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The Society of Madmen

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The SOCIETY of MADMEN, Inc.

The Society of MADMEN is dedicated to the continued development of magnetics technology. It is the hope of those who founded the society that it will become a forum for the exchange of ideas and a focal point for the military, industrial and academic communities interested in magnetic detection.

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First International Symposium of Madmen

(Magnet. Anomaly Detection)

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The Society of Madmen

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Comments by the Grand MADMAN

Thanks to your participation the First Symposium of the Society was able to be held. It was held with much enthusiastic support by the Technical community. Unfortunately due to the sensitive nature of our business and our name (MADMEN indeed!) there was some reluctance to our magnetic information flow. Several papers that were not presented for security or other reasons are listed herein. Fortunately the symposium did happen much to the pleasure of many. I sincerely believe the difficulties of the First Symposium are over and will benefit the Second.

Thanks, also to RADM R.D. Johnson, the Assistant Commander for Systems and Engineering of the Naval Air Systems Command, Washington, D.C. for sponsorship of the Symposium.

Thanks again,

Bob Smith
Your Gamma Servant
Bob Smith - Grand MADMAN

Next Symposium? Spring 1984

MAD IN RETROSPECT

George D. Bender

The attacks by Axis submarines against Allied shipping during the early years of WWII were devastating and seriously threatened the Allied cause. Something was urgently needed to strengthen the Navy against this terrible threat. Effective air strength in Allied Anti-Submarine Warfare (ASW) was required. At that time, airborne radar was in its infancy and sonobuoys were not in operational use. In other words, aircraft were not effective detectors of submarines except with visual means such as sighting an occasional periscope or surfaced submarine, for example, and this capability suffered many obvious limitations. An airborne device to detect a submerged submarine would help the Navy combat this serious threat. An airborne magnetometer could be used against a submerged submarine. However, magnetometers or magnetic detectors known at that time were not compatible with flight environment; furthermore, they lacked sufficient sensitivity to provide useful detection range. A new magnetometer would have to be developed. The servo-positioned saturable-core magnetometer invented by V. V. Vacquier had promise and was selected for developement. A powerful force of engineering and technical talent was established under Columbia University, a WWII division of National Defense Research, and located at Mineola, New York for development of Magnetic Anomaly Detection (MAD). This group was known as the Airborne Instruments Laboratory. A smaller MAD program was supported at the Bell Laboratory.

My initial contact with MAD was during the summer of 1942 while attending the USNTS (ARM) at Corpus Christi. My next meeting with MAD was at Lakehurst during the 1942/1943 winter and the first MAD equipment I saw in airships looked like homemade ham gear. The MK-IVB-2 MAD equipment was in early production and soon replaced the experimental gear. The MK-IVB-2 had a sizeable cable-driven detecting head. However, the electronics packaging was very professional and the units were neatly racked in the airship. It used battery power for its detector/amplifier circuits and detector bias. It employed the durable Esterline-Angus recording milliammeter. The detecting head was housed under the airship's envelope about midway between the gondola and the airship's nose. Although this equipment was well-designed and well-constructed its effectiveness was marginal because of modest sensitivity and demanding detecting head maintenance. A more sensitive, smaller, and updated MAD set was needed. This requirement led to the AN/ASQ-1 system. This MAD set had completely redesigned and updated electronics, no batteries except for detector bias, and it had a small detecting head which was cable-driven at first. A gear-driven 3-axis detecting head came along after early production. The noise level of this equipment was about 0.25 gamma. Dual installations were made in airships and the CM-2 comparator was used for automatic release of flares and bombs. This equipment was produced by AIL and, later, by Altect-Lansing. Its quality was excellent.

AIL went commerical at the end of WWII and became incorporated. A government laboratory was established at Lakehurst and staffed largely by former AIL employees. Mr. James H. Stein was the director. At first it was called the Humm Laboratory but the name was changed later to the Naval Air Magnetics Laboratory. This group accomplished a lot from the end of WWII to its move to NADC in 1948. Towed MAD received a lot of attention. At one time NAML succeeded in towing two MAD detectors, working with the two detectors mounted on the airship's envelope. This arrangement produced data for Jim Stein's obsession with sum, difference, and ratio circuits. Navigation experiments began with the airborne magnetometer. Outside test sites, with nonmagnetic buildings and rocking devices, were established and numerous measurements and tests were made. Laboratory experiments were conducted to improve permalloy, annealing, and strip configurations for better detector performance. A variety of dc amplifiers were developed to convert MAD for total field measurements. Several aeromagnetic surveys were conducted. NAML teamed up with AIL, Inc. to develop the AN/ASQ-8 MAD system. This system, whether towed or installed inboard, was to have a noise level no greater than 0.1 gamma.

AIL attempted to improve the stability of servo circuitry so inflight orientation and servo gain adjustments would not be required. This attempt failed and later on controls were made available for adjustment during flight. A field site was set up to monitor geomagnetic noise. Mr. John Anderson joined the laboratory before its move to NADC. Magnetic conditions at NADC were far from ideal and NAML personnel did not want to go there. Much of the outside work done at Lakehurst could not be continued at NADC. However, most laboratory work continued at NADC like it was handled at Lakehust but, at first, the NADC laboratory facilities were rudimentary. Improved laboratory facilities were available by 1952.

The AIL designed AN/ASQ-8 MAD system was subjected to technical evaluation at NADC as towed as well as inboard equipment. One towed system was lost during an airship flight and, sometime later, another towed system was lost during a P-2 flight. Towed MAD for fleet service was questioned and, as a result, the AN/ASQ-8 was redesigned and repackaged by TII for inboard use only. However, NADC continued with towed MAD and a variey of towed housings and tow cables were experimented with. NADC hoped to circumvent the difficult and expensive task of compensating inboard MAD by the use of towed MAD. However, operational aircraft were marked for inboard MAD only. Some were sent to NADC for magnetic evaluation. A few are: PBY, P-2[*1], AD-5S and, for NADC experiments and fleet training, the R4D. A twin jet was the last one measured and that was about 1967. TII produced AN/ASQ-8 equipment mainly for the P-2, P-5, AF-3S, and S-2 airplanes and the airships.

Electronic compensators were developed by AIL and tested at NADC during the early 50's; however, passive methods were called out for operational aircraft. Maneuver noise was observed in airships equipped with the more sensitive AN/ASQ-8. Nonmagnetic suspension cables were installed in some airships and compensation was considered. The P-5 Marlin seaplane had special problems. Severe vibration at the detecting head on both the conventional enpennage model and the "T" tail model forced Martin to hard-mount the detecting heads.

Leliak advanced the AIL compensation theory for precise analysis of an aircraft's magnetic features and, eventually, the P-5's became very successful MAD airplanes. Grumman's S-2's, steadily improved by George Klaus and his group, became the Navy's best all-round MAD aircraft. Canada's CP-107 Argus arrived on the scene in the late 50's and its MAD performance was outstanding. It became more and more apparent that the magnetic cleanup and compensation required of an aircraft for increasing MAD performance standards would steadily and forever escalate in cost and difficulty. In addition, MAD compensation has to be checked and/or adjusted periodically in flight; it is a very tedious and disagreeable tase. NADC, on the other hand, favored towed MAD as a way to avoid the expense and difficulty associated with inboard MAD.

After successful demonstration of an inhouse developed towed MAD system NADC received support for contractor developed service test models. This equipment became known as the AN/ASQ-46 towed made and the contract was awarded to Dalmo Victor. Grumman was the subcontractor for aerodynamic parts of the program. After lots of difficulty and delays AN/ASQ-46 towed MAD arrived at VX-1 for operational evaluation; the outcome would be disappointing. The 50's ended with development of the Varian proton precession magnetometer as the AN/ASQ-60 towed MAD system for the DASH program, Gyrodyne's QH-50C remotely-controlled helicopters. The DASH program failed before MAD was tried in the QH-50C but it was hoped that AN/ASQ-60 towed MAD would be used in other helicopters.

Basic MAD tactics were prescribed early in WWII. To begin with, a trapping circle was executed when the submarine was suspected of being within close range of the MAD aircraft. After contact, the trapping circle was usually followed by the clover-leaf tracking pattern. Another tactic, resembling a racecourse, was to be used as a barrier ahead of a convoy or across a narrow strait such as at Gibraltar. Although these tactics were set down for MAD in WWII, MAD was more often used in a helter-skelter manner with little or no chance of success. After WWII, however, OPTEVFOR put some rhyme and reason to tactical use of MAD. Work by West at VX-1, followed up with noteworthy contributions from McKee, Kistler, Kent, Waller and Wilson, greatly improved tactical use of MAD and increased interest in its value and potential for ASW. Some MAD equipped aircraft evaluated by VX-1 and/or used in development of tactics were: Consolidated's PBY, Grummans's AF-3S and S-2 aircraft, the Douglas AD-5S, Martin's P-5's, the Lockheed P-2's, P-3's and S-3's, and the Kaman H-2 and Sikorsky H-3 helicopters. LTA had ZX-11 for a similar mission with airships and these were: the WWII K class; the post-war updated K class, the ZP4K (afterwards ZSG-4); the ZP5K class (afterwards ZS2G-1); and MAD equipped N class airships. When thinking of LTA memories of Verberg's enthusiasm and leadership are still vivid. Many WWII equipment contractors provided field services. For example, AIL's Daniel Humm led MAD field services for LTA while stationed at Lakehurst. He died in a WWII airplane accident and the MAD laboratory at Lakehurst was named after him but later changed to Naval Air Magnetics Laboratory. There were many engineers and technicians trained and organized for field services during WWII. After it ended some formed the nucleus of the Naval Air Electronics Service Unit. Instruction of fleet personnel and technical guidance at the maintenance level were their principal functions. The NAESU Digest, published periodically, was very helpful to fleet tecnicians. NAESU feedback to developmental and equipment production activities substantially helped improve MAD maintenance and performance. Some NAESI men who specialized in MAD were: Davidson, Graham, Brewer, McDaniels, and TII's Lawson.

There were above 30 people working on MAD at NAML and after its move to the NADC in 1948 the group was reduced to about 18. It built up some during the Korean War then dwindled to 3 or 4 part-time workers by the time of the Project Sorrento meeting in 1959 where interest kindled in Varian's work with alkali-metal vapor magnetometers. With impetus from this memorable meeting the Bureau gave support to NADC for development of an optically-pumped magnetometer which was to be towed by fixed-wing aircraft. This was to be known as AN/ASQ-81 MAD with sensitivity of 0.01 gamma. The NADC MAD group ballooned to about 20 people. With advice from Dr. Bleil of NOL and his group metasable helium was favored over alkali-matal vapor and TII, advocating helium, was awarded the contract. About the time the first AN/ASQ-81 equipment was ready for tests at NADC bad news came from VX-1 about AN/ASQ-46 failures and it was eventually rejected. The Bureau lost its interest in towed MAD except as a last resort for helicopters. The DASH program was dying the its AN/ASQ-60 towed MAD, undergoing tests at NADC on a H-3 helicopter, was in trouble. Maneuver noise, temperature, and duty-cycle interruption of data flow were the main AN/ASQ-60 problems. Because inboard MAD did not look promising for helicopters, AN/ASQ-10 MAD with a S-2 boom were tried, towed MAD appeared as the only resort.

AN/ASQ-81 developmental effort quickly changed from towed MAD for fixed-wing aircraft to towed MAD for rotary-wing aircraft. During this time period Lockheed prepared the P-3 for AN/ASQ-10 MAD. A problem similar to the detecting head predicament associated with the P-5 seaplane confronted Lockheed and their solution was to hard-mount detecting heads in the P-3 aircraft. Another problem was the close proximity of the aft radar antenna. Compensation maneuvers were difficult to do manually with P-3's so Lockheed provided an electronic manuever programmer, Grumman perfected magnetic cleanup and compensation of their S-2's and improved the tail boom design. These airplanes were the criterion for MAD excellence.

Signal processing for MAD, also stimulated by Project Sorrento, started in the early 60's with a study program at TII. A disturbing amount of vacillation followed this study, but, eventually, a program was set up at RCA for development of MAD signal processing using feature recognition technique. In the meantime, Lockheed made a signal marker, known as MADAM, to improve operator efficiency. NADC developed its own signal marker, the AN/ASA-64, which had some use in P-3's. RCA's Feature Recognition Processor (FRP) suffered funding loss and was dropped about the year 1968. Aside from data collection and some in-house experimentation by NADC no significant amount of contract MAD signal processing work was done, aside from CDC's studies, until LAMPS and S-3A programs came along. NADC decided to abandon the FRP concept and go for Anderson function abstraction with use of digital technique.

Magnetic compensation, passive in all MAD-equipped aircraft, was looked at in different light with CAE's active compensators were examined by the Navy. Active compensation began with a servo-controlled system for perm compensation only. More sophisticated compensators quickly followed and by the mid-60's automatic control of all 16 terms appeared to be feasible. However for simplicity a 9 term compensator was considered adequate at that time. This led to the CAE development of the AN/ASA-65. This compensator and the AN/ASQ-81 helium magnetometer, installed in the P-3 were evaluation by VX-1. The desire for automatic 16 term compensation lingered, however, and this was accomplished in the 70's.

The AN/ASQ-81 had plenty of trouble during the evaluation by VX-1. Amplifier overloading when the system was operated in areas of severe magnetic gradients caused a great deal of concern and corrective action was required. RF radiation by the detecting head assembly became another distressing characteristic of this magnetometer. The AN/ASQ-81 program was not without plenty of critics and skeptics. The program was almost lost; nevertheless, production was arranged for inboard models of AN/ASQ-81 for P-3's and a towed version for LAMPS, initially the H-2 helicopter. The perseverance and ability of NADC's Gasser and TII's Beckmann made a success of the AN/ASQ-81. Yannuzzi's work with helicopters added measurably to the success of this program. Wilson, at VX-1, saved the AN/ASQ-81 with his positive attitude and his unyielding desire to improve the Navy's MAD capability. Schneider led NADC's MAD signal processing program from the doldrums and made a viable program of it.

Land target MAD dates back to WWII when AIL gave it some consideration; however, little was done about it. During the early 50's NADC conducted tests for the USAF with an AN/AQS-8 equipped B-25. The AN/ASQ-8 bandpass was modified and a special amplifier was included for detection of 60 HZ power sources. From the early 50's to the mid-60's land target MAD was virtually dead but resumed after NADC's 1965 MAD symposium, again, with support from the Air Force. This was called Project Egad and involved an NADC S-2 airplane equipped with a Varian cesium magnetometer. A variety of signal and background data amassed. Both NADC and the Air Force analyzed the data with, in mind, the possible use of land target MAD in Vietnam in May 1970 and remained there through most of the summer. Ft. Belvior sent a Bell helicopter equipped with a dual boom arrangement of Varian cesium vapor magnetometers. The MAD results in Vietnam were mixed and the opinions were mixed but NADC contended that the towed MAD was promising in Vietnam and its effectiveness could be substantially increased with some obvious improvements. In the spring of 1973, with NADC working with NCSC, at LAMPS H-2, equipped with an AN/ASQ-81 towed MAD, was used to detect mines and check backgound noise in the Haiphong harbor area.

It was in the early 50's when Lee Godby, representing Canada, visited NADC for information on MAD installations. Then Canada installed AN/ASQ-8 MAD in a few carrier-based airplanes. Later, the National Aeronautical Establishment (NAE), under Canada's National Research Council, made a fine magnetics laboratory and field test site near the Ottawa airport. They made many contributions to magnetometry as well as improvements to MAD installations and compensation. NAE collected a great amount of flight data that attributed much to the understanding of MAD performance and/or noise problems in flight. Canadair Ltd. built the Argus and assistance was provided by NADC and NAE. The Argus became the best MAD airplane of its time. The Canadair MAD group moved to CAE where they continued MAD work, particularly in the area of compensation. Their compensators, the AN/ASA-65 for example, opened new horizons for inboard MAD. In addition, CAE developed and produced an optically-pumped magnetometer system. Their IDM system can reduce the effects of aircraft maneuvers to a level never thought possible by most oldtimers. Canada supported facilities for recording geomagnetic noise and made extensive study of wave noise phenomenon.

France has been a major contributor to magnetics. Kastler's work with optical pumping was paramount. France produced Breguet Atlantic aircraft for NATO that were equipped with CSF cesium vapor magnetometers. After NADC's 1965 MAD symposium Lockheed made contact with CENG concerning their nuclear magnetic resonance magnetometer and self-adjusting compensation system. Eventually, an experimental CENG system was demonstrated in a P-3 at Burbank. An improved system, installed in a Breguet Atlantic, was demonstrated to a NATO group at Nordholz during the late summer of 1970. This demonstration was moderately successful and some interest was generated, particularly in the compensation. Magnetometer noise was as low as 0.01 gamma and the FOM of self-adjusting compensation was 2.2 without eddy current origin. Most of the residue was thought to be of eddy current origin. They observed a FOM at Niemes with only partial eddy current compensation. In addition, France developed towed MAD for helicopters.

During most of my career in MAD the United Kingdom has had MAD simmering on the back burner. However, during that time they expressed interest in MAD for some Shackleton and Nimrod airplanes and considered towed MAD helicopters. At Bascomb Down, in 1970, I saw a well-engineered installation of AN/ASQ-10 MAD and the AN/ASA-65 compensator in a Nimrod.

The 70's introduced a new era. AN/ASQ-81 towed MAD was in production for H-2 and H-3 helicopters. Lockheed was working on a new MAD suit for P-3's which consisted of: AN/ASQ-81 MAD gear, the AN/ASA-64 signal marker, AN/ASA-65 compensator, RO-32 recorder, and a maneuver programmer. During the 70's additional improvements were developed and provided for P-3's. These included a display system and a very sophisticated and effective compensation system. TI and CAE were alternately involved in this effort. A lot of effort went into the MAD installation design for the S-3A Viking. After much disagreement over the tail boom design and compensation, aside for an attempt to dump the AN/ASQ-81 for the CAE magnetometer, the program eventually got underway. Even towed MAD was considered for the S-3A. Univac would work out some signal processing for MAD in the S-3A. Later, they received a contract to develop MAD signal processing for LAMPS helicopters. Interest increased in the potential of superconducting sensors and NCSC put together a strong group to work in this field of technology.

It is not proper to end this review without mention of the Washington D.C.

support MAD had throughout these many years because without that support there could not have been a viable program. It used to be the Bureau of Aeronautics and, after WWII, George Miller was their first MAD officer. He was followed by: Tom Faulders, Art Frost, Roy Whalen, Scotty Umbarger, Bill Mott, Ray Miller, Larry Berkeley, Dave Siegel, Tom Kline and, presently, Bob Smith. Furthermore, it is important to note that Swede Holstrom's influence was felt throughout most of those many years. In the meantime, BUAER was changed to Bureau of Naval Weapons (BUWEPS) and finally, after extensive re-organization, to Naval Air Systems Command (NAVAIR).

This completes my review of MAD. Only major highlights have been covered. There was much more to the MAD program and I would welcome the opportunity to present additional events sometime in the future. I took calculated risk when mentioning names of people because, surely, I would inadvertently overlook someone who should be mentioned along with the others. However, in closing I will take additional risk and mention some more. Ray Schneider led NADC's signal processing program from the doldrums and made a viable program of it. Andy Ochadlick and Ray's letters have kept my interest in MAD alive since my retirement from NADC in 1973. So have the letters received from George Klaus. ORI interest in me, particularly Paul Hallowell and Ernie Holmboe, has been a major morale factor and I cannot find adequate words to express my thanks. Finally, I thank the Society of madmen, especially Robert Smith, and the U.S. Navy for allowing me to participate in this symposium.

Copies of Mr. Bender's charts are avialable from the Society. Please send request to

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TWO TRAINING DEVICES FOR MAD AIRCREWS

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The Expendable Mobile ASW Training Target (EMATT) for training aircraft or ship crews has been in engineering development by industry since early 1982. A second training device has been proposed to help introduce EMATT to the fleet and provide signals for on-deck stimulation of aircraft MAD systems. The technology for the EMATT was developed at the Applied Physics Laboratory and transferred to industry. EMATT provides signals for passive and all active sonars and magnetic signals for magnetic anomaly detection systems. The target will weigh 20 lb, will be air launchable from Sonabuoy tubes, and will run for 3 hours at 10 knots providing MAD signals for 1 hour.

The document "MAD Simulation Technology for an Expendable ASW Target" (APL-UW 7826, Applied Physics Laboratory, University of Washington, February 1979) describes most of APL's effort in this area. A key problem for a small target is simulating a submarine magnetically with very limited material resources. This problem is solved by sending current down a towed wire with return through the ocean. Pulses rather than continuous current are used. The compatability of existing MAD systems with pulsed signals and the pulse durations necessary were determined by direct field tests. For the MAD bandwidth of 2 Hz, the expected rise time of 0.25 second was observed, thus establishing the minimum pulse duration.

Consultants from the MAD community suggest a minimum field strength of 0.12 gamma at 1500-foot range. Various wire lengths vs peak currents are considered. A 100-foot, number 22 wire requires 16 amperes to meet the specification and provides a good balance between drag and drive power.

Pulse intervals as long as 2.5 seconds are shown to be tolerable even for fixed wing aircraft yielding a duty cycle of about 0.25/2.5 = 0.1. At a speed of 10 knots, the total MAD power needed is about 100 watts.

A demonstration test of a pulsed-wire simulation was carried out in a magnetically "quiet" area near San Diego, using a standard ASW helicopter to probe the field of a 100-foot submerged wire. The test plan and results are presented and discussed. Both pulses and direct current were used on North and West magnetic headings. Figure 1 shows the aircraft flight patterns and navigational aids (the wire is under the red float) and the results on a North heading as recorded by the MAD operator. The test results were well within expectations both qualitatively and quantitatively. The wire current was monitored on the boat, and the helicopter's speed was held constant so that range estimates were possible. The results show that the envelope of the pulses is like the signal of a real target and that pulses are readily detected. Detection ranges were 1400 feet perpendicular to the wire and 900 feet directly aft.

Noise effects on MAD, in particular geological noise sources, are considered. Earlier targets designed for use on underwater ranges were severely affected by local noise. NORDA has proposed add-on airborne filters to reduce this noise problem. Noise maps, called MAD Operational Effectiveness (MOE) charts can be useful in planning target exercises. From published (1979) MOE charts, we estimated that EMATT will be usable over 95% of the deep ocean.

For our pulse-compatability field tests, several signal sources were developed. These signal generators used wire loops placed under the aircraft's MAD boom or bird. The simplicity and accuracy of this signal-injection method suggested a more powerful signal simulator that could be used for training or system testing. The simulator would be self-contained and battery operated. Placed under the sensor, it would generate noise, typical submarine signals, and EMATT-like signals at various signal-to-noise ratios and at random intervals.

In our observations at the Naval Air Station at Moffett Field and in hangars at the Naval Air Station at North Island, ambient mangetic noise seldom exceeded 1 gamma peak to peak. We would expect the situation would be no worse on ship flight decks or hangar decks. Hence, such a simulator would not need excessive power.

Using this simulator, MAD operators could practice identifying signals in noise, observe the effects of filters, and become familiar with EMATT signals. Thus the simulator would help to introduce the EMATT to fleet users and provide training opportunities in the aircraft environment but on the deck, at very modest cost. A prototype unit is under development.

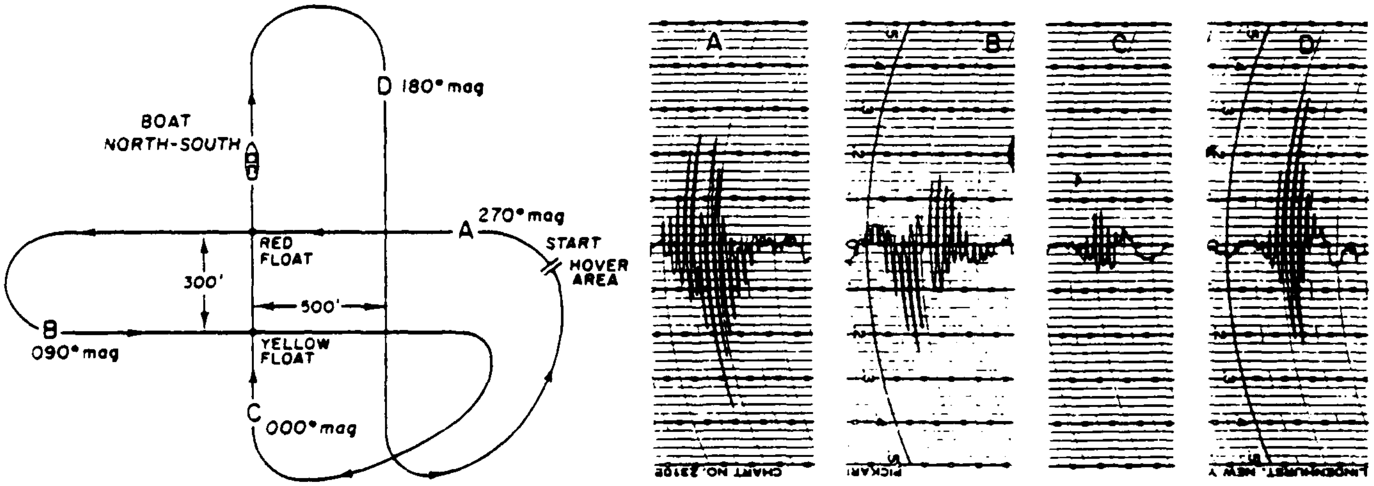

Figure 1. Flight pattern and results recorded on North heading.

A THEORETICAL NOISE MODEL FOR THE FRAHM INVERSE

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The Frahm Inverse has been the traditional method for localizing magnetic dipoles. However, an understanding of how the Inverse behaves in the presence of random noise has been limited by the lack of a theoretical noise model. This presentation describes the derivation of such a model and its application to the prediction of localizer performance.

Our method is a small-perturbation (i.e., first-order) analysis which turns out to have great validity even in regimes where noise levels are not low. As is well known, the Frahm Inverse allows one to deduce from the magnetic field gradient matrix G, the unit pointing vector $\hat{r}$ and the composite gradient or Frahm moment $\vec{M} = 3\,\vec{m}/r^4$ where $\vec{m}$ is the dipole moment vector and r is slant range to target. Suppose that a small perturbation G + dG is added to G, where dG (like G) is a symmetric, traceless matrix. Then there are perturbations $\hat{r} + d\hat{r}$, $\vec{M} + d\vec{M}$ in the two Frahm output vectors. Formulas for $d\hat{r}$ and $d\vec{M}$ as (linear) functions of dG are derived. A simplified derivation of the Frahm Inverse based on eigenanalysis makes this derivation possible.

The perturbation formulas are then applied to dipole localizers operating in random noise. If $\vec{e}$ is the position vector of the dipole as estimated by the localizer from a gradient G + dG, then the localizer is called *linear* if $\vec{e}$ has the form

$$\vec{e} = X d\hat{r} + Y(d\hat{r})\hat{r}$$

where Y is a linear function of $d\hat{r}$. For a linear localizer it is shown that if σ^2 is the variance of the estimated position $\vec{e}$ of the localizer, then

$$\sigma^2 = \vec{x}\,\Phi\,\vec{x}^T + \vec{y}\,\Phi\,\vec{y}^T$$

where Φ is the (5x5) continuous-time correlation matrix of the stationary noise process dG, and where $\vec{x}$ and $\vec{y}$ are linearly independent **5**-vectors uniquely associated to the localizer type.

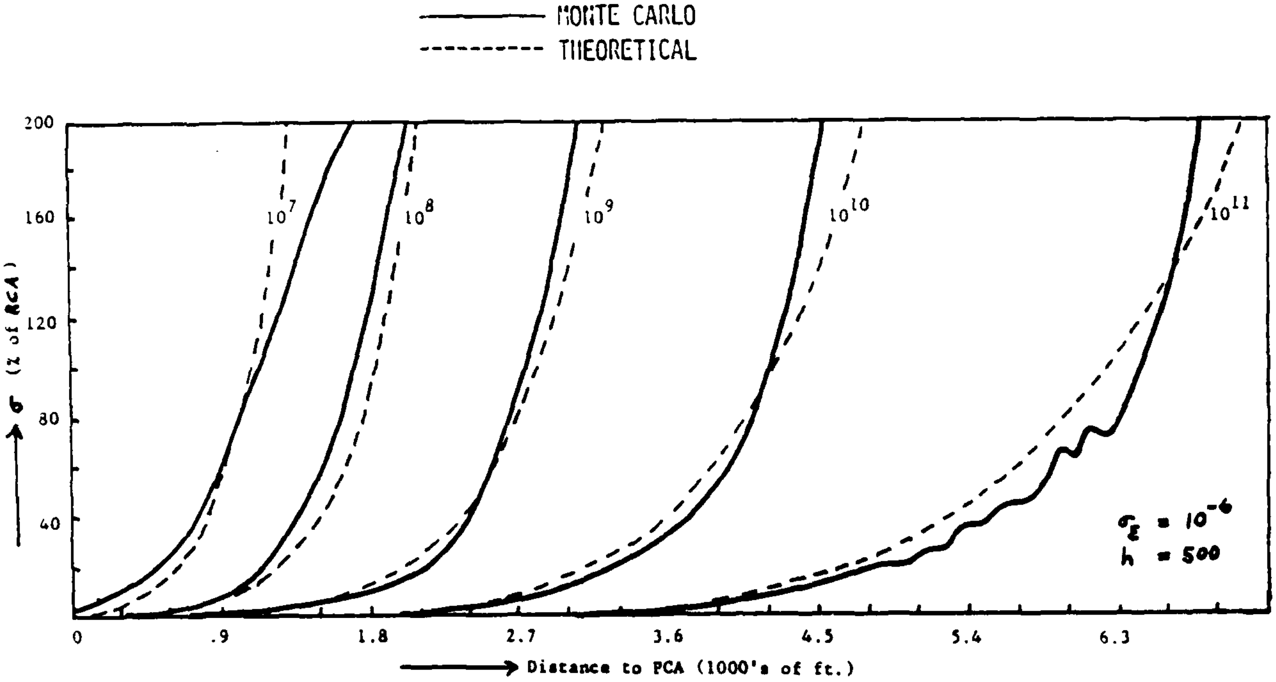
The above formula is applied to two ideal localizer types: the Perpendicular Projecting Localizer (PPL), in which the pointing vector r is projected onto a perpendicular plane containing the dipole, and the Horizontal Projecting Localizer (HPL), in which r is projected onto a horizontal plane containing the dipole. If dG is assumed to be white with continuous-time variance σ_{ε}^2, and if σ_P^2, σ_H^2 are respectively the localization error variances of the PPL and HPL, then formulas for σ_P and σ_H are derived. In particular, these formulas show that σ is a piecewise linear function of r when plotted on log-log paper. Approximately

$$\sigma_p \approx K r^5 \sigma_\varepsilon / m$$

$$\sigma_H \approx K' r^6 \sigma_\varepsilon / hm$$

where h is altitude and K, K' are constants. (Actually, K is a slowly-varying function of $\hat{r}\cdot\hat{m}$ and K' is a slowly-varying function of $\hat{r}\cdot\hat{m}$, h and $\hat{m}$).

It was possible to test the validity of the exact formulas for σ_p and σ_H by comparing them with performance curves (plots of σ vs r) generated by Monte-carlo simulation of actual localizer algorithms. The theoretical and empirical curves are in close agreement, provided that a scaling factor of $\sqrt{2}$ is included in the formula for σ_H. (since the HPL localizer is not actually linear, a linearized version of it was used for the theoretical derivation, and this accounts for the discrepancy). The figure shows a comparison of theoretical and empirical performance curves for the HPL, for several moments (moment direction is vertical, and horizontal offset = h = 500 ft). These results have several implications: first, that the effect of noise on localizer performance may be analytically predicted by developing models for noise processes, calculating their correlation matrices and then applying the model; second, that localizers may be simulated accurately by simple equations; thirdly that expensive localizers may be simulated using cheaper localizers and a suitable scaling factor. For further details about the Frahm gradient-inversion method, see IEEE MAG-11 #2 March 1975 pg. 701.



POWER SPECTRAL ANALYSIS OF MAD COMPENSATION SYSTEMS

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Since the development of airborne MAD, maneuver noise has been the primary noise source which has limited the operation of inboard magnetometer systems. Present fleet compensation systems detect and reduce maneuver noise by a flight process called compensation. Compensation equipments, which have been designed to utilize data generated by dedicated maneuvers are based on the Tolles and Lawson model. This model assumes that aircraft associated fields can be defined by 16 magnetic parameters. The S-3 and P-3 aircrafts compensate for only the 9 most significant parameters by use of the AN/ASA-65 compensator system.

During 1980 the NAVAIRDEVCEN conducted a series of flight tests in an effort to evaluate two advanced compensator sysytems; namely, the Compensator Group Adapter (CGA) system from CAE Electronics and the Integrated Digital Magnetometer (IDM) from Texas Instruments, Inc. Although these systems are similar in that they are both based on the Tolles and Lawson model, they are significantly different in that one is an active system while the other is a passive system. The CGA, which is part of the active AN/ASA-65 system, was designed to determine quickly gain coefficients for field coils housed in the tail of the aircraft. In contrast, the IDM is a passive system which mathematically removes aircraft induced noise by use of a microprocessor algorithm.

In the past, magnetometer systems and compensator systems have been evaluated by another flight maneuver process titled Figure-of-Merit (FOM). Results of the maneuver process produced a single number by which overall system performance was judged. Although the FOM is quite acceptable for fleet use, this technique seems primitive for evaluating new systems. In addition, FOM maneuvers are performed at two discrete frequencies while submarine signatures produced by various aircraft/submarine encounter geometries can exist over a spectrum of frequencies.

Fortunately, NADC has a sophisticated digital MAD data collection system aboard one of its P-3C's which enables data collection for wideband spectral analysis. A flight test was conducted in attempt to gather actual magnetic flight data for the CGA and the IDM which would contain a spectrum of known maneuver frequencies so that compensated output signals could be compared. The approach for generating broadband frequency signals for the analysis was to have the aircraft execute random roll maneuvers on each of four cardinal headings. Data from the aircraft roll, pitch and yaw inertially derived signals along with simultaneously collected magnetic signals have been spectrally analyzed and compared.

Results of the analysis show that although these systems significantly reduce compensation time; neither one fully solves the compensation problem. A more detailed examination of the data shows a large amount of magnetic signal at the frequency of the random roll frequency, even after both systems obtained good

FOM measurements (0.75 for the CGA and 0.5 for the IDM). There are several possible explanations for these results: the Tolles and Lawson equations do not adequately describe the aircraft's magnetic state, the magnetic state of the aircraft significantly changed after compensation, or eddy currents are frequency sensitive and not constant as the model assumes. In any case, an effort is required to understand better the limitations of existing systems in order to determine whether compensation is model or equipment limited.

Reference

Swyers, R., "Power Spectral Analysis of MAD Compensation", NADC-81269-30 (To be Released) (Unclassified).

REPRESENTATIVE MAGNETIC GEOLOGY FROM DISTINCTIVE STRUCTURAL REGIONS

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Introduction

Magnetic anomalies caused by magnitized material within the earth's crust will often mask the signature caused by an ASW target. A program to investigate and reduce these geologic anomalies is underway at the Navy Air Development Center (NADC). It is well known, that the reduction of geological magnetics as it pertains to MAD is a complex and difficult problem. The solution is to enhance the distinguishing characteristics that are unique to the submarine signature and diminish those of the geologic source. Traditionally, this has been accomplished through the use of a bandpass filter. The low frequency cutoff point is optimally set to attenuate both the long wavelengths generated by an extensive magnetic source and the regional earth's field gradient as the aircraft passes through these static magnetic fields. The submarine, being smaller and closer, produces a much shorter wavelength anomaly. Consequently, it suffers less attenuation through the MAD filter since its signal is higher in frequency.

Problems occur when the geologic anomaly is so large that, in spite of the 48 dB/octave attenuation of the AN/ASQ-81 filter, the target signal remains obscured. For the past 38 years, this approach to the detection of targets in MAD has remained unchanged. However, confusion exists among fleet operators regarding the correct adjustments of the MAD filter and sensitivity controls to optimize a MAD contact.

Approach to Reduction of Geological Magnetics

The scientific community has been interested primarily in geologic processes of crustal development and the exploration for oil and minerals. The magnetic fields relevant to such problems are studied with data lacking the sensitivities of current MAD. What we needed was high resolution, high density survey data that would be useful for algorithm development and testing.

During the summer of 1981 we conducted a series of aeromagnetic measurements to acquire the geology data necessary for algorithm development. Oceanic regions of distinctive geologic structure were investigated using specialized survey patterns. We believe this data sample provides representative examples of five sources of magnetic geology.

The data was collected aboard a Naval P-3C aircraft equipped with three ASQ-81 sensors; one in the tail and two towed from the wings. This configuration provides for the first time the measurement of longitudinal, vertical and transverse total field gradients at the resolution and data rates of MAD.

Our approach is based on the belief that to effectively reduce the magnetic geologic anomaly requires an understanding of the geologic structure of the material within the earth's crust. It seems reasonable to summarize all magnetic geologic anomalies as naturally occuring from one of the following geologic sources (reference (1)).

1. Magnetic lineations
2. Topographic features
3. Shallow basement influences
4. Coastal sedimentary effects
5. Magnetic quiet zones

Consequently from this view, the magnetic anomalies are further classified according to the geologic parameters that characterize their physical structure. Some examples of important geologic parameters are: the size, shape, direction of magnetization, magnetic susceptibility of the source material, and the depth to the source. These several parameters are often generally-related to the overall oceanic province, and therefore a complete description and classification of the geologic anomaly is possible. The advantages of classifying magnetic geology according to its physical structure provides the physics for linking the observed geologic anomaly with the fundamental geologic parameters by means of a mathematic model.

With an understanding of the structural geology, one can often choose a simple geometric shape that is an idealized abstraction of the actual formation of the magnetic material within the earth's crust. The model is compared to actual magnetic noise for the region. With proper adjustment, the geologic parameters are identifiable. This is precisely a technique utilized in geophysics for prospecting of oil and minerals. Thus, for a particular data set, an accurate model is made, permitting variation of the tactical encounter geometry and the inclusion of real or simulated target signals. This provides an important advantage for any signal processing and detection scheme because at least one type of all possible sources of MAD noise, namely, geologic noise, is well characterized. Additionally, after the model has been validated a wide range of geologic anomalies, characterized by different parameters can be simulated.

Data Analysis

To clarify some of these concepts an example is presented using some magnetic lineations data from the JUAN DE FUCA RIDGE in the North Pacific, west of Seattle. Early results in the form of time series plots through MAD filters with different bandpass settings are presented along with associated power spectral density plots for this geologic region.

A model of these magnetic lineations has been developed by geologists to prove that sea floor spreading theory associated with the study of plate tectonics. The magnetic anomalies are modeled, as originating from large blocks of magnetic materials paralleling the ridge axis, or spreading center. From analysis of the data the determination of source size is possible. With additional geologic information an accurate simulation of the magnetic anomaly is then developed and refined by iteration. Summing up individual anomalies in the correct sequence provides a reasonable simulation to the magnetic lineations along the flight path.

1. (C) "Magnetic Anomalies of Geologic Origin (U), "P. R. Vogt, et al, in MAD Symposium, NOLTR 72-49, Naval Ordance Laboratory, 1 Mar 1972, p. 113.

AEROMAGNETICS RESEARCH ACTIVITIES AT THE NAE

by

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1.0 Introduction

This paper describes various research activities that are taking place at the Flight Research Laboratory of the NAE in the area of aeromagnetics with possible applications to MAD. The work discussed here covers digital compensation techniques for MAD including gradient compensation, the acquisition and compensation of wide-band MAD data for gradiometer configurations, and the use of a high resolution non-orienting total field sensor on the Convair 580 research aircraft.

2.0 Automatic Aeromagnetic Compensation

For some ten years now, NAE has been developing digital methods of compensating the MAD signal for both aircraft and gradient magnetic interference effects (Ref. 1). Aircraft interference compensation has been considered as basically a problem of linear least-squares regression analysis. Multicollinearities or near-linear dependencies have been found in the 18-term aeromagnetic interference model under certain conditions, and an advanced regression technique known as ridge regression has been used to improve the predictive power of the aircraft interference model in these cases. In general, use of the ridge regression technique ensures that the solutions for the aeromagnetic interference coefficients are always stable and meaningful regardless of the conditions under which the FOM manoeuvre data is acquired. Application of a simple 3-term magnetic gradient model is demonstrated to provide additional improvements in the calculation of the correct aircraft interference coefficients. Techniques have been developed at NAE for mapping an assumed near-constant 3-component gradient in any area, and even a slowly changing horizontal gradient can be tracked using these methods. Implementation considerations for the inflight calculation of the aircraft interference coefficients in 'pseudo real time' are addressed, and the subsequent real-time digital compensation of the MAD signals is discussed (Ref. 2).

3.0 Convair Gradiometer Configurations

The horizontal and vertical gradiometer configurations on the NAE Convair 580 (i.e. a magnetometer in each wingtip and one in the tail) are described, and methods of compensating these gradiometer modes are shown to be very similar to those used for the individual magnetometers themselves. The acquisition and compensation of a high resolution (i.e. 0.3 mγ/meter) gradiometer signal with a wide-band frequency response (i.e. 0 → 1 Hz) is discussed (Ref. 3). This type of signal is of much interest to the geophysicists, but may also have potential for MAD work as well. It is shown that total field magnetometers used in a gradiometer configuration can be compensated right down to 0 Hz with very significant reductions in the aircraft manoeuvre interference - the degree of motion interference suppression is generally greater than for the more usual band-pass filtered MAD signal. Compensation coefficients calculated from band-pass filtered gradiometer manoeuvre data are shown to cause significant low frequency and 'DC level' distortion when used for wide-band gradiometer compensation. It is therefore important to filter the manoeuvre data used for computing the compensation coefficients in the same way that the MAD gradiometer signal of interest is filtered in order to optimize the compensation for a given bandwidth.

4.0 A High Resolution Airborne Non-Orienting Magnetometer

Most MAD development at NAE has been carried out using CAE ASQ-501 self-orienting cesium magnetometers. However, size and weight constraints related to locating a total field magnetometer in the tail of the Convair were met by the use of a much smaller strapdown (i.e. non-orienting) Varian VIW-2321A2 single-cell cesium sensor having a heading error of ±.5γ over its 65° active zone. There was considerable concern about the possible interference effects from this heading error during aircraft manoeuvres; but it was found that the normal aircraft interference compensation algorithms could account for these orientation error effects even in the wide-band signal mode extending down to 0 Hz. To date, this sensor has been flown over the flight envelope of the Convair for magnetic dip angles from 90° down to 29° and the results appear quite comparable to those obtained using self-orienting magnetometers.

5.0 References

1.	Leach, B.W.	Automatic Aeromagnetic Compensation. National Research Council, NAE Technical Report LTR-FR-69, March 1979.
2.	Jordan, J.E.	The NAE Software Aeromagnetic Compensation System. National Research Council, NAE Technical Report LTR-FR-78, December 1980.
3.	Hardwick, C.D.	NAE Convair 580 Aeromagnetic Program. National Research Council, DME/NAE Quarterly Bulletin No. 1979(4).

FIXED WING TRIALS OF THE ACO MAD SIGNAL PROCESSOR

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1. Introduction

In 1977 a research study was begun to investigate methods of improving the clartiy of the operator display of MAD equipment with a possible increase in the probability of detection and of providing an anomaly recognition system to automatically alert an operator.

A study contract was placed with Cambridge Consultants Ltd in 1978 and this was followed by a contract to produce a flyable system in 1979. Flight trials have now taken place and both in-flight an post-flight analysis has been carried out.

This paper outlines details of the equipment and summarizes the results obtained.

2. System Configuration

The equipment was designed to operate with any of the current commercial magnetometers providing an unfiltered MAD output. The existing NIMROD AN/ASQ-10A fluxgate magnetometer used in the trial required a suitable internal connection to be made via a simple interface unit which provided gain and minimal filtering of the MAD signal. For the flight trials, codenamed DULCIMER, the inputs and outputs of the processor were recorded on 1" wide intermediate band magnetic tape to allow more thorough post-flight analysis to be carried out. Additionally, a keyboard/printer unit allowed operating commands to be issued to, and data to be received from the Texas TW990 micro-computer contained within the processor unit. A six channel paper chart recorder was also provided.

3. System Operation

The minimally filtered MAD signal (historically called "pre-HTA") has a number of operations carried out on it in parallel. These operations provide the following outputs:

3.1 Improved Operator Trace (IOP)

This is a version of the conventional AN/ASQ-10A bandpass filtered output but with filter parameters chosen to compensate for the amount of noise present at the time. Selection of the desired lower cut off frequency options can either be controlled by the operator or it can be automatic: the automated selection is performed by comparing the estimated runs input signal (at the pre-HTA input) with fixed thresholds. The upper cut-off frequency is fixed at 1.1 Hz.

3.2 Prewhitened Signal (PW)

Prewhitening of the pre-HTA input is performed by using a 2nd order non-recursive digital filter. The coefficient values for this filter are determined by Maximum Entropy Analysis of sample sections of background noise (40 samples in 9 seconds) gathered during the sortie. The MEM processing takes some 20 seconds after which time the filter coefficients are updated and printed out on the console. Noise data collection is continued until stopped by the operator. The prewhitened signal is displayed as an operator trace.

3.3 Prewhiten and Threshold Detectors (PAT)

The prewhitened output referred to above is full wave rectified (ie. the modules is taken) and then thresholded. This is then fed through an automstic gain control which causes the output to display prewhitened signals from values equal to the threshold level up to twice the threshold level before clipping, thus alerting the operator to a possible detection.

3.4 Range Gated Matched Filter Detector (RGMF)

Each range gate contains three matched filters which are designed to respond to the Anderson Functions 1, 2 & 3 cooresponding to a target at a given range at CPA.

The input to the RGMF system is the prewhitened signal output from the prewhitening filter. The values of the coefficients k_1 -k_1 in each matched filter correspond exactly to samples of the signal (in the time domain) which it is intended to detect, in reverse order. If the prewhitening filter was not needed then these signals would be the Anderson Functions themselves. However, because the prewhitening filter is included (to make the background noise white for correct operation of the matched filter) not only the noise but the target signals are modified by the prewhitening filter and the coefficients of the matched filters therefore correspond to Anderson Functions which have been passed through the prewhitening filter.

First the noise data vector is collected and analysed by the MEM precedure. The outputs from this are then used to update the prewhitening filter coefficients and the estimate of the rms value of the whitened noise. Each Anderson Function in turn is generated and passed through a duplicate prewhitening filter (ie not the "real prewhitening filter which is being used continuously to process the actual input samples); the outputs from this filter are the desired matched filter coefficients. The mean square values of the coefficients for each matched filter are computed and the required scale factors and correction filters are stored. Finally the appropriately scaled matched filter coefficients are stored in the matched filters, which are then ready to run.

The form of the output signal is as follows:

A positive deflection (to the right on the chart recorder) proportional to the degree of confidence in the detection, followed by a deflection to the left indicating the range gate concerned.

4. Trials Performed

Two individual series of trials have been carried out using in-service NIMROD LRMP aircraft.

DULCIMER Pt I consisted of a series of clover leaf flights at ascending heights over submarines either on the surface, or at preiscope depth with their masts exposed. The trial was performed to provide a data base of typical anomaly signals obtained under various conditions.

DULCIMER Pt II consisted of MAD trapping circles at aircraft heights of between 200ft and 2600ft, the submarines being on the surface. On each occasion, the runs started with a significant period prior to the first "on top" to allow noise data to be gathered in the absence of the target. When required this period was used to update the parmeters of the processor.

5. Results

DULCIMER Pt II was the trial dedicated to providing an assessment of the ACO processor and the results presented in this report are based on this exercise. Because of reduced visibility caused by bad weather, the E. Atlantic trials provided few meaningful results since, with sea level visibility restricted to 1 Km and a cloud base of 1000ft, "on top" passes were exceedingly difficult to achieve on the day of the trial.

For these reasons, results for DULCIMER Pt II are restricted to the Mediterranean activities where clear skies and good wheather provided ideal trials conditions.

It should be noted that, in order to maintain visual contact with the submarine, the aircraft altitude was increassed in steps so as to reduce the signature of the target. Under these conditions, this would lead to a reduction in the geological/wave noise in the operating area.

The response time of the magnetometer system is virtually instantaneous, the anomaly indication being shown as the aircraft flies over the magnetic change. Both the PAT and the RGMF systems, however, introduce a processing delay of approximately five seconds, prior to the operator alert being given. For an operational system, such a delay would need to be programmed into the tactical computer to provide positional information to allow accurate revisits.

The performance of the IOP system did not improve the operator's ability to detect longer range MAD marks. Improved performance could perhaps have been obtained by altering the bandwidths of the IOP filters relative to the spectrum of the background noise, rather than simply its amplitude.

6. Conclusions

The PAT and RGMF systems have been shown to provide useful operator alert functions for the data gathered during trial DULCIMER Pt II. By combining the detection capabilities of the PAT and RGMF sub-systems, detection performance comparable to that of a dedicated operator could be obtained. The algorithms are equally applicable to rotary wing operation, where the absence of a dedicated MAD operator makes such an alert system more desirable.

MAD SIGNAL PROCESSING: MAN VERSUS MACHINE

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Background - MAD signal processing in various forms has been under development since the mid-1960's. This author is personally familiar with six signal processing efforts, each fairly successful: (a) RCA-Feature Recognition Signal Processor (1964-1969); (b) Computing Devices of Canada-Matched Filter Processor 1966-1970); (c) Texas Instruments-Anderson Function Fitting Processor (1968-1972); (d) Sperry Univac-Feature Recognition Processor (1966-1970); (e) Sperry Univac-LAMPS MAD Signal Processor (1970-1978); (f) Naval Air Development Center-MADTACS (1972-1981...). Except for (d), which is implemented in the S-3A aircraft, none of these processors has reached the fleet. In the later stages of MAD signal processor development it has become traditional to expect aircraft program managers to ask the question - "How does this MAD processor thing compare in performance to what I already have?" The development community has traditionally done a poor job in answering this question-frankly, because it isn't an easy question. Sperry Univac and IBM, in their roles as signal processor developer and system prime contractor for the LAMPS Mark III program respectively, sought to answer this question in the late 1970's. Sperry Univac developed an operator training/test capability which was used to explore human MAD detection performance in a static fashion. The results of this testing contributed to the design of the IBM testing conducted using fleet MAD operators in a dynamic fashion. This distinction between static and dynamic tests turned out to be important. A static test was defined as one in which the operator looked at a pictorial representation of the data as it would appear on a display and without significant time constraints made a decision. By contrast, a dynamic test was one in which the operator saw the data evolve in real time on a strip chart recorder and had to make his decision by marking the chart before it disappeared (perhaps a minute). The Sperry Univac test had semi-dynamic features. Each particular test event was drawn on the face of a Tektronix 4002A Graphic Computer Terminal at about 3X realtime. This gave the operator the experience of signal dynamics followed by a freeze frame time while he made his decision.

The data used in the test consisted of a carefully prepared mixture of real turn noise, real straight and level runs and synthetic submarine signals. Turns, always began an event to simulate a "rolling in" maneuver. The turn end was visually marked. Following the turn end was the signal insertion interval. A signal could be mixed into the data anywhere in this interval. The data was intentionally straitified to assure uniform distribution in signal-to-noise ratio, however the actual mixtures and straitification goals were achieved by pseudo random Monte-Carlo processes under computer control to avoid unconscious population biasing. Both the Univac and IBM operator tests used the same underlying data base; however, there were minor differences in the details of the test event populations used.

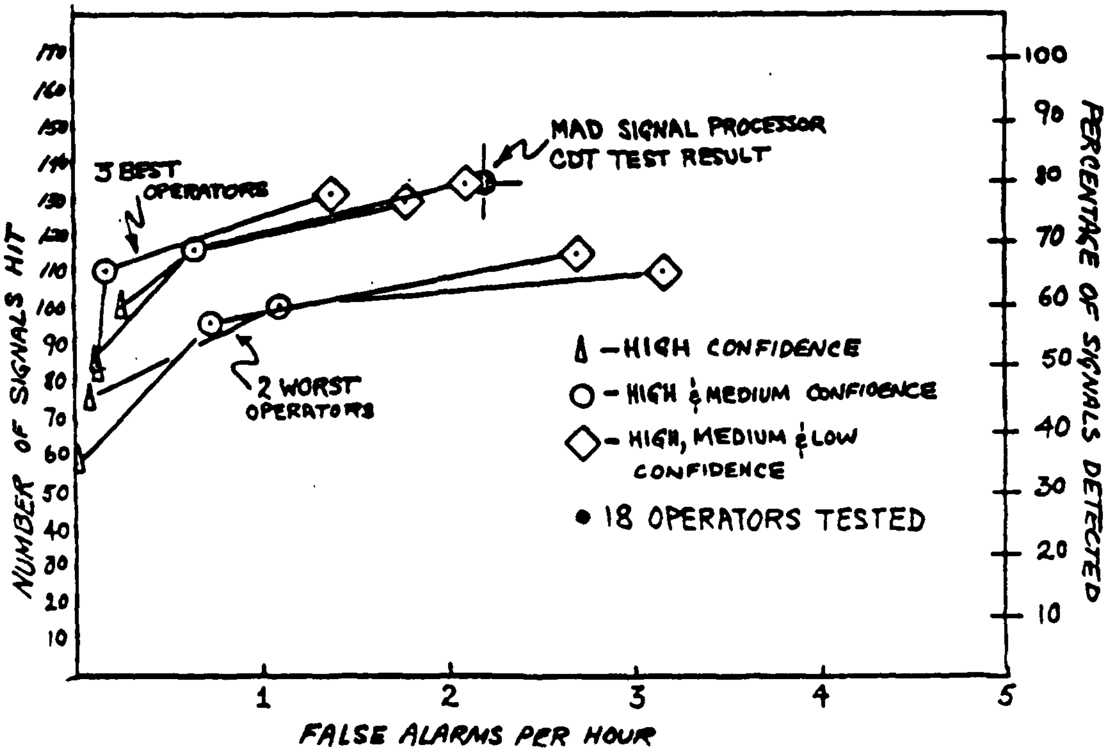
The Univac test was composed of a 34 event training set which each operator was required to execute prior to admission to the main test. The main test consisted of 347 events of which 168 were signal + noise events and 179 were noise-only events. The operator had to decide whether a signal was present, show where it was and declare his confidence in his decision; high, medium or low. The test events were presented to each operator in a unique random order. This precaution minimized the possibility of collusion since event numbers meant nothing among operators. An additional precaution was provided through the use of passwords, preventing one operator from working on another operator's test. The test was performed in 30 minute sessions and required about thirteen sessions to complete. The test population consisted of 18 Sperry Univac engineers and technicians.

During the course of the test, the individual test participants were free to work at their own pace. The results were stored to diskfile event by event. When the test was complete, these diskfiles were available as a detailed record of each operator's test. Analysis programs were written to examine the performance in more detail. In particular, human operator results were empirically fitted to equations of the form:

$$P_D = 1. - \exp\left\{-X \,({}^{S}/_{N})**Y\right\}$$

Generally, the resulting fit was excellent.

Summary of Results - The MAD signal processor used for this comparison, exceeded human operator performance in all cases. In the Sperry Univac testing, which was static, three operators, when their combined confidence levels were used (H-M-L), came very close to equaling the processor. It is considered unlikely that low confidence recognitions would be used in tactical situations. These three operators, interestingly enough, were the three most experienced in signal processor development. Comparisons of static and dynamic testing indicate that static testing arbitrarily inflates results. A rule of thumb is that doubling the false alarm rate of the static test result gives a likely dynamic test result. These findings helped to determine the design of the subsequent IBM operator test which clearly demonstrated processor performance superiority.



MAGNETOMETER OBSERVATIONS OF OCEAN WAVE NOISE

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Ocean wave noise is the term used in the MAD literature to describe the geomagnetic field fluctuations caused by ocean waves. The source of the fluctuations is an electric current flowing in the sea induced by the wave motion of the sea in the presence of the main magnetic field of the earth. Magnetic measurements made from a stable platform at sea and from an aircraft flying over the sea are presented and compared with a model of ocean wave noise developed by Weaver (1).

In order to test Weaver's theoretical model, the height of the ocean waves and the magnetic field above the ocean were measured simultaneously from the Naval Ocean Systems Center's oceanographic tower located about 1.6 km off the San Diego coast in about 20 m of water. The oceanographic tower was equipped with a non-magnetic boom of about 20 m in length for magnetic measurements away from the tower.

In his paper (1), Weaver points out that the motion of a sea platform makes reliable magnetic measurements over the ocean surface difficult. Fortunately, motion of the oceanographic tower was not a problem in this experiment.

The magnetic field measurements of the ocean waves were made as a function of time with an optically pumped metastable helium total field magnetometer (the AN/ASQ-81(V) MAD sensor) located near the end of the boom. The wave height measurements were obtained as a function of time from a pressure transducer located below the ocean surface. The angular frequency of the ocean wave was determined from the period of the wave height oscillation. The analog signals of both the pressure transducer (wave height) and the magnetometer output were displayed simultaneously on a paper chart recorder. An example is shown in Figure 1. The correlation of the magnetometer output with the transducer output is apparent. Based on this and similar data, Weaver's model was found to agree with the experimental measurements to within 6%.

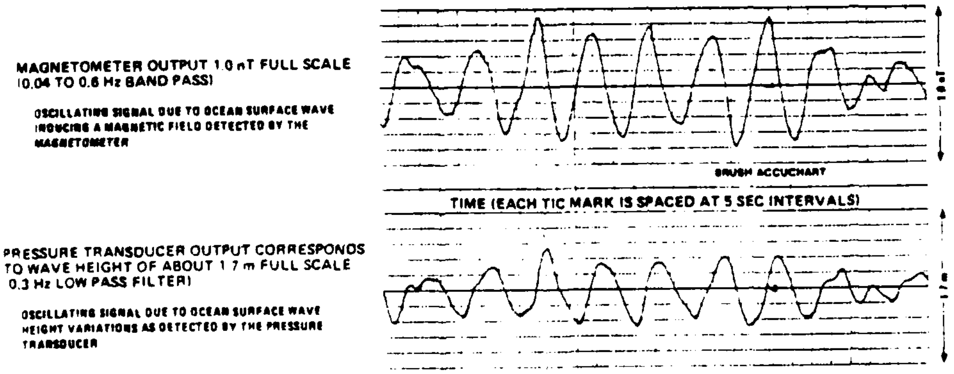

Figure 1

The airborne observations were made at 50, 84, 100 and 200m above the ocean surface on August 21, 1981. At the lowest altitude, the amplitude of the fluctuations caused by the ocean waves exceeded 1.0nT. This large amplitude was due to the large swell being generated by the distant tropical storm Dennis. The dotted curve in Figure 2 represents the mean of Weaver's model. It is bounded above and below by solid curves representing an uncertainty in the ocean wave period. The vertical lines represent the mean plus and minus the standard deviation obtained from the aircraft data. Figure 2 shows that the **measured** values fall well within the model values. The magnetic field amplitudes observed as a function of altitude and the apparent frequency of the fluctuations observed as a function of aircraft heading were found to be consistent with the theory of magnetic fields associated with ocean swell as developed by Weaver.

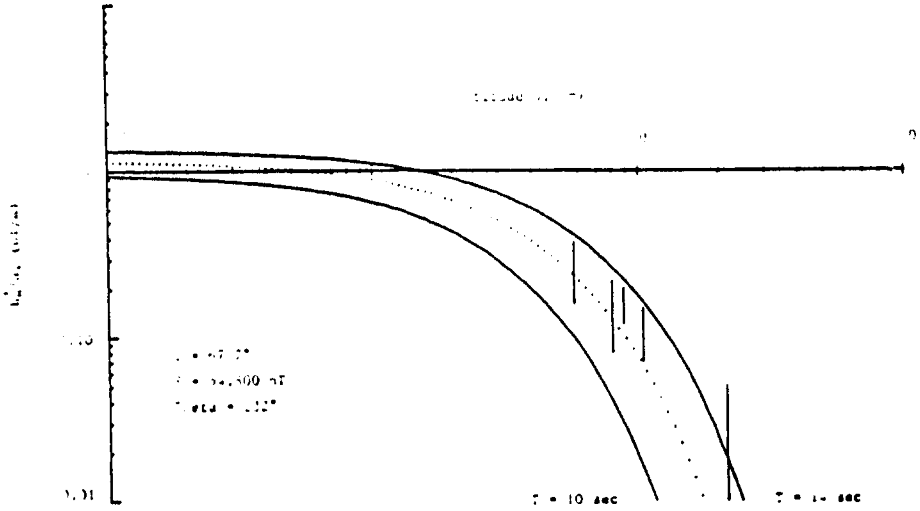

Figure 2 (Symbols shown are those used by Weaver)

(1) J. T. Weaver, J. Geophys. Res., 70, 1921-1929, 1965.

Acknowledgement: The author wishes to thank W. Podney of Physical Dynamics and D. Good and J. Olson of the Naval Ocean Systems Center for their help and cooperation with the oceanographic tower experiment.

A PROPOSED MAD INDEX OF GEOMAGNETIC ACTIVITY

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The U.S. Navy presently uses two versions of the A index of geomagnetic activity as indicators of natural noise in the frequency ranges used for its MAD operations. One of these indices is the Fredericksburg A index (A_{Fr}),which is a measure of the geomagnetic activity occurring near Fredericksburg, Virginia, and the other index is the so-called planetary A index (Ap), which is a composite index derived from the geomagnetic activity measured at 12 locations around the world. Both indices are used extensively in geophysics to monitor the state of general geomagnetic activity and the progress of geomagnetic "storms" and other disturbances. When used this way, it is difficult to fault either index. Unfortunately, the indices where never intended to give a measure, or even an indication, of geomagnetic activity in the frequency range currently of interest in MAD. As a result, it is not uncommon for those involved with MAD operations to observe strong activity in the MAD frequency range when the indices are low, or little activity when the indices are high. The principal purpose of this paper is to show that, with modern technology, there is no reason for this situation to continue. Indices can now be derived quickly, and probably automatically, which will provide an accurate and nearly real-time measure of geomagnetic activity specifically in the MAD bands. These indices can also be predicted ahead on both a short- and long-term basis by a variety of techniques that have already been developed. Finally, because the equipment required for the derivation of the indices should be compact and inexpensive, measurements can be made in each geographical region of operation, giving indices appropriate to those regions.

The unsuitability of the A indices for MAD work becomes evident when the details of their derivation are considered. As described by Lincoln [1967], the A indices are 3-hour range indices, meaning that the upper and lower limits of variation of the geomagnetic field in a 3-hour interval are measured and the A indices are assigned according to the size of the difference between the upper and lower limits (i.e., according to the range of the variation during the 3-hour interval). This means that the indices are sensitive to geomagnetic fluctuations covering a wide range of periods: not just the MAD period range (roughly 0.5 - 25 sec), but a very wide range extending from periods of less than 1 sec down to periods as great as several hours. Unfortunately, it is known that the amplitude of geomagnetic fluctuations varies approximately with frequency f as f^{-n}, with n in the range 1.0 - 1.3, which means that the amplitude of the fluctuations increases as the frequency decreases. It can be seen, therefore, that in a 3-hour interval it is activity with periods of an hour or more that largely determines the range of changes in the geomagnetic field, and that activity in the MAD period range has little if any effect. Clearly, there can be no direct link between geomagnetic activity in the MAD band and the A indices.

The fact that the A indices can be used at all, however unsatisfactorily, as indicators of activity in the MAD band is the result of correlations between the occurrences of the higher-frequency MAD activity and the low-frequency activity that influences the A indices. These correlations do not ever appear to have been studied in detail, but it is known that both the MAD band and the relevant low-frequency band include different varieties of geomagnetic pulsations, each with their own distinctive properties. It appears that some of these pulsations must (1) correlate, and (2) predominate in the two bands on occasion.

Given the remarkable computational power and speed of modern microprocessor-based minicomputers, there is no reason now why compact, automated, pulsation measuring stations cannot be established within each geographical region of relevance to MAD and geomagnetic activity specifically in the MAD band measured continuously and converted to indices. There are a great variety of possible indices: they could cover whatever interval of time was to be considered most convenient for MAD operations, and they could measure amplitude ranges (like the A indices) or possibly more appropriate quantities such as average power.

Recent work by one of the authors has also demonstrated the possibility of predicting the indices on both a short-term (1-10 days) and long-term (1-10 year) basis [Fraser-Smith, 1980, 1981]. By the use of these or other methods, preferably combined with an updating capability based on real-time solar flare occurrence information, it should be possible to transmit both immediate and estimated future values of the MAD indices to the users on a regular basis.

In summary, we propose eliminating the use of the A indices of geomagnetic activity in MAD work, and their replacement by specifically-derived MAD indices. These latter indices can be made much more appropriate to MAD both in their frequency content and in their applicability to particular regions of operation. They can also be derived essentially in real-time, predicted ahead by known techniques, and updated as often as is needed. Finally, the cost of these changes should be small or negligible compared with the cost of MAD operations.

REFERENCES

Fraser-Smith. A.C., "Short-term prediction and a new method of classification of Pc 1 pulsation occurrences," Planet. Space Sci., Vol. 28, 739-747, 1980.

Fraser-Smith, A.C., "Long-term prediction of Pc 1 geomagnetic pulsations: Comparison with observations," Planet. Space Sci., Vol. 29, 715-719, 1981.

Lincoln, J.V., "Geomagnetic indices," pp. 67-100 in "Physics of Geomagnetic Phenomena," Vol. 1, edited by S. Matsushita and W.H. Campbell, Academic Press, N.Y., 1967.

GROOMING FOR MAD EQUIPPED AIRCRAFT

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Objective

The objective of this paper is to exorcise the stigma that successful compensation is all "Black Magic".

Primary Requirements

Successful, consistant compensation results and the maintenance of an aircraft in a continuous state of MAD readiness requires methodical dedication and an understanding of the effect various interference sources have when detected by the magnetometer. It has been demonstrated that excellent results are obtained when an individual or a team is given exclusive responsibility for maintenance of the boom area and installation of replacement MAD equipment.

The 10 Fundamental Grooming Commandments

90 percent of all unsatisfactory operation conditions can be eliminated if the following fundamentals are "Religiously" maintained.

1. Thou shalt have verbal intercourse with the Sensor Operator if Failure Report is not clear or incomplete, so one does not begin by chasing the wild goose.
2. Thou shalt ensure all MAD related replacement equipment and subassemblies are of the correct nomenclature for that aircraft and check said equipment connectors, including those connected thereof, for bent pins and frayed wiring shields.
3. Do not be presumptuous regarding permanently fixed subassemblies such as vector magnetometers and output coils for they should be checked for correct alignment, proper orientation and contaminated mounting hardware.
4. Thou shalt use non-magnetic tools when making repairs to boom or detector except in dire emergencies when only squeaky clean, degaussed steels tools are to be used.
5. Thou shalt honour the boom and keep the surface clean at all times and keep metal lightning conductors, static wicks, and all connecting contacts in good repair.
6. Thou shalt not contaminate the boom by rubbing rusty stand rails against the surface and shall never place the removable tail capsule or detector assembly on the ground or store without first placing clean foam or bubble-wrap under or around said article.

7. Let no man ever, ever use, install, paint or affix anything of any type or manner to, or within 10 feet of the detector magnetometer and/or its mounting position without first knowing it is non-magnetic in nature.

8. Be resourceful and colour-code all attaching hardware with non-magnetic dye or paint to show it has been successfuly tested and store coded hardware in separate bins from other contaminated materials, preferably in a restricted access area.

9. Thou shalt properly degauss boom (including detector) from time to time to minimize effect of stray magnetic contamination.

10. Strive to ensure that all flight crew personnel understand that no tool boxes, steel tie-down chains or any other manner of steel material shall be stored, loose, or otherwise within the rear half of the aircraft during MAD Compensation or MAD Operational flights.

Go forth and multiply this knowledge to the masses and ye shall be rewarded with the smiling faces of many happy Sensor Operators.

THE TEN COMMANDMENTS

By

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(As told by him to the people at the First International Meeting of the Society of Madmen)

Thou shalt:

1) Have intercourse
2) Check your equipment
3) Protect yourself
4) Use proper tools
5) Honour your boom
6) Not contaminate
7) Be discriminating
8) Beware of foreign objects
9) Clean your boom
10) Have swap session

SOM Audience Replies

Amen, Brother

ROTARY WING TRIALS OF A MODIFIED AN/ASA-64 SUBMARINE ANOMALY DETECTOR

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(0753 42231)

1. Introduction

Recent trials of helicopter-borne MAD equipment have highlighted the problems associated with the lack of a dedicated operator who can devote a significant amount of time to MAD during tactical operations. It has become apparent that some form of operator alert system, capable of recognizing anomaly-like signals and attracting the operator's attention would be desirable.

Recent studies indicated that one such system is the AN/ASA-64 Submarine Anomaly Detector (SAD) manufactured by GAE Electronics Ltd, Montreal for fixed wing operation. ASWE/ACO Slough obtained a loan equipment for evaluation in 1981 and arranged for an airborne trial to be carried out with a Sea King helicopter of 826 Sqn., RWAS Culdrose. The loan equipment was modified to be applicable to rotary wing operation and incorporated an automatic threshold setting circuit.

2. SAD Equipment Description

The SAD electronics is housed in two hardware units which interconnect with the basic MAD equipment. The trials equipment was configured to operate with the Texas Instruments AN/ASQ-81 magnetometer with an associated Crouzet chart recorder.

SAD derives its input from the MAD operator display signal. In the SAD equipment the signal is band-pass filtered, rectified and integrated. The level of the processed signal is compared to the level averaged over the previous 80 seconds. If the integrated signal exceeds the average by a pre-determined factor (in this case 1 7/1) an alert signal, whose amplitude is proportional to the level of the signal above the average, is generated. To avoid repeated alert signals on long duration MAD marks, an inhibit circuit is activated which prevents further alerts for a period of 10 seconds. After this period a further SAD mark can occur for long duration MAD marks, but this can be ignored. The inhibit facility can also be activated by a signal from the altitude compensator of the AN/ASQ-81. This is particularly useful in avoiding false alerts caused by anomaly-type signals generated during rapid maneuvers. The level at which this inhibit function operates is set by a potentiometer on the front panel of the SAD Control Unit.

The alert signal generated by SAD is fed to the second (previously unused) pen of the paper chart recorder. A "MARK" lamp and an optional warble tone of 1.5 seconds duration in the operator's headset are also provided.

It can be seen from the above that the signal on which SAD operates is dependent on the setting of the sensitivity control ( ) of the AN/ASQ-81. Good operating practice dictates that the sensitivity control should be set to a level which produces approximately 2 major divisions of noise on the paper chart. This technique allows SAD to be operated in various noise environments with the minimum of adjustment.

3. Trials Performed

Flight trials were carried out using a MAD-equipped Sea King HAS Mk 5 helicopter in co-operation with a British SSK submarine. The water depth was approximately 300 feet and the whole area is considered to be moderately noisy geologically. In addition, the area contains a large number of wrecks.

The SAD-related maneuvres consisted of a series of clover leafs at ascending heights over the surfaced submarine. In addition, a number of offset passes were made.

4. Results

SAD can only operate successfully when it receives a MAD mark from the AN/ASQ-81. If the anomaly signal is very small and is buried in the noise, even a trained operator will be unable to detect it. The true test of SAD therefore is whether, upon receipt of a perceptible MAD mark, the SAD alerts the operator. In addition SAD should not make too many false detections. In this trial, false alarms were counted whenever they occurred during the controlled pass. The few which occurred during the tight maneuvres performed to position the aircraft for the runs were ignored.

The definition of a false alarm was a deflection of the SAD pen of 25% FSD (2 major divisions in the figures of this report) or more obtained from a MAD pen deflection which it was considered would have been classified "non submarine" by a reasonably experienced MAD Operator. Thus SAD marks obtained from trains of oscillations of geological or geomagnetic origin were counted as false alarms but those obtained from submarine anomaly-type signals e.g. from known or suspected wrecks were ignored. The latter were counted MAD marks in the absence of a mark from the target. A SAD pen deflection of 25% FSD was normally accompanied by the sounding of the audio alert tone and the illumination of the MARK lamp.

In evaluating the performance of SAD, passes where the equipment was not fully operational due to trial related problems, have been discounted since these should not occur in an operational fit.

For 30 MAD marks, 25 SAD marks were correctly obtained. During these passes, a total of 15 false alarms occurred.

5. Conclusions and Recommendations

The trial demonstrated that the modified AN/ASA-64, albeit a relatively simple system, was capable of alerting a MAD operator to the presence of submarine-like anomalies. The performance of the equipment was considered to be such that continuous monitoring by a dedicated MAD operator would not be essential. However, validation by the operator is still required.

CAE intend to include further minor modifications as a result of the trial, which should have the effect of improving the performance.

If an operator alert system is considered to be desirable for rotary wing MAD operations, then the modified SAD system should be considered.

REFLECTIONS ON MAD SIGNAL PROCESSOR DESIGN AND DEVELOPMENT

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Some of the lessons learned while living through a new sensor signal processor development are sufficiently troublesome and timeless to deserve review. It is the nature of our business that the complexity of problems we attempt to solve progresses in step with the increasing capabilities of the supporting digital technology. Because of this complexity, the likelihood increases that the sensor system development, particularly those that incorporate increasing levels of automation, will be perceived as a failure at some point along the way. The dismal statistics on the number of new starts that reach production status bear this out. There is no single, simple reason why this happens. The pressures to quickly produce and qualify a new system before interest wanes and shifts toward some newer technology often is involved. The inability to fund even all the good system concepts through to production is an important factor. As the poor sister in the ASW stable, magnetics has never received the high level of support it deserves but as system developers we can influence the way the relatively small magnetics investment is spent so that purely technical failures become less likely.

A processor(1) development is conveniently organized into seven activities: 1) mathematical modeling of physical phenomena, sensor signal and background noise, 2) processor concept formulation, 3) processor design and implementation, 4) field data collection, 5) phenomena, signal and noise model validation, 6) laboratory evaluation by simulation and 7) field qualification. These activities most naturally proceed serially with frequent looping back to an earlier activity in order to adapt the models and processor design to the growing knowledge of phenomena, sensor operating characteristics, background noise sources and the relative power of processing techniques. As the sensor system progresses through the first six activities toward field qualification, the performance projections must be increasingly accurate which in turn requires that the mathematical models be increasingly precise and comprehensive. The operational need must be firmly established and the field qualification gate for proceeding with system development must be precisely defined and realistically attainable. The most common technical cause of field qualification failure in the authors opinion is attributable to 1) mathematical models that are non-existent or inaccurate because too little was invested in collecting well documented and referenced signal and background noise samples and 2) too much being expected out of the field qualification tests.

The performance of sensor systems is more often limited by our knowledge of how to deal with the sensor environment than by either intrinsic sensor sensitivity or procedures for extracting signals of interest out of a cluttered background. For example, operational scalar magnetometers have not consistently achieved the target detection ranges that could reasonably be expected based upon their internal noise levels. The MSP(2) development project demonstrated that magnetometer detection ranges could be significantly extended beyond that of even a trained and alerted sensor operator observing the signal from such a magnetometer(3). There is growing evidence that more complete and accurate mathematical models(4),(5) can lead to still further performance improvements of both the conventional and newer sensors. But the ability to improve the existing models is limited by the availability of and care with which samples of the environment are collected. Historically, the reference ties between sensor, aircraft and the signal sources have not been good enough to support rigorous model development and/or verification. We should not settle for the false economy of hurried and non-rigorous magnetic sensor data collection programs.

In-the-field live tests are a poor way to estimate the capability of a system, for the interpretation of the results is tightly circumscribed by the relatively small number of events (in a statistical sense) that can practically be collected. In-the-field tests can at best verify but a few individual points on a performance curve that has previously been developed through extensive simulation in a laboratory environment. There seems to be an irrestible urge on the part of decision makers to draw general conclusions from a few specific events. It follows that the time spent in carefully specifying and conducting a field test exercise will pay handsome dividends in time saved trying to explain test results that try to accomplish too much.

(1) As used here, processor includes all the hardware, firmware and software that implement the signal processing and decision making functions.
(2) MSP is an abbreviation for MAD Signal Processor. This processor was developed by Sperry Univac to automatically detect magnetic anomaly signals from the AN/ASQ-81 towed by the LAMPS MARK III helicopter.
(3) "Sensor Operator Field Evaluation Tests" IBM CD3-078-0202 dated 9 August 1978.
(4) Poduey, W. and Sager, R., "Measurements of Magnetic Gradients From Ocean Waves".
(5) Nelson, J., "A Geological Magnetic Noise Model", Sperry Univac Technical Report.

DETECTION OF A THIN-SHEET MAGNETIC ANOMALY BY SQUID-GRADIOMETER SYSTEMS: APPLICATION TO HYDROFRACTURE AZIMUTH DETERMINATION*

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We have carried out an experimental and theoretical study of the signal physics of magnetic anomaly detection by superconducting gradiometer and magnetometer loop systems with SQUID sensors for possible application to the Los Alamos hot-dry-rock (HDR) geothermal energy program and to hydrofracture azimuth determination in petroleum geophysics. In particular, the crack produced by hydrofracture of a deep HDR geothermal borehole would be filled with a magnetic material, such as ferrofluid or ferrous loaded fracture sand. When polarized by the earth's field, these materials would produce a localized crack magnetic anomaly that is characteristic of the azimuth, with respect to magnetic north, of the vertical crack emanating from the borehole. Knowledge of this azimuth is technically and economically important, especially in the HDR program.

In one method, the signature of the anomaly is determined by taking borehole gradiometer/magnetometer rotation data before and after filling the crack with magnetic material. We have found a mathematical description for such signatures[1] as seen by magnetometer, first-derivative and second-derivative axial gradiometer. We show in Figure 1 a schematic of a superconducting first-derivative axial gradiometer loop system in a borehole with a thin-sheet or crack (width greatly exaggerated) emanating radially from it. Using standard formulas[2] we estimate the earth's field for any geographical location. The anomaly produced by the earth's field is characterized by the azimuth angle ϕ of the sheet with respect to magnetic north. We use the standard magnetic boundary conditions to determine the angles of the magnetic field lines at the sheet edges. Each volume element of the sheet becomes a localized dipole moment. Integrating the field elements due to these over the whole sheet leads to the fields at any arbitrary point (x_o, y_o, z_o) outside the sheet. Thus, the field components at any point in the borehole are modified by the presence of the sheet anomaly in a predictable way. Although the integrations are complicated, the results reduce to simple forms. We find,

$$H_x = 2\, m_o t \sin\psi'(a \cos 2\phi - x_o \cos\phi + y_o \sin\phi)/D \quad , \qquad (1)$$

$$H_y = 2\, m_o t \sin\psi'(a \sin 2\phi - x_o \sin\phi - y_o \cos\phi)/D \quad , \qquad (2)$$

$$D = [a^2 - 2\, a(x_o \cos\phi + y_o \sin\phi) + x_o^2 + y_o^2] \quad , \qquad (3)$$

$$\sin\psi' = \sin\psi \cos q/(1 + \chi_{in} \sin^2\phi) \quad ; \quad k_{in} \tan\phi = \tan(\phi - q) \quad , \qquad (4)$$

where $m_o = \chi_{in} H_o$ is the induced magnetic moment per unit volume of sheet, $\chi_{in} = (k_{in} - 1)$ is the magnetic susceptibility of the ferrofluid, $B_o = \mu_o H_o \approx 0.5 \times 10^{-4}$ Tesla is the magnitude of the local earth's field, ψ = angle between $\vec{B}_o$ and the local vertical axis z. Angle q varies between 1.4° and 19° for permeability k_{in} between 1.1 and 2.0 ; a is the borehole radius and t the crack thickness. The signal current induced in a single superconducting magnetometer pickup loop with axis in the x-y plane of Figure 1 and centered in the borehole is found to be,

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* Work performed under the auspices of the U. S. Department of Energy.

$$I = (\mu_0 A/L)[(H_x + H_0 \sin\psi)\cos\gamma(1 - d\theta^2/2) + H_y \sin\gamma(1 - d\theta^2/2) + H_0 \cos\psi\, d\theta] \quad , \quad (5)$$

where $d\theta$ is the angle of tilt of the loop axis with respect to the z-axis, γ is the orientation angle of the loop normal, A = loop area, and L = loop inductance. The portion of (5) due to the polarized magnetic sheet is

$$I_m = (\mu_0 A/L)(H_x \cos\gamma + H_y \sin\gamma) \quad . \quad (6)$$

The remainder of (5) is an undesirable signal I_u. Methods of determining and subtracting I_u from $(I_m + I_u)$ must be devised. As mentioned earlier, one method is to take data before and after the ferrofluid is introduced into the hydrofracture crack.

When two such superconducting loops are separated by a distance 2s, one has the first-derivative gradiometer. For the axial gradiometer the signal current takes the form,

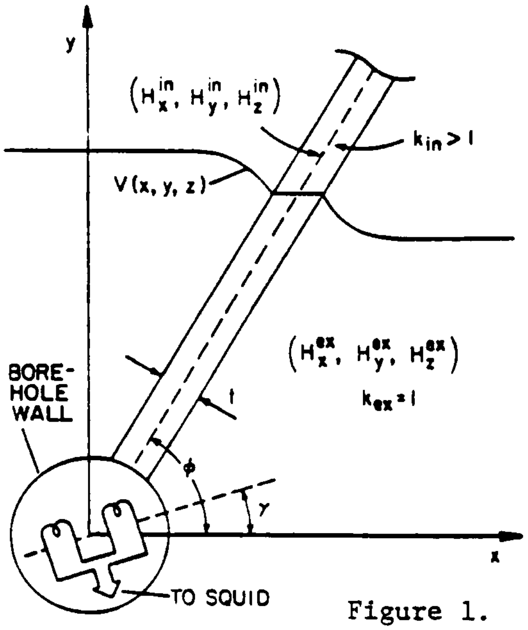

Figure 1.

$$I_g = (\mu_0 A/L)(4\, m_0 \sin\psi')(t\, s/a^2)[\cos 2\phi - 2\cos(2\phi - \gamma)\cos(\phi - \gamma)] \quad . \quad (7)$$

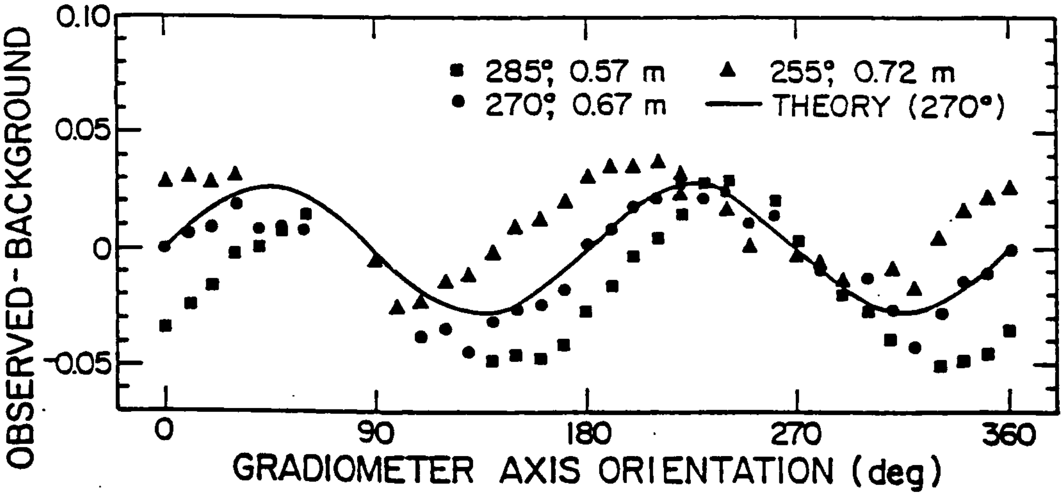

Figure 2. Gradiometer rotation signal data for ferrofluid filled sheet azimuths 255°, 270°, and 285°. Background is rotation data before ferrofluid sheet was introduced. Solid curve is theory as given by Eq. (7).

The ferrofluid-filled sheets (thickness t = 1.5 mm) were set up in a field experiment to simulate actual borehole hydrofracture conditions. The goal of this work was to be able to determine the azimuth angle ϕ of the sheet to within ± 15°. Computer cross-correlation analysis between Eq. (7) and the experimental data showed a standard error of less than ± 8°. It was only necessary to operate the SQUID gradiometer system in its lowest sensitivity (x 1) mode.

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1. W. C. Overton, Jr., SQUID Applications to Geophysics, edited by H. Weinstock and W. C. Overton,Jr., Society of Exploration Geophysicists, Tulsa, OK, 1981.
2. M. Seguira and J. Heppner, American Institute Physics Handbook, 1972.

Papers Received by the Society But Not Presented

Avery, Otis E. "The effects of large magnetic anomalies on MAD" (CONFIDENTIAL)

Bobb, Lloyd C. "Optical fiber magnetic field sensors"

Bubenik, D.M. and R. Abileah "Power spectra and cross coherence of magnetic fluctuations recorded on land and undersea"

Fraser-Smith, A.C. and Otto Heinz "A proposed MAD index of geomagnetic activity"

Hardwick, C.D., J.E. Jordan and B.W. Leach "Aeromagnetics research activities at the NAE"

Hastings, Roger "Dipole localization in the presence of severe background magnetic anomalies"

Heacock, John G. "Geomagnetic research supported by Code 425GG ONR"

Jacobson, Joseph P. "Platform/sensor noise"

McGregor, D.D. "Improvements in the ^{3}HE free-precession nuclear magnetometer"

McGregor, D.D. "Laser pumping of ^{4}HE resonance magnetometer"

McGregor, D.D. "Uncertainties in estimates of scalar MAD tactical parameters"

Ochadlick, Andrew R. Jr. "Magnetometer observations of ocean wave noise"

Overton, W.C. Jr. "Detection of a thin-sheet magnetic anomaly by squid-gradiometer systems: application to hydrofracture azimuth determination"

Payton, Warren H. "Representative magnetic geology from distinctive structural regions"

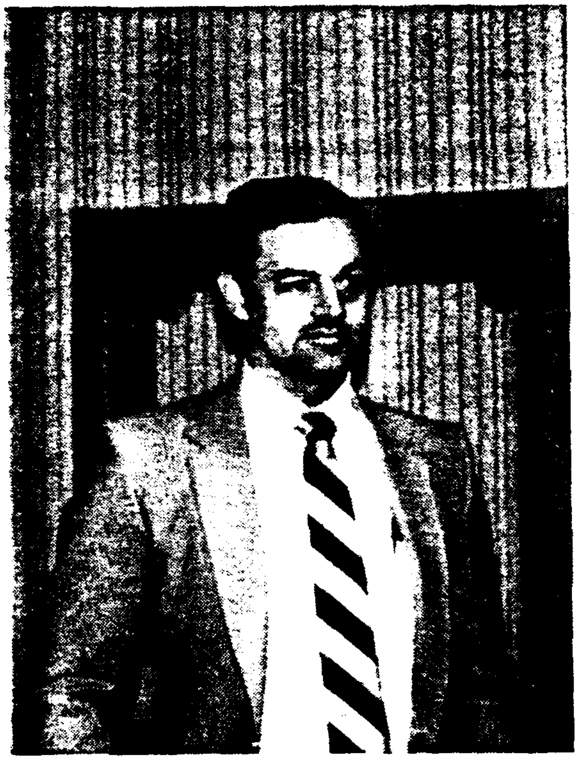
Petty, J.V. "Magnetic anomaly detection performance methodology"

Petty, J.V. "Magnetic anomaly target tracking, velocity estimation, and classification using scalar magnetometers"

Schmidt, William A. "Automatic submarine detection and localization via processing magnetometer data" (CONFIDENTIAL)

Shannon, John G. "Misconceptions in airborne MAD" (CONFIDENTIAL)

Widditsch, H. Robert "Two training devices for MAD aircrews"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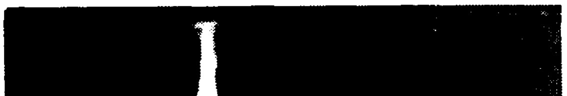

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