of these variables for high and low ability readers, we could find out if there are differences in word recognition strategies that are related to reading proficiency. The average of these two measures is given in Figure 6. The drop in decoding indicators is greater for poor readers than it is for high ability readers. Thus, when they are reading common English words, the poor readers appear to rely less on word-analysis procedures and more on holistic perceptual processes for recognition.

Fig. 6. Percentage drop in the summed value of decoding indicators, for high-frequency words compared with low-frequency words and pseudowords.



The use of several tasks for measuring each component enabled us to test the validity of theoretical interpretations we have given for each of the measures we have presented in Table 1, using confirmatory maximum-likelihood factor analysis. (4) This statistical technique allowed us to compare and test four alternative skill models that attempted to account for observed covariations in task performance on the information processing measures derived from our four tasks. In each of these models, the measures were hypothesized to be linear functions of one (or in a few cases, two) underlying components or factors. (9) Table 2 portrays the hypothesized relations between measures and components for one of these models—the one that was implicit in our previous discussion of the experimental tasks. As it turned out, this was the only one of four models tested that yielded a satisfactory fit to the data. We can conclude from this exercise that each of the distinctions we have drawn between perceptual and decoding processes represents a necessary distinction among components.

It is worthy of note that there were interactions among the component skills in our sample of high school readers. These were revealed in the pattern of intercorrelations among the factors. In particular, readers who were most skilled at perceiving the multiletter constituents of a word or pseudoword, were also most efficient in their methods of decoding, and they tended to utilize their efficient word analysis skills in reading even the more common English words.

Importance of Component Skills in Reading

In addition to identifying skill components and their interactions, we were interested in establishing what role the component processes play in setting levels of reading skill, as measured by conventional tests of reading ability and comprehension. In our study of high school students, three reading test scores were used as criteria: the Nelson-Denny Total Score (the sum of Vocabulary and Reading Comprehension subtests), Nelson-Denny Reading Rate, and the Gray Oral Reading Test (which includes number of pronunciation errors and reading rate). Performance on these test measures was highly

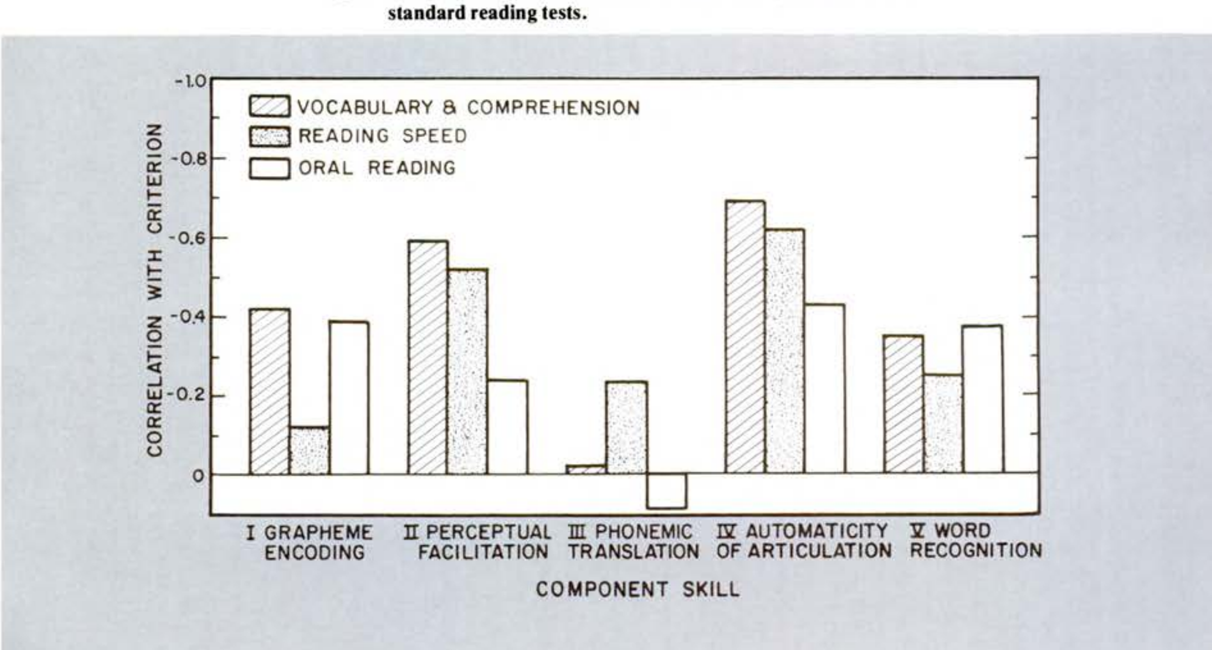
	FACTOR I Grapheme Encoding	II Perceptual Facilitation	III Phonemic Translation	IV Automaticity of Articulation	V Depth of Processing in Word Recognition
Measures*					
1. Letter Encoding	+	0	0	0	0
2. Scanning Speed	+	+	0	0	0
3. Percept. Facilitation	0	+	+	0	0
4. Bigram Probability	0	+	0	0	0
5. Length: Pseud.	+	0	+	0	0
6. Syll: Pseud.	0	0	+	0	0
7. Vowel: Pseud.	0	0	+	0	0
8. Syll: Pseud. (Dur.)	0	0	0	+	0
9. Vowel: Pseud. (Dur.)	0	0	0	+	0
10. Decod. Indicators Pseu.-HFW	0	0	0	0	+
11. Decod. Indicators LFW-HFW	0	0	0	0	+

*All measures except 8 and 9 are based upon response onset latendies.

Table 2. Hypothesized factor structure for the set of chronometric measure of component reading skills.

predictable from the component skill factors, with an average multiple correlation of .86. The contribution of particular component skills in predicting reading test scores is shown in Figure 7. The strongest predictors appear to be Perceptual Facilitation in Encoding and Automaticity of Articulation. Subjects scoring highly on the reading tests also tend to be efficient in Grapheme Encoding, and they tend to use their decoding skills in recognizing familiar English words as well as less familiar items. Low scoring subjects, on the other hand, are less efficient in encoding individual graphemes, in preceiving multi-grapheme units, and in their degree of automaticity in the final stages of decoding. And, as we have seen, they tend to recognize familiar words on the basis of their visual characteristics.

Fig. 7. Correlations between component skills and performance on standard reading tests.



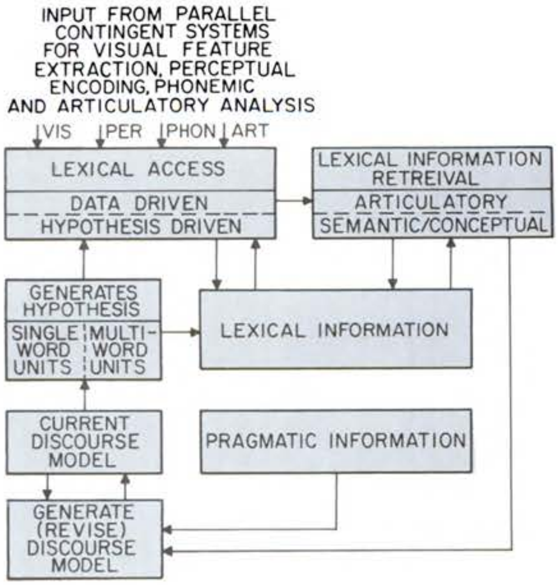


Fig. 8. A schematic rendering of processes involved when reading in context.

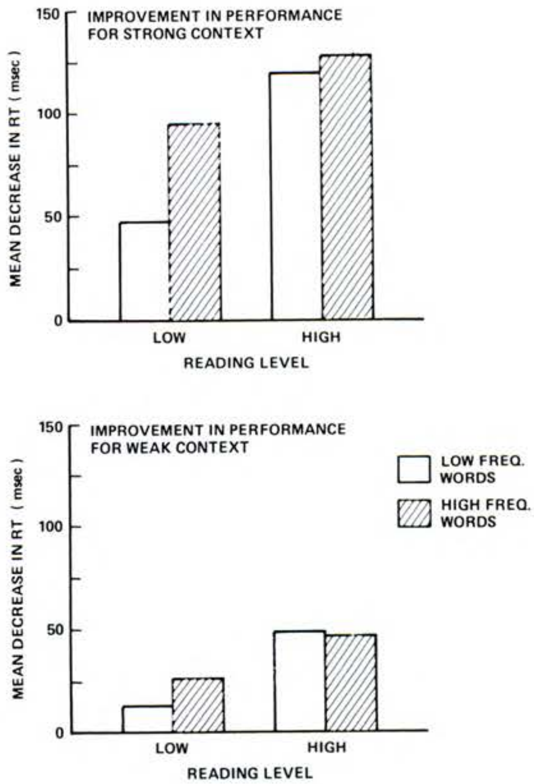


Fig. 9. Improvement in performance (decreases in word naming latencies) when a prior sentence context is provided for a word.

Integrative Processes

Our ideas for extending our component skills analysis to reading of words in context are illustrated in Figure 8. In addition to input from systems for feature extraction, perceptual encoding, and phonemic and articulatory analysis, the lexical access process has available to it information derived from the analysis of previous text encountered by the reader. In other words, the reader has a memory. This information, encoded by the reader in a "discourse model," furnishes the basis for generation of hypotheses about subsequent text that may occur. Accordingly, we distinguish a process of *hypothesis generation,* which is characterized by the quality of inferential analysis it performs and by the nature of the hypothesized units that are generated (e.g., single words, or words in likely-occurring, meaningful sequences). And the lexical access process is then further characterized by *the extent to which it is driven by perceptual* data ("bottom-up" processing) or by *hypotheses* derived from text ("top-down" processing).

Finally, as a result of lexical access, semantic/conceptual information about the lexical category becomes available which, along with pragmatic information and information contained in the discourse model, furnishes the basis for generation of a revised discourse model. The information-processing involved in building and revising a discourse model (of Kintsch & Vipond, Note 3) will determine the rate at which perceptual hypotheses can be generated and, therefore, the degree to which a subject can profit from context in accessing lexical information.

Work has been completed on two experiments that were designed to uncover the characteristic ways in which readers integrate information derived from context with that from the printed page, as they identify words and phrases of text. Here, briefly, is described the form of each experiment, along with some of the key findings.

Word Recognition in Context

In the first experiment (Frederiksen, Note 2), readers of high and low ability were asked to pronounce target words that were either tightly or loosely constrained by a prior context sentence. Consider, for example, the following sentence in which the final word has been omitted:

(1) I reminded her gently that this was

something that she really should not ________.

This sentence provides a context for a target word, which could be any one of a number of possibilities: *buy, do, take, see, read, tell,* etc. Look now at a second sentence:

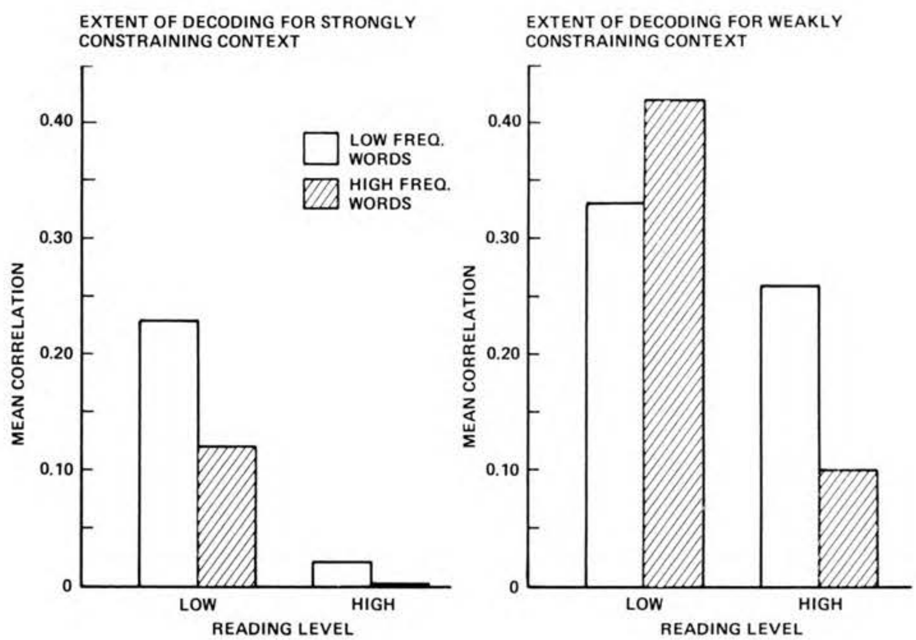
(2) Grandmother called the children over to the sofa, because she had quite a story to ________.

Here, there are only a few words that might fit the sentence: *tell, relate, present,* and the like. In our experiment, we were interested in how readers use the weak context (as in the first sentence), or the strong context (as in the second), in decoding and identifying a final target word. Subjects first read the context sentence. They then pressed a button, and were shown the target word. We measured their latency in pronouncing the target word. Some of the key findings are presented in Figure 9.

Low ability readers appeared to employ a controlled, serial process for generating contextually relevant lexical items to test against perceptual evidence when the final word appeared. Their performance improved with the addition of a context sentence, but only when the context was strongly constraining, and even then, the only extensive improvement was when the target word was a high probability word (such as *back*) which was the first one they were likely to guess. Context was of little help to this group of readers when the target item was an uncommon word, such as *buns,* and higher probability options existed for them, such as *rolls.* "Good" readers, on the other hand, appeared to use a parallel, automatic process for facilitating the identification of contextually relevant lexical items. This process operated for them even when the context pointed to a large set or domain of items, and the degree of facilitation due to context was no different for high or low probability words within the context-relevant domain.

In addition to evaluating the overall ability of readers to utilize context in recognizing words, we were interested in how readers would reduce their reliance on bottom-up, word analysis processes when they were reading words as part of a sentence. To this end, we developed a measure of the depth or degree of orthographic decoding in reading. We used a subject's onset RTs in pronouncing *pseudowords* made up of a variety of orthographic forms (varying in length, number of syllables, in type of vowel, etc.) as a measure of his difficulty in decoding those

Fig. 10. Mean correlation of pseudoword vocalization latencies obtained over a variety of orthographic forms with corresponding word recognition latencies. This correlation provides a measure of the extent of decoding activity when subjects read words in sentence context.



forms. Reading times for *words* (having the same variety of forms) were then correlated for each individual subject with decoding times for the corresponding pseudowords. Our notion was that, if decoding activity continues in the processing of words in context, we would find this to be a high correlation—since whether it is dealing with words or pseudowords, the decoder will have the same degree of difficulty with each of the forms it is processing. If decoding is not employed, then we could expect to find a correlation of zero.

In Figure 10 we have plotted the mean of these individual correlations for each context condition. Baseline values of these correlations are those for words presented alone: the mean r was .52 for low frequency words and .41 for high frequency words. Subjects are clearly using a decoding process in recognizing isolated words, and there is a greater depth of decoding for low frequency than for high frequency items. The provision of context brings a reduction in depth of processing, and this is particularly evident when the context sentence strongly constrains the missing word. Here, word analysis can be said to proceed to lower depth, or perhaps to high depth on fewer occasions. The poor readers, who showed the lowest skill levels in decoding, are also the ones who appear to be the least able to reduce their dependence on their inefficient decoding skills when context is provided. For the strong readers, however, contextual information is traded off against effort expended at orthographic analysis. Indeed, when these readers are presented words in a highly constraining context, they appear to be able to completely circumvent the use of a decoder ($r = 0.$).

Context and the Effective Visual Span

A second procedure we have developed (Frederiksen, Note 1) allows us to distinguish several ways in which contextual redundancy might influence the amount of information a reader can take in within a single fixation (called his *visual span*) when he is reading a text. First, readers might differ in their capacity to profit from sequential redundancies among the set of words occurring within a single fixation. Second, as we have seen in the previous experiment, readers might differ in their ability to use a prior semantic or linguistic context to increase the accessability of the individual words employed in the test phrase. And third, readers might differ in their ability to generate semantically and syntactically appropriate word sequences or phrases

Frame 1

They notice that the heat changes
from hour to hour. So the day is
carefully planned. They know it is
hottest during the afternoon. So
they do not work then. Instead
they rest. They may take a nap. As

Frame 2

a rule they do their jobs later.

Fig. 11. The sequence of diplays used in the study of reading in context. Frame 1 contains the context, and is terminated by the subject. Frame 2 contains the test phrase, herepresented with words in normal sentence order.

based upon a prior paragraph context, and in their capacity to utilize such hypotheses to guide lexical retrieval.

In the test we have devised, subjects began by reading a context paragraph, as we have illustrated in Figure 11. When they reached the end, they were asked to fixate a spot appearing in the final line of the display and to press a response key. After a brief interval, a test phrase was then presented for 200 msec., and the subject was asked to report as many words or word fragments as he could see in the test line. We tested our subjects using several conditions. In one session, subjects were presented 80 segments of text *with a context passage presented* in each case prior to the test phrase. In a second session, the subjects were presented 80 new test phrases, this time with the context passages omitted. Within each session, half of the test phrases were presented with their words in *normal sentence order* (as in the illustration), and half with their words in a *scrambled order* (as in, "a later do rule their they jobs").

An index of the subject's *ability to process redundant word sequences within a fixation* was obtained by comparing performance for test lines presented in the normal and scrambled word orders, when there was no prior context. On the average,

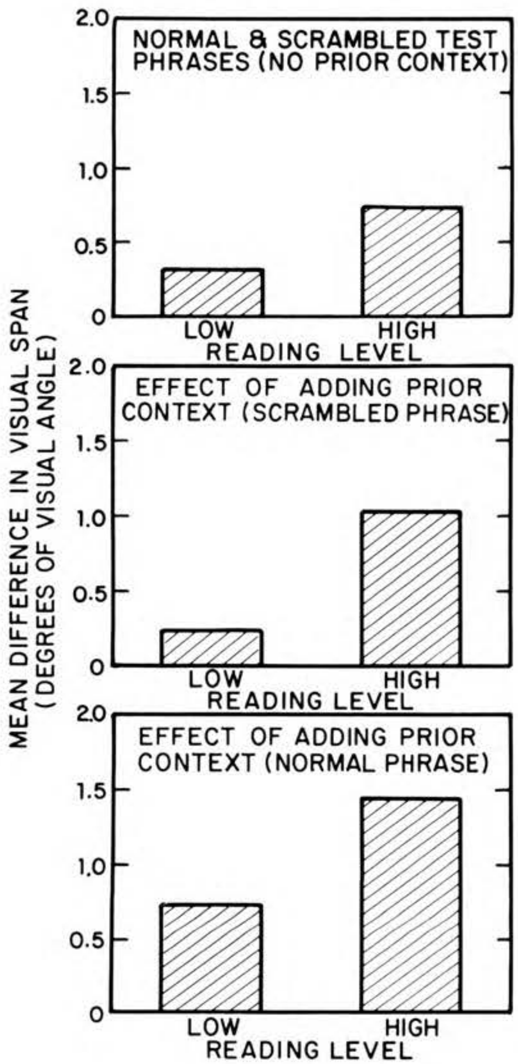


Fig. 12. Increments in visual span brought about restoring words of the test phrase to normal sentence order (top) and by the addition of a prior paragraph context, when the test phrase was scrambled (middle) or in normal order (bottom).

there was an increase in visual span of .53 degrees of visual angle when the test words were presented in normal sentence order. Thus, readers in general appear to have the capacity to exploit sequential redundancies among words, even within the time constraints of processing within a single fixation. Moreover, this increase in visual span was accomplished with a reduction in processing time of 169 msec, suggesting that there was an accompanying reduction in processing load. We have plotted the increment in visual span shown by our readers at the top of Figure 12. High ability readers showed a larger improvement in span when test words were presented in correct, sentence order than did the low ability readers.

The *effect of prior context on word recognition thresholds* was measured by comparing performance in encoding scrambled word sequences when a prior context is provided, with that when the context is omitted. In general, the addition of a prior context brought an increase in visual span of .64 degrees. However, there was no change in response time under these two conditions, implying that the increase in width of the effective visual field was achieved with an actual *reduction* in the processing time per unit encoded (e.g., per letter). Again, we found that there were differences between good and poor readers in the effects of prior context, shown in the middle panel of Figure 12. High ability readers showed greater use of context in making lexical identifications than did our low ability readers.

A measure sensitive to the subjects' use of context in *generating and testing multiple word hypotheses* was obtained by evaluating the effects of prior context on their performance in encoding sequences of words that were presented in normal sentence order. We anticipated that increases in visual span brought about by the presentation of a prior context would be greater when the words in the test line were in normal sentence order than when they were in a scrambled order. In fact, the effects of context on visual span were nearly twice as great in the former case (normal word sequence, span increase of 1.10 degrees) as in the latter (scrambled word sequence, span increase of .64 degrees). Interestingly enough, here the effect of context on response time was to *increase* the average processing time by 79 msec. This finding is consistent with our interpretation that the sequence of words is in this case actively evaluated (which means increased processing load) in the light of contextually-derived hypotheses. Again, high ability readers show greater increments in visual span with context presented than do low ability readers. This suggests that readers may differ with respect to their skill in utilizing context as a guide in encoding subsequent text that they encounter.

Importance of Sensitivity to Context in Reading

Data bearing on the external validity of each of our measures of sensitivity to context are presented in Figure 13. Plotted here are correlations between our three measures of sensitivity to context and three

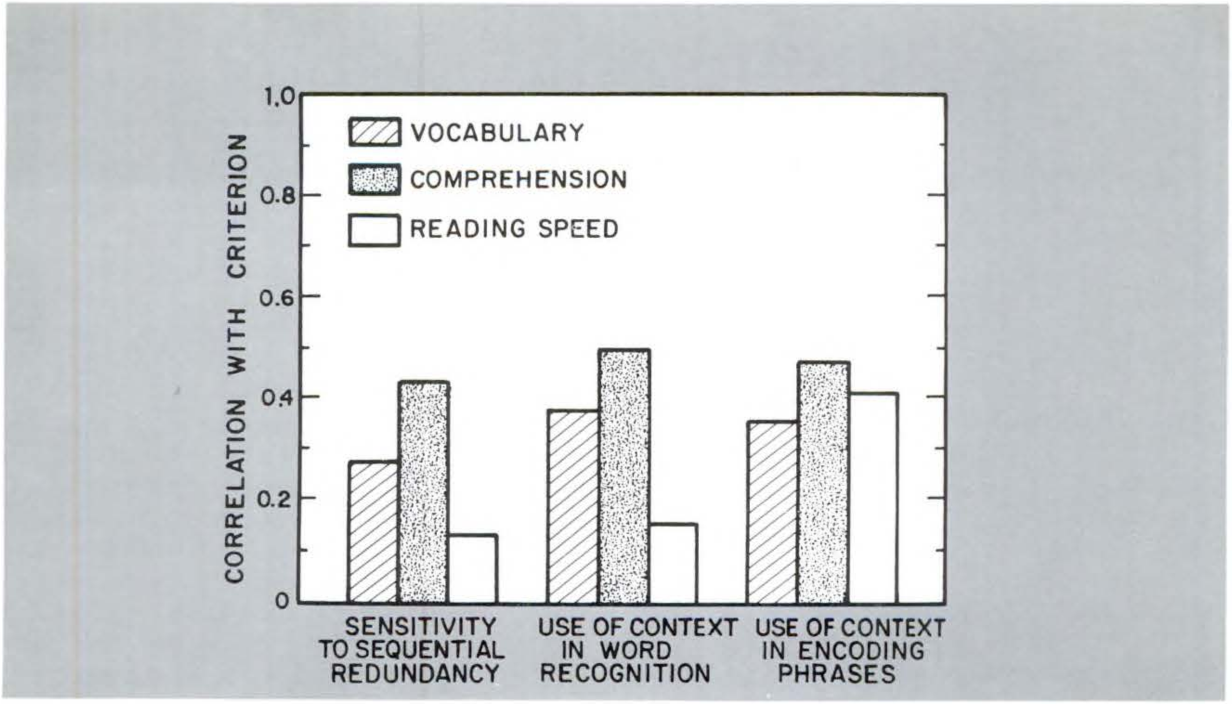


Fig. 13. Correlations between measures of subjects' use of context with their performance on subscales of a standard reading test.

conventional measures of reading skill: Vocabulary, Reading Comprehension, and Reading Speed.

Perhaps the most prominent feature of the correlational data presented in this figure is the fact that, for each of the contrasts we have calculated among our measures of visual span, the largest correlation is with scores on the *Comprehension* subtest. The multiple regression of Comprehension Scores on the three contrast measures yielded a statistically significant multiple correlation ($R = .623$). The regression weights indicated that the first and third contrasts made sizeable contributions in predicting reading comprehension, while the second contrast made no independent contribution, once the other two contrasts were included in the prediction equation. We concluded that *Sensitivity to Sequential Redundancy* and *Use of Context in Encoding Phrases* represent separable components contributing to a subject's general skill in reading comprehension. There is, we might say, a perceptual ramification of skill in understanding prose, and that is the ability to utilize hypotheses generated on the basis of contextual discourse as a guide for lexical search and retrieval.

While Comprehension Scores were generally predictable from our three measures of context sensitivity, Reading Speed was related only to our third measure: *Use of Context in Encoding Phrases.* Subjects who show sizeable increments in visual span when reading phrases in context are the ones who show the highest reading rates when reading a text for speed and comprehension. And these are also the readers who are able to utilize prior context to generate hypotheses about the propositional and syntactic forms that are to follow. It appears that an *active* reading strategy, one that makes use of prior context in the encoding of incoming segments of text, contributes both to reading comprehension and to reading fluency.

Discourse Analysis Processes

Some promising beginnings have been made in developing componentially specific measures of discourse processes. Following the model of our earlier studies, the research has focused on a single subskill—that of *finding referents for pronouns*—and has sought to identify text characteristics that influence a subject's difficulty in resolving such problems of, specifically, pronominal reference. Table 3 shows some of the text characteristics that have been explored. For example, in the first sentence pair (a), *he* could potentially refer to either *engineer* or *fireman* while *it* can only refer to the *brake lever.* In (b), a sentence intervenes between the pronoun *they* in the final sentence and its

(A)	**Number of Potential Referents** The engineer told the fireman to pull the brake lever, but **he** said **it** was stuck.	
(B)	**Number of Intervening Sentences** Arnold asked Raymond to play ball. But unfortunately it started to rain. So **they** waited for **it** to stop.	
(C)	**Mediated versus Nonmediated Intervening Sentences** Alice rubbed her eyes, and looked again. She couldn't make out what had happened at all. Was **she** in a shop? ——————————— The sun had just set, and there was little light.	
(D)	**Parallel Syntactic Function** Modern advertising does not, as a rule, seek to demonstrate the superior quality of the product. **It** plays up to the desire of Americans to conform, to be like the Joneses. ——————————— The superior quality of the product is not, as a rule, what modern advertising seeks to demonstrate.	
(E)	**Foregrounding the Incorrect Referent** The congressman's early struggles were a subject he reminisced about, in two candid interviews. The interviews were filmed in the spacious corner office which he had occupied for the past thirty years. **They** were pieces of a past that was still clearly alive, and very much part of the current picture.	

Table 3. Discourse processing: Finding referents for pronouns.

referent, *Arnold and Raymond,* in the initial sentence of the set. In (c), we have a set where an intervening sentence uses the pronoun *she* in the same way as does the final sentence, to refer to *Alice.* (This would not be the case if the alternative intervening sentence, beginning "*The sun had* . . . had been used.) In (d), both the referent *modern advertising* and pronoun *it* are subjects of their respective sentences. If the paraphrase of the first sentences printed at the bottom were used instead, this would not have been the case. And, finally, in (e), there is following the initial sentence, an intervening sentence that brings to the foreground an "incorrect" potential referent (*interviews*), and thus places the correct referent for the target pronoun—*struggles*—in the background. Each of these text variables has been explored in this research. In the experiment, the subject reads a text, sentence by sentence. From time to time, an underscore appears beneath a word (pronoun) in a current sentence, and the subject must at that time supply (vocally) the correct referent for the pronoun. However, the primary data obtained are the reading times per syllable for each sentence in the text.

Some of our preliminary findings are presented in Figure 14. Readers, particularly poor readers, appear to use a strategy, simply, of selecting the grammatical *subject* of an initial sentence as the preferred referent for a pronoun occurring in a following sentence. As seen at the top of Figure 14, their reading times were faster when the referent for a pronoun in the target sentence was the subject of the prior sentence. This result is at variance with proposals such as that of Kintsch and van Dijk (10) that subjects develop a propositional base for each sentence as they progress through a text.

In the second panel of Figure 14, it can be seen that introducing additional sentences between the initial and final sentences (i.e., between the sentence containing the referent and that containing the pronoun) results in an increase in time for finding the correct referent, presumably due to the need for memory search and retrieval. This increase in reading time was greatest for the poorest readers. (However, where it was the case that semantically related information was contained within such intervening sentences, it appeared that this information had the effect of offsetting performance decrements occasioned by memory search and retrieval.) Bringing an incorrect but possible referent to the foreground (a noun agreeing in number and gender with the target pronoun) lengthened the time for finding the correct referent for a pronoun occurring subsequently, as shown in the third panel of Figure 14.

When they encountered pronouns, good and poor readers, both, appeared to retrieve *all* of the alternative referents that were available for a pronoun (that is, nouns that agree in gender and number), and then select from among them the referent that fit the semantic constraints of the sentence in which it occurred. This was apparent when we compared reading times for ambiguous target sentences (that allow either referent) with those for unambiguous target sentences (in which only a single meaning was correct), as is shown in the fourth panel of Figure 14. Reading times were greater when the target sentence was semantically compatible with either of two prior text referents than when only one referent was sensible—even though both referents in principle constituted a correct response. Finally, an *overall* estimate of time for solving a pronominal reference problem was obtained (see the final panel of Figure 14). This measure, the increase in reading time found when a pronoun was employed in place of a repeated noun, was greater for our poor readers than for our good readers.

In summary, when we manipulated a number of text variables thought to alter difficulty of resolving problems of anaphoric reference in a text, we found a consistent pattern of differences among readers of varying abilities, suggesting that there are differences in automaticity of skills employed in dealing with this problem. Readers appear to be sensitive to surface grammatical structure of the text in selecting the proper referents for pronouns. Text variables that emphasize the importance of a particular noun phrase serve at the same time the function of making that noun phrase more readily available as a referent for a pronoun. And good readers appear to make better use of these text variations than do the poorer readers.

Conclusions and Future Directions

This report is an initial experimental attack on the problem of identifying component skills in reading. The results have supported our notion that there are separable component processes to be considered, concerned with what we have termed the word analysis, discourse analysis, and integrative processing domains. Moreover, evidence from factor analytic studies we have carried out so far suggests that, while these various component skills are not highly correlated with one another, alternate measures of a single component do show appreciable intercorrelations. The implication of this result, if should it be borne out in future research, is that the sources of reading disability are not the same in all individuals. Moreover, the deficits in component skills are reflected in their degree of efficiency or

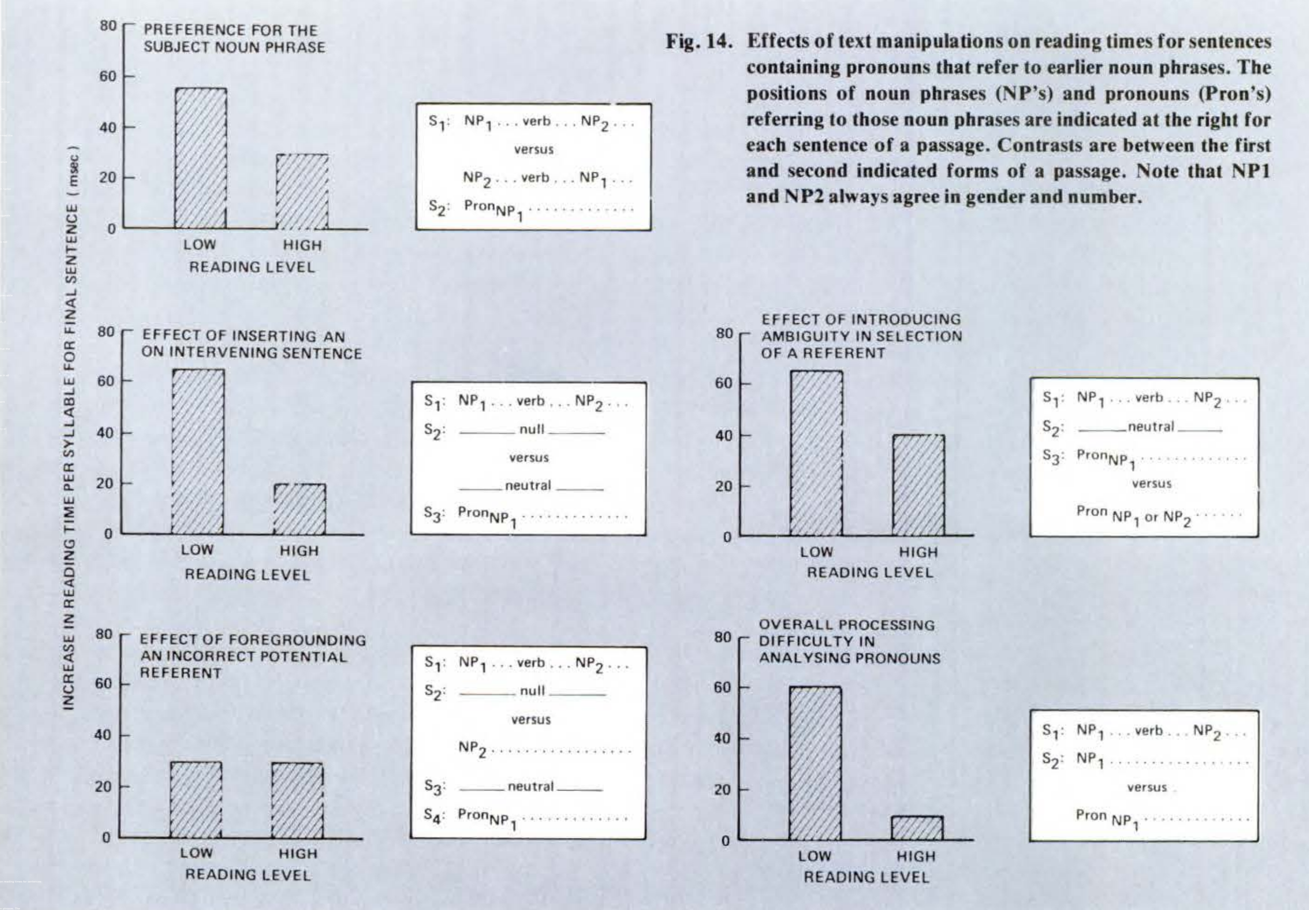


Fig. 14. Effects of text manipulations on reading times for sentences containing pronouns that refer to earlier noun phrases. The positions of noun phrases (NP's) and pronouns (Pron's) referring to those noun phrases are indicated at the right for each sentence of a passage. Contrasts are between the first and second indicated forms of a passage. Note that NP1 and NP2 always agree in gender and number.

automaticity, and not in their ability to correctly carry out their processing functions to completion. We believe that poorly skilled readers may have disabilities in specific components of the reading process that can be eliminated through proper training, focused on developing automaticity of processing in the area of disability.

The picture we have gained is that of a proficient reader who constructs a discourse model as he reads, and utilizes the model to generate hypotheses about likely-occurring propositional and syntactic forms that are to follow. The processes of lexical retrieval, in such a reader, are to a large extent guided by hypotheses derived from context. However, when recourse is made to data-driven processes for lexical analysis, our proficient reader has a complement of efficient word-analysis skills that he can utilize. We speculate that, at any moment, the lexical retrieval system is not exclusively operating in either data-driven or hypothesis-driven modes, but rather, it is simultaneously engaged in word-analysis processing, while attempting to confirm contextually-derived hypotheses on the basis of the evidence that is available. It may be that it is the high degree of automaticity developed by proficient readers in the analysis of orthographic forms that makes the integrated processing of perceptual and contextual data a real possiblity.

The important research issues that we must face in the future deal with the application of our knowledge of component skill deficits to the task of training young adults who have specific reading disabilities. This research will focus on analyzing the *trainability* of the skill components, and on developing instructional strategies for improving performance in such specific reading skills. Finally, it will attempt to learn if improvements in component skills will lead to gains in performance in more typical reading situations, where reading serves as an information-seeking component within a more general problem-solving framework. ■

Reference Notes

1. Frederiksen, J. R. Test comprehension and the effective visual field. Paper presented at the annual meeting of the Psychonomic Society in Washington, D. C., November 12, 1977.

2. Frederiksen, J. R. Word recognition in the presence of semantically constraining context. Paper presented at the annual meetings of the Psychonomic Society, San Antonio , Texas, November 11, 1978.

3. Kintsch, W. & Vipond, D. Reading comprehension and readability in educational practice and psychological theory. Paper presented at the conference on Memory, University of Uppsala, Uppsala, Sweden, June, 1977.

References

1. Shapley, Deborah. "Navy Meeting Drifts on a Sea of Unanswered Questions." *Science,* 1978, 30, 282-283.

2. United Press International. "Competency Movement Is Taking Schools Back to the Three R's and More." *Boston Sunday Globe,* June 4, 1978, p. G20.

3. Frederiksen, J. R. "Assessment of Perceptual, Decoding, and Lexical Skills and Their Relation to Reading Proficiency." In Lesgold, A. M., Pellegrino, J. W., Fokkema, S., [Glaser, R. (Eds. *Cognitive Psychology and Instruction.* New York: Plenum, 1978 (a.)

4. Frederiksen, J. R. "A Chronometric Study of Component Skills in Reading." ONR Technical Report No. 2 (BBN Report No. 3757): Bolt Beranek and Newman, Inc., 1978 (b).

5. Frederiksen, J. R. "Component Skills in Reading: Measurement of Individual Differences Through Chronometric Analysis." In Snow, R. R., Federico, P.-A., and Montague, W. E. (Eds.) *Aptitude, Learning, and Instruction: Cognitive Process Analysis.* Hillsdale, N. J.: Lawrence Erlbaum Assoc., 1979.

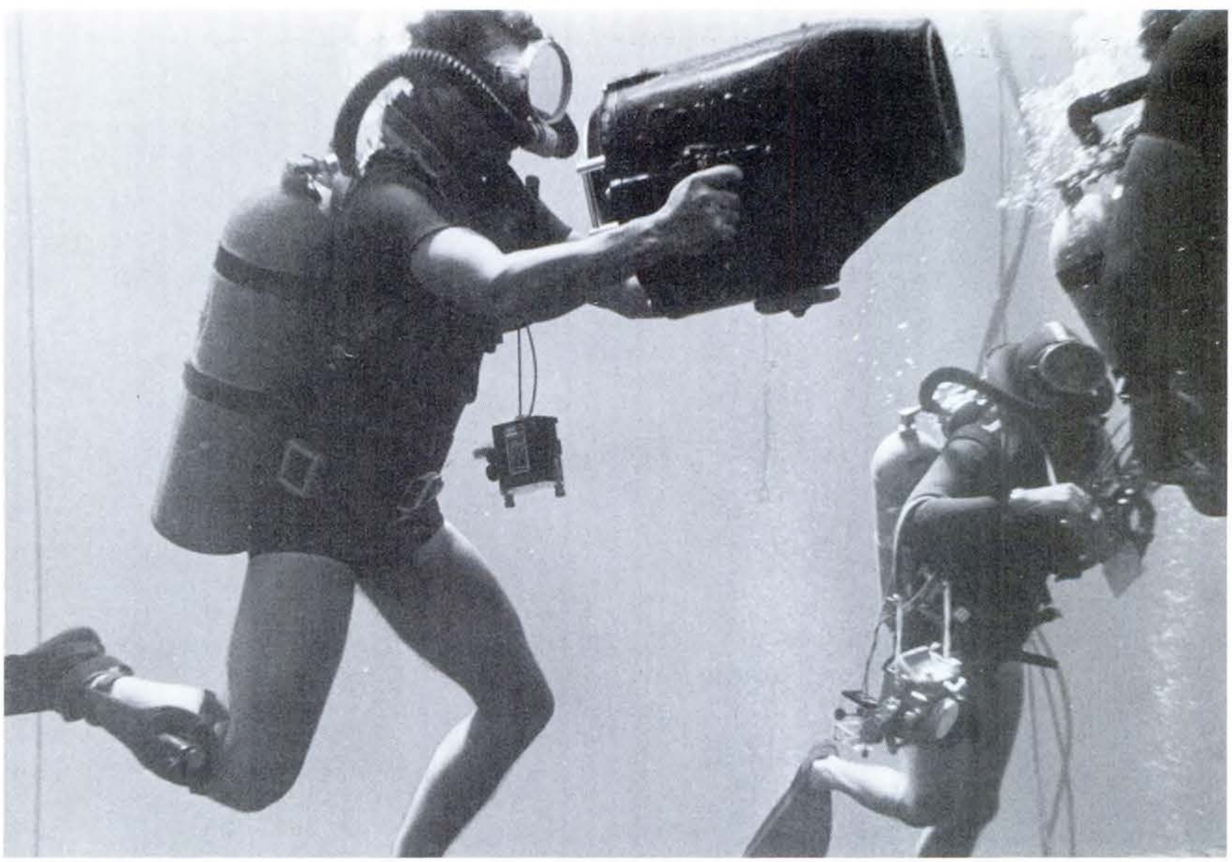
6. Norman, D. A., & Bobrow, D. G. "On Data-Limited and Resource-Limited Processes." *Cognitive Psychology,* 1975, 7, 44-64.

7. Posner, M. I., & Mitchell, R. F. "Chronometric Analysis of Classification." *Pyschological Review,* 1967, 74, 392-409.

8. Mayzner, M. S., & Tresselt, M. E. "Tables of Single-Letter and Diagram Frequency Counts for Various Word Length and Letter Position Combinations." *Psychonomic Monograph Supplement,* 1965, 1, 13-22.

9. Joreskog, K. G. "A General Method for Analysis of Covariance Structures." *Biometrika,* 1970, 57, 2, 239-251.

10. Kintsch, W., & van Dijk, T. A. "Towards a Model of Text Comprehension and Production." *Psychological Review,* 1978, 85.



research notes

Flux Stability of Permanent Magnets

Satisfactory performance of gyroscopes in inertial guidance systems requires extreme long-term stability of the inertial axis and the sensor system that continually references it. Translated, this calls for a new level of flux stability in the magnetic torquers, the permanent magnets in the system that sense changes in the orientation of the gyro float (Figure 1). Whereas commercial magnets exhibit a variation of the flux in the air gap of from 3 to 12 ppm in 1 day, designers call for magnets showing changes reduced by a factor of 100 or even more. At the same time a very high energy product level is required, a value from 15 to 20 mega gauss oersteds.

Extremely high quality permanent magnet materials suitable for the demanding requirements of inertial navigation instruments are best made from samarium-cobalt (Sm-Co) alloy, but the rare-earth Sm is difficult to handle because it oxidizes so readily, and preparation of nonporous defect-free magnets is elusive. Materials scientists and engineers at the Charles Stark Draper Laboratory have undertaken a broad program in rare-earth magnetic material technology, using several new processes including advanced powder metallurgy techniques. Initial progress made in this approach depended upon preparation of the alloy powders with a fine grain size and with a low oxygen content. Now alternative treatment of the magnetically aligned compacts are being explored under Office of Naval Research sponsorship, including evaluation, using precision metallurgical analyses, magnetic property measurements, and the correlation of both. Magnets produced by die pressing and controlled atmosphere sintering and

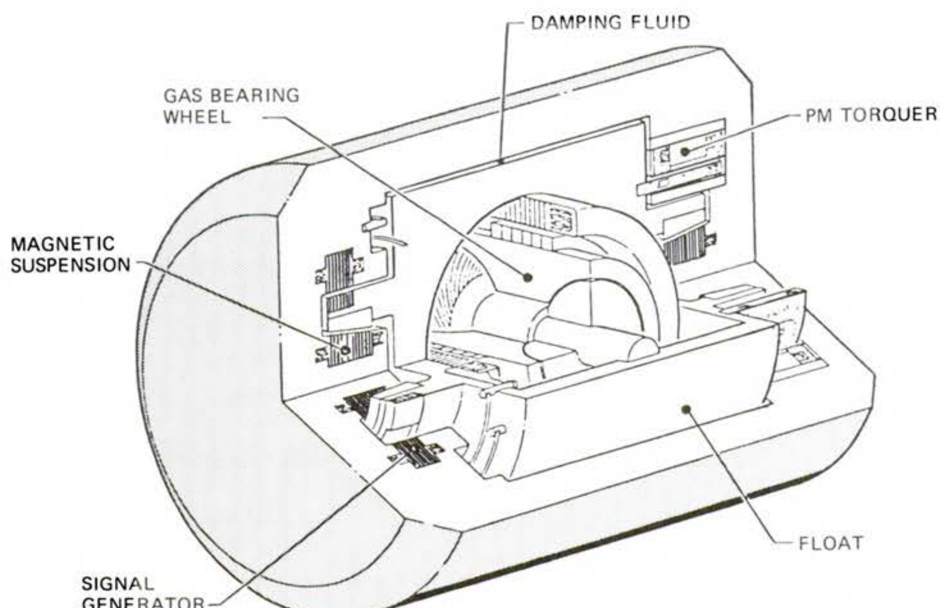


Fig. 1. **Cutaway View Typical Floated Gyro**

aging have demonstrated new high values of intrinsic coercive force (H_{ci}) and resistance to demagnetization (H_k), properties favoring flux stability. Other magnets subjected to cold isostatic pressing (CIP) before the cited furnace sintering and aging treatment show not only the enhanced properties mentioned, but also an improved energy product (BH) max. Currently, still other magnets are being consolidated by hot isostatically pressing (HIP) and given finish thermal treatments. The lower temperatures and shorter time exposures of this process are expected to yield magnets of even higher quality than produced up to now. ■

(Frank Gardner, ONR—Boston)

Chemicals Used to Convert Solar Energy

A practical method of converting solar energy into usable electrical power was demonstrated recently through a unique chemical energy conversion process called *Solchem*. The demonstration was carried out by Dr. James McCrary at New Mexico State University's Physical Sciences Laboratory. The project is cosponsored by the Department of Energy and the Naval Research Laboratory.

Solchem as a chemical approach to harnessing solar power, is a system that uses a new type of NRL-designed chemical converter into which methane and carbon dioxide are piped. The converter is superheated to some 1700 degrees Fahrenheit, causing the methane and carbon dioxide to form into a mix of carbon monoxide, hydrogen and subatmospheric pressure steam, called synthesis gas. The synthesis gas that flows out of the converter has a temperature of between 200 and 250 degrees, while the remaining thermal energy (in the neighborhood of 1500 degrees) is transformed into latent chemical energy in the gas, thus providing a capability to store the energy and reconvert it to heat at some later time.

The *Solchem* test constituted the first demonstration of a conversion of heat energy into chemical energy in a cavity-heated thermochemical receiver. During the experiment, the chemical converter-heat exchanger was energized by heaters. Current plans call for fabrication of a similar receiver, but one that would be heated by the sun. Testing the sun-heated receiver is scheduled for later this year at the White Sands, New Mexico, Solar Furnace. This solar furnace test could be the forerunner to construction of specialized solar thermal collectors to capture sunlight for energy conversion.

Thermochemical capture of solar energy, as envisioned in the *Solchem* project, would permit many solar collectors to deliver the sum of their energy output to centrally located industrial parks or power stations. At the central stations, the chemical energy could be stored and converted back to heat to provide high temperature steam for turbine generators and other industrial uses. ■

(Delford Simmons, NRL)

Debris-Avoidance Radar Concept

A unique design concept for a debris-avoidance radar for high-speed ships has been designed by Bernard Lewis and James Hansen at the Naval Research Laboratory. The design is based on radar sea-return characteristics.

Conventional radar for debris avoidance would be of little help for high speed ships because radar echoes from the debris are masked by the sea-return signals. So a special radar that could distinguish between sea-return echoes and other radar echoes would be of great value for fast seacraft.

Lewis and Hansen conducted experiments to measure the echoing characteristics of the disturbed sea surface and of rigid floating debris such as oil drums, logs and other smaller articles in various sea states. They noted some significant differences in the amplitude modulation of pulse-to-pulse echoes from the sea and those from floating debris.

For example, radar echoes from floating debris exhibit much lower amplitude modulation frequencies than those from sea-return. This was consistent in all of the sea states tested and for any polarization used. Also, the radar echoes in a range-resolution cell with rigid debris were more continuous than those from the sea alone.

These differences, say Lewis and Hansen, can be exploited with a radar design concept which examines the pulse-to-pluse modulation characteristics of radar echoes in individual range resolution cells. This permits sea returns to be suppressed and echoes from rigid debris to be detected. ■

(Bernard Lewis, NRL)

conrad award

The Conrad Award

Dr. Harold E. Bennett

The Robert Dexter Conrad Award is the Navy's highest honor for scientific achievement. The award is given annually to a scientist who has made such outstanding contributions to the Navy's research and development program that his achievements are acclaimed by the entire scientific community.

The award is named in honor of Captain Robert Dexter Conrad. Captain Conrad was the primary architect of the Navy's basic research program and head of the Planning Division of the Office of Naval Research at the time of its establishment in 1946.