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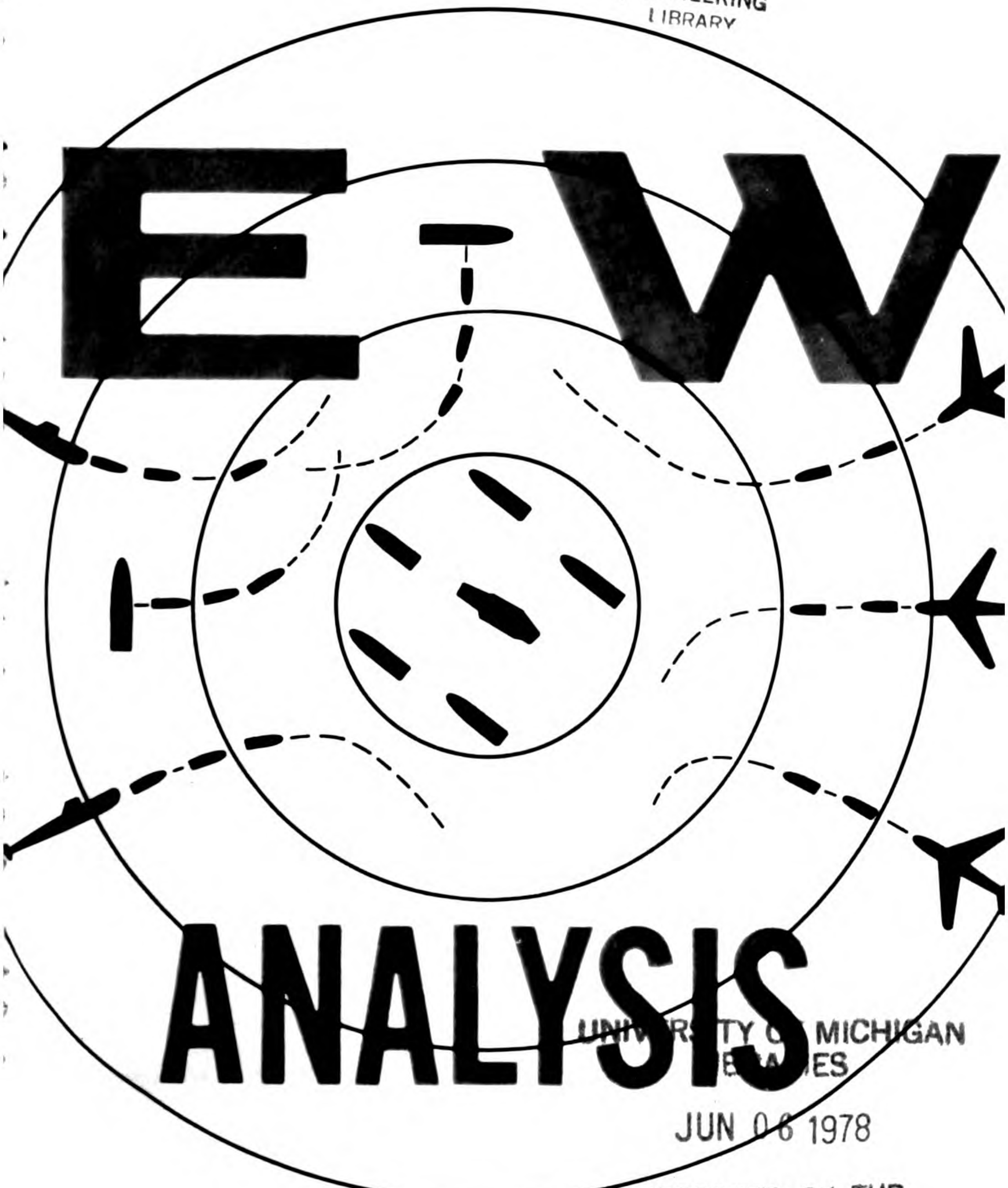

PROFILES IN SCIENCE

Dr. Shirleigh Silverman

Dr. Shirleigh Silverman's untimely death in February 1978, terminated a distinguished career as scientist and administrator. His career embraced research in academic institutions, industry, Naval laboratories, the Office of Naval Research, and the National Bureau of Standards. His publications in physical statistics and molecular spectroscopy received international recognition. From 1955 to 1964, Dr. Silverman was Director of the Physical Sciences Division and then Research Director of the Office of Naval Research. Due largely to his encouragement several outstanding ONR programs developed during this period; these included the successful STRATOSCOPE balloon borne telescope project, the INJUN satellite measurements of the trapped radiation due to the STARFISH nuclear test, the deep submergence research vehicle ALVIN, and the first DoD high energy laser program for ARPA. From 1964 until his retirement in 1977, Dr. Silverman was Associate Director of the National Bureau of Standards where he initiated a program in university relations. After retirement he remained active in the Optical Society of America, organizing the excellent R.W. Wood memorial symposium at Johns Hopkins University. One of his last accomplishments was leading a study under the National Academy of Sciences on experiments that could be conducted in the Space Shuttle. His kindness, encouragement, and critical sensibilities will be greatly missed in the research community.

Closed Cycle Gas Turbine Ship Propulsion

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Introduction

As ship performance requirements become more demanding, the pressure builds on designers to provide power plants with higher output and better efficiency in the same or smaller space. Figure 1 illustrates the weight constraint that must be satisfied by the power plant for various vessel designs, with fuel weights included. The lower end of each bar is the design power plant specific weight. As plant specific weight approaches the upper end of each bar, platform payload approaches zero. Advanced ships with today's propulsion are, in general, limited to a 2000-4000 mile range. Which of these advanced ship concepts will come into the inventory in large numbers is not clear. It is clear that all of them realize approximately the same 40% limit of weight fraction available for fuel and payload. Superimposed on this is the economic constraint — "How many can the Navy afford?"

The Closed Cycle gas turbine is an alternative to the open cycle. One of its most desirable characteristics is apparent in the comparison of specific fuel consumption shown in Figure 2. Since most of a ship's operating time is spent at low power, the increase in miles per gallon can be large. An economy of space is also possible for the rotating unit as a result of higher power density. Also, the closed cycle can accept a variety of heat sources.

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†Mr. Parker and Mr. Mock are both research scientists and project managers for the ONR funded research described in this article.

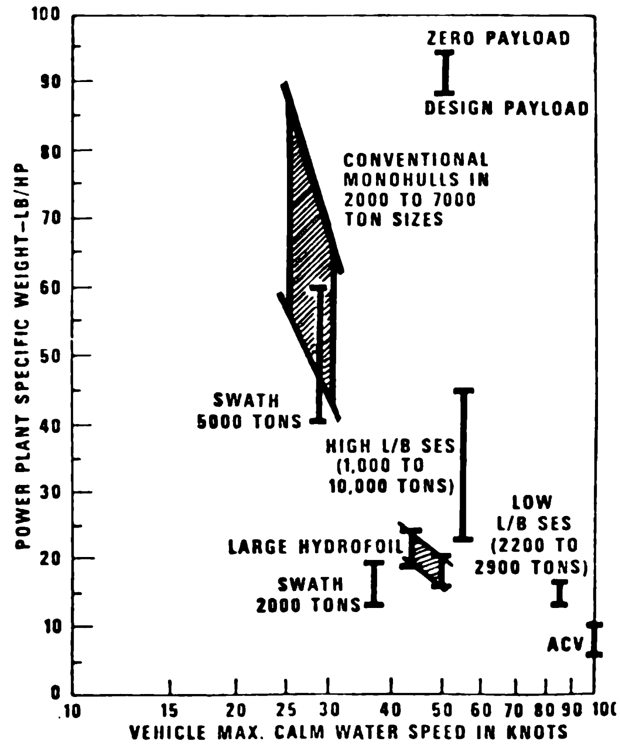

Figure 1 — Powerplant specific weights

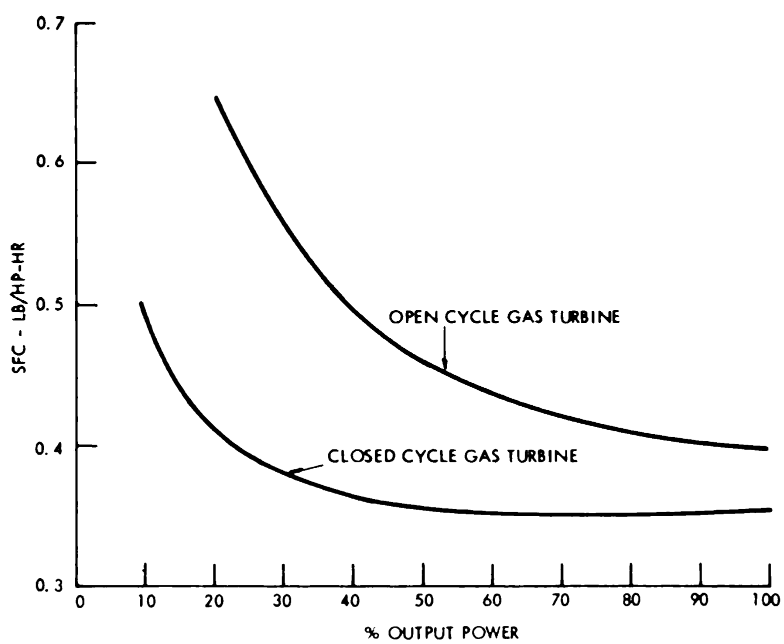

Figure 2 — Specific fuel consumption comparison

Of equal importance with reduced weight and volume is reduced cost. However, initial cost must be viewed in a larger frame than the propulsion plant alone. While the cost of the propulsion components may increase, the overall cost may decrease because a smaller and lower cost ship may do the same job - smaller propulsion plant, smaller ship with same payload. Also, with the internal environment of the plant being exposed to a benign environment, like helium, it may be possible to design and build the turbines, compressors and secondary heat exchangers to have a lifetime approaching that of the ship. In addition, life cycle costs may be reduced because of reduced fuel usage.

To determine the extent to which these superficial appraisals translate into realizable goals, the Office of Naval Research initiated a research effort, including materials testing, in May of 1976. Highlighted here are the results obtained from the first year of study evaluating the feasibility of a closed Brayton cycle power conversion system for compact lightweight naval propulsion plants.

The first year studies have defined the reference requirements, provided detailed considerations of critical technologies, defined critical interface conditions that must be considered, accomplished significant materials testing in helium, and provided intial definition of the Compact Closed Cycle Brayton System (CCCBS) design concept.

To accomplish the objective of the program, feasibility must be evaluated in the context of a coherent set of representative top level requirements. These requirements must be representative of those which could reasonably be expected to be placed upon a plant for naval propulsion applications. The requirements must also be sufficiently stringent to support generalized conclusions regarding feasibility. Based upon these considerations, a set of top level requirements was defined and is summarized in Table 1.

Table 1

TOP LEVEL REQUIREMENTS FOR CCCBS

- **Reference Application -- Surface Effects Ship**
- **Power Output per Unit -- 70,000 SHP**
- **Specific Weight of PCS -- 2 LB/SP**
- **Lifetime -- 10,000 Equivalent Full Power Hours**
- **Shock -- MIL-S-901C (Navy)**
- **Heat Rejection -- To Sea Water at 85°F**

CCCBS Design Concept

The integrated assembly of the design concept is shown in Figure 3 which illustrates the flow path of the working gas in simplified form. High temperature gas from the heat source enters the module through the inner pipe of a concentric duct and enters the high pressure turbine inlet plenum. The high pressure turbine extracts the work necessary to drive both low and high pressure compressors which are of the axial type for high efficiency. After leaving the high pressure turbine, the gas flows to the low pressure turbine (power turbine) where the work necessary to drive the load is extracted. A free power turbine was specified because of the requirement to be able to interface with either fixed or variable speed loads. The gas then enters the low pressure side of the recuperator and is subsequently cooled in the precooler. The gas is then compressed in the low pressure compressor, cooled in the intercooler and further compressed in the high pressure compressor. The high pressure gas from the compressor then flows through the high pressure side of the recuperator, where it is heated by the energy extracted from the low pressure side gas. The heated gas then passes into a collector manifold from which it is piped through two check valves in series to the outer annulus of the concentric duct to the heat source.

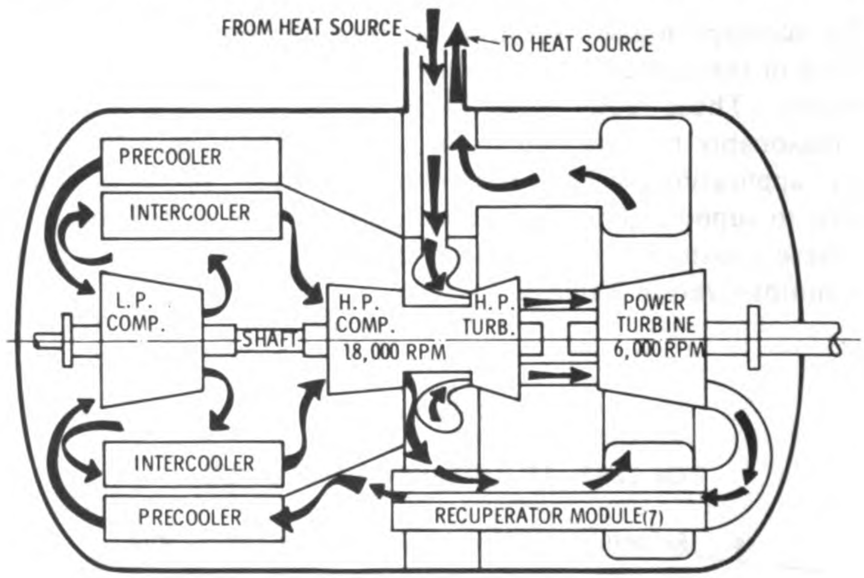

Figure 3 — Working gas flow path

The CCCBS power conversion assembly is designed as an integrated package whose major components can be individually assembled and checked and which can be completely assembled and checked out as an assembly. Consideration has been given to providing access to the turbomachinery for maintenance through providing for its removal and reinsertion into the CCCBS power conversion assembly. A trial design layout is shown in Figure 4.

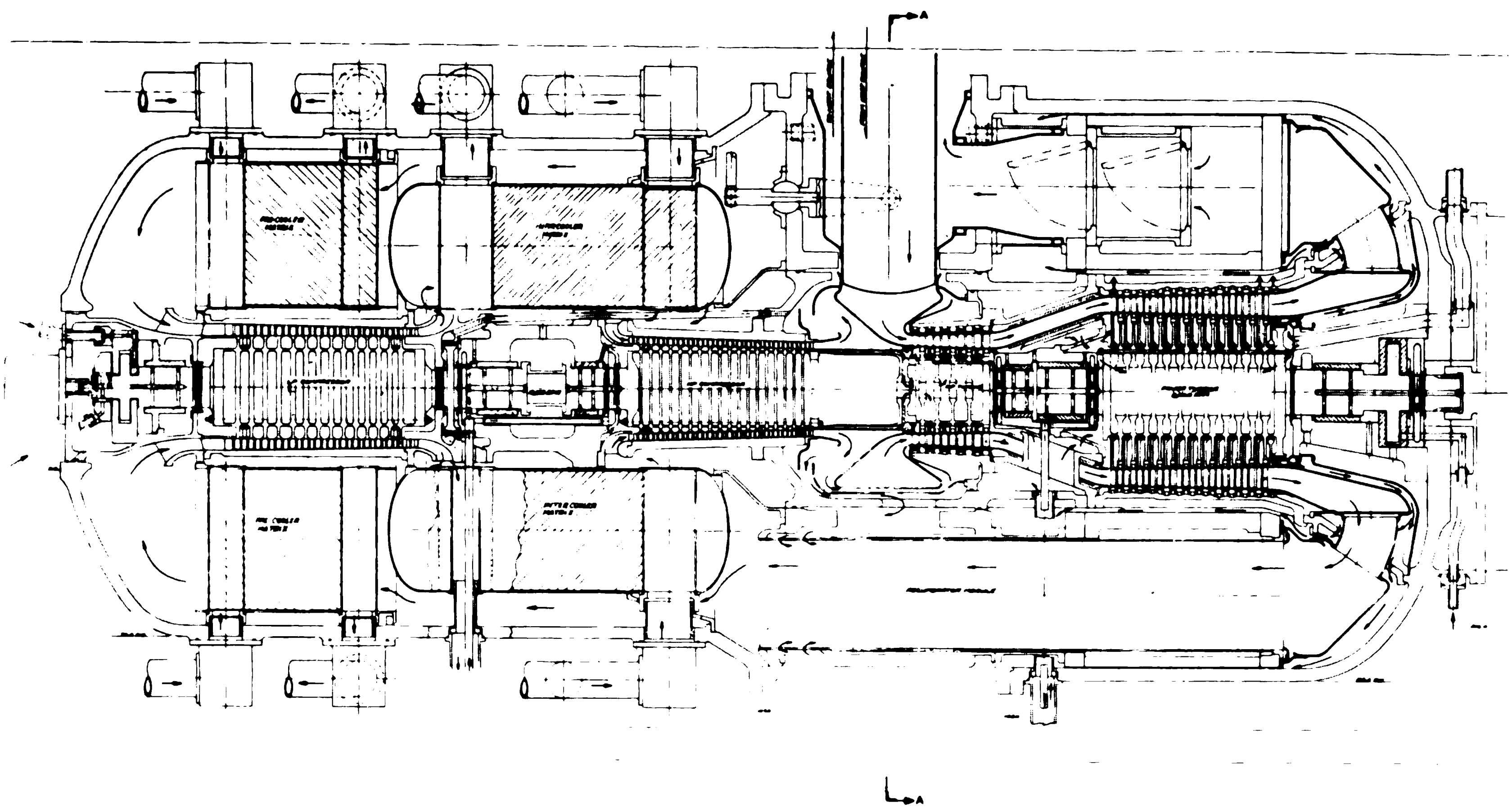

Figure 4 — CCCBS design concept

The power conversion assembly consists of an integrated assembly of low and high pressure compressors and high pressure turbine rotating at 18,000 RPM, low pressure free power turbine rotating at 6,000 RPM (at full power), recuperator, precooler and intercooler. Trade studies between candidate types of heat exchangers and bearings were an important part of the first year efforts. This definition of the design concept incorporates the results of those trade studies. The turbomachinery rotors are supported by gas bearings, the recuperator is the tube and shell type, and the coolers are cross counterflow turbular heat exchangers. These components are assembled into a casing capable of withstanding full system pressure.

Although local pressures throughout most of the power conversion assembly are lower than maximum system pressure, consideration of operation with one of two parallel units shut down dictates casing design conditions. Pressure throughout the inoperative unit will tend to approach full system pressure because of leakage through the shut-off valves. The complete power conversion assembly is therefore contained within a cylindrical pressure vessel, made of a low alloy steel, capable of accommodating the maximum system pressure. The pressure vessel is made in three sections, a center frame structure and forward and rear sections. The three sections are joined together by bolted flanges. Sealing of the flanges can be effected by metal or elastomer O-rings or alternately seal welded.

The center frame structure consists of a relatively short cylindrical section of casing having two diaphragm membranes, one at each end, which extend radially inward towards the center. The diaphragm members have central holes which provide radial support for the turbomachinery casing. The two diaphragms are supported in the axial direction, one from the other, by eight essentially radial webs. Each of the diaphragms, in the spaces between the radial webs, is pierced by seven large diameter holes. These holes accommodate the seven recuperator modules. Only one of the diaphragms is pierced at the eighth interweb location which accommodates the ducting connecting the powerplant with the heat source. A bolted flange penetration is provided on the exterior cylindrical portion of the center frame structure at this location. During operation, the center frame structure is pressurized by high pressure compressor outlet gas and serves as the recuperator high pressure inlet plenum. Sealing of the turbomachinery to the center frame is effected by elastomer O-rings, carried in grooves on the turbomachinery casing, which engage with prepared surfaces at the inner diameter of the center frame diaphragm members.

The recuperator modules are constructed in the form of long circular cylinders and are housed in tubular support members which extend axially from the center frame structure. The tubular members support a toroidal pressure vessel which functions as the recuperator high pressure outlet plenum. During operation, the high pressure gas, after being heated on the shell side of the seven recuperator modules, is dumped into the toroidal vessel and flows around it to the eighth pipe location through which it passes into the outer annulus of the coaxial duct to the heat source.

The recuperator modules are inserted through the toroidal vessel into their tubular support members and fastened into position by means of bolted flanges at their hot ends. Relative thermal expansion between the recuperator module and the support members and between the tubing and the shell of the recuperator modules is accommodated by sliding joints sealed by elastometer O-rings at the cold end. In this arrangement, the tubular support members are separated from the recuperator modules by a thin layer of stagnant helium. On their outer diameters the tubular support members are exposed to the relatively cool gas inside the external pressure casing.

At the eighth tubular support member, the collector pipe from the toroidal vessel passes through two check valves in series and into a short inner pipe separate from the tubular support member. The inner pipe is sealed to the toroidal vessel and to the outer coaxial duct to the heat source by means of piston rings or other similar sealing devices. Piston rings are also used to seal the separate coaxial duct component to the center frame structure. The piston rings allow the separate inner duct components to expand and contract freely, under the influence of the hot gases they convey. The tubular support member and the center frame structure are exposed only to the relatively stagnant compressor outlet gas on their inner surfaces and to the cool gas inside the external pressure casing on their outer surfaces.

The rear section of the pressure vessel supports the interfacing load machinery (e.g., an electric generator) and the aft or power turbine outlet end of the turbomachinery. Under normal operating conditions, the rear section of the pressure vessel locates the turbomachinery in the axial direction and provides support in the radial direction at the outlet end. The turbomachinery casing receives additional support in the radial direction from the center frame structure and from the forward section of the pressure vessel. The turbomachinery is free to slide axially at these locations to accommodate thermal expansion. Sealing of the turbomachinery to the pressure vessel components is effected by elastomer O-rings.

The turbomachinery assembly can be removed from the power conversion assembly as a unit together with the generator and the rear casing pressure vessel section. During this operation, the rear section of the casing conveniently functions as a lifting fixture. Jacking screws in the attachment flange of the rear section are used to apply axial force to the turbomachinery to overcome the friction of the O-ring seals at the powerplant/turbomachinery interfaces. The turbomachinery, generator and rear assembly can be removed axially from the assembly while suspended at its center of gravity from a crane or transporter device.

During removal of the turbomachinery from the powerplant, the internal flow path is separated at sliding joints in the low pressure recuperator entry plenum. The entry plenum is a sheet metal vessel which receives the power turbine outlet gas from eight radial pipes which pass through the rear turbomachinery support structure. The sheet metal plenum confines the relatively warm turbine outlet gas as it enters the recuperator modules. The rear pressure vessel section is exposed to cooler gas originating from the power turbine balance piston labyrinth seal. This cooler gas also cools the power turbine casing before passing through the center frame structure in a number of transfer pipes and joining the main cycle flow path at entry to the precooler. The transfer pipes are sized so that the pressure drop of the balance piston leakage gas in traversing them is slightly greater than the pressure drop of the hot side recuperator flow path. This ensures that the leakage flow at the sliding joints of the recuperator entry plenum is from the cold gas outside to the hot gas inside the plenum thus minimizing the heating of the cooler gas adjacent to the pressure vessel.

The forward section of the pressure vessel accommodates the precooler and intercooler in an annular arrangement around the turbomachinery. The precooler and intercooler are similar in design. Each cooler employs finned tubing arranged in a helical matrix around the turbomachinery. The tubing is headered in four equally spaced radial pipes at each end of the matrix. A "four-start" arrangement of the tubing provides compatibility with the header pipes. Cooling water is piped into the radial header pipes through "bobbin" and O-ring connectors, flows through the helical tubing and leaves through the radial header pipes and connectors at the other end. The helium cycle gas flows axially across the finned tubing.

The intercooler matrix is accommodated within a cylindrical pressure shell which is terminated at each end in pressurized headers. The headers convey the helium gas from the low pressure compressor outlet into the intercooler and from the intercooler into the high pressure compressor inlet. The intercooler/header/vessel assembly is supported by a conical support member from a flange on the powerplant pressure vessel and is sealed to the turbomachinery by means of rubber O-rings. Complete separation of the higher pressure gas in the intercooler from the lower pressure gas entering the precooler is thus achieved while permitting the turbomachinery to be freely withdrawn from the assembly through the O-ring seal interfaces. The conical support member is penetrated by a number of large diameter holes which allow the passage of the low pressure gas from the recuperator to the precooler inlet. The precooler and its header are integrated into a similar assembly and supported from a flange on the powerplant pressure vessel.

The coolers have been carefully located in the axial direction to avoid interference with the radial pipes supplying the pressurizing gas to the gas bearings. Pressurizing gas is fed to the bearings through the smaller diameter pipes which are accommodated inside the larger turbine cooling and balance piston supply pipes. The pressurizing gas enters the bearing rotating members via a small chamber surrounding the shaft and sealed by the double labyrinth seals.

Heat Exchanger Technology Evaluations

Compact heat exchangers are very important components of the CCCBS. Various types of compact heat exchangers which can be considered for the CCCBS have been evaluated and compared. The results of these evaluations of gas-to-gas and gas-to-water heat exchangers are discussed separately because of their different design requirements.

Gas-to-Gas Heat Exchangers (Recuperators)

Over the last thirty years, the fixed boundary recuperator, of both turbular and plate-fin constructions, has been used for industrial, marine, locomotive, aircraft, vehicular and closed-cycle applications, and has demonstrated a high degree of reliability.

The recuperator initially found acceptance in the large European industrial open and closed cycle gas turbines, introduced about thirty years ago. The recuperator was essentially a supplement to the cycle to provide reasonable specific fuel consumptions with the low component efficiencies of that era. These recuperators, of mainly tubular construction, were conservatively designed and have demonstrated a high degree of reliability and in many cases, have run virtually maintenance free for over 100,000 hours of operation.

Plate-fin recuperators historically have been used to achieve competitive closed cycle gas turbine designs for applications requiring efficient, compact lightweight powerplants. The first closed Brayton cycle engines, designed for low power space applications, used conventional solid closure bars in the plate-fin recuperator designs. The result was competitive powerplant designs, but the recuperators imposed restrictive thermal transient and cycle limits on the powerplant operation. As a result, two key technology issues must be addressed before the plate-fin recuperator technology can be seriously considered for the reference compact lightweigth powerplant: (1) thermal transients and thermal cycles and (2) fabrication of compact recuperator designs for integration with the rotating group.

Evaluation of the design concepts consisted of comparing a number of characteristics of the two types of heat exchangers, each of which met the design point performance.

Plate-fin heat exchanger configurations usually result in a small flow length with a relatively large frontal area. In contrast, the tube and shell designs usually produce relatively large flow lengths and small frontal areas. However, due to different packaging arrangements to

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achieve the desired modularization, the annulus area required is approximately the same for each. These trends can be noted in Table 2 in the physical size comparisons of the two concepts. The plate-fin concept has a slightly larger outer diameter and slightly larger pressure loss, both of which produce a small weight penalty. As seen in Table 2, the two concepts are about equal in the impact on powerplant weight and volume.

Table 2

PHYSICAL SIZE AND WEIGHT IMPACT OF RECUPERATOR ON POWERPLANT

	Concept 1 Shell & Tube	Concept 2 Plate-fin
Outside Annulus Diameter (inch)	70.7	71.0
Heat Exchanger Core Length (inch)	70.0	34.3
Overall Length (inch)	84.0	47.6
Total Heat Exchanger Weight* (lb)	23,220	17,580

*Represents ~ 1% of the total powerplant weight

In evaluating the recuperators, several other criteria were considered including reliability, technology base, development cost and compatibility with other powerplant components. From the evaluation, the two types of recuperators were judged to be quite close in overall rating. The shell and tube type was selected for further evaluation in the CCCBS design concept based upon its slightly higher ranking and technology base. However, it is important to note that both types of recuperators meet the design requirements and that the feasibility of a closed cycle Brayton power conversion system for this application could be demonstrated with either type of recuperator.

Gas-to-Water (Precooler and Intercooler) Heat Exchangers

The intercoolers and precoolers are units in which heat is transferred from a gas to a liquid. In most instances, for this type of exchanger, the heat-transfer coefficients on the gas-side are much lower than those on the liquid side, and hence finned surfaces may be advantageous. However, with helium as the gas, the gas side heat transfer coefficients are within a factor of 2 or 3 of that on the liquid side, so that bare tubes may be effective. Four different types of precooler - intercooler heat exchanger concepts were evaluated with the object to select the best concept for further design studies. The four candidate types were shell and tube, plate-fin, helical, and cross counterflow tubular. Evaluation of the design concepts consisted of comparing a number of characteristics of the four types of heat exchanger.

The CCCBS recuperator is located in an annular region around the free power turbine and the recuperator frontal area then determines the diameter of the turbomachinery/heat exchanger module. This module diameter then determines the containment vessel diameter in a nuclear powerplant. The recuperator frontal area has a significant effect on powerplant weight and volume. However, as long as the precooler/intercooler packaging does not increase the module diameter, the powerplant volume is not affected and the type of intercooler/precooler has only a secondary effect on powerplant weight. Therefore, the impact on powerplant weight and volume for the various types of coolers is judged to be about equal.

Considering the same criteria used in evaluating the recuperators, three of the four types of coolers could meet the requirements (cross counterflow, helical and shell and tube). Thus, feasibility of the CCCBS could be demonstrated with the selected type or with either of the two alternates. Based on these results, it was concluded that the cross counterflow tubular concept has the greatest promise and was selected for incorporation into the design concept and associated further study.

Bearing Technology Evaluation

Bearing capabilities can have a major impact upon the reliability that can be expected for the power conversion system turbomachinery. Bearing design concepts also can effect the dimensions of the turbomachinery which in turn can have a major impact upon the compactness of the power-plant. The bearing and seal concept also affects the auxiliary systems that must be provided. Early studies therefore were necessary to provide the data base for evaluations of turbomachinery capabilities and to provide the basis for subsequent design efforts. Both gas bearings and oil lubricated bearings were evaluated. The resulting assessments were compared and the most promising bearing type was selected for inclusion in the design concept. The evaluation of the oil and gas bearings consisted of rating the candidates with respect to a set of criteria. From the evaluation, it was concluded that either type of bearing could suitably fulfill the CCCBS requirements. Each of the two types would require essentially the same size bearing cavities. Thus, selection of one type or the other for inclusion in the design concept would not constrain the design. This is important because it indicates that demonstration of CCCBS feasibility will not depend upon a specific bearing type.

Based upon these study results and comparisons, gas bearings were selected for inclusion in the CCCBS design concept. This will enable design attention to be focused on the gas bearings which are inherently most compatible with closed cycle powerplants, especially with those utilizing nuclear heat sources, and appear to have the potential for even greater advantages in the CCCBS application.

The gas journal bearings employ the hydrodynamic foil concept with hydrostatic pressure augmentation to permit operation in the low speed regime. The thrust bearings are designed to be primarily hydrostatic in operation with backup provisions for hydrodynamic operation during engine transients.

Materials Testing and Evaluation

In this reference design, the highest combination of stress and temperature occurs in the first row turbine blades. First stage stator vanes and blades are expected to operate at elevated temperatures for a system life in the range of 10,000 to 40,000 hours. The working fluid will be an inert gas, helium, with equilibrium concentrations of various impurities. Based on past helium turbine design technology, and based on expected materials properties, it has been concluded that a turbine inlet temperature on the order of 1700°F pushes but does not exceed the state-of-the-art for uncooled turbine blades and stators in inert gas. This conclusion regarding materials capability, however, is based on engineering extrapolation of materials properties data obtained in inert gas at lower temperature and on properties data at comparable temperature in air for shorter test time periods. To demonstrate material performance feasibility, material testing is necessary to confirm properties and to provide baseline data for feasibility evaluation.

Historically, superalloy alloy development has been aimed at problems associated with aviation and land gas turbines where hot corrosion and oxidation are the primary factors which limit component life. While creep-rupture behavior is an important design consideration in such systems, hot component life is limited to a large degree by materials compatibility with combustion products, including fuel impurities such as sulfur compounds and catalytic agents — vanadium pentoxide, from fuel processing. In the case of CCCBS, creep behavior is expected to be a primary design consideration for turbine components. Minor amounts of active contaminants in the inert working fluid are expected to produce surface reactions which may or may not influence creep behavior. Most superalloys are designed for and are tested in air and fossil fuel combustion products and, as a result, are optimized for these environments. This is particularly true with respect to creep-rupture properties.

The objective of this test program is to determine the feasibility of component materials to function under CCCBS conditions for the design life of the system. To achieve this objective, a number of candidate turbine alloys were selected for creep-rupture testing. Five ultra-high vacuum creep-rupture test units were modified for ultra-high purity helium (UHP-He) operation.

Initial testing during the first year of the study was initiated to establish baseline data under ultra-high purity helium environmental conditions. The alloys selected for the initial testing program are listed in Table 3.

Table 3

SELECTED ALLOYS AND NOMINAL COMPOSITIONS

Alloy	Density (lbs/in^3)	Composition (wt. %)
1. Alloy 713LC	0.289	Ni-12Cr-4.5 Mo-2 Cb-5.9 Al-0.6 Ti-0.05 C
2. IN100	0.280	Ni-10 Cr-15 Co-3 Mo-4.7 Ti-5.5 Al-0.9 V-0.18 C
3. MAR-M509	0.320	Co-23.5 Cr-10 Ni-7.0 W-3.5 Ta-0.2 Ti-0.5 Zr-0.6 C
4. MA 754	0.300	Ni-20 Cr-0.5 Ti-0.3 Al-0.6 Y_2O_3-0.05 C
5. TZM	0.368	Mo-0.5 Ti-0.08 Zr-0.02 C

Creep rupture testing of all five materials in an ultra-high purity helium environment was initiated. Tests in air for four of the selected materials were also initiated to characterize the creep-rupture behavior of each particular heat of material to provide a basis for comparison with published air creep-rupture data. The status of the creep-rupture test program at end of the year of effort is summarized in Table 4.

Approximately 29,000 hours of creep-rupture test hours in ultra-high purity helium have been accumulated. There has been no gross deleterious effect of the ultra-high purity helium environment on the creep-rupture behavior of the five selected materials; Alloy 713L, IN100, MAR-M509, MA-754, and TZM, for the temperature and time periods of the creep-rupture tests.

Conclusions

- The studies to date have been directed primarily toward providing technology research specifically directed toward Navy needs and provide on integrated foundation for the subsequent efforts of the program. A design concept has been defined, which has the necessary characteristics for an integrated power conversion system and which is

Table 4

CREEP-RUPTURE DATA FOR SELECTED CCCBS MATERIALS AT 1700°F

Material	Stress (ksi)	Test Atmos.	Time to % Strain (Hours) 0.5%	1.0%	3.0%	Total Strain (%)	Rupture Time (hrs)	Reduction In Area (%)	Status
Alloy 713LC	20.0	He	84	192	268	6.4	269	16.7	Completed
	20.0	He	260	495	691	8.0	755	22.0	Completed
	18.0	He	128	943	1522	4.8	1527	8.4	Completed
	15.0	He	1060	2500	3150	5.6	3182	10.2	Completed
							5733		
	20.0	Air	212	395	572	9.6	623	25.8	Completed
	20.0	Air	8	86	324	10.4	397	8.7	Completed
	18.0	Air	29	119	405	9.6	476	8.3	Completed
	15.0	Air	100	740	1870	5.6	1959	8.1	Completed
							3455		
IN 100	22.5	He	700	1170	1982	16.0	2271	17.6	Completed
	16.0	He	--	--	--	--	2416	--	In progress
							5187		
	30.0	Air	8	70	211	6.4	271	6.7	Completed
	30.0	Air	22	93	285	7.2	334	8.5	Completed
	25.0	Air	1	7	490	7.2	685	4.3	Completed
	22.5	Air	110	550	1130	8.5	1346	6.0	Completed
	18.0	Air	1460	2890	2985	7.2	3110	12.1	Completed
	16.0	Air	--	--	--	--	430	--	In progress
							6176		
MAR-M509	15.0	He	--	--	--	--	2500	--	In progress
	12.5	He	--	--	--	--	693	--	In progress
							3193		
	18.0	Air	2	5	264	21.6	618	34.1	Completed
	15.0	Air	1	570	1910	16.8	2507	19.6	Completed
	12.5	Air	5	25	--	--	2330	--	In progress
							5455		
MA 754	20.0	He	--	--	--	--	5957	--	In progress
	22.0	Air	--	--	--	--	1559	--	In progress
	20.0	Air	70	3480	--	--	5378	--	In progress
							6937		
TZM	60.0	He	220	425	1095	12.0	1483	98	Completed
	55.0	He	450	1010	2000	14.5	2256	98	Completed
	52.5	He	790	2000	--	--	5115	--	In progress
							8854		

appropriate for the most stringent requirements associated with the various energy sources, fossil or nuclear, which the Navy could desire to use.

- Critical components such as bearings and compact heat exchangers have been evaluated and shown to have more than one suitable design solution. In each of these cases, the most desirable configuration has been selected for incorporation into the power conversion system design concept for further evaluation. These selections are the shell and tube recuperator, cross counterflow finned tube precooler and intercooler, and gas bearings.

- Creep rupture material tests in ultra-pure helium at turbine inlet temperatures have provided important indications of the probability of suitable material availability. 28,924 total hours of creep-rupture testing on five candidate materials have been accomplished in ultra-pure helium at temperatures up to 1700°F. These data are supplemented by by 22,023 total hours of testing in air at temperatures up to 1700°F. These tests provide valuable new information to the materials science community. There have been no deleterious effects of the helium environment on the creep-rupture behavior of the materials tested.

Automated Analysis of Output Data from EW Simulations

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Modeling of Electronic Warfare systems and simulation of engagements has become commonplace because of the unique advantages computer simulation studies provide in the development, selection, and modification of effective but reasonably priced Electronic Warfare radio frequency (EW) systems. System operation and performance in dense and dynamic RF environments can be evaluated through the use of EW system models. In general, it is not always feasible or wholly possible to arrange complex and coordinated enagagements in the field or to assure repeatability of completely known test conditions. In addition, modifications and adaptations to system configurations can be readily implemented in models, as opposed to real equipment, often merely by changes in input. The effect of these alterations on overall performance can be quickly assessed. When considering deployment of EW equipment, modeling and simulation studies are useful in selecting among competing products. Moreover, simulation can contribute to the enhancement of a system's capabilities by enabling the analysis of system performance under various system control configurations and signal environments. Finally, experience in the effective utilization of the sophisticated features provided by the equipment can be gained through the use of simulation when actual field experience may be impractical because of the tremendous costs in time and funds required by large fleet exercises.

The evaluation of the military worth and effectiveness of the performance of an EW system depends upon many factors. Each simulation is comprised of a series of significant events. In addition to the final outcome which may be expressed by the last occurrence (e.g., a missile hitting or not hitting a ship) the reasons for a system's behavior are obtainable from the sequence of prior interrelated simulation

*Ms Emmans and Mr. Leroy are staff scientists at the Naval Research Laboratory. Their primary field of interest is in the computer simulation of electronic warfare systems.

events. The determination of the intricate logical relationships which produced the final results is usually impossible in field tests. By cataloging event occurrences an analyst is able to provide causes and explanations of end results. The level to which a system and an environment are represented in terms of complexity and detail may determine the nature of the data that can be extracted. Frequently an extensive amount of data requiring further analysis may be obtained. In particular, large-scale, comprehensive and sophisticated simulations generate too much data to be evaluated through manual analysis within a reasonable period of time.

Since its inception in 1972, the Effectiveness of Navy Electronic Warfare Systems (ENEWS) Program, sponsored by the Naval Electronic Systems Command, has been involved in the continuing development of simulation facilities at the Naval Research Laboratory to allow U.S. Navy investigation of the interaction between anti-ship missiles and shipboard defense as related to EW systems. Efforts to date have included studies of complex receiver systems for airborne, shipboard and submarine applications. In addition to automated receiving systems, efforts have been directed toward simulating complete EW systems including manual operators and their interfaces with the EW systems.

As additional EW system models were developed, it became apparent that a more orderly data collection process was needed to manage the voluminous output data from model executions. Since computer memory and run time limitations prohibit the collection, storage, and on-line analysis of all the data items needed to evaluate system performance, the obvious solution was to store the data extracted from model runs on magnetic tape (or disk) for subsequent off-line analysis. This not uncommon approach has facilitated the examination of the results of model runs in many ways without the need to rerun the simulations. With this capability in mind, an extensive programming structure known as the Model Analysis Programs (MAPS) has been developed. By utilizing MAPS, it is possible to perform any desired analyses automatically from the output tapes generated by simulations of greatly differing EW systems. The capability to perform highly adaptive, automated off-line analysis following from the on-line data storage process has provided analysts with a powerful tool for performing timely and comprehensive system performance evaluations employing the extensive data generated by detailed EW system models.

The words modeling and simulation are frequently used interchangeably but each suggest several varied interpretations. The MAPS has been used primarily by event driven digital models of EW systems in digitally generated dynamic environments. Figure 1 shows the typical relationship between the modeled EW system, the environment, and MAPS. However, the concepts embodied in the MAPS do not limit its application solely to this type of simulation. MAPS will even per-

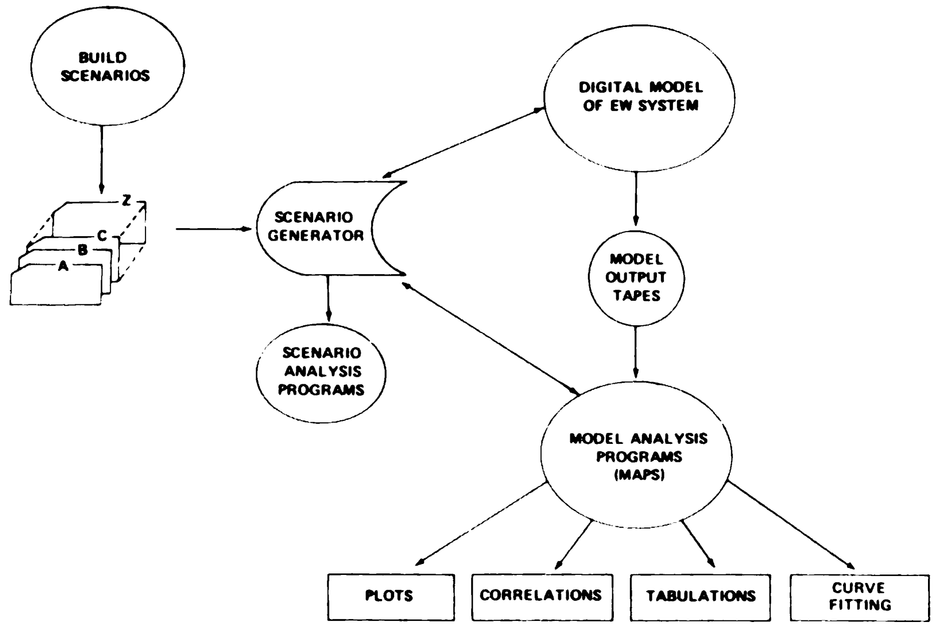

Figure 1 — Scenario/model/analysis interfaces

mit the manipulation and analysis of real-world test data, providing the data conform to the required formats.

Reasons for Development

To better understand the concept behind the development of the MAPS, it is necessary to realize the type and volume of data requiring additional analysis resulting from a typical simulation run. Typically, the primary output from electronic warfare simulations is a record of the actions taken by the modeled EW system on each emitter present in the scenario. This type of data is essential in order to analyze the system's effectiveness not only against the simulated environment as a whole, but also against specific emitters as well.

The data are accumulated and updated by random access throughout the execution of the model game, providing a summary of system performance in terms of each emitter. In the past, the only access to these emitter data was at the model execution time when snapshot summaries of the data were periodically printed out on paper. Now, with the implementation of a permanent storage capability, the basic product of simulation consists primarily of model output tapes, supplemented by limited printout during model execution.

In order to quantitatively characterize an EW system's response to emitters in a scenario, events are defined whose occurrences during a simulation trigger the collection and storage of data referenced by emitter. With the level of detail employed in the models currently utilizing MAPS, there are typically about fifty data items of interest. The data describing significant events can essentially be categorized into four types:

(a) Actual game clock times at which major EW system events occur on each emitter. These times include the first and last time an event occurred for an emitter.

(b) The number of times that major EW system events occur on each emitter. These data items are referred to as counters or accumulators.

(c) Time accumulators for the amount of time that an EW system spent performing specific functions in response to each emitter.

(d) Flags indicating the status of an emitter in processing.

It should be noted that the above data do not usually include the instantaneous status of emitters at the time of major system events. For the modeling efforts currently employing MAPS, a dynamic environment generator has been developed which makes it possible to query a scenario at any point in time to determine the values of dynamic parameters describing an emitter. For these simulations it is not necessary to store scenario information because the environment existing during the simulation can be recreated. However, scenario data can be stored by emitter along with simulation event occurrences for the analyses requiring such information.

The volume of data collected and stored for each simulation is largely a function of the scenario size (i.e., the number of emitters) and the number of periodic summary reports. A typical simulation game might last twenty minutes in a scenario with four hundred emitters with approximately ten periodic reports requested. If fifty items of data are collected on each emitter, two hundred thousand words of data coupled with approximatly five thousand words of descriptive information about the game result as typical output per model game. When several model games are run or with several modeling efforts in progress at any given time, each generating tapes of data to be analyzed, the amount of data readily amounts to tens of millions of words.

Features

The volume of data described above is not unusual in EW simulation work. What the MAPS have achieved is the ability to easily perform any type of analyses desired. This ability is primarily due to the structure of the MAPS program and its numerous supporting routines. The structure of the MAPS computer program has specifically been designed to be completely modular and resembles a library of model output analysis programs. The analysis program add-on capability is virtually limitless. A complex executive routine performs the required mundane tasks necessary to perform program initializations and to read in and prepare the data for analysis. The manner in which all these functions are performed is completely transparent to the analyst, making it unnecessary for him to be concerned with the required internal mechanics. Furthermore, the program file contains a myriad of utility routines that perform a variety of necessary and useful functions. The analyst need not be concerned with the fine details of these utilities, but benefits from all these routines when he requests particular analysis programs for execution.

An important attribute of the MAPS utility routines which is particularly useful and often necessary is the automated selection of specified data by data filtering. MAP data filtering means the capability to isolate subsets of emitter data on the basis of any combination of emitter characteristics (as presented in the scenario) as well as on the basis of data that appear on the output tape. For example, it is possible to request that a particular analysis be performed on only those emitters within a specified frequency band, whose pulse widths lie between some specified values, and which were first intercepted by the EW system between specific models game times. (The latter, of course, requires that the times of initial intercept have been collected for each emitter in the scenario.) It is clear that such a filtering capability permits a virtually unlimited variety of analyses to be performed. For each MAP, a wide variety of runs can be made solely on the basis of varying the filters specified in the input.

Analyses

At present, there are approximately thirteen analysis programs or options in MAPS. Each option is quite broad in scope and allows for presentation of various forms of analyzed data as well as a variety of selected raw data. Outputs are available in the form of both printed data and plots. Statistics on the analyzed data are also computed.

Within the MAPS file, each analysis option is identified by a numeric value, such as MAP 1, MAP 2, etc. As new MAPS are created, they simply receive the next number available. This procedure simplifies the executive calling structure as well as providing a unique identifier for each analysis program.

In order to illustrate typical analyses, brief descriptions of some of the most widely used MAPS are given below: The MAPS options to be discussed include:

(a) MAP 4 — Response Time Analysis
(b) MAP 11 — Cumulative Response Analysis
(c) MAP 7 — Observer Range/Bearing Analysis
(d) MAP 3 — Time History Plots
(e) MAP 12 — Summarization of Events by Emitter
(f) MAP 8 — Emitter Parameter Time Analysis.

Response Time Analysis (MAP 4)

The primary purpose of MAP 4 is to allow the analyst to measure system response time for a given system function relative to some base time, usually the earliest time the emitter could become visible to a system (ETV). This is accomplished by taking the difference between these two event times for all filtered emitters and then binning the resultant differences. Histograms (as illustrated in Figure 2) of the number of emitters which fall into each response class are then produced. The values that are closer to zero on the x-axis scale of response times represent better system response for the function being analyzed. Plots of this type facilitate the comparison of the response time characteristics of different systems and/or system configurations. Percentage and cumulative percentage histograms as well as polynomial fits of these curves are also available.

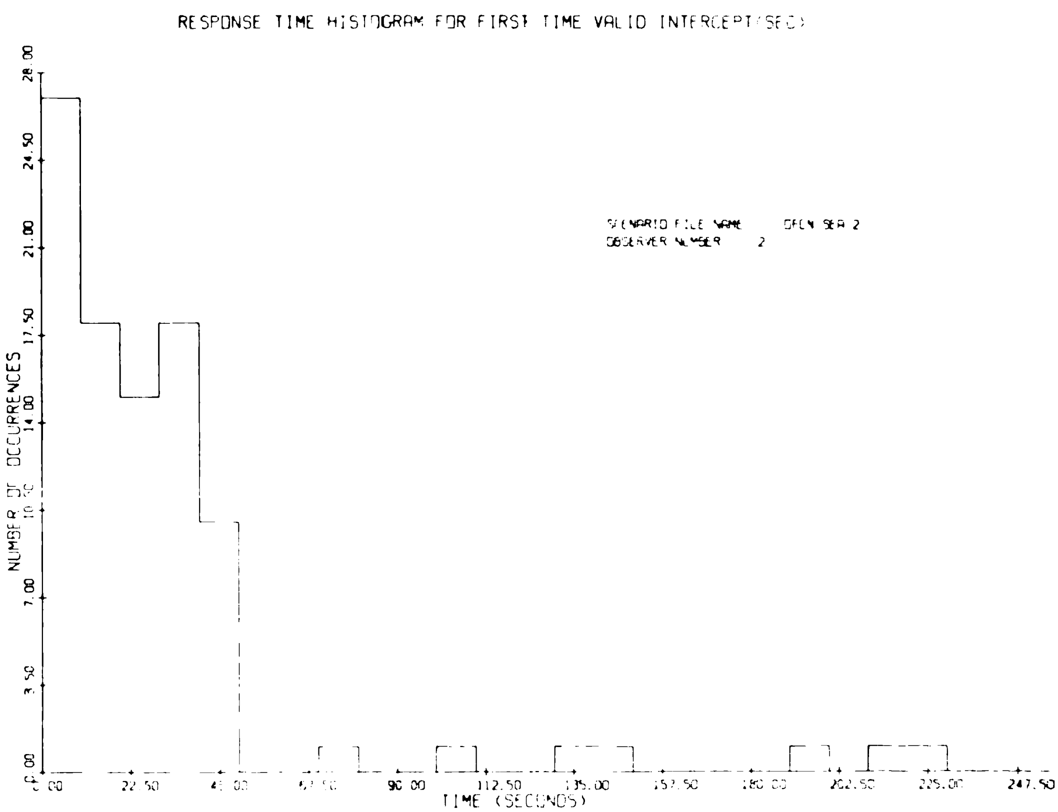

Figure 2 — Response time histogram

The timeliness of correct emitter identification has been used as a major measure of the effectiveness of several EW systems. For example MAPS analysis of one system under development pointed out a relatively poor response to low PRF (Pulse Repitition Frequency) emitters and improvements to the system processing were added to the production version of the system as a result. For one superheterodyne

EW system, MAPS results showed that although the instantaneous probability of intercept was reduced when the system was modified to shorten the dwell period at each frequency, tuner sweep revisit times were substantially shortened and the overall response time was improved. Several systems have been studied in differing signal densities to determine the effects of system loading on response time. Because of the importance of response time as a criterion for effective performance, MAP 4 has been made fully integral to the analysis of output data from all EW system models.

Cumulative Response Analysis (MAP 11)

This MAP enables the analyst to plot cumulative histograms (as shown in Figure 3) of data indicating the time of the initial occurrence of any event, such as the time of initial intercept by an EW system. This MAP uses the same type of data as does MAP 4 but displays the output in a cumulative fashion and allows for several system functions on the same plot. The x-axis represents the time relative to the beginning of the simulation game. The plot shows the cumulative number of initial event occurrences or, equivalently, the cumulative number of emitters for which the event occurred at least once at each point in time since the game began.

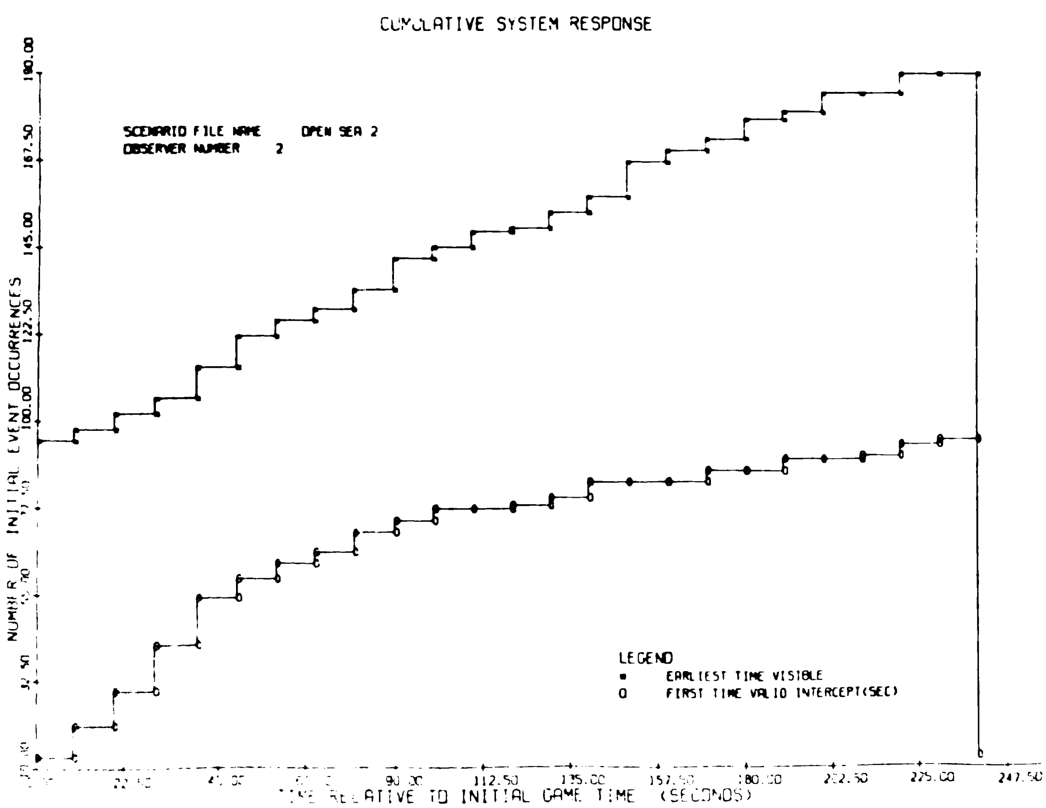

Figure 3 — Cumulative system response

From the MAP 11 plot, an analyst can readily determine major EW system function delays between various events as compared to some base time such as ETV. For example, if there had been one hundred emitters visible up to a point in time, there would ideally be one hundred emitters for which the events of interest occurred and the lines on the plot would overlap. The degree to which the lines do not overlap represents the time lag in the system processing. By reading difference values on the abscissa, delays such as those between first time of intercept and first time of successful signal identification can be determined. The buildup of queues causing these delays also can be determined by reading difference values on the ordinate scale.

MAP 11 has been used extensively to study and detect delays in signal processing. MAP 11 analyses have been used to select the most desirable among competing systems and to determine the best processing schemes for systems under preliminary development. A primary criterion in these studies is the system processing efficiency as reflected by a minimum number of delays and queues. MAP 11 has been used additionally to evaluate the sensitivity of various system processing values. Parametric runs of these values are analyzed to determine their effects on system delay times.

Observer Range/Bearing Analysis (MAP 7)

MAP 7 provides an analyst with plotted range and bearing (from a specified reference observer) for each emitter in the scenario at the time of a significant system event. For example, it may be desirable to display the range and bearing of emitters at the time they were first intercepted. MAP 7 produces three plot outputs. The first is a range histogram which records the number of emitters falling in each range bin at the time of the selected system event. This is illustrated in Figure 4 in which the chosen event is the first time an emitter is validly intercepted. The second is a polar plot depicting the relative location of each emitter from the observer platform at the event times (see Figure 5). The third is the same type of plot at the times the emitters first become visible (see Figure 6). All three plots are produced from one of the periodic reports so that they are bounded by a common report time. Therefore, only those events occurring on or before the chosen report are included in the MAP 7 analysis. The circle of equidistant range about the observer on the polar plots is an arbitrary value input to the program.

In the cases where emitters are visible but have not yet been processed, plots such as those in Figure 5 and Figure 6 graphically display the lag incurred by the system. Figure 5 may show fewer emitters than in Figure 6 since all of the visible emitters may not yet have been processed through the event of interest. For incoming threats, the range from the observer will be less in Figure 5 since the cataloged event necessarily occurs after the time each emitter becomes visible.

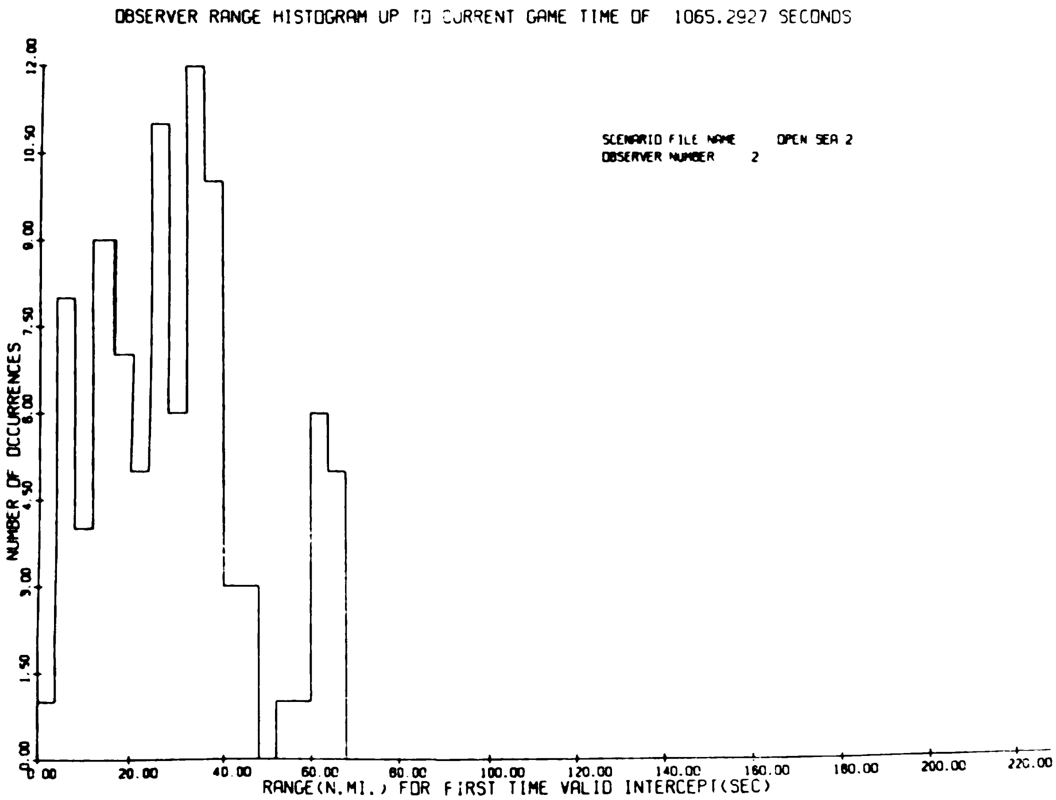

Figure 4 — Observer range histogram

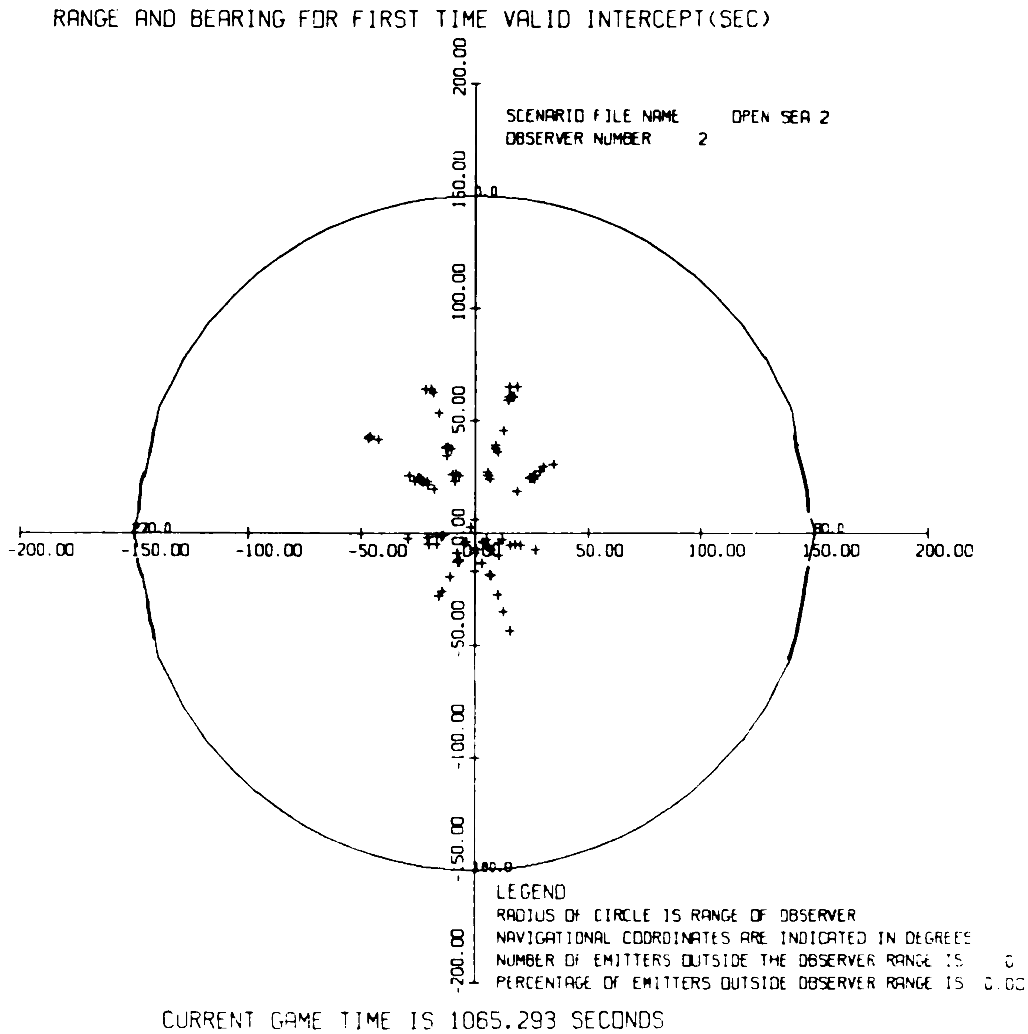

Figure 5 — Relative range and bearing plot for a major system event

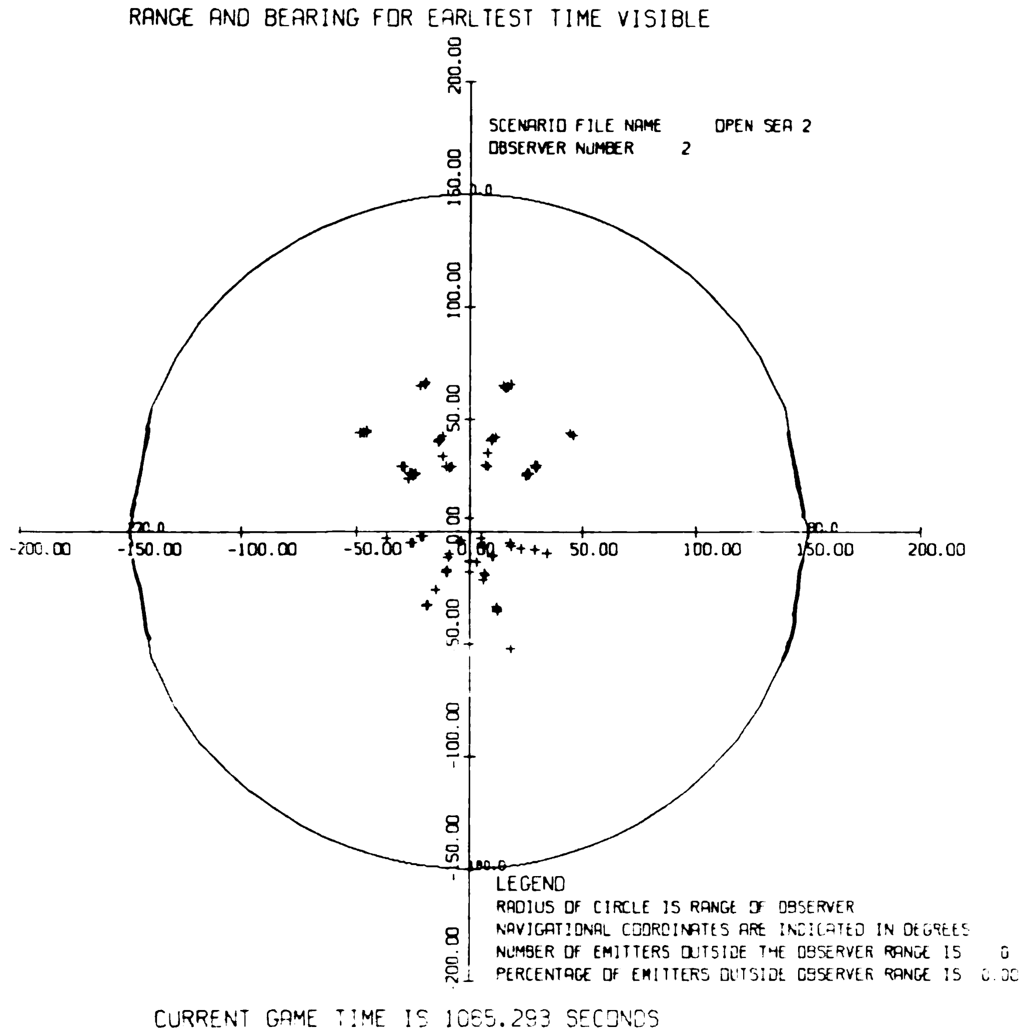

Figure 6 — Relative range and bearing plot for earliest time visible

It is frequently of great concern that an EW system successfully identify threats sufficiently early so that adequate time remains to counteract these threats. Based on the radar coverage of the potential threats, a critical detection range can be determined. To be effective, an EW system must validly intercept and correctly identify the threat signals outside each threat's critical detection range.

The MAP 7 output immediately identifies threats which pose problems for a system and delineates cases where modification of system processing or internal threat libraries may be needed to improve the system performance against those threats.

Time History Plots (MAP 3)

The primary purpose of MAP 3 is to exhibit system activity as a function of time. Since all reports that were generated at different model game times are on the tape, this MAP can display the changes in any set of accumulators stored on the output tape as a function of report time. Each data point represents the number of times the event occurred during the last report period (over all the filtered emitters). Clearly, the more reports on the tape, the finer will be the resultant plots. A sample MAP 3 plot (Figure 7) shows the system queuing activity incurred by an EW system as filtered according to frequency. Plots of this type may be compared against signal activity in the environment to determine cause and effect relationships.

Typically, MAP 3 is used in conjunction with other plots showing environmental conditions as a function of game time, such as plots of pulse density or number of emitters visible to the system. Such comparisons reveal the effect of the environment on system processing. In particular, the degree and frequency of system saturation becomes clear.

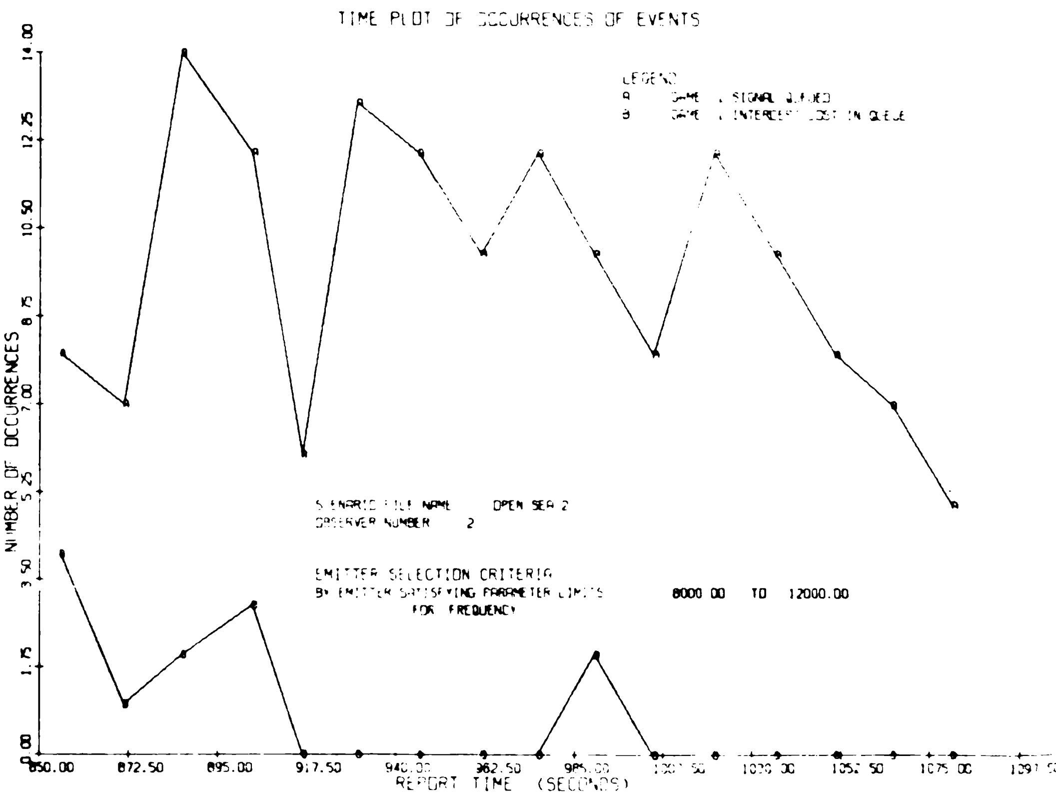

Figure 7 — Time plot of intercept and queuing activity

Summarization of Events by Emitter (MAP 12)

This MAP permits an analyst to obtain histograms of the number of emitters that had any occurrence of defined major EW system events as a function of time. MAP 12 differs from MAP 3 in that it does not count the number of times an event occurred for each specific emitter.

Rather, if an event occurred at least once for an emitter during a report period, MAP 12 counts the emitter as contributing over that period. In a sample MAP 12 plot (Figure 8) the number of emitters that were not intercepted because their signal levels were below system threshold is displayed as a function of game time. The data points necessarily occur at the report times at which emitter data summary reports were produced.

MAP 12 sifts through all the processing performed by a system to detemine the number of emitters that were processed as indicated by the occurrence of some event. This analysis evaluates how effectively a system dealt with an environment as a whole. If only a few emitters had any occurrence of an event, then it could be concluded that these few signals had been able to tie up or confuse the system.

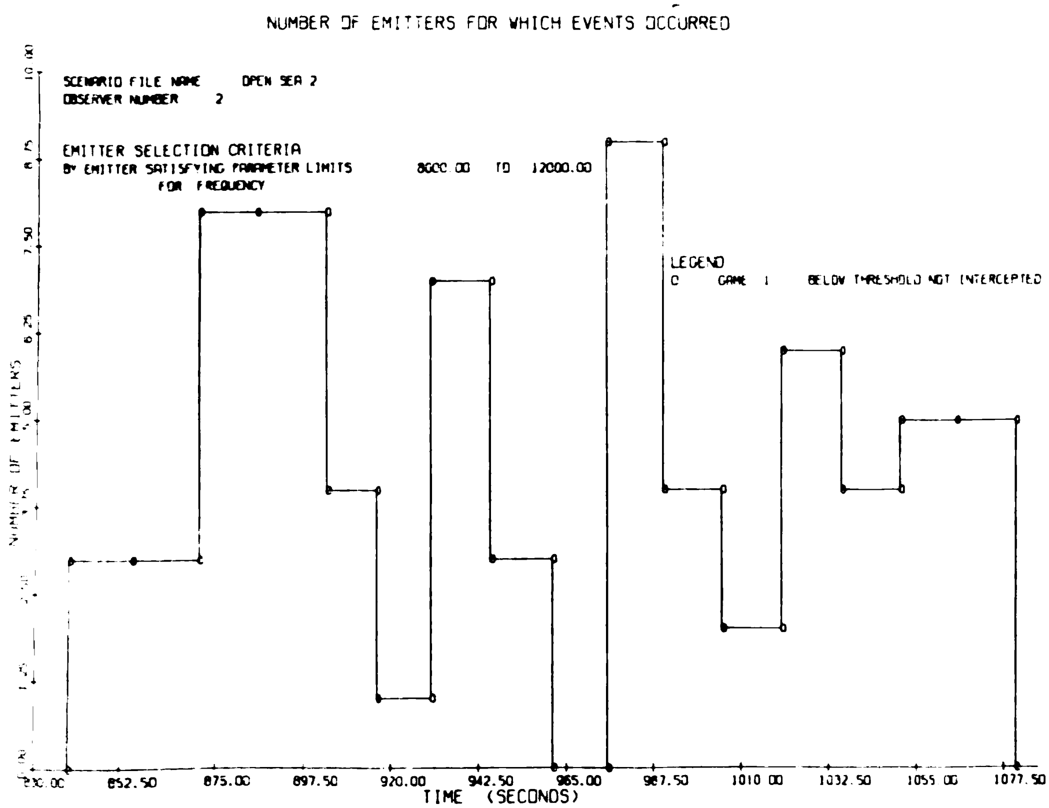

Figure 8 — Number of emitter occurrences

Emitter Parameter Time Analysis (MAP 8)

This MAP generates plots of any emitter characteristic versus any other at the time that any major event occurred. Figure 9 is a sample display where the lobe in which a signal was intercepted has been plotted versus the received signal amplitude at intercept. The lobe indicators are 1 for main beam, 2 for side lobes, and 3 for back lobes. The emitters chosen were those satisfying some specified frequency band.

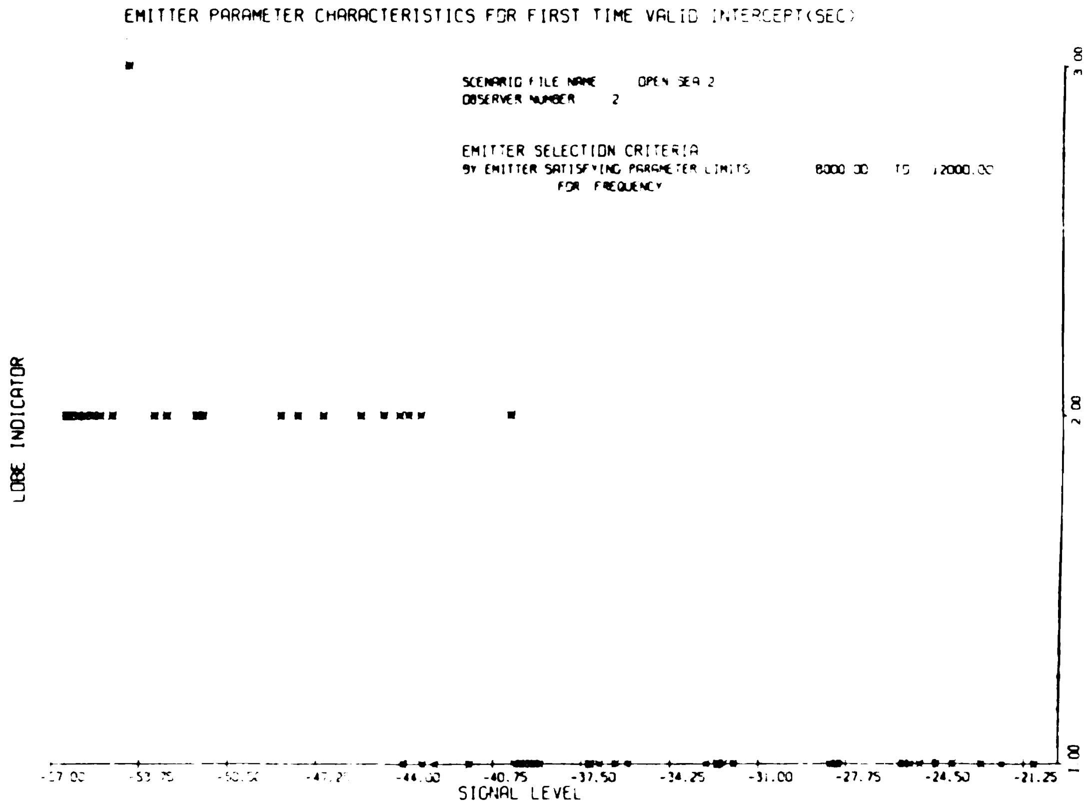

Figure 9 — Emitter parameter characteristics plot

Another frequently requested MAP 8 plot is signal level versus bearing at the time of intercept. Such a plot provides an analyst with dynamic information indicating the reason for system success or failure in performing on-line platform/threat ID correlation. In addition, MAP 8 has the capability to produce facsimiles of operator displays such as frequency versus azimuth at the time of threat identification.

Other MAPS permit the reproduction of periodic report printout, the analyses of system reaction time by a measured factor, the summarization of events, and the calculation of new data items from existing output data.

As mentioned previously, the modular structure of the MAPS program and the wide-ranging utility routines permit the addition of new analyses with great ease. Moreover, an own-code area is provided in the MAPS for the implementation of model-specific analyses.

Summary

In conclusion, the MAPS package provides a vast improvement in data handling and analysis capabilities which makes it possible to conduct timely and thorough studies and comparisons of EW systems utilizing digital models. The applicability of the highly flexible analyses to greatly differing EW systems has been repeatedly proven. The MAPS concept is applicable to the analysis requirements of many different types of EW simulations and could readily be extended to other simulation areas.

Electron Beams Probe Electronic Device Faults

Scientists at the Naval Research Laboratory have developed a new technique to relate bulk and surface electronic properties in electronic device materials, resulting in the development of new methods to examine them for failure and imperfections. Dr. George A. Haas, principal investigator, reports that the basic new concept for investigating electronic properties of materials has been named LEER, (an acronym that stands for low-energy-electron-reflections).

An incident beam of electrons (about 10V and below) is used to probe the surfaces of materials, and this provides a measurement of electronic properties such as the work function (energy difference between the Fermi level inside and the vacuum level outside). With semiconductors there are two components in the work function, the position of the conduction band with respect to Fermi level and the electron affinity. The first is mostly a bulk semiconductor property and the second is a surface property. This is the first time that a simultaneous measurement separating these components was achieved. The separation, Dr. Haas points out, was accomplished by making use of the interaction of the electron's wave length with the lattice periodicity of the solid. It is this interaction which gives rise to the LEER patterns.

As a result of practical implementation of some of these basic studies, three patent applications have been issued to the NRL scientists. Apart from its use as a diagnostic tool to measure electronic properties of materials a second application of LEER is a technique whereby a scanning beam of electrons would give a TV image of the bulk non-uniformity of semiconductor materials without any electrical contact probes being used.

The third application emerging from LEER, is a proposed method for fabricating a sensitive device to detect the amount and types of gas build-up in electron tubes without energizing the tubes.

The use of these techniques is especially important to the Navy and industry when applied to semiconductor and other materials used as components in modern electron devices. Use of the new technology in high-power microwave tubes, for example, has already provided a much better understanding of a major failure phenomenon of one of the tube's components, namely the loss of electron emission from the cathode due to gas poisoning.

Work is also continuing on other basic degradation mechanisms, such as those encountered during shelf-life storage and in fast turn-on requirements of shipboard, expendable traveling wave tubes. Furthermore, application of the LEER technique is being extended to studies of other semiconductors, metallizations and Schottky barrier phenomena.

Research Notes

Acoustic Microscopy at Cryogenic Temperatures

Over the past several years, Professor C. F. Quate, and collaborators at Stanford University have developed scanning acoustic microscopy to a sophisticated and useful technique with the support of the Office of Naval Research. Simply stated, a scanning acoustic microscope (SAM) is constructed in such a way that an object is mechanically scanned through the narrow waist of a focused beam of high frequency sound to obtain a "picture" of the acoustic reflectivity (or transmissivity) of the object. The resolution is limited by the waist size which is ultimately limited by the minimum acoustic wavelength attainable. The maximum useable frequency (minimum wavelength) is limited by acoustic absorption in the coupling medium. Absorption generally increases with frequency. At room-temperatures, the resolution attained is about 0.52 microns (comparable to *green light* in a good optical microscope). The motivation for going to cryogenic temperatures and ultimately into SAM operation using superfluid helium as the coupling liquid is to realize more resolving power (shorter wavelength) as a consequence of both lower acoustic absorption (permitting higher operating freqency) and a lower sound velocity. However, it is important to point out that, aside from the resolution question, the picture obtained from differences in *acoustic* parameters is *different* from the optical picture, and in many instances more informative.

Recently the cryogenic SAM project has concentrated on development and testing of components for an *initial* reflection instrument to operate at a temperature of 1.95°K in superfluid, helium and at a frequency of 500 MHz. At this temperature and frequency, the acoustic wavelength in helium is about 0.45 microns (comparable to blue light in a good optical microscope). The apparatus with lens was successfully tested at 500 MHz in room-temperature water. Everything looks very promising for operation of the complete instrument at 1.95°K in the near future. According to current thinking, a ten-fold increase in resolving power, over an optical microscope and the near-fruition SAM, is attainable by the acoustic instrument operating in superfluid helium at lower temperatures. This resolution range is between the ranges for optical and scanning *electron* microscopes, and the SAM gives information different from that of optical and electron microscopes.

Navy Experiment to Gather Acoustic Data on Arctic Basin

Scientists on a moving ice floe in the Arctic Ocean are engaged in an experiment aimed at learning more about the sound propagation of the ocean in the Arctic Basin.

Dubbed CANBARX (Canadian Basin Acoustic Reverberation Experiment) the experiment is funded by the Office of Naval Research and involves scientists from the United States and Canada. The scientific team is composed of investigators from the Bedford Institute of Oceanography, Nova Scotia, the

Lamont-Doherty Observatory, Woods Hole Oceanographic Institution, the Massachusetts Institute of Technology and the University of Rhode Island.

The ice floe is located in the Arctic Ocean north of Barrow, Alaska, and is large enough to allow supply planes to land and take off. Logistic support and other assistance for the experiment and the scientific team is provided by the Naval Arctic Research Laboratory, Barrow.

By using a variety of sophisticated instruments, the scientists hope to obtain a more accurate acoustic "map" of the ocean and its boundaries, by artificially producing acoustic signals and then measuring how these signals react and are affected by the environment of the Arctic Ocean such as sea floor ridges, bottom geology, the topography of the continental shelf and the ice cover.

The signals are produced by explosive charges detonated at determined locations and return signals are received by arrays of hydrophones under water and other sound recording instruments under water and on the ice cover.

Other aspects of the CANBARX project will include measuring the ambient noise of the Arctic Basin, the sound produced naturally by sea organisms and the constant movement and cracking of the ice. Also included in the project will be a test for determining the rate of corrosion of various metals by the action of the water and marine organisms in the cold environment.

Solid State Polymer Stress-Relieved Extrusion

A new solid state extrusion technique, which overcomes many limitations of previously studied cold extrusion methods, has been discovered by Professor Roger Porter of the University of Massachusetts with funds provided by the Office of Naval Research. High density polyethylene was used to demonstrate the technique. Conventionally, a semi-crystalline polymer has been extruded as a solid plug or billet through wedge-shaped or conical dies. The new technique involves the cold extrusion of longitudinally-split billets through a conical die only. A film strip has also been interposed within the split prior to extrusion. This process involving a split billet is called stress-relieved extrusion (SRE). A salient feature of the new technique is that either films or filaments may be ultradrawn at much faster rates, at relatively lower temperatures and pressures, and in the absence of lubricants. Ultradrawn films and filaments are formed, respectively, by inserting between the split billet low orientation films and filaments prior to extrusion. Thus, the new solid state coextrusion technique allows, for the first time, continuous production of unflawed film strips and filaments having extrusion draw ratios of > 30X. In addition, the method efficiently orients and elongates the polymer chain. Of course coextrusion is an old metallurgical technique; the utilization of this approach to obtaining extended chain polymer morphologies is new.

Stress-relieved extrusion offers a heretofore unexplored approach to the problems of solid state deformation of polymers in contained geometries. The technique has profound advantages and these are: (1) it is more rapid, continous and reproducible; (2) it requires only moderate processing pressures; (3) the process operates without the requirement of lubricant or a second liquid; (4) it is a very convenient technique since it allows the preparation of continuous films or filaments using the same conical die. In addition, the technique promises wide application. It is highly efficient in producing continuous lengths of films or filaments and allows the preparation of extremely thin films and filaments. In this process of solid state co-extrusion, the components, even for different composition and molecular weights, extrude with integrity and at the same rate.

Potential Population Inversion for X-Ray Emitting States

Professor Browne, University of Texas, has recently completed calculations of cross sections for the collision of He^{2+} with Li, under sponsorship of the Office of Naval Research. Their calculations indicate that the cross sections for charge transfer to $He^{+}(31)$ is of the order of $10^{-15}\,cm^2$ around 7 keV. The He^{2+}-Li(2s) system is approximately resonant with the $He^{+}(31)$-Li^{+} system. Consequently, the attractive $^2\Sigma$ molecular potential curve from the former system crosses the various molecular potential curves arising from the latter system between 33 and 44 a.u. At this large distance the coupling $^2\Sigma$ molecular state arising from the He-Li^{2+}(1s) system which crosses the $He^{+}(31)$-Li^{+} molecular states between 7 1.u. and 14 a.u. and strongly couples with the former $^2\Sigma$ state around 5.5 a.u. This $^2\Sigma$ then in turn strongly couples to the $^2\pi$ which correlates outward to the 3p states of He^{+}. As the Li^{+} and He^{+} separate, however, all $n = 3$ states of He^{+} will be coupled. The actual final distribution between the ^2S, ^2P, and ^2D states of $He^{+}(31)$ would require the solution of an extremely large 6 states coupled problem.

Another ONR contractor, Dr. J. Leventhal, University of Missouri, has subsequently performed preliminary experiments on this sytem. Although, his present apparatus is not capable of observing x-rays, he could study the radiative decay from the $n = 5$ and $n = 4$ states of He^{+}. He found that the $n = 5$ radiation is substantially less than the $n = 4$ which is in agreement with what one would expect from the theoretical results. He is presently studying the feasibility of incorporating an x-ray spectrometer into his system to study the $n = 3$ radiative decay.

This sytem appears to be one of the most promising possibilities for a population inversion for x-ray producing states. Emission directly to the ground state yields photons with an energy of 48.4 eV while cascading through the $n = 2$ level yields 7.7 and 40.8 eV photons.

Low-Cost Underwater Sound Source

Scientists at the Naval Resarch Laboratory have devised a unique continuous-wave, broadband underwater sound source for long-range propagation studies, as well as calibration of large, low-frequency receiving arrays. The project was sponsored by the Office of Naval Research.

Most sources, says A. M. Young, principal investigator for the NRL program, are large, cumbersome and expensive. This three-element line array reduces these undesirable characteristics, and its output power capability and bandwidth satisfy many requirements.

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Each element of the unit is a planar array consisting of three radiators (USRD Type J15-3). It weighs about 545 kilograms (kg) (in air) and is 2.18 meters (m) high. Each of the array elements is pressure-compensated by a passive air-bag system to depths of 240 m.

The array concept offers several advantages over a single-surface, large-force, mechanical or hydraulic transducer. When a single-surface, large-force transducer is used at sea, failure can mean total loss of the source capability. To carry a spare source would be prohibitively expensive.

With the new source, however, the failure of a single element would not necessitate retrieval. Individual radiators or entire elements could be replaced relatively inexpensively and quickly from an inventory of spare parts that can be carried at sea. The array concept permits flexibility in rearranging the number and distribution of radiators to adapt to various acoustical requirements and tow body configurations.

Ionization Enhanced Migration of Impurities in Silicon

In a paper presented at the Washington meeting of the American Physical Society in March 1978. Professor G. D. Watkins of Lehigh University reported the observation of ionization enhanced migration of impurity atoms (aluminum) in silicon. This process was proposed several years ago as a possible mechanism involved in ion implantation and radiation effects studies, but no one has previously detected it. In the Lehigh experiments, which were funded by ONR, electron beam irradiated silicon doped with aluminum, was investigated by electron paramagnetic resonance (EPR) techniques. The temperature of the sample was below that required for thermal annealing. Laser radiation was directed on the sample and the change in EPR signal was monitored. The results indicate that interstitial Al(+2 charge) ions moved until coming in contact with aluminum (−1 charge) ions on substitutional sites, and there the two different types of ions were bound together. Several other types of defects involving carbon and/or vacancies were not affected in this experiment.

A recent technological development, referred to as laser annealing, is currently of intense scientific interest. Damaged crystalline materials undergo a modification to a less damaged state under irradiation by an appropriate laser. The mechanisms for the annealing are not well understood. This report by Professor Watkins suggests that ionization enhanced diffusion may be involved.

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Cover Caption

The cover depicts an Electronic Warfare (EW) engagement showing an enemy missile attack on a surface task force located in the center. The shipboard electronic warfare systems developed with the assistance of computer simulation and analysis are successful in processing the electromagnetic environment and in employing countermeasures to divert the missiles. (See Page 15)

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