AERONAUTICAL CHARTS AND MAP DISPLAYS

A JANAIR SYMPOSIUM

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AERONAUTICAL

PROCEEDINGS OF A SYMPOSIUM HELD IN WASHINGTON, D.C., NOVEMBER 8-10, 1966, UNDER THE AUSPICES OF THE

JOINT ARMY-NAVY AIRCRAFT INSTRUMENTATION RESEARCH COMMITTEE

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CHARTS AND MAP DISPLAYS

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PREFACE

Military aviation during the past 20 years has been marked by major changes: a continuous increase in the performance capabilities of manned aircraft, a mounting complexity of avionics systems, a sophistication of ground-imaging sensors, an increased dependence on inflight rendezvous for refueling, a growing demand for fast, flexible, accurate air support of ground operations, and the development of low-altitude tactics. Civilian aviation has been marked by similar changes in the complexity of vehicles and operations, and because of the swelling volume of traffic, has an urgent need for more accurate control of the horizontal positions of aircraft aloft. These developments punctuated the need for better systems of air navigation and more efficient means for displaying navigation information to aircrews. Aviation experts, early in this period, recognized the need for dependable, accurate, easily interpreted navigation displays.

STATEMENT OF THE PROBLEM

The essential function of a navigation display is to present to the pilot, in the most readily understood and most immediately usable form, information that will tell him where he is, where he has been, and where he is going with respect to the geographic places relevant to his mission. The key component of such a display is the earth reference, usually some form of aeronautical chart. In the development of navigation displays the major design problems have been, and still are, those encountered in specifying and producing an optimum earth reference. For example, displays that use the roller-map principle of design are able to incorporate standard, paper, aeronautical charts, but are seriously limited by an excessive amount of time required to prepare charts for a particular mission, a restricted corridor of operation, and a lack of flexibility for changing charts in flight. Displays that use the microchart-projection principle overcome these limitations, but face the problems of attaining adequate image resolution and a capability for chart annotation. Displays that use the raster-scanning principle face even more serious problems of image resolution and have limited capability for presenting color-coded information.

Each approach has encountered major difficulties in adapting aeronautical charts to display application. Thus, the central problems in the development of effective navigation displays are not the problems associated with cartography alone, nor the problems associated with display instrumentation alone, but the problems of integrating cartographic products with display instrumentation to produce a map-display *system*.

THE NEED FOR A SYMPOSIUM

During the course of our work for the JANAIR Committee, Gail Borden and I have consulted with most of the organizations which design and produce aeronautical charts; we have also consulted with many organizations engaged in research and development of navigation display systems, and we have interviewed hundreds of pilots. We both concluded from these discussions that one of the reasons for the difficulties encountered in developing adequate cartography for display applications was the conspicuous lack of communication between the map-makers, the display-makers, and the users of map-displays. With a few exceptions, the individuals engaged in cartographic development were not fully aware of current developments in navigation display systems. Conversely, few display designers had an adequate understanding of the technical problems of chart design, compilation, production, maintenance, and distribution. It was our general impression that the men who design aeronautical charts were not taking into account the special requirements of the navigation displays which may eventually incorporate those charts; and the men who design the displays were not fully considering the special requirements they impose on cartographers. In addition, there did not seem to be a timely role for the pilot in determining the ultimate design and utility of such displays. The problems of inter-disciplinary communication were further aggravated by a paucity of technical literature in the field of map-displays. Little experimental or operational data have been published, and there has been a total absence of theoretical discussion.

The lines of communication between cartographers, systems managers, design engineers, research scientists, and aviators would have to be opened if advances were to be made in navigation displays. And so, this symposium was proposed as an initial step toward that goal.

OBJECTIVES OF THE SYMPOSIUM

The central objective of the symposium was to gather together the leading authorities in the various technological fields relevant to aeronautical charts and map-displays, to provide a format for a dialogue among these individuals, and to afford an opportunity for face-to-face contact and exchange of information and ideas. The specific tasks of the participants were to describe the current state of the art in their respective fields, to assess the major problems and issues confronting them in their work, and to provide guidelines for coordinating efforts toward common research and development goals.

The emphasis of the symposium was to be on the integration of cartographic products into navigation display systems, and on problems involved in their operational use. Aspects of navigation displays which are independent of the chart or earth-reference component were not regarded as relevant to this symposium. The symposium was also planned to emphasize the military application of map-display systems, as opposed to their use in general aviation.

PARTICIPANTS

More than 200 individuals, representing more than 80 different organizations, participated in the symposium. They included experts in the fields of cartography, display design, air operations, systems management, avionic instrumentation, optical and photographic sciences, and human factors engineering. They constituted the most knowledgeable group of authorities on aeronautical charts and map displays that has ever been assembled.

A roster of participants, a directory of their mailing addresses, and descriptions of some of the participating organizations are given in Part IV of this document.

SYMPOSIUM ACTIVITIES

The symposium met in general assembly for three consecutive days. Technical papers were presented to the assembly, and following each paper the participants were given an opportunity to question the speaker or comment on his topic. These papers are published in Part II of this document.[1] The discussions were tape-recorded and then edited. They are published in the sections entitled *Discussion Abstract* which follow the papers in Part II. The *Discussion Abstracts* include the comments made from the floor of the symposium and those which participants submitted in written form.

During the afternoon of the second day of the symposium, the general assembly adjourned and six small discussion groups convened. These groups were organized and directed by guidance committees of two to four men. The groups were assigned specific topics for consideration and engaged in open debate on these issues. On the afternoon of the third day, the guidance committees delivered to the general assembly summary reports of the deliberations of their groups. These summary reports are published in Part III of this document.

To make this report a more useful source document, the participants submitted references to the technical literature relevant to the topics of the symposium. These references have been compiled in the bibliography presented in Part IV. The bibliography is not exhaustive, but provides a source of references for those readers who wish to obtain further information on this problem area.

ASSESSMENT OF THE SYMPOSIUM

It had been my intention to prepare a formal summary of the findings

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[1]The paper entitled *Criteria for use in design of navigation map displays*, presented by Maj. William L. Polhemus, was not available for publication. It should also be noted that many speakers made extensive use of color slides, cartographic prototypes, motion pictures, and other visual aids which could not be reproduced in this document.

of the symposium. But, as the reader will find upon examining the contents of this report, the number and complexity of the issues raised defy simple summation. Any abstract of the findings of this symposium would do injustice to the efforts of the participants. Therefore, I shall let the participants speak for themselves with regard to the current state of the art and the critical issues that prevail.

There were two main currents of thought which were almost universally expressed by the participants. The first was a recognition of the communication problem which led to the symposium, and which the symposium, so it was agreed, constituted a major step toward solving. The second was a recognition of the need for a coordinated program of basic research which concentrates on specifying the optimum content, encodement, and display of navigation information presented to the pilot; which explores the full range of media and techniques for portraying graphical information; and which expedites the logistics of chart distribution.

ACKNOWLEDGMENTS

The efforts of many individuals were needed to organize and conduct the symposium. I wish to take this opportunity to recognize those to whom I am particularly indebted.

Capt. David D. Kilpatrick, formerly Chairman of the JANAIR Committee and now ONR's Director of Air Programs, was the keystone of administrative and financial support for the symposium. I most especially commend his efforts.

The members of the JANAIR Committee, individually and collectively, have given their full support to the symposium. They are Lt. Cdr. Francis L. Cundari (Chairman), Lt. Paul R. Chatelier, Sol Domeschek, and Jack Wolin. I also wish to thank the former members of the JANAIR Committee who were active at the time the symposium was organized: Len Evanson, Brad Gurman, and Cdr. H. G. Heininger.

Col. Robert E. Herndon, Jr., is DIA's Assistant Director for Mapping, Charting, and Geodesy. As such, he heads the organization that has primary management responsibility for military cartography. Without the cooperation and participation of that organization, the symposium would have been incomplete and even meaningless. Col. Herndon not only lent the full support of his directorate to the symposium, but vigorously devoted his personal attention to it. I am, therefore, greatly indebted to him and to Loren A. Bloom, John F. Gantt, and James L. Stahl, all members of the DIAMC-1 staff, who participated in planning the symposium. In addition, I wish to recognize the contributions made by William R. Campbell of the Naval Oceanographic Office to the concept and organization of the symposium.

I wish also to thank Col. John Kelsey and the many other participants from England, Scotland, and Canada who made the special effort to attend this meeting and lend international scope to its deliberations.

My friend and colleague, Gail J. Borden, was principally responsible for the management of the meeting and succeeded in memorable fashion. Assisting him were Mrs. Amy Smith, who managed the registration desk, and Charles F. Wilber, who coordinated the audio-visual requirements of the speakers. Miss Lily Odaka and Mrs. Nadine McCollim prepared the workbook materials for symposium participants and the manuscript for publication. Cdr. Robert Lawson, ONR, acted as liaison with the publishers. I am sincerely grateful for their dependable and efficient help.

In the last analysis, the value of a symposium derives from intelligent, authoritative speakers and an attentive, responsive group of discussants. I am sure that I speak for all of the participants when I express our gratitude to the symposium speakers for the thoughtful presentation of their views and to the guidance committees for their work in directing and documenting the discussions.

Finally, I wish to add a special word of thanks to our keynote speaker, Maj. Gen. Richard W. Whitney who promoted the candid exchange of views which made the symposium a valuable experience for us all.

James J. McGrath

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I
INTRODUCTION

WELCOMING ADDRESS

Capt. David D. Kilpatrick
Director of Air Programs
Office of Naval Research

Good morning, gentlemen.

On behalf of the Joint Army-Navy Aircraft Instrumentation Committee and the other organizers of this symposium, I extend a hearty welcome.

In order to identify and give due credit to the agencies and individuals who have participated in planning and organizing this meeting, a description of its evolution is in order.

First: the Joint Army-Navy Aircraft Instrumentation Committee, which we call the JANAIR Committee. This group comprises members from the Naval Air Systems Command, the U. S. Army Electronics Command, and the Office of Naval Research. In addition to its technical participation, ONR serves as the administrative agency for the committee.

In 1962, Dr. James J. McGrath approached the committee with a suggestion that the problem of geographic orientation in pilots be studied in an orderly manner. The committee was responsive, but did not know the severity of the problem nor its consequences, and asked first for a problem validation. The results of that first survey showed that pilots become lost in flight far more often than most aviation authorities had realized. The facts were that a substantial number of pilots were being killed, aircraft were being destroyed, and missions were being aborted because of geographic disorientation. In short, our pilots were having difficulty maintaining an exact awareness of their navigational positions, particularly during low-altitude operations. The study of geographic orientation was immediately authorized by the committee.

By 1965, it had become apparent that a much broader effort than ever previously undertaken would be needed if we are to provide the pilot an optimum geographic reference system in the cockpit. It was also apparent that a large number of map-display problems have remained unsolved because of the lack of a fully coordinated effort among the many different scientific and technological disciplines involved in the process of developing map-display systems.

We felt that many of the problems might be overcome if they were simply made known, and decided that one way of publicizing them would be to convene a small seminar where a leading group of intensely interested experts would identify the problems and suggest potential avenues of solution to them. This assembly has turned out to be the "small" group of interested experts.

We recognized at the outset that no progress could be expected from this meeting unless it received the full blessing, encouragement, and support of the Defense Intelligence Agency. That Agency is assigned cognizance of many aspects of cartography in the Department of Defense. Accordingly, the progress of the geographic orientation studies was reported to DIA, and their vigorous support in organizing this assembly was forthcoming. I want to take this opportunity to thank the members of DIA who have actively donated their time, energy, and guidance during the planning stages of this meeting, and to particularly acknowledge the efforts of Mr. Loren Bloom, who has been the principal point of contact.

* * *

Major General Whitney, the Chief of Staff of the Defense Intelligence Agency, has had a long-standing interest in the problem of concern to us here today. He has consented to give us some time from his heavy schedule to open the session and to set us to our tasks.

General Whitney.

KEYNOTE ADDRESS

Maj. Gen. Richard W. Whitney
Chief of Staff
Defense Intelligence Agency

On behalf of General Carroll, the Director of the Defense Intelligence Agency, and speaking for the intelligence community of the Department of Defense, I also wish to extend to each of you a sincere welcome to this important symposium. I can also assure you that our agency has a natural and very keen interest in the scheduled presentations and deliberations of this highly qualified forum.

The old expression that history repeats itself can hardly be applied to this occasion. There may have been a gathering of cartographers, instrument designers and navigators some time in the past, but to my knowledge, there has never been a symposium of as many talented people representing such a variety of scientific specialties in these fields as are here gathered. I am sure you have met with each other, shall I say bilaterally from time to time, to resolve some specific technical problem. However, I do believe that this is the first time that representatives of *all* the disciplines involved in providing aeronautical charts and navigation display systems and their use by the aviator have gathered to exchange knowledge, experience and opinions.

I want to compliment those connected with the Joint Army-Navy Aircraft Instrumentation Research (JANAIR) project for initiating, and the Office of Naval Research for sponsoring this symposium. The studies made under the JANAIR project for the improvement of aircraft navigation components and display systems and the requirements being placed on the cartographic community for aeronautical charting products have certainly indicated a need for a symposium of this nature. Aircrews are required to process an enormous amount of information to complete their mission successfully. It is essential that information be presented to them concisely, and when feasible, in an integrated manner that will allow rapid assimilation. It is quite apparent that if the body of information concerning navigation and orientation to Earth's features are combined in one effective horizontal and vertical display, the crew will be relieved of some tasks to allow for more time and concentration on their mission. The primary purpose of this symposium is, therefore, to provide for the exchange of knowledge concerning the techniques and capabilities of your respective specialties and to explore, discuss, and resolve subjects or problems involved in meeting the aviators' need for prompt recognition of his geographic position.

Some of you, particularly our foreign guests, may not be fully aware of the intense interest of the Defense Intelligence Agency in the field of maps, charts and topographic displays and the advancements in the techniques and technology associated therewith. Traditionally, in our military services it has been the responsibility of the intelligence officer to provide to the forces he supports that information and those informational aids which will facilitate maneuver in a strange environment, whether it be hostile or friendly, and which will improve or expedite the employment of our weapons systems. Thus, in our scheme of things, the map or chart, the compilation of geodetic data, the device which displays environmental information is every bit as much as an intelligence product as the estimate of order of battle and capabilities of an actual or potential opposing force.

About four years ago, the Defense Intelligence Agency was assigned responsibility for managing all Department of Defense mapping, charting and geodetic activities. Organizing, staffing and implementing Secretary McNamara's directive has been a good-sized job, and we believe that we have made progress toward a better integrated Department of Defense mapping, charting and geodetic program. Managing all of these activities is a world-wide enterprise and entails extensive coordination problems. We are assigned functions which require that our staff must be technically involved to fulfill the degree of management envisioned by the basic directive. Colonel Robert E. Herndon, who heads the Directorate responsible for the overall management function, and his staff, are vitally concerned with the many varied tasks involved in providing the best possible maps, charts and related products for all our military forces. I am sure that Colonel Herndon will indicate what is involved and how we go about providing maps, charts and geodetic products to include the type of effort required for display systems.

It may interest you to know that, in the Consolidated Intelligence Program of the Department of Defense, more resources in terms of dollars and manpower are devoted annually to mapping, charting and geodesy activities than to any other single functional area of intelligence. But perhaps of more interest and pertinence in the context of this symposium is the wider range of utility of the products emanating from our mapping, charting, and geodesy efforts as compared to other intelligence products. Whereas, the intelligence study or estimate is utilized at all echelons from our National Command Authorities down to field commanders and their staffs; maps, charts, and topographic displays must be responsive not only to the needs of the highest civil and military echelons of our government, but also through all echelons down to the individual pilot, navigator, and forward observer. Furthermore, the demands of today's conflict environment for more rapid maneuver and reaction impose a greater requirement for responsiveness in terms of both timeliness and quality. As the manager of the mapping, charting, and geodesy activities of the Department of Defense, DIA's goal is to improve our responsiveness. That is why we have such an intense interest in this seminar.

As you all know, the satisfying of a variety of requirements for the highly mobile air elements is a large undertaking in itself. These elements span the spectrum, from relatively slow-moving vehicles, such as Army helicopters, to the MACH-speed aircraft of the Navy, Marine, and Air Force--those that "skim the tree tops" and those that fly at extreme altitudes. Of particular note is the development of low-altitude tactics which has intensified the need for an effective navigation display system. In addition, to exploit the capability of high resolution surface-mapping radars, displayed map references must be developed and integrated with the radar systems. Both of these developments in air operations have made it increasingly important for the cartographic industry to become intensively involved in the system's development process.

For many years research and development of map display systems has emphasized the development of sensor devices, servo mechanisms, optics and projection systems, symbology, and computer design. These are all essential elements in a navigation display system, but in heeding the demands of these elements, system designers have paid scant attention to the earth-reference component of the system. Now earth-reference looms as a major system component that requires research and development attention.

Certainly the topics that are included on this three-day agenda provide the opportunity for exchange of information on many subjects involved in developing and producing aeronautical charts and map displays. I hope that each of you will take this opportunity to fully pursue these topics and any other related subjects with your fellow conferees. Our staffs in the Office of Naval Research and the DIA Directorate for Mapping, Charting and Geodesy (in fact, the entire DoD R&D community) want to benefit from your experience and thinking on these matters.

In consonance with the foregoing, we are pleased with the interest you have shown. The fact that you have come to this symposium is evidence that you also recognize a need for *exchange of information and understanding* between the cartographic community, the developers and producers of display equipment, and the ultimate users.

I am sure you experts within any one of these three categories know each other well, either personally or by reputation. But do you cartographers know the display people? Do you operators know the people who produce navigation aids for you? Do you understand each other's language? I mean the words that each of you use in your respective work, the technical terms, the scientific language of each discipline. This problem of communicating with each other is one which we in the Pentagon constantly face. As you know, DIA, like many other Department of Defense organizations, is staffed by Army, Navy, Marine Corps, and Air Force personnel and by civilians, most of whom have had their primary experience in one or the other of the Military Services. With these varied backgrounds, we often find it necessary to adjust our thinking; to bridge language barriers, both the lingo and the technical terms used in each Service; and to broaden our knowledge to encompass all the Services as we develop and establish policies or programs and provide for specific types of information or technical support.

I would think that you who are specialists in any one of the disciplines represented here would have a similar problem of communicating, not only in the language and technical terms used, but also knowledge concerning all the types of products and hardware with which you collectively deal. You may even have different interpretations of what should be a commonly understood basic requirement. Consequently, let me stress the need to know and understand each other in order to tackle the solution of our air navigation problems with a common and unified approach.

We hear much these days about systems engineering. It appears to me that this matter of solving the aviators' needs for a means of knowing where he is and where he is going, should be solved in somewhat of a systems-engineering manner. I am sure that the cartographers, the display engineers, and the aviators should work closely together in providing the pilot the best means of determining or knowing his geographic position. Your objective should be a joint approach to these problems. The cartographers should seek and apply the experience of the display engineers. The display engineers should do likewise. Also bear in mind that aviators are human beings who (like the rest of us) regardless of how much we are trained to see things alike, somehow see things differently. Consequently, the solution of what to include on charts and in display systems must provide for a degree of flexibility.

We have a lot invested in our airmen and the equipment they operate. They are a high-caliber people who have gone through extensive training. They operate complicated, elaborate, and expensive weapons systems in an environment that can be most hostile and difficult for most of us to fully appreciate. To develop the subsystems which provide what they must have--accurate geographic orientation at all times--is going to require the closest collaboration between all the respective expertise assembled here.

In short, to achieve effective map displays we need a multiple disciplinary approach to systems development. Specifically, the development of effective navigation displays requires the cooperative efforts of specialists in cartographic design and production, instrumentation engineering, display design, optical engineering, graphic arts, photographic chemistry, human factors, and air operations.

How you achieve the systems-engineering approach is for all to work out. This meeting is a start. I hope that you experts can provide the basis for developing the most effective navigation system for air operations.

OPENING REMARKS

Col. John Kelsey
Ministry of Defence
United Kingdom

May I first of all introduce myself and attempt to explain why I have the privilege of addressing this symposium. I am the Deputy Director in the Directorate of Military Survey in the Ministry of Defence in London. This Directorate is responsible for producing the maps and aeronautical charts required by the United Kingdom Defence Forces. I am therefore attending this symposium as a cartographer.

My visit to the United States was made possible by Capt. Gilchrist of the Office of Naval Research. I therefore found myself in an embarrassing situation at the Navy and Duke Football game last Saturday, since I did not wish to offend my hosts, the U. S. Navy, but on the other hand as a loyal Army man, I just had to cheer for Duke. However, I certainly wish to thank most sincerely Capt. Gilchrist and Dr. McGrath for making it possible for me to attend this important symposium.

It seems to me that the symposium will serve a most valuable function by providing a meeting ground for systems engineers, cartographers, research workers and users, and by providing a forum at which each group can explain their particular problems. From the cartographic viewpoint, the available resources are inadequate to meet the demands for mapping and charting--currently only about 20% of the land surface of the world is adequately mapped--and hence every new requirement should ideally be met by using the standard chart series. If this is not possible, the cartographic effort must be switched from producing and revising these standard series to meet the new requirement. Our further problem is the lack of standardization in the requirements for cartographic products placed on cartographic agencies by systems engineers.

On the other hand, I feel that too often in the past, the cartographer may have tended to dictate to the user the design of the chart to meet a specific requirement. Therefore, there is a need for research into the scientific methods of evaluating charts to establish if the existing charts really meet the requirements of the user.

Above all, I look forward to hearing the impressive list of speakers that Dr. McGrath has assembled and to discussing our mutual problems with the distinguished participants.

II
SYMPOSIUM PAPERS

CARTOGRAPHIC COMMUNITY SUPPORT OF AIR OPERATIONS

Col. Robert E. Herndon, Jr.
Assistant Director for Mapping, Charting, and Geodesy
Defense Intelligence Agency

I am greatly pleased with the interest and response from all of you to this symposium on Aeronautical Charts and Map Displays. I am sure we will all go from this meeting with a better understanding of the problems associated with air navigation, as well as a better understanding of each other and what we do. We are particularly happy that our Canadian and U. K. friends have made that required extra effort and are here to lend their support. We work very closely with them in pursuing our joint interests on cartographic programs, and I am especially glad that they could come for this meeting.

The Cartographic Community's support of air operations covers such a wide range of disciplines, specialities and techniques; such a variety of products, and so many organizations that I can only briefly summarize these subjects to give you a broad concept of what is involved. General Whitney mentioned in his address this morning, "This is a world-wide enterprise." I would like to add that it involves not only the Department of Defense, but also other Departments of the U. S. Government and agencies of a number of other nations. Actually, all cartographic and geodetic agencies in the world, that is, those of friendly nations and in some instances those not so friendly, contribute to the support of our air operations. My present position provides a keen appreciation for the extent of cartographic, geodetic and other activities that are in one way or another involved in contributing to the production of cartographic materials for air operations.

Later in this presentation, I will touch on the various types of technical activities involved; but, first, I believe you should know the structure and interrelationships of the U. S. Cartographic-Geodetic Community. Since my interests are primarily in mapping, charting and geodesy in Department of Defense, I will start with the DoD MC&G family and progress into our relationships with other United States agencies and the world community.

In the history of military cartography and geodesy, the Army has traditionally been responsible for carrying out surveys in the field and for the compilation and publication of topographic maps. The Navy has been responsible for hydrographic surveys and for the publication of the resulting nautical charts. With the advent of military aircraft, the Air Corps, and later the Air Force, began to produce charts for air navigation and various special graphics needed for delivery of airborne weapons. The development of carrier-based naval aircraft began to complicate the picture, since the Navy undertook production of air charts to support their own aircraft. Just before World War II, photogrammetry began to have a major impact on the production of maps and charts, and after the war it became evident that without some coordinating system, the three Services would waste considerable effort by duplicating basic compilation work in achieving their end-product responsibilities. Other coordination problems also began to appear. The advent of missiles brought the Air Force strongly into an area with which the Army had normally been principally concerned--the determination of the size and shape of the earth and the geodetic position relationships of major land masses.

The Polaris missile systems and the development of new navigation control systems also increased the Navy's interest in the field of Geodesy. The problem of coordination was first given attention when the Joint Chiefs of Staff, in 1949, set up a small coordinating unit in its Intelligence Directorate. Various studies of this coordination problem were undertaken by the Office of the Secretary of Defense as early as 1953. The most recent of these was in process about the time that the Defense Intelligence Agency was being established in 1961. Apparently, within the huge DoD organizational structure, mapping, charting, and geodesy was not of sufficient stature to warrant establishment of a separate Defense Agency, so the Secretary decided to assign the function to DIA, even though it differs considerably from the Agency's other responsibilities. After consideration of the problem, it was the Secretary's decision that it would be too disruptive to bring all of the production activities into DIA. As a result, he decided to leave them with the Military Departments and with the Service components of the Unified and Specified Commands, assigning DIA the responsibility for maintaining management control over all Defense activities of this type. DIA was to utilize the capabilities existing in the Defense components to meet the total DoD requirement as effectively and economically as possible.

This simplified chart (Figure 1) portrays our relatively complex operation. The technical facilities represented in the figure, some of them the best of their kind in the world, include precision photographic laboratories, advanced photogrammetric instrumentation centers, major computer centers, major lithographic printing plants, a world-wide depot system for storage and distribution of maps and charts, a fleet of aircraft specifically designed and equipped for precision aerial surveys, a fleet of hydrographic survey ships, and scores of support aircraft and special purpose survey vehicles. Our main production plants in the United States are largely civilian manned, operating under military command. Among the technical skills which we employ, in addition to geodesists and cartographers, are engineers, photogrammetrists, geographers, hydrographers, mathematicians, astronomers, surveyors, graphic arts specialists, and cartographically trained air survey pilots and crews.

The dashed line in Figure 1 indicates the management control channel from DIA to the production facilities in the Departments and Commands. In the Army, the Chief of Engineers, General Cassidy, through his Director for Topography and Military Engineering, General Hayes, is our point of contact. General Hayes supervises the activities of the Army Map Service, as well as those of the Geodesy, Intelligence, and Mapping Research and Development Agency (GIMRADA). In the Navy, Admiral Waters, the Oceanographer of the Navy, is also the Commander of the Oceanographic Office. In the Air Force, the Assistant Chief of Staff for Intel-

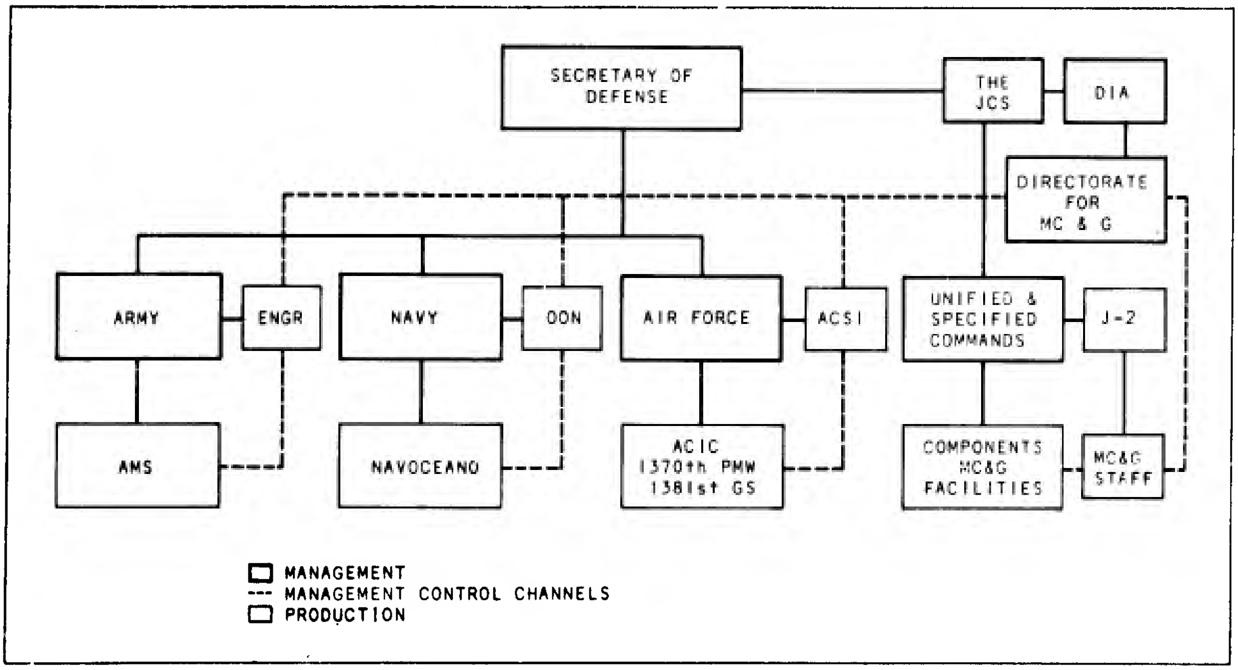

Figure 1. Simplified organizational chart showing the role of the Defense Intelligence Agency (DIA) in Mapping, Charting, and Geodesy.

ligence, General Thomas, is our point of contact. I will describe only very briefly each of the production agencies. If you have questions about any of them, I will be glad to answer them to the extent that I can.

The Army Map Service, which has about 5,000 employees, has its main plant in Washington and field offices in San Antonio, Kansas City, Louisville, and Providence. The primary function of AMS is the production and distribution for topographic maps and related publications. AMS also operates field survey organizations in Iran, Ethiopia, Libya, and Liberia, and geodetic satellite tracking teams which operate world-wide. The Army Map Service also operates the Defense Topographic Map Library and the Geodetic Data Library.

The Naval Oceanographic Office at Suitland, Maryland, employs about 1,650 people and its primary function is the production and distribution of nautical charts and related oceanographic and hydrographic data. The Oceanographic Office directs the operation of the Navy survey ships to acquire oceanographic and hydrographic data throughout the world. They also operate the doppler tracking stations in the satellite geodesy program. I should mention that DIA does not have management cognizance over *all* activities of the Oceanographic Office. Oceanographic surveys and studies not directly related to hydrographic charting or other aspects of mapping, charting, and geodesy are not under our management control.

The principal cartographic production agency in the Air Force is the Aeronautical Chart and Information Center at St. Louis with about 4,200 people. Primary function of ACIC is the production and distribution of most of the air navigation charts produced by the Department of Defense, although some are published by the Oceanographic Office for Naval aviation. ACIC is also producing the Department of Defense Flight Information Publications. In addition to its main plant, ACIC has air information offices and chart depots in Japan, Hawaii, Germany, Alaska, and Panama. The Air Force also operates, under the control of the Military Airlift Command (the new name for MATS), the 1370th Photo Mapping Wing with headquarters at Turner Air Force Base in Albany, Georgia. The 1370th has the specific mission of flying cartographic aerial photography and airborne electronic control systems needed for mapping, charting, and geodesy. Under the 1370th, Air Force also operates the 1381st Geodetic Squadron now located at Francis E. Warren Air Force Base in Wyoming. The 1381st carries out the precise surveys necessary to connect the Inter-Continental Ballistic Missile (ICBM) sites to basic geodetic control to achieve weapon positioning and orientation. The PC-1000 camera stations for optical tracking of geodetic satellites are also operated by the 1381st.

A part of the mapping, charting, and geodesy production capability of the Department of Defense is assigned directly with the field combatant commands, such as the European Command, the Pacific Command, and the Southern Command, and, of course, with the Strategic Air Command. These production activities provide the commander a capability for immediate local cartographic and geodetic support. There are also some activities assigned to the commands for reasons of their geographic location. For example, the U. S. Southern Command supervises the activities of the Inter-American Geodetic Survey, which operates in most Central and South American countries, carrying out a long-range survey program which is not in direct support of command operations. As you can see on this organizational diagram (Figure 1), each commander has a mapping and charting staff at his headquarters level which maintains management control over the production capability assigned to the Army, Navy and Air Force component commands. None of the production facilities are operated at the Unified Command headquarters level. The extent of this production capability assigned at each command differs between commands. However, the majority of our production work is still performed in the three principal agencies--AMS, NAVOCEANO and ACIC, and through contracts which each of these agencies have with commercial firms. The units assigned to the overseas commands are generally concerned with printing and distribution problems.

Now, I'd like to describe the concept of the DoD management system. This is a list of the five major management phases through which DIA carries out its mission. These are the steps that you would normally expect a management agency to follow in doing its job. The significance of these management steps comes from the fact

MAJOR PHASES OF MANAGEMENT
1. PRODUCT REQUIREMENTS VALIDATION 2. AREA REQUIREMENTS AND PRIORITIES VALIDATION 3. INTEGRATED PROGRAMMING AND BUDGETING 4. EVALUATION OF PERFORMANCE AGAINST PROGRAM AND COST OBJECTIVES 5. TECHNICAL PROCESSES IMPROVEMENT

that it represents a major change in cartography and geodesy in the Department of Defense. While maps, charts, and geodetic data have, for many years, been common Service items; that is, the map produced by the Army is used widely by Navy and Air Force and vice versa, the design of products and the determination of what products should be made have largely been based upon a determination of the need of the Military Department carrying out the production. Because of this, slight differences in user requirements frequently resulted in similar products being produced by two or more of the Services. This was not only a wasteful practice, but it frequently resulted in the operational use of maps and charts which failed to meet all Defense requirements. Today, DIA validates the need for products against all potential uses for DoD weapons systems and operational needs and only those products authorized by DIA can be produced. The products are produced according to specifications we approve to meet the total Defense requirement.

In the second step, I'm sure you realize from your experience that the functions of mapping, charting, and geodesy are so expensive that even with the significant improvements that have been made and are continuing to be made in techniques and equipment, it just isn't possible to cover all of the world in a short time. We must, therefore, establish a guide for programming our production resources to make sure that we apply them to covering the geographic areas where Defense interests are most likely to be directed. DIA now operates a system for gathering from all the military planners in the field commands and in the Service general staffs their best analysis of the need for maps, charts, and geodesy to support the various military plans on which we base our Defense posture. This analysis of requirements and resulting recommended priorities is cleared with the Joint Chiefs of Staff, who have the final word on our military planning. After approval by the JCS, it becomes the basic guidance for programming production.

The third and fourth steps in our management function are standard steps --the control of the resources, and the review of performance against production goals. Under DIA management, the Department of Defense now reviews all of its mapping and charting programs and budgets together to eliminate gaps and to discourage unnecessarily overlapping activities. We can reasonably assure the Congress that we are planning the most effective use of the resources which we must seek each year.

The fourth step is the normal manager's "look see" to make sure that the program objectives are being accomplished, and, if they are not, to direct the necessary corrective action, including adjustment of work assignments.

I needn't emphasize to you the importance of the fifth step--the improvement of techniques and equipment, because you must be aware that a technological revolution is taking place in mapping, charting, and geodesy as it is in other technical fields. Research and development for mapping and charting in the Department of Defense is now a 50-million-dollar-a-year item. There are also many millions being spent by industry and by civil agencies with which we must coordinate our Defense research and development. The Director of Defense Research and Engineering (DDR&E) actually manages all Defense research and development, including that for cartography and geodesy. The DIA job is to establish the requirements and priorities to assure that research and development is planned to keep ahead of production-line requirements. DIA also provides technical support to DDR&E in monitoring the progress and effectiveness of mapping, charting, and geodetic research and development projects, and follows up to make sure that the results are effectively incorporated into the production agencies across the board.

Now that I've gone through the basic management principals that we employ, I'd like to show you how mapping, charting, and geodesy management fits organizationally into the Defense Intelligence Agency. A simplified chart of our Agency is shown in Figure 2. You can see that the Directorate

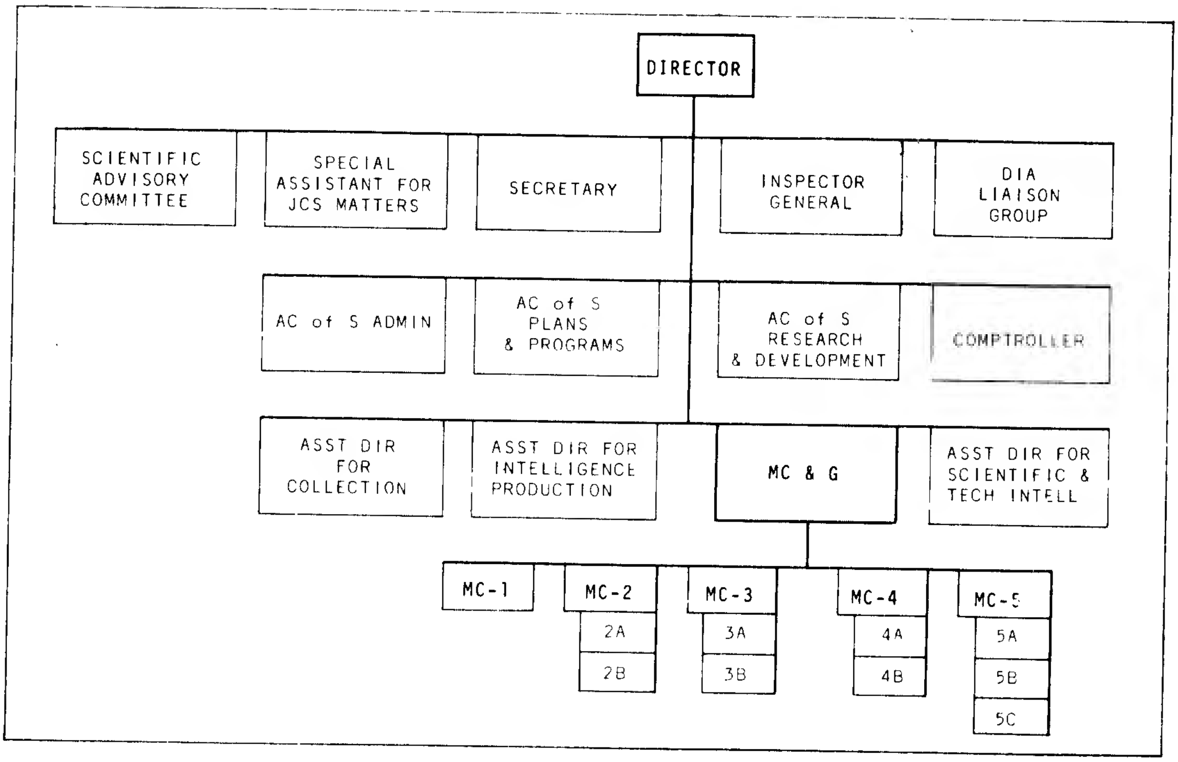

Figure 2. Simplified organizational chart showing the Directorate for Mapping, Charting, and Geodesy (MC&G) within the Defense Intelligence Agency.

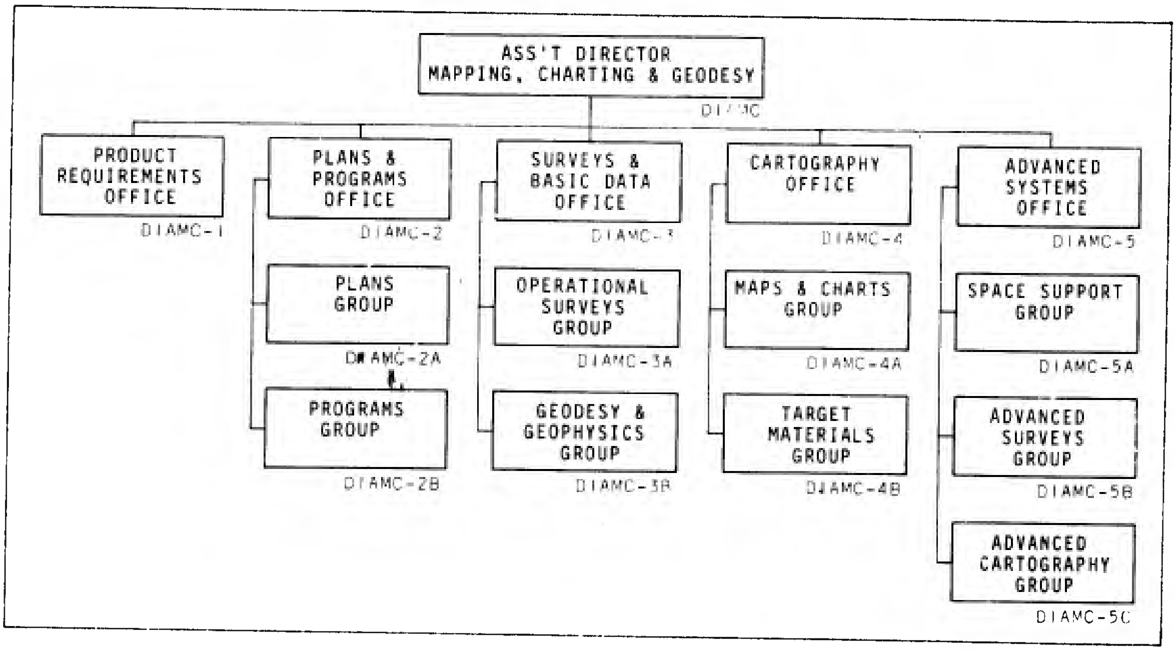

Figure 3. Simplified organizational chart of the DIA Directorate for Mapping, Charting, and Geodesy.

for Mapping, Charting, and Geodesy (DIAMC) is a line element, even though all of its production operations are carried on outside the Agency. We have no in-house production capability.

As you can see from Figure 3, our Directorate is organized on the basis of the management tasks that we have to accomplish rather than on the basis of a product/Service breakdown. We are a Defense agency with a jointly manned team which means that we have officers from all of the Military Services. Our military grade structure ranges from Brigadier General to Major with most jobs at the Colonel and Navy Captain level. In each of the offices, we have a senior civilian professional as deputy chief and all of our professional civilians come from long service in mapping, charting, and geodesy agencies of the Military Departments. We have no depth in numbers in any of our functions. We must, therefore, depend to a large extent on the production agencies for technical staff support and for training personnel for assignment in DIAMC.

DIAMC-1 validates requirements for all types of maps, charts, and geodetic products; establishes specifications; and handles standardization of products between DoD and other government and international organizations. DIAMC-2 establishes area requirements and priorities, provides security policy, monitors mobilization planning, international activities, and performs program and budget functions. DIAMC-3 and DIAMC-4 are the production management organizations. The titles of the groups under these two offices describe the kinds of production operations which are supervised in each of these offices. DIAMC-5 has the research and development function.

Let's now examine the kind of a program we're managing. While it is a world-wide operation (and some extraterrestrial as well), the Department of Defense depends largely upon the Department of Interior, U. S. Geological Survey, and the Department of Commerce U. S. Coast and Geodetic Survey for meeting Defense cartographic and geodetic requirements for areas of the United States. We have extensive standardization, coordination, production, and exchange arrangements with the other Departments of the United States Government which perform cartographic and geodetic work. Consequently, practically all Defense cartographic and geodetic effort is applied to non-U. S. areas.

The most effective way of making maps and charts anywhere is, quite naturally, to have access to the area being mapped. In foreign areas, this is normally achieved through cooperation with the cartographic agencies of the country concerned. Although we must, and do, make maps and charts of many areas where such access is impossible, we have mapping and charting agreements with most of the countries of the free world. The scope of these agreements varies from country to country. Under some of the agreements, such as that with Libya, the United States has performed all phases of the aerial and ground survey and cartographic and geodetic production with the host country having very little, if any, cartographic capability. In others, such as Thailand, the U. S. effort has included assisting the country's cartographic agencies by providing training and assistance in modernizing their facilities, with a sharing of the mapping work between our U. S. production agencies and the national agency. In the most progressive countries such as those of the North Atlantic Treaty Organization (NATO), most of our requirements are met by the products of the foreign country's national agency. These agreements, essential to doing a sound cartographic and geodetic job to meet U. S. Defense preparedness needs, at the same time provide a significant contribution to the development of world cartographic and geodesy capabilities. The resulting data are already providing a big boost to the national development of many of these countries.

Most of our agreements operate at the agency level--Army Map Service to Royal Thai Survey Department for example--but the policies are established by State Department, by the Assistant Secretary of Defense for International Security Affairs, and by DIA. We are attempting to consolidate agreements so that we won't have two or three Defense agencies contacting the same foreign agency for data.

The various international professional and scientific societies in our field, including the International Society of Photogrammetry, the International Cartographic Association, the International Union of Geodesy and Geophysics, and the IAG have done a great deal to stimulate the exchange of data on techniques and the development of compatible data systems throughout the world. There is in this area a great deal remaining to be done. With the advent of automatic equipment and the application of computers to cartography and photogrammetry, international standardization is becoming a most important key to progress. The United Nations has also begun to have an impact on progress in cartography and geodesy through its regional conferences and its studies for establishing regional centers. In the Western Hemisphere, the Pan American Institute on Geography and History (PAIGH) has provided this base for international cooperation. It was through the auspices of the PAIGH that the Inter-American Geodetic Survey was established and has prospered in its work in Central and South America. We encourage active participation by the Department of Defense agencies in these international organizations and their work. While the results of a part of our Defense cartographic and geodetic effort must be kept under security control for obvious reasons, and sometimes because of the wishes of the country with whom we are cooperating, the vast majority of the data and maps and charts produced by our organizations are unclassified and provide fall-out products which can be applied directly to meeting the economic and scientific needs, as well as the Defense needs, of the country concerned.

In my opening remarks, I said I would touch on the various types of technical activities involved in meeting the requirements of air operations. Actually, it is safe to say that all types of cartographic and geodetic activities are required to support air operations. For example, traditionally, geodetic surveys are associated with the need to establish control for topographic maps. This is a basic requirement for ground forces. However, if this requirement did not exist we would still have to establish control for cartographic products required for air operations. Additionally, many of today's air navigation and weapons systems require direct geodetic coordinate data inputs for the delivery of their payloads.

Here is a very basic list of types of geodetic and cartographic activities that are involved in one way or another in our community support of air operations. I could spend several hours talking only about geodetic surveys; i.e., the various equipment used, the techniques, systems, programs, developments (such as use of geodetic satellites), and the direct application to various types of aerospace weapons systems.

TYPES OF ACTIVITIES INVOLVED IN SUPPORT OF AIR OPERATIONS

1. GEODETIC SURVEYS.
2. GRAVIMETRIC SURVEYS.
3. PHOTOGRAPHIC SURVEYS.
4. TOPOGRAPHIC SURVEYS.
5. HYDROGRAPHIC SURVEYS.
6. MAGNETIC SURVEYS.
7. REDUCTION OF ALL TYPES OF SURVEY DATA.
8. RESEARCH AND ANALYSIS OF SURVEYS AND MAPS.
9. PHOTOGRAMMETRIC COMPILATION.
10. TOPOGRAPHIC COMPILATION.
11. ACQUISITION, ANALYSIS AND COMPILATION OF AERONAUTICAL DATA.
12. DRAFTING, SCRIBING AND ARTWORK.
13. PROCESSING AND COMPILING GEOGRAPHIC PLACE NAMES.
14. PHOTO-COPY.
15. LITHOGRAPHIC REPRODUCTION
16. DISTRIBUTION OF PRINTED CHARTS OR DATA.

Each one of the activities listed here is likewise a topic which can be similarly discussed at length and which demands considerable effort in the support of air operations. This list is only a condensation of the type of information, data, and subject matter that is involved in providing to the aircrews the capability to navigate to selected geographic positions. It represents the type of work the cartographic-geodetic agencies accomplish to support not only air operations but all our military forces. This brings me to another facet of our endeavors which I want to be sure is understood.

The data acquired through each of the various types of surveys have one common denominator in that they all apply to the derivation of positions or to locating objects on the earth's surface. Also, while these surveys are accomplished as separate functions, the resultant data must be tied together to be of value in establishing or identifying a location on the earth's surface. Consequently, the combining and reduction of raw surveyed data into basic formulae for determining positions and for relating physical objects to these positions is required to produce what may be termed a basic compilation. It is as though we tossed the results of all types of surveys into a hopper and a mixing bowl sorts and digests all geodetic, topographic, photographic, and other basic information into a form from which we can derive any type of product desired. From this basic source we select the particular information to fit the design of a map, chart, or other product to satisfy a specific requirement. Currently, we have about 300 different general types of products required for various uses by the military forces. Of those 300, somewhat less than half are for use in or support of air operations. These include aeronautical charts at various scales, electronic navigation charts, target charts, geodetic data sheets, flight publications, special film strips and related computer programming tapes, and many others.

My objective in talking to you this morning has been to give those of you who are not directly involved in cartographic-geodetic activities some concept of what the military cartographic-geodetic community is and the type of work it does to support air operations. Please consider the Directorate for Mapping, Charting, and Geodesy of DIA as a point of contact and also as a point of departure into any detailed investigation for solving navigation problems. Our staff is established and has the technical capability to monitor and direct any action regarding these problems. Now, are there any questions that I can answer during this allotted period?

DISCUSSION ABSTRACT

Dr. Miller: In view of the wide scope of your programs, I would be interested in knowing how they are selected and scheduled. Can you tell us what types of people evaluate proposed programs and decide which ones will be pursued? Can you also tell us what criteria are used for establishing priority?

Col. Herndon: You couldn't have selected two better questions to kick off a very difficult response. I believe you addressed your first question to the type of people who evaluate requirements. It may surprise you to know that Captain Folsom, the Chief of the Requirements Office, has had virtually no previous experience in cartography. His selection was based on that fact. The people that we want in our Requirements Office, we feel, should have a full understanding of the user's point of view. We can provide the cartographic technical support from the other personnel in the organization, but for the Requirements tasks we want people that have been exposed recently and extensively to the operational aspects of the use of our products. We have airmen, we have experienced people from the Navy, the field artillery, the infantry, and so on. We want those who have an understanding of the operators' viewpoint and good rapport with those operators to be the intermediaries between the cartographic agency and the user. As soon as the user has described the kind of product that he thinks he needs, then the technical work begins to convert this statement into specifications for the end product that the user really had in mind. That function will be described later by Loren Bloom.

The second part of your question asks how relative priority is established. This is a difficult problem because there are almost always two aspects of priority. First, what is the priority of this kind of chart to some other kind of chart? Second, what is the priority of the areas that should be covered by this chart? We rely heavily upon the Unified and Specified Commanders, who control the bulk of our tactical or military users of the end products, to express to us their requirements for *types* of products by priority, by *areas*. And it's from the collation of their inputs that we establish the overall priority recommendations which are in turn furnished to the Joint Chiefs of Staff for approval. If you'll excuse me, I won't attempt to go into the factors that establish the priority either of products or of areas. The priority of products is difficult enough; the priority of areas is even more difficult to assess. May it suffice to say that we now have a recently issued paper, controversial, of course, which attempts to define why priorities of various geographic areas are established the way they are. The paper has already created some discussion in the Joint Chiefs of Staff and probably will create more; but we need just such a statement for our guidance. I hasten to add that this particular priority-guidance document is for a longer range period; the present production document is different because it must consider the present availability of source materials. In other words, it doesn't really make much difference how high your priority is for a given kind of sheet for a given area if you do not have all of the source materials from which to produce it.

Mr. Campbell: One of the greatest problems in cartographic support for navigation displays is the inability of the operational user to state a requirement for a device he doesn't know he is going to get. Would you care to comment on the lines of communication open to the system designer into DIA, directly from the military service departments or otherwise?

Col. Herndon: The thrust of your question is: since we rely heavily on unified commanders for the expression of requirements, what system is employed to introduce and accommodate the requirements of new weapons systems which the unified commander is not yet aware of? Well, there are two approaches to this. First, within DIAMC we have responsibility for following the development of new weapons systems and trying to convince those who are responsible for that development to include an early recognition of the need for cartographic or geodetic inputs. If developers fail to recognize this need, serious problems are bound to ensue, because they inevitably come up with some non-standard size or scale which is not consistent with the products we could prepare for them. They may base their designs on requirements that cannot be precisely met: for example, a guidance system which is dependent upon very precise magnetic data, something that we cannot provide over the Sino-Soviet area. This goes on ad nauseum So, our own in-house office attempts to follow the research and development program, looking at each new system as it comes along, to determine whether or not they can predict a requirement for cartographic or geodetic support. If they can predict one, then they go into that particular development area, into the Special Projects Office, or whatever it might be, to determine what requirements might be expressed and to give guidance early in the development stage.

There is a second approach to the problem. The directive, which established our responsibilities in DIA, also charged the departments and the Unified and Specified Commands with responsibilities for stating their research and development requirements. The research and development functions are all still with the departments, not with DIA. So there is a double-barreled approach in each of the departments: responsibility for accomplishing a research and development project and the responsibility for stating research and development requirements. So both of these should act to cause the department to recognize and to express their requirements for new cartographic products.

Dr. McGrath: Col. Herndon, would DIA also develop the cartographic requirements for map-display systems being developed by private industry?

Col. Herndon: It's not likely that DIA would become involved unless private industry has recognized the cartographic or geodetic significance *and* comes to us with an indication that they're developing something along a particular line and asks for comments or advises us of what's going on. For example, a navigation guidance system could be developed commercially without our knowing of it because it has never been brought to the attention of a prospective military purchaser. My pet peeve is, however, that so many times these proposals are made to military agencies by commercial organizations before there is any hardware development, while the development is still a concept, and the military agencies still do not bring the cartographic/geodetic problems to our attention until after the hardware development is well down the road and the cartographic/geodetic support is thus more difficult to achieve.

Dr. McGrath: Could a private industry go directly to DIA if they anticipate a need for special cartographic support, or must they go through the military agencies?

Col. Herndon: Yes, they should come directly to DIA if their anticipated "support" is something *other* than a standard product which is already being produced. Now, with regard to support, we will be glad to give them an ear, listen to their proposal, their concept, and tell them what we can do in terms of the cartographic/geodetic support already available or the possibility of providing it at a later time.

Mr. Erickson: You say it is desirable to contact DIA for information during the conceptual and early development stages of aircraft/weapons systems when cartographic requirements are indicated. Who is the contact and what is his address?

Col. Herndon: In addition to my responses to the preceding four questions, I would add the following specific information:

Matters concerning operational or developmental requirements for cartographic or geodetic support can be directed through normal command channels to DIAMC addressed as follows:

Defense Intelligence Agency
Assistant Director for Mapping, Charting and Geodesy
Washington, D. C. 20301

They will be referred to the proper elements of my office and if appropriate to the elements of the OSD (Office of the Secretary of Defense) and to the Departments for further inputs or actions.

Service organizations operating under the Military Departments will communicate through the Departmental MC&G staffs (point of contact) to DIAMC. Department MC&G staffs are as follows:

Chief of Staff
Department of the Army
Washington, D. C. 20315
ATTN: COFENGRS (D/T&ME)

Oceanographer of the Navy
Department of the Navy
Washington, D. C. 20390
ATTN: OON

Assistant Chief of Staff, Intelligence
Department of the Air Force
Washington, D. C. 20330
ATTN: AFNINCB

Service organizations attached to a Unified or Specified Command will communicate through that Command's MC&G staff to DIAMC.

System designers not associated with a military contract or project may obtain advice and consultation by direct communication with DIAMC.

The system designer of any organization in the Military Services or otherwise may informally contact members of the DIAMC staff for information, advice, or consultation.

It is important that systems development agencies and DIAMC collaborate during the conceptual and development stage of aircraft/weapon systems. This is essential to assure that any indicated cartographic requirements are in consonance with available MC&G capabilities or to indicate where R&D actions are required for mapping, charting and geodetic equipment, materials, and facilities to support new requirements.

Mr. Wolin: If we have a specific requirement for cartographic support of a weapons system--let us say, for example, a requirement for some non-paper material on which to print maps--how long would it take DIA to go through an R&D process? How much lead time would you need, and how would you proceed?

Col. Herndon: If you have a new requirement, how long does it take DIA to come up with a solution in meeting that requirement and how is it done? Well, in the first place, we within DIA aren't going to do it because we do not have these kinds of resources in-house. If it's a research and development project, the procedures for doing it are very clearly established. If you came along with a weapons systems development contract and you need assistance in finding a specific cartographic or a display organization to help you develop the cartographic support, the approach is through DIAMC. We will also help you find support in DDR&E or in ARPA, the Advanced Research Projects Agency. Your biggest problem probably will be to find the funds, if you haven't already programmed them, for the R&D effort. You will also have the problem of being sure that a separate or independent development of a cartographic product is really compatible with the weapons system with which you intend to use it. So in most cases, you should plan to develop your cartographic components along with, and as a part of, the overall development package which involves the basic weapons system. All we're saying is that when special cartographic development seems necessary, for goodness sakes let's look at all of the things that are available, let's evaluate the difficulties of having different or unusual scales, unusual sizes, unusual materials, different approaches to production of information, to be sure that they are within the state-of-the-art or to be sure that we can adjust our program to adequately accommodate them without a crash effort at the last minute. Please recognize that in many cases weapons systems have gone into the field without the necessary cartographic or geodetic support to properly provide for their full effective utilization.

Dr. Wright: I was quite impressed with your comment that you had approximately 300 general types of products, one half of which were used in air operations. Obviously, you have to reduce the number of such products to the absolute minimum. What procedures do you use in deciding on what types of products will actually be produced?

Col. Herndon: That's a very simple question. It's resolved for us primarily by the Congress and the Bureau of the Budget, every year. I think one thing you need recognize is that many products once completed, once established as an operating requirement, are carried on by a maintenance program. When the initial cost have been written off, so to speak, the item can be carried at a much lower cost in a maintenance mode. Many of the items are special items that are produced by contract on an initial basis. These are then ultimately carried through the maintenance cycles either at the DoD production agency or, in some cases, by the Unified and Specified Command resources. SAC, for example, produces special simulator mats or plates to provide inputs to their simulator devices. These are separate, individual products. They're not in the general run-of-the-mill in which we must be personally involved on a day-by-day basis. How you establish a relative priority is again pretty much a matter of the priority and significance of the system. It involves the number of other product support items that are requested and the scope and duration of the requirement. For example, we would not turn down under any circumstances a logical requirement for cartographic or geodetic support of an approved new weapons system, but we could turn down a one-time request for a relatively small item, or a relatively large item for that matter, if it did not have some direct association with the operational requirement of a unit or a weapons system. In other words, if it falls into the category of nice-to-have-but-not-absolutely-necessary, then it's going to fall by the wayside under the pressure of our work load in the higher priority items and the work load of large geographical areas of coverage.

THE NAVIGATION CHART AS A DESIGN ELEMENT OF AN INTEGRATED AVIONICS SYSTEM

Eric S. Guttmann
Technical Manager, Electro-optical Systems
ITT Gilfillan Inc.

INTRODUCTION

Next to the printed book, the map or chart is perhaps the greatest visual communication tool ever invented. It orients you on earth in any detail you wish, it is internationally useful, and it can be mass produced inexpensively.

Yet in modern aviation, the advent of the supersonic multimillion-dollar aircraft with its complex avionics system has created the need for mechanizing the navigation chart beyond its traditional paper format. A new type of war requires rapid and intimate geographic orientation of a pilot who has no time to waste on an unwieldy format. He wants a present-position display with a computerized moving chart rather than a primarily synoptic chart which he must scan to place himself.

HORIZONTAL SITUATION DISPLAYS AND THEIR CHARTS

A solution is offered by the so-called Horizontal Situation Display. This device is essentially a computer-servoed navigation chart which tells the pilot at a glance where he is and where he is going. From a multitude of early developments, a few basic types have emerged gradually. I will describe them briefly by means of representative examples, and I hope to be forgiven if the list of names which I will give is not complete.

Direct-View Chart Displays

In the first group, a bug representing the aircraft moves over a fixed chart which is centered on an intermediate or on the final destination (Figure 1). This display is simple in design, is most useful for terminal navigation, and requires the preparation of a series of special terminal charts which are inserted individually. These instruments are offered by AC Electronics, Lear Siegler, Sperry, and ITT, among others. A Bureau of Naval Weapons version is described in MIL-D-23863.

Another class of displays is the so-called roller map (Figure 2) which uses a strip map, representing a flight corridor. The strip progresses underneath a cross-moving, present-position pointer which may also be a flight recording pen. Simple versions use a long chart-strip which is tailored from common paper charts, unless their repetitive use in commercial navigation justifies special printing. To overcome the mission dependence of the strip chart, other versions cut conventional area charts into North-South strips, which are then put together serially. These instruments, first developed by the Decca Navigator Company in England, are now offered by Bendix, LFE Electronics, Lear Siegler, Applied Sciences Industries, and others.

Projection Displays

In contrast to instruments which view the chart directly, a second group of horizontal situation displays uses it in the form of a microfilm that is reproduced full scale on a rear-projection screen. Microcharts can swallow wider geographic areas and obviously need not favor one wind-rose direction to the disadvantage of the one at right angles to it. They are therefore more useful in omnidirectional tactical mission planning when coping with a highly mobile and evasive enemy. On the other hand, they complicate the instrument design with optics.

One group of moving-chart projection displays uses either 35mm or 70mm film strips. I mention the MA-1 Display by Hughes Aircraft, used among others in the F-106, and similar displays by the Royal Air Force Establishment and Ferranti in England, Computing

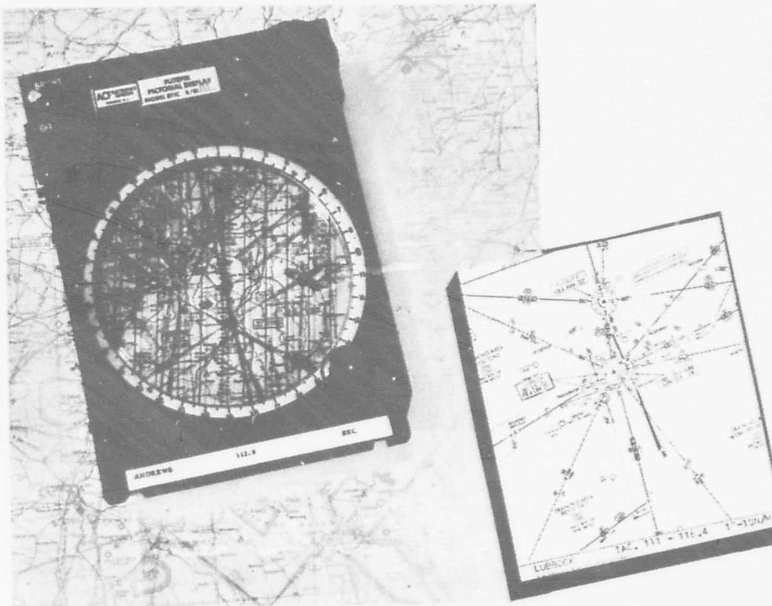

Figure 1. Flitefix Pictorial Situation Indicator.

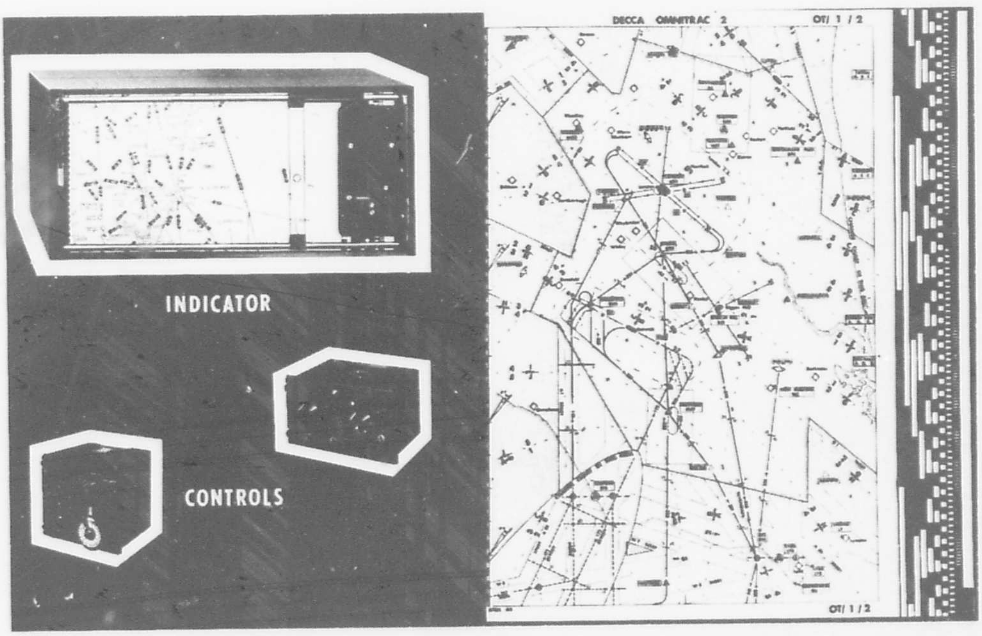

Figure 2. Roller chart of General Precision, Decca Systems.

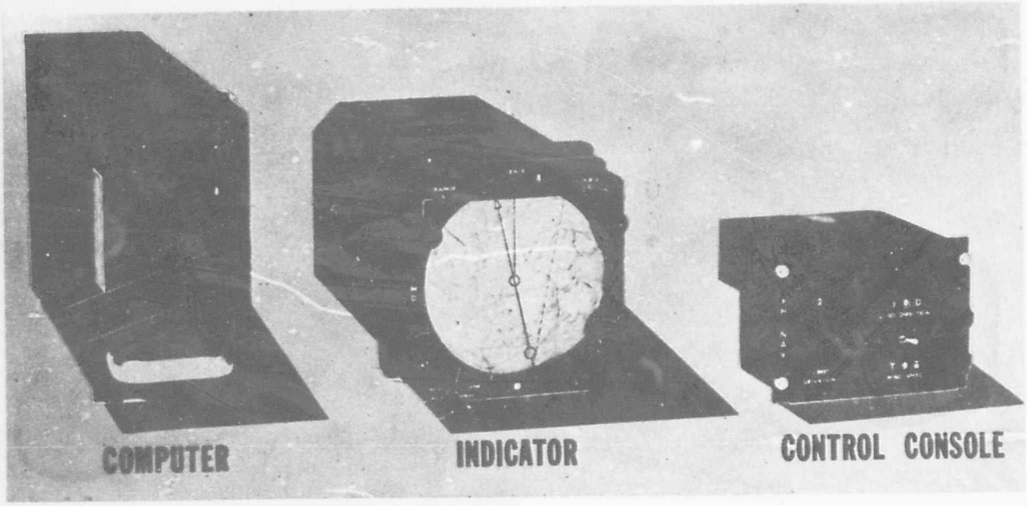

Figure 3. "TOPOMAP" produced by Computing Devices of Canada.

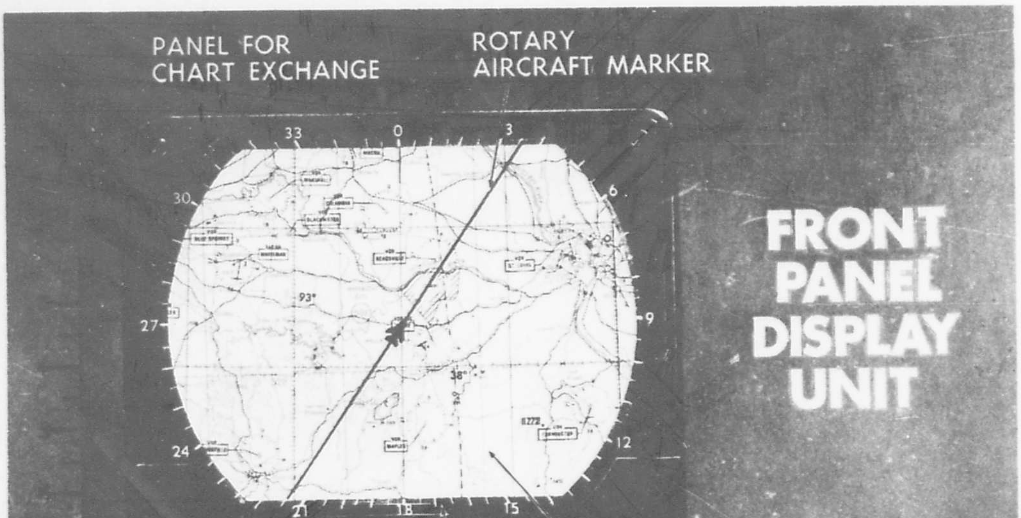

Figure 4. Front panel display unit of the AN/APA-115 of ITT Gilfillan.

Devices of Canada (Figure 3), Douglas Aircraft, and ACF Electronics. We will hear more about them tomorrow.

A second type of horizontal situation displays, represented by the AN/APA-115 of ITT Gilfillan in Los Angeles, uses, instead of a film strip consisting of a sequence of microchart frames, one or several microchart chips which are inserted into a cylindrical chart carrier drum and can be exchanged conveniently (Figure 4).

Integrated Displays

The problem with all these displays is the space limitation of the cockpit instrument panel on which more instruments than ever struggle for the attention of the pilot. With today's advanced avionics and weapon systems the pilot has to master many information inputs almost simultaneously. The moving chart furnishes only background to navigational, mission, target sensor and weapon information (Figure 5). The JANAIR program recognized years ago that in order to earn its place in the crowded cockpit the horizontal situation display must perform multiple chores. It thus created the concept of the integrated display as part of an integrated avionics system. JANAIR was first to call for a combination of electronic cathode-ray tube (CRT) imagery of the immediate tactical environment as acquired by sensors with the navigational situation as represented by the computerized moving chart.

As an integrated display, therefore, the roller map uses a transparent chart strip which is servo-motored in front of a CRT face. This chart strip presents all information in the horizontal plane as generated by sensor and computer data in register with or as an alternative to the chart

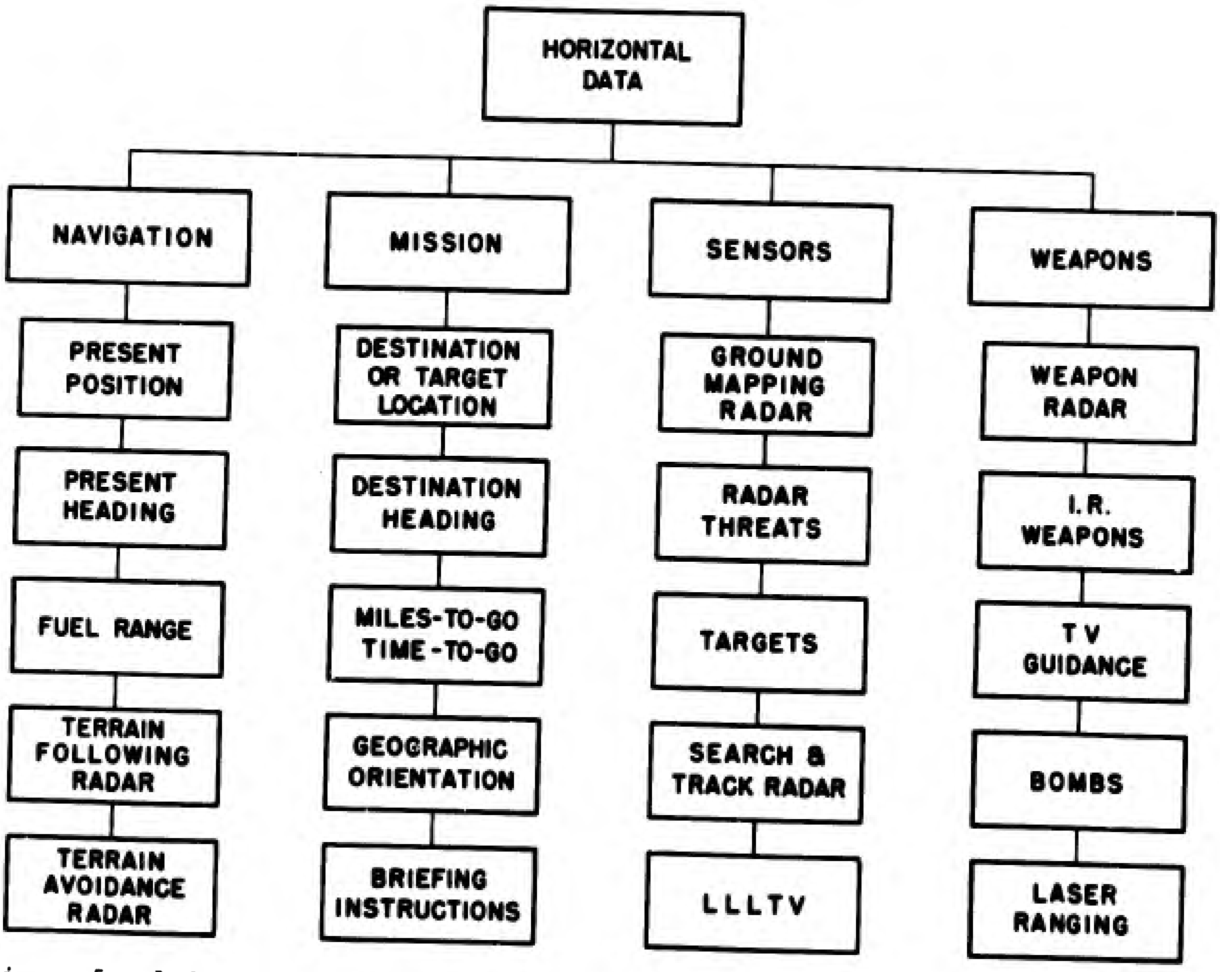

Figure 5. Information that may be provided by a horizontal situation display.

present position. Displays of this nature will be used in the IHAS (Integrated Helicopter Avionics System) under development at Teledyne in Los Angeles and in the ILAAS (Integrated Light Attack Avionics System) under development at Sperry in Syosset, Long Island.

My firm, ITT Gilfillan, has developed an integrated display of the projection type (Figure 6). Its face shows a moving chart underneath a centered, rotating, aircraft marker which interplays with directional information on a peripheral compass rose. The information generated by a direct-view storage tube is projected in register with the chart, as shown in the schematic of the optical system (Figure 7). The display uses a dual projection system for chart and CRT and a beam combiner for a common image. The chart beam is modified by servo-motored reticles and a servo-motored rotation prism with the result that the chart image also shows the shadow of a compass rose with cursor, and that the pilot can rotate the screen image at will, to be either North or forward oriented. This instrument, called the AN/ASA-61, is under development for the Air Force 666A Program for high-speed, low-altitude flight.

CHART REQUIREMENTS

The state-of-the-art of moving chart displays, which I have tried to outline, gives you an idea of the tremendous chart problem under consideration by this symposium. The full-sized terminal or strip chart and the microchart, be it as strip or as chip (Figure 8), form a new requirement which obviously can be a first-class logistic bottleneck in the increasingly dense air traffic of the future or in any coming military conflict, if its operational, logistic, and technological problems, now in flux, are not solved in step with existing hardware requirements.

Starting with the operational problem, we must consider the new chart formats for their utility in tactical planning and in tactical use. If we realize the enormous labor and care going into every individual chart, we must also appreciate the additional logistic problems of having the right chart available at the right time. Finally, a chart concept once primarily graphic must now be integrated into a computer-oriented avionics concept, which poses new technological problems to be considered.

Operational Problems

Our political commitments, paralleled by the increasing range of our carriers and our aircraft, require a worldwide concept of strategic and tactical planning. A strike force, for instance, must be ferried to strike bases anywhere and be ready for immediate strike. Low-altitude missions over Viet Nam today and possibly over the vast territory of China in the future require intimate and detailed knowledge of the earth texture.

It is usually agreed that both high-altitude enroute charts and low-altitude mission or target charts are required. This covers the chart scales from 1:2,000,000 to 1:250,000 of the well-known JN (Jet Navigational), ONC (Operational Navigational Chart), PC (Pilotage Chart), and AMS (Army Map Service) or JOG (Joint Operations Graphic) charts--even with wise selection a formidable wholesale problem for the cartographer. I am guessing that manual chart drafting will eventually give way to partly or wholly computer-controlled charting from what may ultimately be a huge store of aerial and satellite photographs. To suit the binary computer logic of digital computations, therefore, it is wise to stick to chart scales which are different by powers of two.

But what about final chart selection immediately before the strike? It is necessary to develop the chart component of the horizontal display to a form which--whether chart strip or chart chip--permits rapid selection of scales and areas to suit the specific mission. It is our opinion that microchart film-strips which dissect a chart and which make it into a sequence of some eighty frames of the same scale are difficult to servo-motor accurately (see Figure 5 , p 90). It is simpler to use a special chart strip from base A to target B, as in the roller map, or to combine individual chart chips in random choice.

With scale and area selection settled, the tactical planner, the cartographer, and the display designer must fit the charts of their choice to specific missions. It is no longer

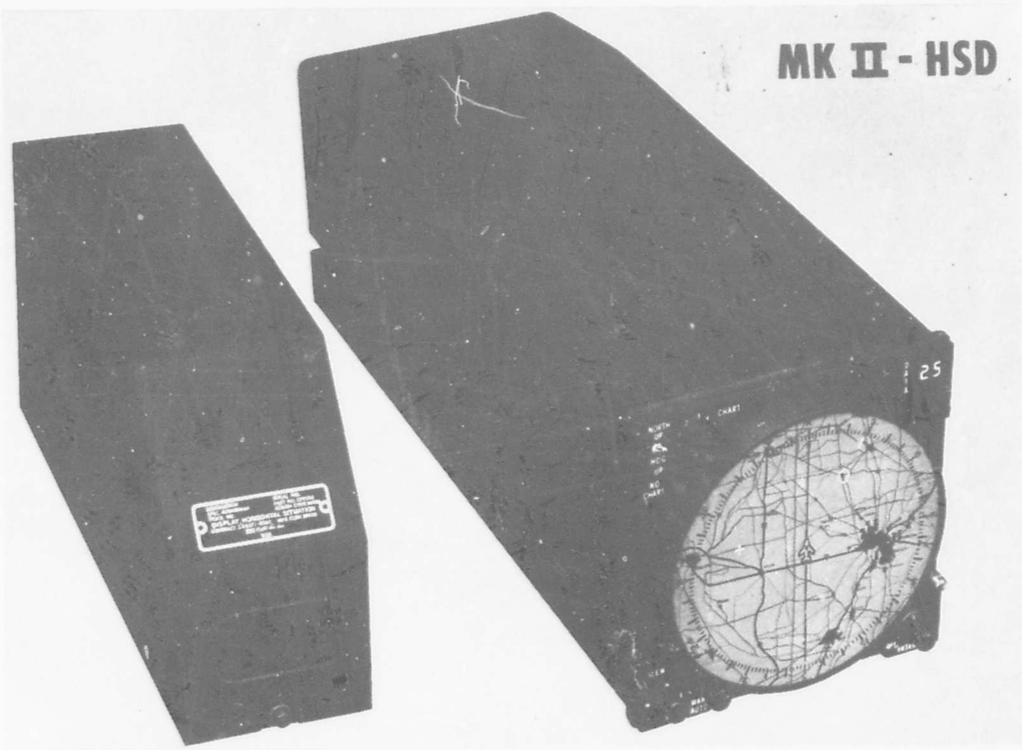

Figure 6. ITT Gilfillan Mk II Horizontal Situation Display face.

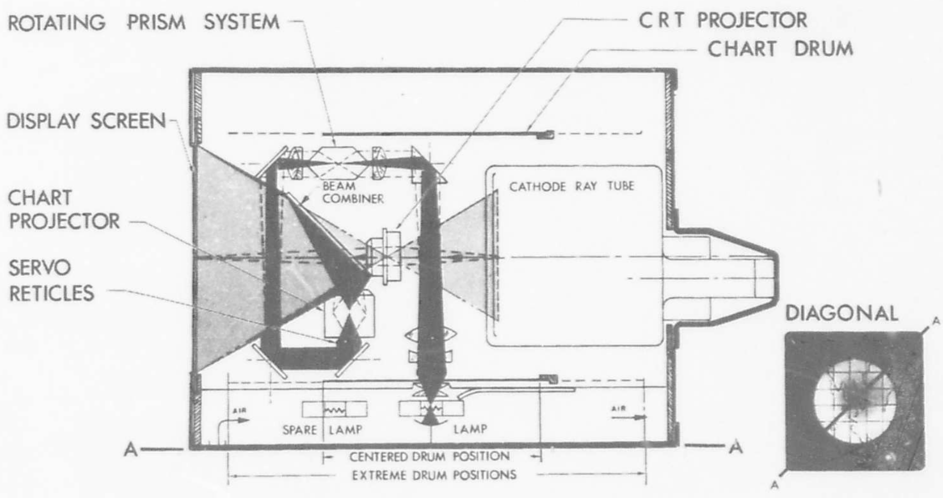

Figure 7. Optical system of ITT Gilfillan Mk II Horizontal Situation Display.

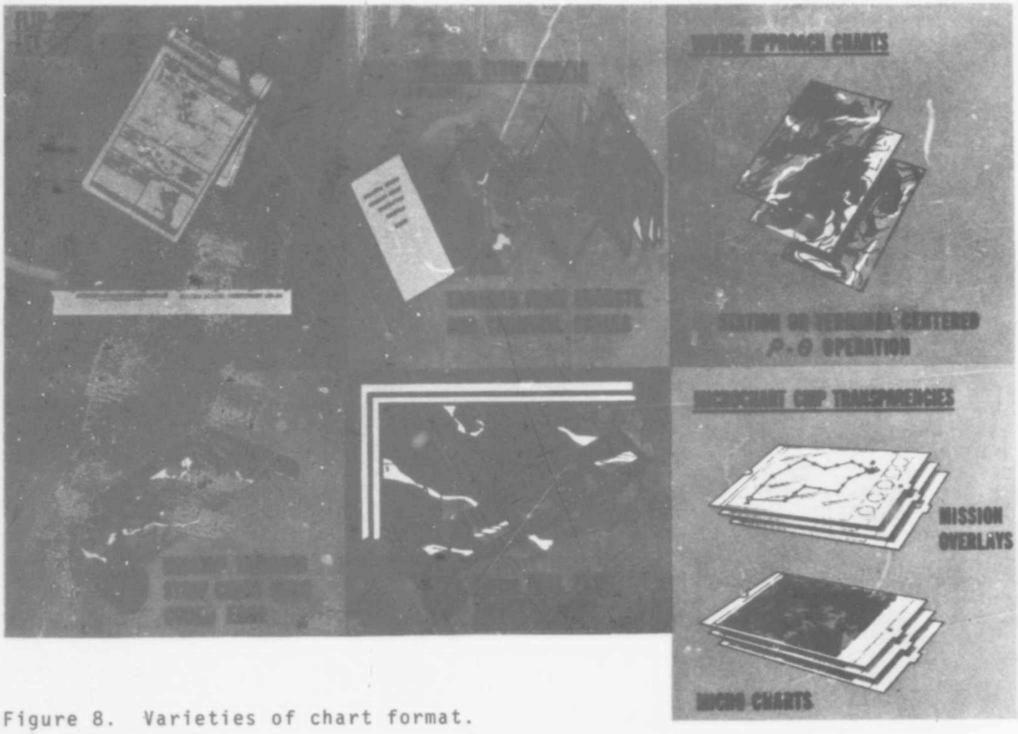

Figure 8. Varieties of chart format.

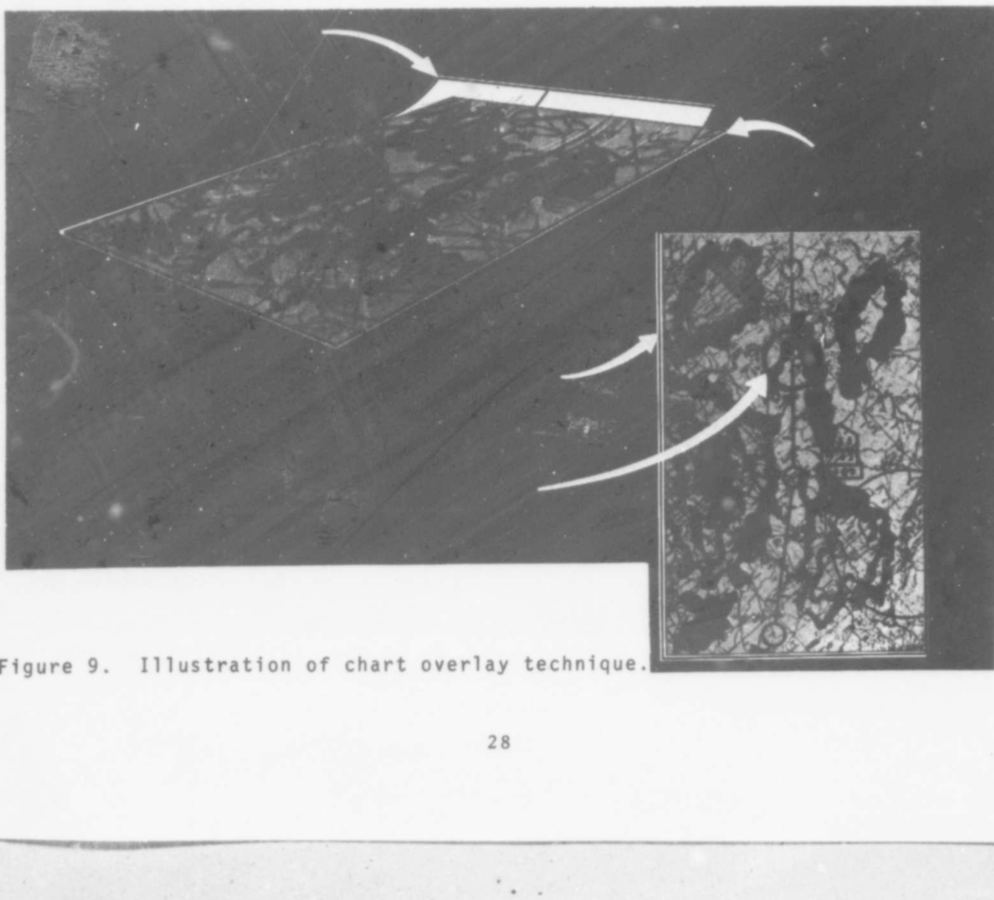

Figure 9. Illustration of chart overlay technique.

feasible to use various folded paper charts on which mission annotations are entered with a pencil. The roller chart requires that a continuous strip of various chart sections and scales be assembled. This task is simple for a straight A to B mission which can be extracted from a single chart. It gets to be complicated, however, when several charts are involved, when enroute and terminal needs require different scales, and when the mission zig-zags between widely dissipated checkpoints. The mission dependence of such a strip chart gets to be a headache when quantity production for many aircraft and many missions between a mobile base and a mobile target is required on last-minute notice.

In this respect, the omnidirectional microchart is more versatile. It does not require special tailoring, and it permits multiple mission planning and deflection of a mission to a new and substantially different target location even while enroute. Moreover, a chart which is optically projected permits the use of a separate overlay transparency that carries all mission data and is in register with the chart itself (Figure 9). This offers the interesting aspect of separating durable geographic and navigational data from the essentially perishable data of an individual mission. It leaves the chart to the cartographer, who can deliver it with unadulterated accuracy and integrity. On the other hand, it gives the tactical planner at the strike base last-minute flexibility. He can now use less accurate, suitcase-type, copying cameras without affecting the accuracy of the actual mission, which gets its backbone from the chart itself.

It is clear, however, that for reconnaissance flight the roller chart offers the advantage of direct enroute annotations, which the projected display does not possess or, better, cannot provide as simply.

Logistic Problems

A comparison of the different servochart formats from the logistic viewpoint is most interesting. Charts which are centered on intermediate or final destinations or checkpoints may well be excluded from our logistic considerations, except perhaps for domestic usage or for use in an essentially static war. For other applications, the possible varieties are so great that they would have to be generated by the user in the field.

As to strip charts, their mission dependence also suggests that they be prepared at the strike base. For this purpose a substantial stock of paper charts or of full-sized transparent charts must be provided together with personnel trained in the preparation and coding of the final product. It is desirable to develop a strip chart printer which can fill this requirement by selective reproduction from chart masters, similar to the multicolor electrostatic printing machine developed for Geodesy, Intelligence and Mapping Research and Development Agency (GIMRADA) at Ft. Belvoir.

The 70mm film strip containing a sequence of many individual chart photographs seems to offer the most streamlined logistic package for domestic mass production. However, almost certainly it would have to be cut and spliced or selectively reprinted at the strike base to fit the special mission requirement.

This leaves the individual chip, shown in Figure 10, which is used in the Gilfillan display. This chart chip is prepared on 105mm film, which permits photographic 1/10-size reproduction of the largest navigational chart in the format of the microfiche in accordance with Federal Standard PB-167-630. The display can be fitted with five enroute interchangeable chips of varying scale. Two of these chips cover the Viet Nam war theatre in 1:1,000,000 scale.

Technological Problems

This brings us to the substantial technological problems that are presented by the new requirement for servo-motored charts. These pertain to the accuracy of the chart as required for its computer operation and to the legibility of the chart as required by its military use in the cockpit.

Unlike the conventional paper chart that is merely spread on a table and then scanned with the eye, the servo-motored chart must be sufficiently accurate to be servoed to a correct present position anywhere on its surface. The chart grid, whether in Lambert, Mercator, or any other projection, must be geometrically true, and each information bit must be in accurate reference to it. The accurate conversion of latitude and longitude information generated by the navigation system into the X and Y or the ρ and θ of the chart drive is handled by the navigation computer. However, the price for the tactical omni-directionality and versatility of the microchart is that it must be by the reduction factor more accurate than the directly viewed roller chart.

It is advisable therefore to use the minimum chart reduction that provides adequate geographic storage with available chart and film formats. The two popular chart formats are the large 41.6-inch by 57.5-inch size preferred for far-ranging air navigation and the small 22.5-inch by 30.0-inch size preferred for targetry. The standard film width of 70mm would require about 1/18 photographic reduction to fully fit the large chart format on it. Greater reductions would require photographic matching of adjacent charts, while smaller reductions would require electro-mechanical matching of adjacent areas. Both are undesirable to the chart maker or the instrument maker. If the large chart format is to be used at all, 1/10 reduction on 105mm film is fine. The 1/8.8 reduction on 70mm film is usually preferred for small JOG and AMS charts, four of which fit into the large format.

Considerations of accuracy and of photographic resolution suggest that reductions in excess of 1/10, while photographically possible, are undesirable. The resolution limit of the human eye viewing the display on the screen is roughly one minute of arc or ten thousandths of an inch at the average 30-inch viewing distance. In terms of photographic resolution this means four lines per millimeter on the screen and 40 lines per millimeter on the microchart. The resolution of color film can be about twice as good. In terms of accuracy, this means that the ten thousandths of an inch resolution limit corresponds to a servo position accuracy of one thousandth of an inch. A larger screen-to-microchart ratio would be unrealistic. In fact, only an accuracy of 0.003 inch can be maintained reliably, which means about 0.8 nautical miles on a 1:2,000,000 chart and about 0.1 nautical miles on a 1:250,000 chart. It is clear therefore that greater position accuracies and resolution should be obtained by a switch to larger scales and cannot be obtained by larger reduction factors.

The accuracy of a servochart cannot be maintained reliably in a military environment using chart paper in the case of the roller chart or a commercial acetate base in the case of the microchart (Table 1). The use of a stable polyester base is recommended in both cases. The chart shows that the polyester base known commercially

TABLE 1

Chart Materials

	Chart Paper	Common Film Base	Stable Film Base
Material	MIL-P-43027 (high wet strength)	Cellulose tri-acetate	Polyester
Thickness (inches)	0.004	0.005	0.004
Dimensional change in climate-controlled processing (percent)	0.1	0.1	0.02
Shrinkage due to aging (percent)	0.08 in length 0.25 in width	0.2	0.03
Thermal expansion (in./in./°F.)	. . .	3.0×10^{-5}	1.5×10^{-5}
Ignition temperature (°F.)	. . .	475	525
Bends before breaking at 40°F.	. . .	1	560
Space saving for 1/10 micromap (percent)	100	1	1

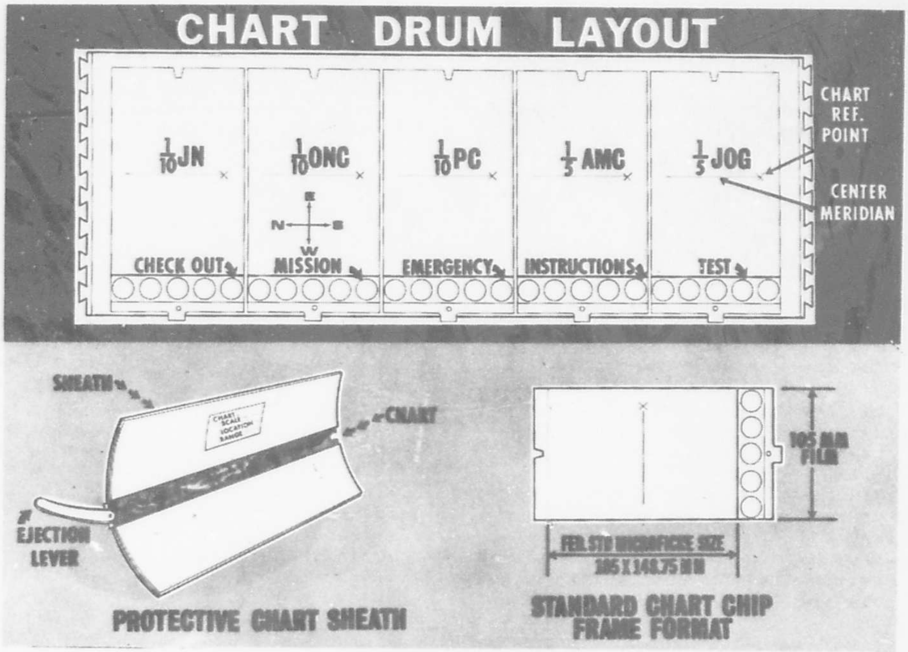

Figure 10. Chart drum layout in the ITT Gilfillan Display.

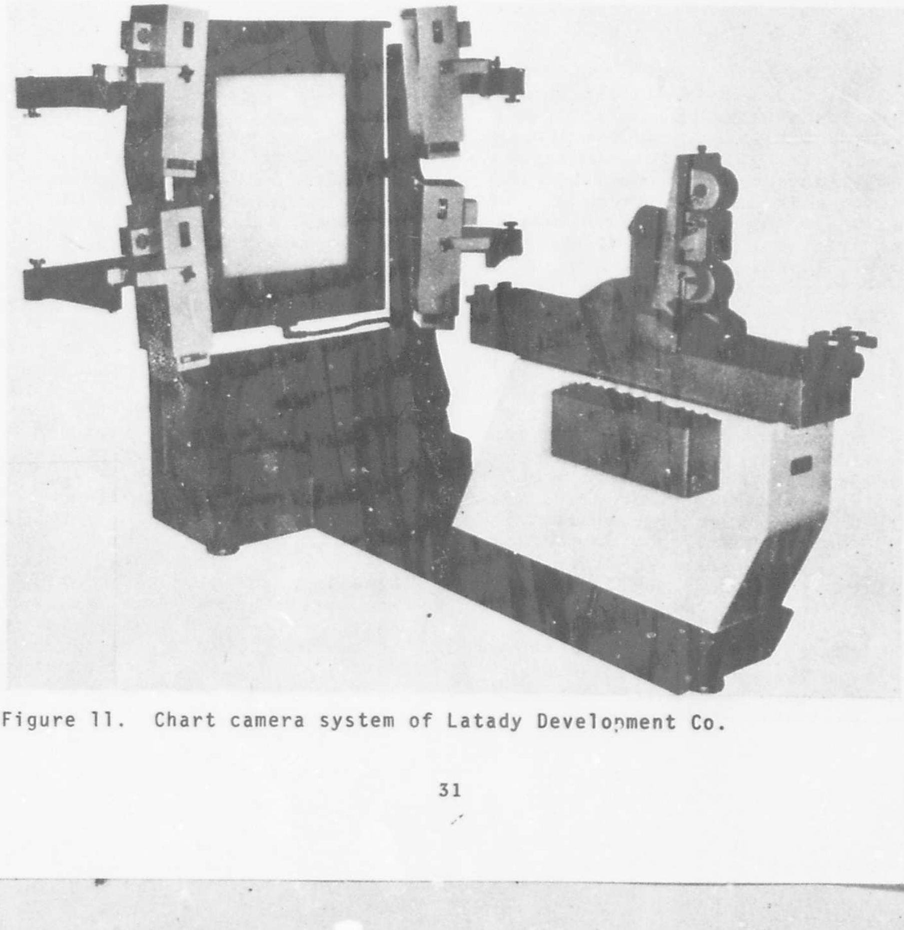

Figure 11. Chart camera system of Latady Development Co.

as Cronar or Estar is comparatively insensitive to wet processing or aging and to low and high temperatures.

Aside from the photographic material, accurate chart photography requires tightly controlled setups and processing climates. The chart camera shown in Figure 11 as an example was developed for GIMRADA by the Latady Instrument Company. It is a precision tool using a high-resolution lens. It is set up with the help of built-in light sources and light meters, a collimator for squaring the original to the center line, and a focalscope for adjusting the correct chart reduction. After the correct setup is completed, it is the beauty of photography that quantity production can take place with comparative ease.

Much research work remains, however, to improve microchart photography and materials. For instance, present emulsions and processing fall short of the color contrast needed for a crisp color transparency. It is desirable also to develop high-resolution color reversal films so that, instead of originals, color negatives can be distributed to the strike bases which in turn will contact print the final copy inexpensively. I predict that once perfected, the microchart will prove as successful as common microfilm in modern commercial life.

CONCLUSION

I have tried to show how the servo-motored chart display has become a firm requirement, in which forms it has been developed, and what its chart requirements are. I cannot think of any other instrument that combines so many different disciplines in one small unit. It is my sincere hope that this symposium will unite and inspire pilots, cartographers, logistics experts, photographic researchers, and instrument designers in a common effort to render our aviation more effective in our self-defense.

DISCUSSION ABSTRACT

Dr. McGrath: Dr. Guttmann has given us a preview of some of the problems of concern to this symposium. He has given us a view of the different concepts that have been employed in the attempt to produce automatic navigation displays and the range of technological problems that are being faced by the men who are developing these displays. I now would like to open this meeting for questions and discussion.

Mr. Wolin: We often get the impression that display designers leave until last the consideration of cartographic support for the display. Could you tell us what criteria the designer of map displays uses in determining the cartographic material for his display? If he requires special R&D charts, does he consider the problems involved in the world-wide distribution of those charts, should the display system ever become operational?

Dr. Guttmann: The system designer should consider and respect the huge investment of labor and time in present navigational charts, as Col. Herndon already explained. Any display system demanding new chart forms would create a potential bottleneck in times of emergency. I am convinced, therefore, that photographic reproduction of existing chart masters should take preference to new cartographic work, whenever possible.

The technological accuracy problem of the photographic setup for microfilmed charts may be difficult. However, it is the beauty of photography that--once the setup is accomplished--it lends itself to inexpensive mass production, making the reproduction of all existing charts on microfilm a relatively small program. Microfilmed charts may be as popular in a few years as microfilm now is in commercial life.

Your second question concerns the logistic problem of R&D charts. Worldwide distribution of new charts presents a formidable logistic problem! Therefore, the system designer should again give preference to a method which utilizes existing charts.

It cannot be denied that the tactical user has a need to modify and supplement the selected charts for his specific mission. Moving-chart displays which are based on optical projection of microcharts permit the use of two co-planar transparencies in overlay with each other, as I have explained in my talk. The logistic problem of the permanent geographic and navigational information for a war theatre--now requiring many tons of charts at a strike base or on a carrier--would be reduced to providing the contents of one cigar box. The tactical individualization of these charts takes place in the field and does not affect the positional accuracy and the integrity of the chart itself.

Col. Kelsey: Your talk, doctor, illustrates one of the problems which I mentioned in my few comments earlier, i.e., the lack of standardization. I would urge that one of the things which should be put across at this meeting is the need for standardization in this field. Three sizes of chips--105mm, 70mm, 35mm--have been used by systems engineers, and this presents tremendous problems to cartographic agencies. I would urge that systems designers be encouraged to try to reach some form of standardization. I know there are difficulties in this, but if you don't, then the task of the production agencies will be greatly complicated. Furthermore, the problem of duplicating color film and getting registration with the sprocket holes to the sort of accuracies you mentioned is not an easy task. So I would urge two things: First, the need for standardization, and second, the need for further research into the problems of processing and duplicating color film.

Mr. Macnab: How can you register the individual chip on the drum to within 0.001 inches? Is there a pilot alignment procedure? Or do the individual chips have registration holes which fit on the dowels?

Dr. Guttmann: We have a cylindrical microchart drum which rotates and which travels back and forth along a lead screw. Its position accuracy is maintained within .003 inch RMS. These are some of the details on accuracy which the instrument designer must consider: The encoder resolution of the servosystem. It represents the granularity of the digital system in use. Next, the encoder cannot sense inaccuracies of the gear and lead screw drive train which connects it to the drum. Only the last gear pair at the drum really matters, meaning that the maximum or "three sigma" error is two thousandths of an inch, if Class-1 gears are used.

There is a twofold accuracy consideration on the drum itself. The chart chip must be inserted into the carrier drum within one and a half thousandth maximum error which is ascertained by placing accurately positioned chart chip holes over dowel pins on the carrier drum. In addition, the five reference points of the carrier drum must be positioned with corresponding accuracy in relation to the servo drive.

Finally, temperature changes present a problem inasmuch as the chart chips consist of Mylar, while the rest of the instrument is steel or aluminum. The differential thermal expansion amounts to 6×10^{-6} degrees per degree inch, which multiplied by maximum temperature change and maximum travel can amount to .002 inch maximum error.

All possible error sources well considered, we are arriving at a root-mean-square (one sigma) error of three thousandths of an inch on the drum, or about one thirty-second on the screen. Translated into nautical miles, the position accuracy of our display increases with the chart scale.

CDR Heininger: You briefed us about the use of overlay chips to provide annotation capabilities for the optical-projection type display. How many man-hours and what equipment is required to prepare such an overlay for a typical Mark II, ILAAS, and IHAS mission?

Dr. Guttmann: The overlay kit was developed for GCA radar overlays and projects pictures of approach patterns, runways, etc., on the CRT face of a ground-based radar display. A similar suitcase-type kit is planned for a typical military mission overlay. It consists of a single-purpose copying camera with a Polaroid-type back. A darkroom is not required. Instead of entering mission annotations directly into the full-size paper chart, they are drawn with grease pencil on a transparent sheet on top of it.

The preparation of an overlay chip consists in:

Registering the full-size overlay on the camera . .	3 min
Snapping the picture . .	1 min
Tripping the built-in positioning hole punches .	.5 min
Withdrawing the developed transparency	1 min
Estimated total . .	5.5 min

The camera may be set up anywhere in about 15 minutes. Please note also that such a camera permits convenient quantity production for formation flights and permits convenient handling of classified mission material.

Mr. Briggs: The ITT Gilfillan horizontal situation indicator, as you described it, appears to have a complicated optical-projection and image-combining system. Can you tell us, Dr. Guttmann, what screen brightness level is obtained with this type of display? I would also like to know whether the map chips stored on the drum can be changed in flight, and whether all five charts on a standard 105 x 148.75mm map-chip format have to be rephotographed when one of them is updated.

Dr. Guttmann: The display of ITT Gilfillan uses advanced multi-layer lens and mirror coatings, a novel, practically loss free beam combiner, Fresnel lenses, and above all a screen surface with low ambient reflectance. Its brightness depends upon the focal length of the Fresnel lens. We have measured peak brightnesses of 1000 foot Lamberts and more depending upon the required width of the light lobe which the Fresnel lens produces. The halfband width of this lobe should be at least three times the interpupillary distance of the pilot's eyes.

Any of the five chart chips can be changed individually in flight. The five overlays also can be changed individually in flight. Any one overlay can be updated and can be rephotographed independently.

Mr. Del Balzo: Could you briefly outline some of the advantages, disadvantages, problem areas (both technical and operational), and relative user costs of each type of displays summarized in your presentation?

Dr. Guttmann: In broad outline, moving-chart displays follow a logical sequence from terminal approach charts via roller charts to the microchart and then to the "integrated" CRT and chart display. Complexity and accuracy problems of their design have grown in that sequence, whereas their versatility in use and their chart logistic problem seems to have simplified in that order. If we consider cost, time, and inconvenience connected with special charts for the simpler displays, the purchase cost for the equipment itself may be less, but the cost of ownership, which also includes logistics and updating, is greater than for projected displays.

This statement is applicable to military, i.e., omnidirectional tactical use, but it is not applicable equally to strictly repetitive commercial navigation which can afford to print special charts. However, there are indications that increasing traffic congestion, increasing complexity of avionics, and increasing chart-updating problems to be expected in future commercial air transport may tip the scale in favor of projected or even integrated displays.

Lt. Col. Spencer: In low-altitude flight, such as over the delta area of Vietnam, there is a requirement to observe prominent landmarks to either side of your flight path. Will the "strip" display allow for this cross check? It has been my experience in the delta that the terrain is almost identical over a distance of many miles, thus requiring dead-reckoning navigation and visual references several miles adjacent to the flight path.

Dr. Guttmann: A chart display is essentially a display of stored information. However, if a navigational computer runs it, and if the mission route including checkpoints is entered into the chart, the pilot has continuous all-weather guidance throughout his mission. For monotonous terrain with landmarks far to the side, a chart display should be able to vary the width of the flight corridor by switching chart scales. Otherwise, it may miss important landmarks at the horizon.

The integrated CRT-chart display also allows the pilot to compare stored information with "live" information on terrain, targets, threats, etc., depending upon the sensors which the aircraft carries.

AERONAUTICAL CHART REQUIREMENTS AND PRODUCTS

Robert R. Bard
Cartographer
Aeronautical Chart and Information Center

BACKGROUND

Approximately twenty-three years ago, a small unit was formed within the Army Air Corps and designated as the Map-Chart Division. One year later an organization was established which is now known as the Aeronautical Chart and Information Center (ACIC). At about the same time, the first comprehensive and coordinated world-wide aeronautical charting program was initiated. Most of you are probably familiar with the World Aeronautical Chart, the Pilotage Chart, and the Approach Chart which were included in that original program.

The designs of the first aeronautical charts were developed by cartographers based on only limited information on users' requirements. This was, at least, partly due to the limited time available to collect requirement data because of our involvement in World War II. However, our charts appeared to be adequate for the aircraft and tactics used until several years after the war when jet aircraft and new tactics were being developed. ACIC has now developed from a small organization of a few hundred people to one of several thousand and our products have risen from the eleven in the original program to a few thousand different items. In addition to increasing the quantity of our products, we have also attempted to improve the quality of our products by tailoring them as nearly as feasible to the users' requirements. For the past fifteen years, we have stressed the need for user requirement data in developing cartographic products. I shall generally describe the pattern we follow to arrive at the cartographic solution to the requirement.

CARTOGRAPHIC DEVELOPMENT PROCEDURES

After a need for cartographic support has been identified, it is necessary to determine all factors which may affect the type of product or data required. Some of these major influencing factors have been determined to be the type of mission involved, navigational or guidance system components, navigational techniques, weapon system capabilities, and environmental considerations.

Secondly, we must analyze the "Production Factors" or, in other words, determine if it is possible to produce that which appears to be required. These factors include such considerations as possible utilization of existing materials as-is or modified, availability and quality of source materials, availability of skills, cost of manpower and dollars, production time available, and limitations of "state of the art."

Next, when all use and production factors have been analyzed, it is necessary to state the solution in cartographic terms. This means the formulation of design criteria upon which production specifications may be prepared. However, in all cases it is not possible to state precise design criteria which can be immediately converted into production specifications. In these instances, it may be necessary to prepare development samples which, when evaluated, will provide the basis for establishing the design. The next to last step is the production of a prototype which will normally be tested and evaluated by the potential customers. Any deficiencies in design that are identified by the test and evaluation will be resolved. As the last step, final production specifications can then be prepared and the production program implemented.

Now that I have generally described how our products are developed, I shall describe some of our standard products and a few of our less conventional items.

STANDARD ACIC PRODUCTS

For many years, the original design of the Pilotage Chart (PC), scale 1:500,000, was more or less the accepted standard chart of the tactical air forces. The small sheet size and the general relief and planimetric information were adequate for the moderate speed aircraft operating at medium to high altitudes. But in the past few years, the tactical forces have acquired high-performance, all-weather aircraft and the emphasis has been placed on low-altitude operations. These factors made it necessary to redesign the Pilotage Chart. The new large sheet size covers four times the area of the old PC, which reduces the number of charts that must be joined for a mission. With this chart, it is possible to quickly appreciate the character of the terrain due to the pictorial relief presentation. This feature is extremely helpful to the pilot of a single-place aircraft traveling a few hundred feet above terrain. There is also much more contour information on the new PC. This data is needed to help establish a safe flying altitude and for making artwork radar-shadow predictions for the various reference points used on the low-altitude mission. The new PC also uses special pictorial symbols to identify features that would serve as a good landmark or reference point.

Our well-known World Aeronautical Chart (WAC), scale 1:1,000,000, is gradually being replaced by the new Operational Navigation Chart (ONC). The development of this chart was also generated by the emphasis on low-altitude operations but this time by the Strategic Air Command. Many of the same design features used on the new PC are also used on the ONC. The new chart covers an area equivalent to four WACs. It too, uses pictorial relief to provide quick appreciation of terrain character. The ONC also contains more detailed contour information than the old WAC. The ONC, too, uses special pictorial symbols to identify features that would serve as a good landmark or reference point. Much of the Northern Hemisphere is now covered by the Operational Navigation Chart.

The Jet Navigation Chart (JN), at 1:2,000,000 scale, is the first chart which ACIC designed to support a specific system as opposed to the prior concept of producing general-use charts. The information contained in the JN was initially designed to support the B-47 aircraft for high altitude, long-range navigation and bombing operations. Since visual pilotage becomes more difficult at high altitude and in adverse weather, reliance on long-range radar navigation is emphasized. Thus the emphasis has been placed on features that have radar significance. On the JN, the transportation network is intensified around the cities. This is done since cultural build-up is usually along the transportation arteries and thereby provides a unique pattern for radar scope identification. Another example of design to support radar navigation is the identification of level areas for radar altimeter calibration. The JN chart has proved to be a versatile tool and is now used by nearly all jet aircraft. We have complete coverage of the Northern Hemisphere with this series of charts.

The B-58 Chart is another example of a chart developed to support a specific weapon system. This is a JN chart overprinted with a special navigational grid and selected radar significant features identified and coded to an accompanying booklet which describes each feature and gives its geographic and transverse coordinates to 1/10 minute of latitude and longitude. The radar significant checkpoint coordinates are used to verify or upgrade the coordinate counters of the automatic navigation system. The special grid is merely a projection which has been rotated 90 degrees. This grid is used when operating in the polar mode basically because the navigation computer cannot keep up with the rapid crossing of the converging meridians in the higher latitudes. This series covers most of Eurasia and North America. Although the Global Navigation and Planning Chart (GNC) does receive limited use for long-range navigation by SAC and MATS crews, its primary use is for planning purposes. The GNC replaced the Aeronautical Planning Chart (AP), which was one of the original eleven programs at ACIC. The GNC was developed to satisfy Navy and Air Force planning requirements. Primary consideration was given to presentation of maximum area coverage so that terminals of highly frequented, long-range flights could be shown on one chart. By a judicious selection of sheet lines, major land masses and primary routes were covered by 26 ONC sheets which replaced 43 sheets of the old AP series. Now that I have covered many of our standard items, let me describe some of our less conventional products.

SPECIAL ACIC PRODUCTS

One of our programs is to support the USAF F-106 which is capable of speeds in excess of MACH-2. Its performance has created a requirement for new and unique cartographic support. Man's reaction time and his ability to function at extreme altitudes and speeds is sometimes inadequate to satisfy the operational requirements of interceptor missions. Therefore, in the F-106 the mechanical functions normally handled by a pilot/navigator system are performed by an automatic navigation system known as the MA-1. The principal component of this automatic navigation system is an airborne digital computer which can operate either from pre-selected navigational data on computer tapes or from data programmed and transmitted from ground stations. ACIC has the task of preparing the computer programming tapes required to navigate the F-106 between pre-selected points. Computations for the large volume of computer programming tapes required is accomplished through use of electronic data processing equipment. Another component of the system is a map-display instrument officially designated as the Tactical Situation Display (TSD). The purpose of this display screen is to provide the pilot with a visual reference of the aircraft's position and heading. This is accomplished by producing a 35mm film strip containing chart images which are correlated to the navigational data contained on the computer tapes. The display screen contains an aircraft symbol which is automatically and continuously superimposed over the aircraft's position on the chart image. A briefing booklet containing the 35mm chart images is provided for pre-flight planning. The chart image contained in the booklet is identical in size to the portrayal on the cockpit display screen. Another aircraft and weapons control system for which ACIC provides cartographic support in the form of 35mm film strip production is the ASG-18. This system is similar to, but more sophisticated and advanced than, the MA-1. It has been designated as the primary navigation and fire control system for the YF 12A, and is currently being tested by the contractor aboard B-58 test-bed aircraft. ASG-18, like the MA-1, is composed of two subsystems, a computer that includes both an analog and a digital capability and an airborne map-display device called the Horizontal Tactics Indicator (HTI) which is the subsystem requiring the 35mm film strip support.

The significance of cartographic support for electronic systems is the new and unique dimensions of cartographic products. Miniaturized formats and unique products suitable for electronic interpretation and exploitation are indicative of future cartography as more and more functions become automated. One device that has necessitated miniaturized cartographic products is the Pictorial Situation Indicator, which is part of a low-altitude guidance subsystem being developed for the USAF. It is an automatic cockpit display device designed to give the fighter pilot an immediate appreciation of his aircraft position and heading, thereby permitting him to give more attention to his many other tasks. The display portion of the device is a ground-glass screen positioned in front of the pilot slightly below eye level. A projected aircraft symbol remains in the exact center of the screen and assumes the aircraft heading while a projected chart image moves under the aircraft symbol to simulate groundtrack. The chart is positioned by input data of longitude, latitude and heading furnished by airborne computers. The chart-storage area of this compact device contains a navigation chart on colored film covering a large area which is stored on a transparent cylinder and provides flexibility of coverage for any route the pilot may choose or be directed to fly. There is also a provision for displaying check-list data, printed emergency instructions, etc., which the pilot can select as required. All of these are positioned on the one piece of film used in the equipment.

The Pictorial Situation Indicator will also be installed in the Supersonic Transport (SST) Simulator at the NASA Langley AFB facility. The NASA simulator flight can be simulated by wire hookup at FAA's National Aviation Facilities Experimental Center at Atlantic City, New Jersey, to illustrate SST penetration into an area congested with subsonic aircraft flights. Color film strips of enroute and terminal areas are prepared for this simulator in support of a joint NASA/FAA study. This study is to identify problem areas involved in flight procedures required to monitor and control supersonic aircraft in a high density air space along with subsonic aircraft.

Another device which requires miniaturized graphics is the AN/GPA-70, which has been developed for use in conjunction with ground radar for en-route air traffic control and radar approach control for landings and departures. To support this new equipment, the USAF is producing miniaturized video charts which provide an electronically positioned cartographic background for ground radar scopes. The Video Mapper consists of three turrets each of which can store ten miniaturized aeronautical charts containing data such as airways, navigational aids, controlled airspace areas and scramble tracks for Air Defense use. This data is superimposed on a live radar display by use of an electronic scanning circuit so that the ground operator can see the relationship of moving aircraft with respect to certain terrain features, airways, obstructions, etc. He can then advise the pilot as to his aircraft's position and give further instructions as the situation dictates. Normally, one turret contains charts for long-range pick-up and identification data, the second turret contains intermediate-range charts and the third turret short-range control data.

The miniaturized charts, which are 1.01" in diameter, are made with great precision and with cartographic detail designed to meet the requirements of the separate air traffic control centers. This equipment will provide greater flexibility to air traffic control centers since the graphic display can be changed by a selection switch without interrupting operations.

One of our products which is tailored to work in an automated display is the Flight Log Chart which is used in the Tactical Air Positioning System (TAPS). This system was installed in our aircraft to provide the United States with a precise positioning capability for air operations in South Vietnam. Navigation in that area is very difficult due to dense overall vegetation and lack of unique features that would assist in pilotage. The TAPS system generates low-frequency radio signals from a master station to three slave responders which results in a hyperbolic navigation fixing technique. The track and present position of the aircraft is displayed on the Flight Log Chart by means of a stylus trace that is generated by the TAPS signals being received.

Due to the characteristics of the TAPS automatic plotter, the Flight Log Chart is not on any projection nor is it of constant scale. As a result, the chart image is quite distorted when compared against a standard navigation chart, although in any given small area the relative position and shape of features are recognizable. The airborne plotter requires paper 11 inches wide and up to 18 feet long with specially slotted perforations along each edge to receive the driving sprockets. These characteristics result in a flight-strip type of chart rather than one of broad area coverage. Consequently, the flight strips cover from strike base to projected terminal areas of operations.

CONCLUSION

In the brief review of some of our products, two factors should be apparent. First, we must continually evaluate our charting program to assure that our products and services satisfy the changing requirements of aircraft, mission tactics, and objectives. Secondly, we should recognize that cartographic products are beginning and will continue to take unique forms. Computer tapes seemingly bear little resemblance to a cartographic product identifying a portion of the earth's surface. However, electronic guidance-and-control systems require very specialized products which may have to serve as an integral part of the system. We can expect that future requirements will be satisfied only by cartographic concepts and materials which support the characteristics and limitations of the systems and tactics employed.

DISCUSSION ABSTRACT

Maj. Polhemus: Bob, you didn't mention the 1:200,000 Radar Target Chart. Was that deliberate?

Mr. Bard: We were supposed to have an unclassified meeting here, so I didn't mention it.

Maj. Polhemus: Well, the format of that chart is an essential piece of information to bring across to a group like this, because the crew so frequently rely on conformality of shapes shown by the sensor and the chart. The Radar Target Chart brings out that conformality, which makes it an important member of the stable of charts.

Mr. Wolin: On the F-106 display, how many colors do you have on the chart?

Mr. Bard: Black and white.

Mr. Wolin: Has that caused any difficulty with the operational people?

Mr. Bard: No.

Mr. Wolin: In some of the studies we have conducted, color has been a significant parameter; so, I was wondering whether the use of black and white would have caused difficulty for the operators.

Mr. Bard: No, actually we've found that information content is the key, not color. You can change the depiction of things by different line weights, screens, and zip patterns, and so forth. You don't need color to do this. Color makes a more impressive display, we'll grant that, but it doesn't improve the function of the graphic.

Lt. Col. Robson: I would like to clarify that point. The original copy used to produce the black-and-white film strip for the Tactical Situation Display is the standard enroute FLIP chart. Only aeronautical information is displayed on this chart, so there is no requirement for, or any advantage to, the use of multi-color.

Dr. McGrath: In other words, we are not talking about an original color chart that is being reproduced in black and white, but a chart which was designed specifically for black-and-white presentation to begin with?

Mr. Bard: Oh yes.

Mr. Russell: What coverage does ACIC produce on the strip charts for the hyperbolic navigation system that you discussed?

Mr. Bard: I'm sorry, I can't really answer your question. There is considerable coverage in Vietnam, but I'd hesitate to say that we have every square mile covered.

Mr. Russell: Do you have any coverage within the United States?

Mr. Bard: Not as yet, but I understand there is a development program for the Army.

Mr. Briggs: It is clear that ACIC has great experience in producing new types of maps and charts for specific purposes. Assuming that a new requirement for special charts for a display system arises, how long would it take ACIC to produce a new series of charts to meet the requirement? A typical problem might be to produce a series of, say, 1:250,000 scale charts from an existing series, but having a modified projection in order to render the series suitable for use in a particular navigation system.

Mr. Bard: Your question cannot be answered without further specifying how many individual charts are involved, the amount of adjustment or rectification in imagery is required, and most important the priority that Headquarter, USAF, would give to production. ACIC can respond quite fast to production of film chips or film strips. One film chip could be made in a matter of hours and a film strip with several chart images could be made in a few days, if no rectification or change of imagery to an existing product would be necessary.

VALIDATION OF REQUIREMENTS AND DEVELOPMENT OF CARTOGRAPHIC PRODUCTS FOR MILITARY FORCES

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INTRODUCTION

Validation of requirements for various types of maps, charts, geodetic and related products, for use by all echelons of the armed services, includes many considerations that may not be generally recognized. Let me remind you of two of the main considerations that I am sure everyone will appreciate. The foremost consideration is that validation involves those actions that provide the specific facts, evidence or sound reasons why a certain type of cartographic product or geodetic data is necessary to effectively support the use of certain weapon systems; or to support certain types of operations; or, as a reference for planning and conducting warfare.

The second main consideration is that validation is the basis for the approval of products and is therefore a very significant function. The facts presented as part of the act of validating provide the basis for initiating production programs or other actions. These may require the production of certain specified maps or charts to cover any or all parts of the world, or they may be the basis for initiating extensive data acquisition programs, or research and development for cartographic-geodetic systems to support an established requirement. Validation, therefore, provides the basis for decisions relating to the expenditure, in many cases, of much effort and huge sums of money.

ORIGIN OF REQUIREMENTS

Requirements are generated by a variety of users; such as, aircrews, naval and ground forces, research and development personnel, intelligence units and staff planners. Types of products or data stated as required include but are not limited to maps and charts of all scales, variable design and content, mosaics, photos, geodetic positions, radar analyses, sensor simulations, radar predictions, film strips, flight publications and certain combinations of many of these. What starts out as a stated requirement must be carefully reviewed to firmly establish the need for and approval of a product. This is primarily a job of determining what specific components or functions of navigation equipment, gunnery, missiles, tactics or other applications require cartographic support or geodetic data inputs. Based on these determinations, the specific details required to be incorporated on maps or charts and in publications are established.

VALIDATION PROCEDURES

Requirements validation work takes on varying degrees of complexity. Some actions can be resolved quite directly by a knowledgeable staff with a minimum amount of investigation and correspondence. Some are basically a mathematical type solution, such as geodetic data and geophysical requirements for missiles. Some relate to human factors, such as the ability to read, interpret and apply mapping information to specific operations. Others have all the variables involved in satisfying joint ground, air and naval operations. In all, the job of validating mapping, charting and geodetic requirements can only be approached by a thorough investigation, assembly and correlation of facts. A complete requirements analysis is important in providing a product which best satisfies the user, be it "man or machine." It also eliminates deadwood and points the way to production economies.

Validation procedures for mapping, charting and geodetic requirements follow clearly defined guidelines within the Defense Department. We have an established system whereby any unit must submit its requirement through command channels to DIA Directorate for Mapping, Charting and Geodesy (DIAMC). The Unified and Specified Commands or Military Departments, as the case may be, review and validate a requirement as it relates to their particular interests. They give the reasons why a product is required, what contents and accuracies are required and why, the urgency and time frame for its use, and the relationship, if any, to existing products. When the requirement reaches DIAMC, our job in the Product Requirements Office (DIAMC-1) is to validate from the overall Department of Defense standpoint.

DIAMC-1 is the initial link in the chain of DIAMC actions that finally result in a required type of map, chart or geodetic data being produced and furnished to the user. DIAMC-1 is not primarily in the production business but rather acts as the connecting link or "go-between" between the user and the producer. Because our first task is to validate requirements, our staff must understand how weapons systems operate, what tactics and operating techniques are employed and any other uses of maps, charts and geodetic (MC&G) type products. The Product Requirements Office, is therefore, staffed with operationally oriented military officers and technical civilians. We have an Army Artillery Officer, Navy and Air Force Navigators and Pilots, geodesist, radar and system engineers, and specialists in product specifications. Their job is to determine what is needed, why it is needed, and to translate these needs into terms and specifications that the cartographers and geodesists must have to produce the required maps, charts and geodetic data.

I want to state at this point that the work involved in assembling the facts concerning the type of support required is a collaborative effort among many people in the Military Departments and operating commands. Our job in DIAMC-1 is primarily one of coordinating and managing the activities engaged in requirements work. We assign projects to one of the Departmental Agencies or establish combined Service teams to accomplish the fact-finding tasks. We, that is DIAMC-1 and the Departmental Agencies, work with and through the Unified and Specific Command MC&G staffs to their component Services in these requirement investigations. Likewise, the physical job of preparing product specifications is accomplished by experts in the Army Map Service, Navy Oceanographic Office, or Air Force Aeronautical Chart and Information Center, and usually by the combined efforts of experts from these agencies.

The first job of the Product Requirements Office is therefore to assure that the U&S Command or Military Department has done its job in providing background information and justification for a stated requirement. We then review existing products to see if any will satisfy the requirement. We must also be sure that all other DoD elements having similar interests are included; that all related weapons or functional uses in ground, naval or air warfare are incorporated, or considered; and finally, that the requested information, contents of a graphic, or accuracies of data are properly related to and compatible with the capability of particular weapon systems, operating techniques, or other intended uses.

DEVELOPMENT OF PROTOTYPE PRODUCTS

These actions lead to the development phase. In the process of investigating and validating a requirement we will, of course, collect the pertinent information and data concerning the type of operation or equipment that involves the use of cartographic or geodetic materials. This information and data must be correlated, consolidated, and translated into cartographic terms and expressions. The orderly process and first step in product development is to prepare a requirement document. The purpose of this documentation is to convey to the technicians and producers information concerning the intended use and type of support required as a basis for the design and specific characteristics desired in the end product.

If, for example, the requirement is for a particular type of map or chart, the main features such as scale, size, graticule reference requirements, amount of topography, emphasis of specific features, and other characteristics are stated to the extent possible. The cartographer then applies his knowledge of symbology, line weights, colors, and production or reproduction techniques in developing specifications to produce a prototype designed to meet the requirement.

In this phase of work the project officer who performs the investigation of the requirement must work closely with the technicians who develop the prototype.

TEST AND EVALUATION

The purpose of a prototype is of course to find out from the users how closely we have come to meeting their requirements. Normally, maps and charts are used by a number of people under varying conditions and for multiple applications. Consequently, we distribute a prototype to a representative number of operational elements for an extensive test and evaluation. To make this test and evaluation as meaningful as possible and derive the basis for improvements, we prepare a questionnaire concerning specific features of the prototype as they apply to various operational uses. We exercise as much control over the test and evaluation (T&E) as possible to assure valid results. To the extent possible, control is established by appointing project officers within each command. Our most successful T&E's result when we can properly brief the project officers prior to the T&E and also have a debriefing of project officers at the end of the exercise.

From these tests, a determination can be made whether the product as developed is adequate or whether more development and testing must be done. I want to emphasize that the final product evolves only after it has been clearly proven that the requirement has been satisfied. This does not mean that we do not continue to strive for improvements in the product. We are always open to any suggestions the users may have for improvements to make a product more effective. In fact, we place a note on published charts for that very purpose. It does mean, though, that we have reached the stage of development where we have determined that the basic requirement will be met. Let me now run through an example of a requirements and development project.

PROJECT JOG: AN ILLUSTRATIVE STUDY

For years we have had two 1:250,000 scale production programs in the Department of Defense--the topo map produced by the Army and the aeronautical chart produced by the Air Force. There has been a great deal of collaboration between the Army Map Service and the Air Force, Aeronautical Chart and Information Center, in the exchange of source materials and base compilations, but we still had two separate programs. Now, under DIAMC management, we have established a single integrated program. In fact, we have common specifications which can be used by any map production agency to produce a ground map version or an air chart version. This is very important because the 1:250,000 scale is used for joint military operations and having identical map detail for ground and air operators is a primary requirement. This is the reason we gave this program the title Joint Operations Graphic (JOG). JOG-G is the Topographic Map for ground use and JOG-A is the Aeronautical Chart.

To arrive at the conclusion for a Joint Operations Graphic, DIAMC-1 initiated a program to determine the specific type, amount and manner of portrayal of information required by ground and air users.

We first established a DIAMC team of technical representatives from the Army, Navy and Air Force to select sample maps and charts and develop a questionnaire to be used in a test and evaluation by the operating forces of the U&S Commands. The questionnaire was developed so that the results could be tabulated by automatic data-processing techniques.

We then asked each U&S Command to designate Product Officers who were briefed on the objective of the T&E and completion of questionnaires.

After termination of Command T&E's the DIAMC team visited each U&S Command to be briefed on the results of the T&E.

This exercise took about a year from the first meeting held on the subject through production of graphics, questionnaires, Command operational evaluations, and the tabulation and evaluation of the questionnaires. The results proved that a separate ground map and air chart was required.

However, the exercise also established that the same basic reproduction material could be used in the production of the ground map and air chart. The following are some of the common findings between ground and air users:

1. Retain identical detail on topo map and air chart.

2. Place names toned down only if clutter is a factor.

3. Layer tints (not slope tints) for both ground map and air chart.

4. Terrain enhancement (shaded relief).

5. Accentuation of prominent features of radar and visual significance, wooded area, and power lines (pylons).

6. Green only for vegetation.

7. Complete Universal Transverse Mercator (UTM) grid and latitude and longitude graticule.

8. Partial margin (bleeding edges).

The only exceptions between the ground map and the air chart which prevented one common product for all users were: The unit of measure (meter vs. feet) and the need for more frequent issue to update aeronautical data on the air chart.

We found that the same contours can be applied on both ground map and air chart by having the foot equivalent of the meter contour applied to the air chart. This is a big saving in production. Numbers are rounded off to the next higher 10-foot increment. Meter-to-foot conversion tables are a part of the JOG specifications.

We have continued requirements investigations and development work to refine these 1:250,000 scale maps and charts. Included in this work is much collaboration with the United Kingdom and NATO countries to achieve standardization for these series of ground maps and air charts.

CONCLUSION

I hope I have given you some concept of how we go about the business of validating and integrating requirements and of developing maps, charts, geodetic data, and related products to best meet the needs of all users in the Department of Defense.

DISCUSSION ABSTRACT

Mr. Kitching: You have been careful to distinguish between Army maps and aeronautical charts. Would you define the difference between a map and a chart?

Mr. Bloom: The main difference between a map and a chart is that normally all features on the Earth's surface are represented relatively, commensurate with scale, on a *map*; while a *chart* includes only selected surface features and also depicts information of special significance, such as aids to navigation, isogonic lines, restricted air space, and electronic aids on *aeronautical charts*, or bathymetric depth curves and marine data such as navigation lights and electronic aids on *hydrographic charts*.

Mr. Bass: As part of your JOG program, do you plan to continue with other, larger scale charts?

Mr. Bloom: Yes. I only described the 1:250,000-scale JOG program as an example of the kind of validation and development exercise that we perform on all scales. We are doing likewise on other series of maps, aeronautical charts, hydrographic charts, and combining, where feasible, those that have similar uses.

Mr. Dunlap: On this last development which you outlined, the JOG, I notice that the chart contains a brief amount of hydrographic information. Is the JOG also intended for use by the Navy or surface units operating in the area? Can they use it as a navigation chart?

Mr. Bloom: Yes. The development of the JOG was a combined effort of Navy, Army and Air Force representatives.

Lt. Col. Howerton: In conjunction with consideration for navigation display systems, have we established a need for similar display of basic flight information as contained in world-wide (free world) Flight Information Publications (FLIPs)? If not, I strongly urge that this basic requirement be favorably considered for inclusion in any navigation display system chosen for current and new weapons systems.

Mr. Bloom: Yes, as appropriate; such as for the F-106/MA-1 Air Defense aircraft. No, for general use.

Weapon system requirements are considered based on the system to be supported (types or missions and requirements for storage and display of information). For tactical aircraft, where the missions are strike oriented, the primary requirement is for a tactical chart-display system more than for FLIP information.

There are undoubtedly desirable aspects to automating FLIP information into a display system. Also, a cockpit display system could normally accept FLIP Chart portrayal easier than standard Aeronautical Charts. However, problems in updating FLIP information would be encountered in a display system. These could be handled if operational units stated a valid requirement for display of FLIP data.

The incorporation of FLIP materials into a cockpit display system would most probably add to the cost of this program. It certainly warrants a feasibility study, particularly as it relates to those aspects of flight information data that can be readily applied in digital form.

Mr. Russell: The pilot's need for a chart-display system is based upon a complex cockpit environment. Detailed analysis of such an environment requires an extensive time/motion study of the pilot in his environment. Do you go through such a human factors study to establish the facts referred to in your talk?

Mr. Bloom: Yes, we try to include as many types of analyses as practical in our requirements investigation; statistical, environmental, and experience. As a specific example to the stated question, a time/motion study developed by the system engineers was used in developing the Tactical Situation Display Graphics produced for the F-106 aircraft.

Mr. Russell: The second question is, you emphasized basing requirements on operational needs. How do you establish these requirements for new chart-display systems when the operational forces may not be aware of what is technically feasible?

Mr. Bloom: We work very closely with the research and development agencies of the military departments. Our office must keep abreast of the various systems that are being used and that are in development so that we can determine where we fit into the picture from a cartographic support standpoint, and to advise on what types of cartographic support would be necessary. This is part of the job of determining requirements. There is also another consideration: if we determine that there is a requirement which involves additional cartographic technical research and development work, the Advance Systems Office, which devotes its time to upgrading the state-of-the-art of cartographic and geodetic capabilities, initiates R&D action.

Mr. Russell: You do have the authority then to establish a requirement for a chart-display system without the users saying, "I need this type of system."

Mr. Bloom: Yes, we do. For example, the use of the ONC in low-level tactics was brought about through the R&D elements long before it came into operational use.

Mr. Erickson: Would you describe more fully the methods used in the test and evaluation of cartographic materials? Do you run experiments and base your conclusion upon performance measures, or rely upon opinions?

Mr. Bloom: Methods used in test and evaluation of cartographic materials depend on the objective of the investigation. These methods encompass measured performance, observation and recording of user actions, and interviews of operators (both new and experienced). The methods used and answers to the stated questions can best be answered by the following examples:

In a project to determine map accuracy requirements to support artillery, a series of 1:50,000 and 1:25,000 scale maps were produced with varying degrees of *known* horizontal and vertical accuracies. These maps were tested under controlled conditions using standard artillery procedures. Live ammunition was used and a record made of the location of each burst. The location of each burst was surveyed relative to target and to established geodetic control. Tabulation and preliminary statistical analysis of records kept on rounds fired by all field pieces tested with each of the maps indicate that a map of Class B accuracy can be used almost as effectively for artillery as a Class A map. In this experiment, Fort Sill was the "laboratory" and all performances were measured.

In testing the effectiveness of prototype Pictomaps, an observer recorded actions of artillery and shipboard fire control, forward observer spotting, terrain and feature recognition during air drop, and ground troop maneuvers. In all cases, Pictomap (a photo enhanced map) provided for quicker identification and more positive recognition of geographic location than normal when using a standard map. In this exercise, the new type product provided quick reaction time and positive location as measure of performance plus the fact that the new product was immediately accepted by amphibious, air, and ground users.

Changes in depiction of certain features on 1:250,000 scale aeronautical charts resulted from direct interviews of operational units in South Vietnam. For example, streams had been depicted commensurate with standard drafting procedures without special emphasis. However, the interviews revealed that streams are a most significant visual aid in that area. Therefore, the depiction was changed to a darker blue and slightly wider line. This is probably not measured performance per se; however, the change was justified based on an experience factor rather than an unfounded opinion.

Capt. Miller: Is sampling operational pilots by using opinion questionnaires a valid approach to determining what types of information will be and will not be placed on aeronautical charts? I agree that getting information from the users is the correct approach. I only question the method being used to secure that information. I am of the opinion that the present efforts being undertaken by Human Factors Research for JANAIR are a much more valid approach to solving this problem than are the present opinion questionnaires. The only valid method of determining the value of a given aeronautical chart is to measure the performance of a large sample of pilots using that particular chart and HFR is undertaking this type of research.

Mr. Bloom: I do not consider that all questionnaires are "opinion questionnaires." I do agree that questionnaires are probably often framed in terms that will result primarily in opinions. However, if questionnaires are framed to get positive reaction from the users (i.e., see or do not see, use or do not use, feature recognized or not recognized, too dark or too light, etc.) during the operational test of a chart, the results provide (to me) factual evidence rather than opinionated views concerning the adequacy of changes needed to improve the chart.

Normally, questionnaires are used in connection with a sample or prototype chart. This occurs at the refinement stage rather than the determination stage of chart development. The determination of "what type of information will be and will not be placed on aeronautical charts" is primarily accomplished during the earlier stages of requirements investigation and analysis of the type of information required to support a particular weapons system or operation. Consequently, I still support the concept that questionnaires properly framed to relate particular chart features to specific use during a specific type of operation should provide user evidence concerning the utility of the chart. Furthermore, these questionnaires provide us an aid in developing the best design and content of a chart to serve the intended purpose.

I am aware of the HFR efforts for JANAIR in determining requirements for aeronautical charts and agree that this type of research should be pursued. I believe, however, that the value of this research would be related primarily to the requirement analysis stage of our work. I believe we would still find it necessary to conduct operational test and evaluation with questionnaires similar to our current practice. We, of course, normally get a large sampling and probably the greatest cross-section of users through test and evaluation accomplished by all pertinent elements of the Services within the Department of Defense.

Col. Kelsey: I would question your selection of the type of individuals who are establishing these requirements on two counts. First, I support the last speaker: that the results obtained from these questionnaires are mainly opinion. The range of user comments vary widely, and therefore I think there is a much greater need for study of the technique of getting an evaluation of such a complex thing as a map or chart. I know you have various ideas in your organization for doing it, and I think this will probably come out later in the meeting--but, second, I question the validity of allowing such a complex problem to be in the hands of military officers without any cartographic experience at all. I appreciate that the only person who can really define the requirement is the man who is going to use the product but, in my experience, he doesn't really have the time, and in some cases the necessary experience, to produce systematic answers to the pertinent questions. Therefore, I think the project officer has got to have a very wide experience; he's got to know the elements of cartography because ultimately the cartographer has to interpret the requirement. One really wants a very much more scientific approach to this problem. I am faced right now in my own organization of wanting to set up a requirements branch, and I personally feel that one wants a scientist, such as Dr. McGrath, in the organization. He's the sort of fellow I'm looking for, I think. He doesn't ask the sort of questions which cartographers have been asking for a long time and is less likely to dictate his views to the user. So I don't think one can leave the user to define the requirement completely. Of course you must have users amongst your requirement branch, but you do not want only military officers to determine the requirement.

Mr. Bloom: The purpose of assigning operational military officers to the Product Requirements Office, DIA, is to facilitate communication and understanding with the field elements who generate the requirements for cartographic products. The combination of operational military officers and technical civilians working as a team and specializing in product requirements work has proven to be a successful means of investigating and determining the validity of stated requirements and of translating validated requirements into cartographic/geodetic terms and expressions.

With regard to depending on "user opinions based on questionnaires," we consider that the experience factor is of primary importance in determining the utility of the map or chart. We also try to design our questionnaires in such a manner as to obtain positive reaction rather than opinion. In any case, we try to properly weigh the answers during our analysis of questionnaires. Furthermore, as previously stated in response to Capt. Miller's question, the use of questionnaires is normally associated with *refinement* and operational user acceptance of a product rather than as a primary basis for *determining* requirements. Basically, requirements for specific types of information are determined in the earlier stages of investigation and analysis of the weapons system or type of operation being supported. I agree with the need to develop scientific analysis methods and an orderly process in determining requirements for maps and charts as well as their test and evaluation to arrive at the best end product.

The philosophy that we employ in having an operationally oriented military officer in charge of the Product Requirements Office is one of being able to view the establishment of requirements unencumbered by all the factors involved in the production business. As pointed out in my talk, the staff of the Product Requirements Office includes technically qualified cartographers, engineers and geodesists whose primary job is to specialize in requirements analysis. The plan, of course, incorporates the need to have good coordination and collaboration with the offices that are directly involved in the production and supply of cartographic materials.

Maj. McDonald: I agree with Mr. Bloom in that it is most important, though certainly not conclusive, that requirements for cartographic products be obtained from operational personnel. We at Fort Rucker recently assisted DIA by completing questionnaires on various types of maps designed for operational use. We felt that it was most important that appropriate comment was obtained from Vietnam returnees on the various maps which were sent to us for field review.

Mr. Bloom: I am glad to hear this response. It supports the DIAMC-1 concept that a team of operational type military personnel working in conjunction with cartographic/geodetic technicians both of whom specialize in requirements investigation work provides the best means of communication with personnel of operating units regarding the experience factor which is an important element in determining requirements for the design and contents of cartographic products.

Sqn Leader Burton: It is essential that mapping and charting requirements should be controlled at the highest level of the appropriate service. It also requires that effective control of the specification should be by experienced aircrew or military personnel throughout its development. Cartographic experts should advise in their specialized field. However, the user opinions and prototype evaluations should be controlled by properly qualified experts in the field of questionnaire analysis associated with mapping and charting.

Mr. Bloom: I agree.

Capt. Kilpatrick: Since the JANAIR program being conducted by Dr. McGrath has been mentioned a couple of times in this discussion, I wonder if he would mind describing that work?

Dr. McGrath: The JANAIR research has been described in a series of technical reports entitled, *Geographic orientation in aircraft pilots*. There is not sufficient time remaining for me to give an account of that program at this meeting, but I will comment on the methods we have used in the research.

We first used operations research techniques to document the impact of geographic disorientation on the success of air operations and to identify the factors that cause pilots to get lost. These studies generally involved the analysis of aircraft accident records, mission critiques, flight assist reports, critical incidents, training records, questionnaire surveys, and individual and group interviews with pilots. Capt. Kilpatrick has already mentioned in his opening address the results of those studies: each year, scores of military and civilian pilots were being killed, millions of dollars were being lost in aircraft destruction, and a significant proportion of missions was being aborted because of the consequences of geographic disorientation. In low-altitude operations, geographic disorientation was found to be very common, and was caused mainly by the difficulty the pilot has in referencing the visual world that he sees out the windscreen to the cartographic world he sees portrayed on his chart.

Our next step was to develop a method of studying geographic orientation under laboratory conditions, where pilot performance could be measured objectively, and where the effects of cartographic variables could be tested under controlled conditions. To that end, we devised a simulation technique which employs motion pictures with synchronized cockpit instrumentation. The method allows the replication of low-altitude sorties under conditions in which only the characteristics of the pilot's chart have been changed. In this way, the effects of cartographic variables on pilot orientation can be measured with surprisingly good accuracy. Some of the cartographic variables that we have tested experimentally are: chart scale, information content, and color coding.

We have also applied analytical techniques to the assessment of navigational checkpoints by obtaining pilot judgment data under systematically controlled conditions. These data allow one to compare the criteria used by pilots in selecting checkpoints, both during preflight planning and during enroute navigation, with the criteria used in the compilation of aeronautical charts.

From these attempts to apply research techniques to this problem, I have concluded that measurements of pilot performance are essential to the development of cartographic requirements and to the objective evaluation of cartographic products. But, one must be careful not to over-estimate the value of performance measurements. Their application is limited mainly to the testing of clearly stated hypotheses. Also, such measurements are very difficult to obtain. A large proportion of our effort has been devoted to the development of research techniques and measurement procedures. There is still an urgent need for methodological research in this problem area.

I do not agree with those who would advocate the abandonment of pilot opinion research in favor of pilot performance research. We need both opinion and performance data, but we need to collect and analyze these data more systematically. Most important, however, is the need to establish a continuing source of operational data. My colleague, Mr. Borden, is presently developing a method of obtaining quantitative data to measure navigation performance and chart use during actual operational sorties. I believe that many of the questions of concern to this symposium will be answered only when we have established an effective method of obtaining continuous feedback from the operational forces.

PROCEDURES UTILIZED BY THE ARMY MAP SERVICE IN CONDUCTING MILITARY MAP EVALUATION SURVEYS

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The Army Map Service (AMS), operating under the direction of the Chief of Engineers, serves as the principal mapping agency of the Department of the Army to accomplish the topographical military mapping mission of the Department of Defense. The Army Map Service believes that its responsibilities do not end by supplying military maps in sufficient quantity, adequate coverage, and appropriate scales to its many DoD customers. It is also of vital importance to supply the best map possible. A map is a military tool and, as such, its design, content and amount of terrain and intelligence information must satisfy the cartographic requirements which are essential to the successful execution of the military missions of the users.

The design and content of military maps have always been a matter of great concern with AMS. Up to World War II, the problems were not too many and AMS could cope with them, but World War II brought with it a drastic revolution in military mapping. Global warfare demanded an inconceivable number of maps of all scales and areas. Time demanded that these maps be produced under crash conditions. The maps printed were of considerable variety in national origin and of still more variety in the map symbolization used. The wartime map training of the average soldier was very brief, allowing him only a bare familiarity with American map symbols, no knowledge of their adaptation to maps of foreign areas, and an equal lack of knowledge of foreign map symbols.

With the termination of the war, cognizance was taken of the wartime deficiencies, and measures were included in the mapping program to allow better maps for national defense. Aerial photography was flown, geodetic control secured, and up-to-date maps were made to replace the wartime editions.

Realizing the importance of reducing the problem of map reading, AMS became the driving force in programs of map standardization. The standardization of map symbols was effected for the three services--first among the U. S. mapping agencies and then among the military forces of the NATO nations. Today the mapping situation is better than it ever has been. For any eventuality, up-to-date, adequately accurate maps explained by standardized symbols would be almost immediately available, reducing the past difficulties of the soldier. Since the end of World War II, there has been a rapid evolution of military concepts and weapons. These changes in turn have engendered changes in the cartographic requirements of the personnel concerned. This emphasizes the need of maintaining a continuous effort to keep the military map in step with the military changes.

Recognizing this problem, initial remedial measures were advanced by AMS early in 1954. These proposals, designed to improve the usefulness of our maps, included the following:

First: That AMS representatives be sent on Field Training Exercises conducted by the United States Army, Navy, and Air Force. It was felt that pertinent data relative to cartographic improvements could be ascertained only through direct contact with the military user and by observations of maneuver exercises.

Second: That AMS cartographers visit the U. S. Army service school in a program intended to derive mutual benefits, i.e., the AMS representatives would be made aware of current military doctrine and new tactical concepts thus allowing the map maker to maintain cartographic pace with changes in military needs. In like manner, personnel of the service schools would be made aware of cartographic design and cartographic limitations and capabilities, in order that proposed cartographic changes and innovations be kept within practical limits.

Third: That military officers from each of the branches which use maps to any great extent be assigned to AMS to represent their branch of the service in advising on design and content of maps.

The need for action along these lines was considered to be of such importance that a separate unit within AMS was envisioned for the specific mission of determining requirements. Accordingly, the User Requirements Division (URD), a staff element of the AMS Plans and Production Staff, was established in the Spring of 1954.

In general, URD was given the responsibility for determining requirements of the military user for maps and engineer intelligence studies, and, for initiating measures to satisfy such requirements.

From the outset, the user requirements program received high-level sanction and support. Direct contact was authorized between the Continental Army Command (CONARC) and AMS, and arrangements were made setting up channels to implement user requirements surveys. The extent of CONARC cooperation was evidenced by directives which authorized and encouraged comprehensive, continuing surveys through questionnaires and direct contact between AMS and subordinate CONARC commands. Periodic visits were also made to CONARC fcr the purpose of presenting progress reports of map user surveys being made of the various commands and service schools. These surveys were conducted in several ways, by questionnaires, conferences, and observation of training exercises in the field.

Where direct liaison has been authorized by CONARC, AMS prepares appropriate correspondence to the installation concerned. The letter usually outlines the survey items, purposes, and objectives for the conduct of the surveys. Groups being surveyed usually consist of 30 to 50 personnel. To assure a cross-section of military personnel, the letter states that the groups be made up of 40% field grade, 40% company grade, and 20% senior non-commissioned officers. When plans are confirmed by the installation, appropriate trip plans are prepared and TDY arrangements made.

Upon arrival at the installation the visitors present an explanation of the purpose and scope of the requirements program.

In conducting the various type surveys the attendance of AMS representatives is considered mandatory in order to provide authoritative answers to any of the questions raised by the respondents. Upon completion of the surveys, the collected data are consolidated and evaluated to ascertain the validity and feasibility of stated requirements.

The evaluation of collected data is not a matter of pure statistics, but necessarily includes interpretation in terms of what is essential to the user, and, for what purpose the requirements is expressed. Interpretation can be made only in conjunction with a familiarity with military weapons, tactics, and techniques. Cartographers gain this knowledge by observing troops in the field, conferring with military personnel concerned with the latest concepts and weapons systems and study of military texts. An example of the interpretation technique is the artillery requirement for accurate horizontal and vertical control on a large scale map. By comparison to the U. S. Army as a whole, the artillery is a numerical minority, however, their requirement is of such major importance that it cannot be disregarded.

Once a requirement is determined as valid, changes to cartographic products must be devised to satisfy the requirement. Numerous design experiments and subsequent preparation of experimental products may be involved. In many instances several experimental products with various design treatments are made. Then experimental products are taken to them for an evaluation survey. Normally, the survey consists of the use of the new products by combat troops under field conditions followed by a questionnaire on the suitability of the products. From this evaluation the product most acceptable to the user is selected for additional treatment or adoption. If additional changes are necessary, the evaluation survey procedure may be repeated.

Subsequent to these final analyses and reviews, interim and/or final reports are prepared including findings, discussions, conclusions, and recommendations. These reports are then submitted to higher headquarters for appropriate action. Upon approval of the recommendation, necessary changes are made in the specifications and design of AMS products to reflect the cartographic requirements emanating from the evaluation efforts.

With the establishment of the Defense Intelligence Agency (DIA), in 1963, the map evaluation program at AMS took on a renewed and expanded growth in light of the inclusion of the Unified and Specified Commands in the map and chart evaluation program. With DIA's tri-service approach in the mapping and charting community, significant progress has been made in evaluation programs. In the DIA approach to this program, all possible combinations of Army, Navy and Air representatives, military and civilian alike, have formed teams to go out in the field on evaluation activities. A typical example of this cooperation among the services is noteworthy of mention in the distillation and refinement of the Pictomap supplement.

The first major field use of the Pictomap was made during a joint field amphibious and airborne exercise involving Army, Navy, Air Force and Marine Corps. This exercise comprised a total military complement of approximately 10,000 and was conducted on Vieques Island, a military testing ground in the Caribbean. The Vieques Island Pictomap was prepared through the combined efforts of the Army Map Service and U. S. Naval Oceanographic Office.

The Army Map Service distributed more than 1,000 Pictomaps for the maneuver; in conjunction with the maps, 1,000 questionnaires were also distributed, in order to determine the operational usefulness of the new product. AMS evaluation of the completed questionnaires revealed that the maneuver participants enthusiastically accepted the product and favored extended production to cover other areas.

Based on the high degree of military acceptance of the Vieques Pictomap, the Commander-in-Chief-Pacific (CINCPAC) validated the requirement for the preparation of a Pictomap at 1:25,000 scale of the Da Nang area in South Vietnam. Through DIA and OCE, the Army Map Service prepared this map and sent it to the field; AMS prepared and sent questionnaires along with the maps for field evaluation. The theater response was immediate and, again enthusiastic. Consequently, only a limited field evaluation of the map was effected. Rather, an urgent request was made for additional copies since the ones sent for evaluation were being used operationally in the field.

As a result of the general military acceptance and favorable field response to the Da Nang Pictomap, the theater stated firm requirements for the entire Pictomap coverage of South Vietnam at 1:25,000 scale. AMS has completed this project.

May I underscore several procedures considered important when conducting surveys:

Direct and continuous contact with military users. Past experience has taught us that direct and continuing contact with the military map users is the best way of acquiring valuable data relating to present and future cartographic requirements. The determination of requirements is a continuing rather than a one-time effort. Military techniques and weapons undergo an ever progressive evolution and to satisfy the necessarily changing requirements, maps must undergo parallel changes in order to provide our troops with maximum cartographic support. Direct user contact also results in a much more rapid response to the needs of the military map users by having their products prototyped and user-approved prior to going into mass production. Furthermore, this liaison provides the lead-time to implement the necessary production and other equipments long before the mass-production need arises which, in the past, has usually been done on a crash basis.

Capabilities and limitations. The analysis of the answers and comments on the completed questionnaires is of critical importance, since the mapping requirements expressed by our military map users represent the crux of the entire survey. To accomplish this it is necessary for cartographers to study the answers and comments on each questionnaire. For example, in several surveys military map users have expressed the requirement for maps to be printed on paper six or eight feet square to obviate the necessity of making mosaics of large numbers of smaller maps on a display board. As valid and ideal as this requirement might be, we are still beset with the limitations of press sizes. This does not mean, of course, that the requirement is pigeon-holed forever; we are constantly alert to changes in the state-of-the-art of military and civilian equipment alike. Knowledge of capabilities and limitations plays a critical role in evaluation activities.

Civilian - Military team concept. The Civilian-Military team concept is considered ideal in map user requirement and evaluation activities. Besides serving as advisors and consultants, the officers team up with civilians in the many surveys undertaken and conferences attended. This Civilian-Military team concept contributes heavily towards the success in achieving "user-oriented" requirement efforts.

DISCUSSION ABSTRACT

Dr. Pelton: I'd first like to identify myself as being closely related not to the cartography industry, but to avionics R&D. So, in that sense, I'm a user of maps, particularly as they apply to low-altitude navigation. The points I wish to make are comments rather than questions.

I'm sure that everybody in the cartography business is trying to do a good job; but, the reason we're having this meeting is because the present products are not satisfactory for some of the applications we're trying to use them for. The one good example is low-altitude flight, where we know from Captain Kilpatrick's remarks that pilots are getting lost and getting killed. From the avionics standpoint, we first approach a problem by analyzing it to find out what is needed in order to accomplish the particular task that we're undertaking. Some people call this the systems approach; you might call it the logical approach also. And in almost any navigation application, you can consider maps a part of the system. The maps must be evaluated in the system, just as any other component is evaluated.

Although Jim McGrath has indicated that the methodology for evaluating maps is not yet adequately developed, if we did the necessary R&D analysis and experimentation we could define the complete system requirements for the map and accurately evaluate the map design. Obviously, this is a big program I'm talking about. But, we have heard how questionnaires are sent out, answers are obtained, and maps are designed on that basis. Such techniques do not constitute the kind of R&D program that will truly define what's needed on the map and how it should be presented for the men to do the job. A much more sophisticated program is needed. So, I ask: is it in the offing that the present deficiencies in maps as system components will lead to a useful R&D program that will get us the knowledge we need to successfully integrate maps into navigation systems? I think JANAIR's program is a start toward this, but it's very small compared to what really needs to be done.

Mr. Shaffer: I wonder if you could say a few words about the value of your check surveys?

Mr. Sorrentino: Let me cite an example of a firm requirement that we received at the very beginning of our program. This was for the accentuation or elaboration of relief information in the form of contours. Our users, unfortunately, normally need a crutch to read contours. There is a ready association of blue with water, green with vegetation, and so forth, but when these little curlicue lines appear on the maps, a mental block is found among the average troop. Maybe a psychologist could tell us why. That unfortunate deficiency in map reading can also be ascribed to the short length of map training. So, we prepared several alternative ways of elaborating contours, and we went into the field with alternative solutions. You must never go to the field with one solution, but must allow the user to make a selection. These alternatives included shaded relief for a 3-D effect and layer tinting. In the evaluation survey, the layer tinting came out ahead of the shaded relief by quite a wide margin. That is an example of how a specific design question can be answered by field evaluations.

DESIGN AND PRODUCTION OF GRAPHICS FOR AIRCRAFT DISPLAY SYSTEMS

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The production of an Aeronautical Chart, whether for conventional use or for automated display, follows a specific pattern which can be divided into the following general phases: (1) design and development; (2) cartographic research; (3) compilation; (4) final copy preparation; (5) final reproduction. These phases are intimately related, and interdependently dictate the various techniques and/or procedures to be followed, as well as the appearance of the final product. I'd like to give you a more-or-less generalized picture of each of these phases, as an aid to understanding some of the problems and limitations, as well as the potentialities, of the cartographic community.

DESIGN AND DEVELOPMENT

Just as one cannot build an aircraft without blueprints, one cannot produce a chart without specifications. Chart specifications (or more simply "specs") marry the user's requirements to the cartographer's limitations. The offspring of this union may be anything from a highly detailed terrain model to a miniaturized film chip, yet it has but one purpose in life, that of enabling an aircraft and its crew to perform their mission.

The specs are formulated in several steps in what we have chosen to call the Design and Development (D&D) phase of chart production.

The D&D phase begins after a requirement for a chart product is generated and validated. As a first step, currently available products are reviewed. If none can be found to adequately serve the requirement, they are given a second look to see if any can be utilized with minor modifications. For example, adding or eliminating information, reproducing in a different color, at a different size or on different media. Time available to produce a chart may or may not be a factor to consider, but economics always is. If an existing chart product can be modified in the final copy preparation and/or final reproduction phases, thereby eliminating or drastically minimizing work in the compilation and research phases, savings as great or greater than 40-to-1 in time and manpower may be realized. At any rate, satisfaction of the initial requirement is the foremost consideration, and to this end, a set of "preliminary design specs" are prepared. These are the prototype blueprints and are drawn up from the initial cartographer/user concepts of what the final product should "look" like. They embody, as far as is possible at this stage of the game, considerations such as the ultimate requirements and conditions of the mission, the aircraft and its associated equipment, the capabilities of the crew, the availability of intelligence data (which we will herein define as everything that goes into the final product from the chart projection or mathematical reference system to the actual symbols and typography which may be placed upon it), and finally, the means of presenting the intelligence data and the methods, and materials required for production.

CARTOGRAPHIC RESEARCH

With the completion of preliminary specs, experimental products and development samples are usually made and are evaluated both theoretically and operationally. The preliminary design specs are then revised and previously published charts may be periodically updated and improved by the addition of this newer or more accurate information. We refer to this aspect as "chart maintenance."

COMPILATION

After the source materials have been collected, indexed and evaluated as to specific utility, the Compilation Phase begins. Here cartographers sift and sort through the source materials selecting the required information from each, transforming or rectifying it, and controlling it to make it conform to the reference system and scale of the new product. In general, this is done by making selective tracings on translucent overlays called pull-ups. Only that detail which will appear on the final product is taken from each piece of source, and the rest is disregarded. Where very large scale source material is used (relative to the final product), the cartographer also "generalizes" the detail he is selecting so that it will not be too intricate when photographically reduced to the scale of the final product. Since the source maps are usually not based on the same reference system as the new compilation, the reduced pull-ups must be "rectified" or transformed to a new shape. This may be done through the use of computer-driven, analog-type, input/output coordinatographs or it may be done manually, for instance, by reproducing the pull-up onto a thin sheet of rubber which can be stretched to fit and adhered over the new projection.

The Compilation phase produces a manuscript or "rough draft" containing all of the detail that will appear on the final product, showing it in its correct geographic location. A further step is now required to refine or polish this rough draft to make it completely conform to the basic specifications.

To again use analogy, the basic compilation resembles an airplane with all components in place, unpolished and unpainted, with welds and raw edges unsmoothed and nuts, bolts, and rivets not secured. Though everything is in place, our compilation "will not fly" until all the loose ends and rough spots are eliminated. In the Final Copy Preparation and Final Reproduction phases we tighten the nuts and bolts and apply the paint.

FINAL COPY PREPARATION

The nature of the final product as defined in the production specifications, dictates the type of final copy to be prepared. If it is to be a chart printed on paper by the lithographic process, smooth-line negatives must be prepared; if the final product is to be a film chip or strip or a plastic overlay, a smooth-line negative or positive must be prepared. If a terrain model is the ultimate end product, a master model must be prepared.

Let us take the case of a typical lithographed chart such as the 1:250,000 scale Joint Operations Graphics or "JOG" chart as it is commonly called, and examine the final copy preparation phase in a little more detail.

A JOG chart may contain as many as ten different colors (blue for drainage, green for vegetation, black for cultural features, etc.). Each color is printed from a separate lithographic plate, made from the negative(s) containing only the detail it is desired to show in that color. In essence, a negative is a thin sheet of clear translucent material which has an opaque coating covering it. Openings in the coating in the form of the various line symbols and typography of the chart permit light to be transmitted through it and thus produce an image on the lithographic plate. These negatives, which may be manually or photographically produced, are the end product of the Final Copy Preparation stage, insofar as the JOG and similar multi-color lithographed charts are concerned.

The litho negatives are prepared directly from the compilation manuscript in what we call the "color separation" process. For color separation, the compilation manuscript is photomechanically reproduced onto sheets of scribecoat (a translucent plastic sheet having an opaque paint coating). One sheet each is prepared for drainage, contours, roads and cultural features. The particular type of detail to appear on each of these separations is manually traced using special tools which very precisely remove the paint. This operation provides a negative image with sharply defined, precise width lines or other open areas, and is called "negative scribing" or "negative engraving." Typography and the various discreet symbols to be shown on the chart are prepared as "stick-up," a high-quality photographic image on a thin translucent film with an adhesive backing. They are applied to translucent sheets laid over the manuscript, again one sheet for each color required. A photographic step then is used to convert those "positives" to negatives. Alternatively, negatives of the typography and symbology are prepared directly with our Automatic Placement and Photocomposition System, an automated typographical preparation and positioning facility. After the line negatives have been completed, they are used as masters for preparing the background tint negatives and masks by both manual and photographic means. Still another reproduction of the compilation manuscript is applied front and back to a sheet of special opaque white plastic material. A special manual-forming operation transforms this sheet into a three-dimensional terrain model. This model is photographed using special techniques to give us the shaded relief negative.

Throughout the color-separation process, the basic integrity of the compilation manuscript must be maintained, that is, all detail on any given color-separation negative must be maintained in its true positional relation to the detail on all of the other negatives. This is done through the use of a pin/slot register system in which all materials have a set of corresponding holes (slots) punched into their edges before any image is placed upon them. Special pins inserted in these holes lock the sheets in precise register with each other, for all subsequent reproduction steps.

We spoke of ten colors as being required for the JOG chart. To print these ten colors we actually use as many as 25 to 30 separate negatives. For example, even though the drainage features, drainage feature names, the open water tint and the Georef grid are all printed in blue, each of them is prepared as a separate negative. This permits us to prepare them simultaneously and greatly speeds the production process. In the Final Reproduction phase, all of the negatives that have been prepared to produce a specific color are composited to make a single lithographic plate for printing.

FINAL REPRODUCTION

And this brings us to the last phase of our chart production process, Final Reproduction. Our original compilation has now been smoothed and polished, its relatively rough line-work replaced with sharp, even-margined, precise-width lines. High-quality preprinted symbols and typography replace hand annotations. If we are to produce a multi-color lithographed chart, the various features have been separated into a collection of coordinated negatives and negative masks, or if the final product is to be monochromatic, a smooth-line composite positive or negative has been prepared. We are now ready to make the actual item which the user will receive. It is in this phase that the lithographic plates are made and the paper chart is printed. Or, where the final positives or negatives are photographed on one of several specialized types of cameras to produce film strips or film chips; or perhaps, where plastic overlays of various and sundry types are prepared by a variety of photomechanical and/or photographic techniques. Final reproduction, often completed in a matter of hours, is somewhat anti-climactic in view of the amount of effort that has been expended to arrive at it.

Since I only wanted to give a general picture of chart production, I have not mentioned aspects such as production and quality control, proofing and editing, intermediate reproduction and the host of administrative and technical support services required. Suffice it to say that there is quite a bit more to the overall picture than meets the eye.

LIMITATIONS

Now let us take a phase-by-phase look at our limitations and potentialities, and also see how graphics for display systems fit in to the scheme of things. In the Design and Development phase, one of our problems lies in communications between the user (be he a pilot or a systems designer) and the cartographer performing the actual product design and development work. Quite often technical data essential to the original requirements become somewhat obscured, in filtering down through the maze of organizational levels. Conversely, in the upward movement, production capabilities and/or potential design innovations often become distorted or are overlooked. This is not to say that we are prevented from coming up with a satisfactory product. However, we find that a considerable amount of time can be saved, and in many cases a better product fabricated with less trouble in the production areas, if and when the people with the requirement are able to sit down at the same table with the people who are doing the actual design and production work.

In addition to communication, we have two other problems in the design area. The first of these is the matter of time available to design a product. Quite often, entire navigation systems are designed, bought and are in the hardware test stage before consideration is given to the design of the cartographic product. We are then faced with the prospect of having to do design research and prototype production simultaneously in the face of near-impossible schedules. It goes without saying for design and development, as well as for the rest of the production phases, that the more time we have, the better the product, and early coordination will result in a highly complementary relationship between product and production methods.

The second problem is a real cartographic one, something that we cannot get around by improving methods. It seems that no matter how much information we put on a chart, someone always wants or needs more. When we put more on, then everyone complains that they cannot read the information because the chart is too congested. The size or scale of the chart we are producing sets a very real limit on the amount of intelligence that we can usefully show. So, we make charts at many scales and find that even this does not solve the problem since most contain many compromises so that they can serve a number of different, but related purposes simultaneously. This is necessary to lessen the volume of items which must be carried about and used. The Automated Display System can conceivably come to our rescue in this area, provided it has a capacity to store and retrieve separate, special purpose charts for each specific phase of a mission or for each type of mission. This would permit us to produce highly specialized graphics designed to serve a single purpose with utmost efficiency.

POTENTIALITIES

I've mentioned our limitations, now what are our potentialities in the design area? They are as broad as the human imagination. We can emphasize or subdue detail through use of color, fluorescence and reflectivity. Sizes and shapes of lines, abstract symbols and typography can be manipulated as a further tool to emphasize or de-emphasize chart features. We have a great variety of new reproduction materials and methods available which can also be used to enhance the value of the final product. Last but not least, there are the as yet untapped possibilities of audio-visual, digital, computer/cathode-ray tube and many other more-or-less exotic presentations.

In the Cartographic Research Phase, our primary problem, of course, is the fact that we do not always have sufficient, up-to-date data concerning the particular area to be charted. All I can say about this is that we continue to do the best we can. Our secondary problem in this phase is the matter of time. In this case it is the time required to index, catalog, evaluate, update, store and retrieve our existing data. This problem is currently in the process of being minimized, if not altogether eliminated, through automation of our data library and its associated functions. At present we are well along the way and fully automated operation will be achieved by 1969.

Again, about the only problem we have in the Compilation Phase is time. We are continually striving to minimize this through the improvement of our techniques and compilation equipment. Nevertheless, compilation is by far the lengthiest of the production operations and will undoubtedly always remain so, since it is the least adaptable to automation.

In the Final Copy Preparation stage, also, time seems to be the primary problem. And again our continuing program for improving methods and techniques as well as equipment and materials keeps us in an advanced stage of preparedness to do whatever job may be required.

Perhaps our greatest limitations lie in the Final Reproduction Phase, principally in the miniaturization and micro-miniaturization areas. Here we run into severe limitations insofar as equipment and materials are concerned. In addition, we encounter production bottlenecks due to the precise image positioning and extremely critical processing techniques required. Since the area of miniaturization is of primary concern to display systems, let us take a look at some of ACIC's miniaturized products, the final reproduction problems encountered in producing them, and how we have circumvented or eliminated these problems.

Under the category of miniaturized display graphics, the most widely known, of course, is the F-106 Tactical Situation Display System. In this system the graphics are reproduced as individual frames on a 35mm film strip in positive form, that is black lines against a white background. The 35mm frame is projected onto an 8" display screen in the cockpit of the F-106. Three basic scales are used having 100, 400 and 800 nautical-mile areas of coverage. Each mission is selected from a magazine of 72 reference charts contained on the 35mm film strip. To make these strips, relatively gross detail is lifted from conventional charts and, in minimized compilation and final copy preparation operations, is reproduced as a composite positive at the 8" diameter size. A pin register system is used to facilitate positioning of the image on each frame of the film strip. The 8" film positives are reduced to 0.8" on a 35mm motion picture titling camera, using a frame-by-frame exposure, to produce a master negative strip. The leading and trailing ends of the master strip are joined to form a continuous loop which is fed through a 35mm contact printer. A continuous run is then made to produce the desired number of positive film strips. Photo processing of both the master negative and final positive strips is performed in automatic equipment. Since the registration required on the final film strip is of the order of only plus or minus .01", we have encountered little or no positioning problems. Polyester base, 35mm, continuous-tone film is used on these strips and since the detail is relatively gross, we encounter no resolution problems.

Our first real problems with display graphics turned up in the preparation of the ASG-18, 35mm, film strip. This strip differed from the TSD strip in three ways: It was a negative strip, the graphics on the strip contained considerably more detail than the graphics on the TSD strip and this in turn necessitated the use of minimal line weights and type sizes, and, registration requirements were ten orders of magnitude greater. Our original drawings were again prepared from existing chart copy, but at enlarged scale. I might mention that the ASG-18 strips contained highly specialized graphics, yet required minimal compilation effort due to use of existing color-separation negatives modified mostly in the Final Copy Preparation phase. Line weights, type, and halftone screens were carefully selected to facilitate a reduction of 32 times onto the film strip. This was the smallest scale at which the basic compilation and copy-preparation work could be done conveniently. The first stage final drawings were reduced 3.2 times on our normal process cameras. This left us with negatives approximately 10" square. Since each graphic at this stage consisted of as many as six separate negatives, second stage, final contact, composite positives were made on pre-punched film again using a register pin system similar to the TSD. In the case of the ASG-18 originals, however, a registration tolerance only $\pm$.001" was permitted between the various negatives to be composited. It was found necessary to take a critical look at the quality of these positives to assure that they had not been degraded in the reproduction and compositing steps. The 10" positives were then reproduced at 1/10 scale, one by one, using a modified, 35mm, vertical, motion picture, animation camera. The result was a high-contrast, polyester base, 35mm, negative film strip. Since many of the lines and halftone-dot screens were so fine (approaching the maximum resolution capabilities of the film), we found that we could not make copies on our 35mm contact printer, and therefore had to shoot each frame of each film strip individually from the 10" original drawing. Final reproduction--a very critical operation in this case--was thus multiplied by a time factor and error potential equal to the number of duplicate strips required. We hope to remedy this situation in the near future, by modifying the contact printer and revising procedures.

From the ASG-18 film strips we were able to develop a number of standards regarding production of miniaturized graphics on *high-contrast*, black-and-white, 35mm film. The minimum image position and orientation errors, relative to the register pin sprocket holes, is $\pm$.0007" for a random frame. Breakdown of this error is as follows:

> $\pm$.0004", the tolerance specified by the manufacturer of the film in punching the sprocket holes.
>
> $\pm$.0001", the tolerance specified

by the manufacturer for the register pins in the film transport mechanism.

±.0001", the tolerance to which we are able to position the copy on the copy board.

±.0001", the accuracy with which we are able to register the various negatives to make the composite positives.

(These latter two tolerances are based on the 10-time reduction factor, and at working scale are actually ±.001".)

We have found that the minimum line weights *at the 35mm scale* which can be produced on a standardized basis are as follows:

Lines, .00035" in width.

Dots (such as halftone screens), .0002" in diameter.

Type (names, etc.), the thinnest portions of which do not fall below .0004".

Using these figures and multiplying them by the number of times the original copy must be reduced, gives us the size of the line weights, type, etc., which must be used at the original drawing scale, e.g., lines appearing .00038" wide on our strip were engraved .012" wide on the 32-time original.

Though finer lines may be resolved, these are the absolute minimums for normal production operations. If finer lines are used, they begin to "plug" and have non-sharp edges, and this reduces "readability." In addition, the overall background density of the negative must be lowered. When the background density is lowered, defects in the film emulsion itself, any dust or foreign matter that may be adhering to the original drawing at the time of exposure, any flaws on the copy holder or in the film of the original, will show up as objectionable spots on the miniaturized negative. With the lowered background density any attempt to opaque out these spots results in a very objectionable darker patch on the negative. With the line weights that we have specified above we are able to maintain background transmission density of from 2.3 to 2.8. This is sufficiently dense to permit opaquing. Also, when finer lines are used, processing becomes so inordinately critical that production of the film strip must be relegated to the laboratory, requiring the use of highly skilled technicians and stringent work conditions. Not only this, but the reject rate soars due to inherent shortcomings of the film itself.

The T-27 Space Flight Simulator posed some quite different problems which might be of interest. This system required a film strip quite different from the two previously descibed. It had to be a continuous strip--not a frame-by-frame sequence, but a strip with an uninterrupted image running the entire length. This image had to be in full color, simulating the natural appearance of the Earth from orbital altitude. Three separate strips were involved, each being three orbits long and consisting of one each of three separate scales. The strips were five inches wide, and depending upon the scale, from 16 feet to 38 feet long. Though formidable problems appeared in the compilation and final copy preparation phases, these were handled in a more-or-less routine manner using some of the more recent techniques which I have previously mentioned. The size of working copy alone, much of it 10 feet in length necessitated new approaches in registering film, processing and even in transporting the materials. A special template and hole punch device was designed and fabricated to provide a uniform banding and registration system and all materials from the compilation phase to the final product were pre-punched using this system. A special, 15-foot-long, vacuum printer with a traveling exposure source had to be designed and fabricated to produce the final continuous film strip. The printer was equipped with register pin system to match that of the pre-punched reproducibles. Our basic final copy consisted of color transparencies of varying lengths shot from realistically painted relief models and overprinted through the use of masks with the various cultural features and open water tone. We had a problem of assembling each of these on the final strip without having obvious "joint" lines. This was taken care of through careful positioning of "cloud cover" masks to hide the joints.

We cannot really consider the T-27 film strip as a true miniaturized navigation chart product, in that detail it contained was very generalized.

Precise geographic control was not maintained and high resolution was not required. We have given a brief idea of what was involved in preparing it to show our capability for developing and devising new techniques and equipment to handle very special and unusual situations.

Over the years we have done a considerable amount of work on miniaturized, full-color, chart graphics. We cannot truthfully say that our efforts have been entirely satisfactory, since almost all work has been concerned with the photographing of printed charts. We have been led along this avenue by restrictions laid down by both user and command. Though we have tested innumerable types of film, our most recent efforts look little or no better than those prepared 15 years or more ago. I personally feel that it is time we cease to beat this "dead horse," and if it is absolutely essential to have a full-color miniaturized graphic, explore other reproduction techniques. It is essential to use high-quality original copy to achieve high resolution on black-and-white films, yet on the more critical, multi-layer, color film, we persist in trying to reproduce from a more-or-less degraded, low-contrast, low-intensity, lithographed original. High-quality, original, negative copy is available for each printed chart. It may be that herein lies the answer to miniaturized color problems. In addition, utilization of these negatives permits us to eliminate many of the items from the conventional printed chart that may not be necessary to the display system. Thus, we can probably produce a more useful graphic as well as a more legible one.

CONCLUSION

In summary, I feel that if we are given early and direct contact with the system designer, reasonable time to perform an in-depth study of the operational requirements and non-contradictory parameters, we can produce graphics to enhance any type of display system. In addition, as shown by our past efforts and experience, we will be able to produce such graphics economically and expediently, using the existing techniques and equipment where possible, and devising new means where necessary.

DISCUSSION ABSTRACT

Mr. Wolin: You indicated some problems in attaining sufficient accuracy in your film strips. Is there something inherent in the type of film material you use that prevents attaining the needed accuracy?

Mr. Sicking: The accuracy with which we can place an image on the film is presently of the order of ±.0007" maximum for 35mm. The larger part of the tolerance is due to the punching of the 35mm film sprocket holes. This tolerance is specified as ±.0004" for standard commercially available film. The remainder of the error (.0003") lies in the camera and our production techniques. Of this, possibly .0002" could be eliminated by special handling of original copy, but this would make production extremely lengthy.

Mr. Wolin: By doing research in the film material itself, would you be able to improve these accuracies?

Mr. Sicking: We are using polyester-base film, which has very low coefficients of linear expansion. Under our production conditions, error that might be introduced by the stability of the materials would be so slight that it would be immeasurable.

Mr. Wolin: Well, I was thinking of the aircraft environment, in which ambient temperatures may range from -55°C to +70°C. How does the polyester-base film withstand such temperature variation?

Mr. Sicking: I don't really know. I would imagine the systems manufacturers could answer that question better than I. We have provided support for three different systems and have received no complaints regarding stability of the film. Undoubtedly, some provision must be made in the system to remove heat generated by the projection lamp.

Dr. Pelton: Did you mention the minimum line width that you could have on your color film and still get adequate density?

Mr. Sicking: I did not mention minimum line widths with respect to color film. I have no specific data on this, however, my experience has been that the minimums are larger with color than they are with black and white. The color or the dyes in the film are faint and the lines do not have a sharp edge, thus there is no valid comparison to a high-contrast, black-and-white image.

Dr. Guttmann: I note your remark about trying to make charts with three layers of different colors. I tried this with the plain 3M material which is available in ten or eleven colors. It's very cheap material, makes very sharp colored lines, and it is on a stable base. When developed in the darkroom, the lines can be superimposed.

Mr. Sicking: I am familiar with the 3M material, but I was thinking more specifically of using ordinary high-contrast, black-and-white films with various types of dyed images. In the case of 35, 70, or 105mm film, the existing sprocket holes could be used as a registration means between the various color separations. We have done some work with the dyed images, and find that a high degree of color saturation is possible, and the chemical reversal process produces a very sharp-edged image. Another thought, again using our final color separation negatives and standard films, is to make a high-contrast, black-background, negative image with colored lines produced by a dye transfer process.

Mr. Fellinger: I'm not sure whether you're the man to answer this, but I'm sure he is somewhere in this room. If we're using white lighting, I can see the role for color on charts, but if we are restricted to red lighting, what is the value of color? As a pilot, I could not accept any color presentation that would hinder my night vision. So, how does red lighting influence color on the various chart displays?

Mr. Sicking: I'm certainly not qualified to answer that. I haven't studied the visual response in any great detail. Are you speaking about reflected color, such as looking at a full-color chart under red light conditions?

Mr. Fellinger: Yes. But a back-lighted display would have similar problems, I think.

Mr. Sicking: The cockpit display, to which I was referring, is an image projected in color into a darkened or red illuminated cockpit. If the level of light used in projection is maintained at a relatively low value, and the background is black or of a negative type such as the ASG-18 display, I would think that this would not greatly affect dark adaptation. Perhaps someone else here can give us more information.

Mr. Choha: We have faced a similar problem at the Oceanographic Office in producing nautical charts, since one of the requirements is that they must be usable under red light conditions. We carefully control the color on the nautical chart so that it can be used under these red light conditions which, in turn, distorts or turns every color on the chart into a shade of gray. We do this by choosing colors which produce distinctive shades of gray under red light, and by using densitometer readings and complementary filters to assure this differentiation under red light. The same thing occurs with an aeronautical chart in the cockpit of an airplane. But, I believe that normally our aeronautical charts do not have this requirement, so that a good deal of the informational content is lost under the red light.

Dr. Guttmann: I'd like to make a remark to Mr. Choha. What about changing the red light? It's possible today to make a very narrow band dichroic magenta which allows you to recognize almost all printed colors.

Mr. Choha: The use of a dichroic filter sounds very interesting. I wonder whether any study has been made to determine whether the use of such a filter would influence the pilot's dark adaptation. If it does not, then I would suggest that the possible use of dichroic filters be seriously investigated.

Dr. Eddowes: In the case of using a map for reference to the terrain over which an aircraft is flying at night, the pilot has greatly reduced opportunity for seeing the terrain. Consequently, his navigation task is changed and his reference to a map and to the terrain is of a different sort than during day flights. Red light, then, and the degradations that accompany its use may not be critical to navigation performance efficiency.

Mr. Sorem: When adapted to the low light levels necessary to preserve night vision, the human eye is practically color blind. All colors are seen in shades of gray. Therefore, color charts have no advantages for *night* flying and, if viewed with red light, may have the serious disadvantage that some details may become invisible. If white light is used and the illumination level is high enough for the pilot to see the colors, his dark adaptation will be lost. So, the preparation of charts with dyes which would be represented in various shades of gray would be the best compromise.

CDR Heininger: In the ASN-67 map display for the A7A aircraft, we took the coward's way out and provided both white and red lighting, so the pilot could have either one at his own option.

Dr. Roscoe: The advantages of red lighting for dark adaptation have been grossly exaggerated. It is not so much the color of the light as it is the uniformity and level of the illumination that determines dark adaptation. So, the use of red lighting should not restrict the use of color in a map display. However, I do think there are some very good reasons for not using color in the basic graphics for map displays. We get much better resolution and contrast with black-and-white film than with color film. Color film may be improved in the future, but at the present time that's certainly the case. We find that the types of charts that we want for airborne map displays are typically uncluttered, very frugal charts, and we can get all the information we need on them in black and white. There may be advantages in using color for symbols which are projected on the charts, but for most of our applications the trade-offs are in favor of using black and white.

Col. Kelsey: I think this discussion does typify the problem which faces the cartographer, that is, the difficulty of establishing the requirement. Within this distinguished audience we've had people who have said that red lighting is essential, and people who said red lighting is of no use, whereas right now the United States and the United Kingdom cartographic agencies are currently tasked with a requirement for the current 1:250,000 chart that the colors must be distinguishable in red light, and this is one of the biggest limiting factors in the design of the chart. Now, perhaps there are people in here who can throw a lot more on this question of lighting on which considerable studies have been done. But I would like to hear the views of pilots and navigators on this subject.

Lt. Col. Spencer: My experience in Vietnam has been that you can forget about red lighting and its effect on map design, because we always used our white lights or flashlights to get a good look at the map.

Mr. Galipault: I have made several 300-mile flights, below 500 feet altitude, blacked out at night, and experienced great difficulty in making comparisons between the terrain and the chart under red light. We should eventually consider the basic question of trade-off decisions in cartographic design.

Capt. Miller: Dr. Roscoe stated that it is not the color but the amount of light that affects night vision. At some future time aircraft may use an amount of white lighting which will not hinder the pilot's dark adaptation, but today's tactical aircraft are such that whenever the pilot uses white lighting it is invariably of an amount which will destroy his night vision. Also, a pilot flying at night has little requirement to see color on his chart, since at best he can see the terrain only in shades of gray. So, as long as aircraft are designed to use red lighting, charts and displays must also be designed to portray their information under red lighting.

Dr. McGrath: I'm amazed to see that we are still arguing about red lighting. Certainly, many of these issues can be settled by reference to the well-documented research literature on the subject. However, it has been suggested in this discussion that color is not required on the chart because the pilot cannot see color in the visible terrain. This suggestion reflects a misunderstanding of the purpose of color-coded information on charts. One does not produce a multi-colored chart simply because the world is multicolored, but rather because color coding is one of the most powerful means of displaying distinctive categories of information. Therefore, the need for color coding on charts is determined by the categories of information that must quickly be discriminated by the pilot. I believe we could profit from an analysis of the types of visual checkpoints that are available to the pilot flying at night as compared with the types of checkpoints available during daylight hours. The number of checkpoint categories that would be potentially useful could then determine the categories of cartographic information that must be discernible under the cockpit lighting conditions, and thus the need, if any, for color coding. It may even turn out that we need a special chart series for night operations.

DESIGN AND COLOR IN CARTOGRAPHY

Thomas R. Yanosky
Cartographer
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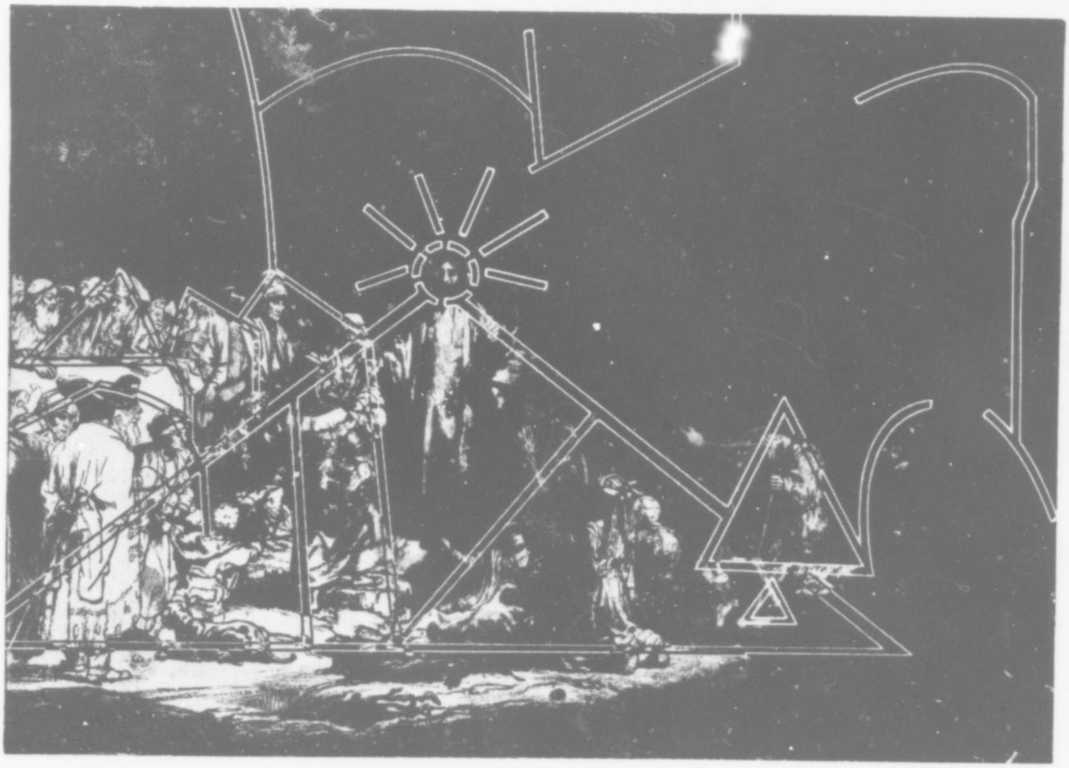
The celebrated etching by Rembrandt, entitled "Christ Healing the Sick," is shown below. Let's disregard, momentarily, the subjective aspect of the print so that we can make an objective analysis of its design structure. At first glance, the composition appears merely to be a crowd of people in a gloomy architectural setting. Upon closer scrutiny, we see that the figures are disposed upon a definite network of geometrical patterns. Lines radiate from Christ, whose face is the focal point of interest. The main group of subjects is arranged to form the classical triangle; smaller groups define lesser triangles and relate to the whole. The interplay of diagonal and lateral transitions create a rhythmic flow that guides and delights the eye. Sensitive drawings, delicate grays changing from light to luminous darks, and, we must not overlook, the penetrating empathy of the artist, are some of the qualities that make this etching a monumental work of art.

The print illustrates, very dramatically, the expressive force of sound, basic design. It proclaims, most eloquently, those qualities that are essential to the design of a forceful instrument of visual communications. In a subtle way, the etching hints at the effect, on the designer,



the influences of nature's "fearful symmetry," man's response to his habitat and the limits of his handmade environment.

Design in graphics, as we have seen in Rembrandt's work, may be defined as an orderly arrangement of parts to create a harmonious whole. These parts may be arranged in the form of dots, lines or tones, smooth or textured, in black and white or in combination with color values. Design should be balanced and its proportions interrelated. Its structure and evoked esthetic feelings must be gratifying to the senses. Essential to any good design are the qualities of unity, balance, completeness of the parts. Also essential is the emphasis and articulation of the parts as related to the overall pattern.

The development of the graphic arts since the fifteenth century has provided us with a rich heritage. Many fine examples of Bibles, engravings, etchings, and, let us not forget, old maps and atlases, still exist. Of particular significance and beauty are the seventeenth century Dutch maps of Mercator, Ortelius, and Bleau. We also have the splendid French maps of the early eighteenth century made by Cassini.

Let us now consider some aspects of color and color terminology. The use of color alone, or combined with black and white, provides a complete and unlimited palette for the expression of ideas and information. We experience the sensation of color from the energy of sunlight. Constantly we are made conscious of, and influenced by, the color of objects in our environment. Our visual senses are continually bombarded by myriads of colors such as neon lights, traffic signals, moving vehicles, multicolored clothing, the colors of landscape, plants, and animals. Therefore, it is logical that we use color associations to express abstract ideas, describe objects and statistics, evaluate or measure factual data, and to promote commerce and entertainment.

Scientists have developed color systems providing specific terms for identification, description, and measurements. The most common, and widely accepted, is the Munsell system. In this system there are five primary and five intermediate colors. Each color is mixed with one of nine shades of gray ranging from black to white.

Colors are identified and described in terms of hue, value, and chroma. Hue is the quality that distinguishes one color from another, as red differs from blue, or green from orange. Value expresses the lightness or darkness of a color. Value is indicated by the terms white, light, dark, and black. Chroma, also called saturation, is the departure of a hue from the gray of the same color value. High saturation describes a hue with very little gray. Low saturation signifies a color with a preponderance of gray. Zero saturation is the gray alone.

Colors are also categorized as primary, secondary, and tertiary. The primary colors are red, yellow, and blue; with the addition of black and white the group is known as the psychological primaries, or, sometimes called the artist's primaries. A secondary color, such as orange is made by a mixture of the adjacent primaries, such as red and yellow. Tertiary colors are made by mixing two adjacent secondaries, as orange and green.

The well-known color wheel provides a means for determining complementaries. Colors diametrically opposed, as red and green, are complementary. By intermixing these complementaries, interesting muted colors can be obtained.

In addition to the psychological primaries we have the additive and subtractive primaries. These are spectral colors dealing with transmitted light, particularly in color photography and the photographic phases of the printing industry. The additive primaries--red, green, and blue--when projected in proper proportions combine to form white light. The subtractive primaries are cyan, magenta, and yellow. We are all familiar with color photography where filters are used to subtract specific colors from white light. A combination of the subtractive colors create black.

Primary ink colors--cyan, magenta, and yellow--form the basis from which an infinite number of color combinations can be printed.

The terminology of mixed colors becomes involved. Basically, black and white make grays. Black, white and a color mix to produce a tone. Black and a color results in a shade, whereas a color mixed with white forms a tint. Such combinations are widely used in cartographic and industrial printing.

The foregoing general observations, of necessity, touch very lightly upon the many faceted psychological aspects of design and color in visual communication. Yet these notations, although basic, are more pertinent and indispensable when directed towards the preparation of the military topographical map. The large and medium scale maps are the most complex and challenging to the designer. Such modern maps portray a vast quantity of diverse information. They depict an abundance of accumulated knowledge from many sciences, such as Geodesy, Geography and Geology, Mathematics, Physics, History, Economics, and other fields of social, political, and industrial endeavors. In essence, the topographical map is a visual summary, or a pictorial document, whose content expresses configuration of natural and man-made features on the surface of the earth.

Of course, modern military needs require that a map reflect the most current and factual information. Based on a geodetic net of precisely measured horizontal and vertical data, it provides the user with reliable information about distances, directions, and values of elevation above sea level.

And now, a few words about Typography. Typography is the perennial problem child of cartography.

The selection and distribution of place names and descriptive notes on military maps command the strictest attention of the experienced map designer; the quality and quantity of typography is most significant. The sizes and styles must be correlated to the symbol, display the principle of contrasting values, and carefully positioned so as not to create ambiguity, or obscure other symbols. Typography provides completeness to the communicative powers of the map. It needs a study in itself.

Symbology is the means by which individual features, both natural and works of man, are represented in graphic terms on the map. Generally, symbols that depict natural features will embody some resemblance or connotation to the condition in nature. For example, water features as oceans, rivers, streams, lakes, appear in blue, which is the traditional color denoting a water feature. Green is used almost exclusively to symbolize vegetation. Contours are very often printed in a brown color to express earthen forms such as mountain ranges, peaks, draws, valleys, etc. By relating the colors on the map to those in nature, each symbol begins to convey a sense of visual identity.

Shaded relief is, of course, a significant ground symbol. It represents, pictorially, the characteristics of terrain. A well drawn and carefully articulated relief rendition gives a map authority and completeness. It must be designed as a vital and integral part of the topographical map.

Now, a few words about map structure. The structure, in graphic terms, of a topographical map is composed of three basic categories of symbols; namely, the point symbol, the line symbol, and the area symbol. Each of these categories conveys a qualitative or quantitative meaning. A qualitative symbol defines the natural disposition, character, or kind of an entity, whereas a quantitative symbol implies amount or measurement. For example, the mine symbol, a crossed pick and hammer, is qualitative; the town circle, which connotes a small population density, would be quantitative. Linear symbols, the most common of the graphic terms, dominate the map complex. Roads, railroads, boundaries, streams, and city outlines fall into the qualitative grouping. Contours, depth curves, isogones convey measured data which are quantitative. Since contours also express topographical form, they may be considered qualitative.

Area symbols, such as a green vegetation tint or a water tint, of course are qualitative, and hypsometric (layer) tints, bathymetric and city tints, road classification fills are quantitative in scope.[1]

In the composition of a map where a complex disposition of points, lines, tones and typography prevails, the design principle of contrasting values must apply. Distinction, or uniqueness of each line, can be obtained by dissimilar line weights, thick to thin, and avoiding lines of equal weights.

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[1]Robinson, A. H., *Elements of Cartography*, Chapter 8. New York: _ley & Sons, 1960.

For instance, two linear features such as a shoreline and a contour, at times have similar configurations but are made more unique by contrasting line weights and color difference.

Contrast of values and variation applies to area symbols. For example, water and vegetation tints must be of sufficient color contrast to be discernible, and yet must not obscure typography, or line symbols.

The topographical map, in its entirety, is a synthesis of many unique but interrelated parts. The arrangement of the parts must be orderly to achieve unity, balance, clarity, and completeness.

As a rapid advance of civil and military technology continues, the need for greater mutual cooperation in the field of visual communications has been noted. The mapping and charting agencies, both civil and military, are constantly reassessing their requirements and capabilities. They are frequently engaged in common efforts to improve the usefulness and efficiency of their respective products.

In conclusion, I wish to recommend that the mapping and charting agencies initiate a concerted program to further enhance the design concepts in graphic presentations. A coordinated effort in design research would permit analysis and evaluation of present methods, seek new graphic ideas, provide a keener insight to the psychological aspects of visual perception, with emphasis on design, color communication, typography and printing techniques. The understanding and appreciation of design in art, as we have seen in the Rembrandt etching, can influence the vision and creative powers of the contemporary map designer. Cartography is a scientific and artistic endeavor. Art must catch up with science, and, if the balance of science and art can be maintained, more useful and finer cartographic products will evolve.

DISCUSSION ABSTRACT

Maj. McDonald: I don't mean to reopen the question on red lighting; however, I have recently used the DoD FLIP approach plates. They are printed in blue on white, and I find them hard to read under red lighting. Is there any significant difference in the ability of the aviator to read these FLIP charts under red lighting as compared with previous charts printed in black on white?

Mr. Yanosky: Assuming you used the same red light, and, because red light usually has a blue component when it is made bright enough to read by, the dark blue on the FLIP chart will appear lighter than the black on the navigation chart. If you had a chart with detail printed in black and the graticule printed in dark blue, under red light the black would be unaffected whereas the dark blue would appear grayish, but lighter than the black.

Under red lighting, black lines or gray tints are not affected. Dark blue lines or tints, as well as green and dark purple, will appear as grays. Certain colors, such as red, orange, yellow, and some magentas, will be filtered out completely or will manifest themselves as very light gray lines or tints. To make red, orange, or yellow more visible under red light, the inks must be mixed with small portions of black, blue, or green.

Maj. Polhemus: Has any work been done in the area of discordant colors? You have conveyed to me the impression that creating harmony on a map is desirable. For example, elevation contour intervals are expressed in grades of green and brown in a smooth transition. But, rather than seeing harmonious colors, perhaps I should be seeing very discordant colors when I'm flying low level. Then those elevations which are significant to the altitude at which I plan to fly will stand out, in fact, they'll annoy me, literally bother me by the fact that they don't harmonize on the map, and therefore demand my attention. It might even be possible to make a display which, as we changed altitudes, produced a filtering effect which caused the next significant elevation band to be presented in even stronger relief. In other words, somehow charts should be designed to talk to us about terrain elevation or other hazards to flight, rather than to create a harmonious picture.

Mr. Yanosky: First of all, what do you mean by discordant colors?

Maj. Polhemus: All I'm saying is, I would like to have colors on the chart that forcefully present the intelligence that is meaningful to safety of flight.

Mr. Yanosky: What you want are colors that are contrasting and visible without any difficulty, normally or under red light.

We have been wrestling for many years with the problem of adequate layer tinting. The tint colors and ranges of elevation are selected for a series of maps. Thus it is not always possible to emphasize particular terrain anomalies within a given band. Other cartographic symbols, such as contours, spot heights, and good shaded relief must point out these potential hazards to the airman. The feasibility and/or use of bright, discordant colors as you describe can be tested in future experiments. Distinct contrast of color between layer bands is difficult to achieve because of the conflict with other areal symbols such as vegetation and shaded relief. The irregular, meandering patterns of the vegetation green tend to minimize the color clarity between layer bands.

Shaded relief portrays the configuration of the Earth's surface. Effective portrayal depends on subtle gradations of light and shade. Layer tints, particularly those in the top elevations, have a flattening influence upon the shading.

Sqn Leader Burton: There has been a tendency in modern chart design to use pastel shades instead of pure colors. Can you comment on that, please?

Mr. Yanosky: The modern map or chart must satisfy a gamut of user requirements. All the features must be legible; the lines, tints, typography and amount of detail must be so disposed as to permit graphic clarity of all the content.

Dark colors, in tint form or in a dense network of lines, tend to obscure subdued symbols. Certain colors when combined with other tints have a neutralizing effect. For example, a reddish brown layer tint will change the green hue of vegetation to a brownish tone. The pastel shades provide chromatic distinction to area symbols as well as sufficient transparency for legibility of linear symbols and typography within the tint.

The need for distinctive symbols to show potential natural and man-made hazards to the airmen is well appreciated by cartographers. The infinite spectrum of users' needs, plus the red light readability, imposes a formidable task to the map designers. Every effort will be made to provide the map and chart users with improved products that satisfy their requirements.

Capt. Miller: Has any thought been given to producing two kinds of maps: one for preflight study and the other for in-flight use? The preflight map might be designed much as the present PC or JOG series, giving as much accurate detail as possible, but requiring time and concentrated study for the pilot to fully understand it. The in-flight version might be designed to show only the checkpoints and terrain features which would be recognizable to a pilot during flight, especially at low level. It might be possible to eliminate on the flight map most of the lettering, such as names of cities, and even the lines of longitude and latitude since, once the pilot is flying low level, such information is of little use to him.

Mr. Yanosky: The design and preparation of preflight and enflight charts that you describe is a matter for the Aeronautical Chart and Information Center (ACIC) to consider. The need and/or feasibility for such products would be surveyed and evaluated by the Commitments Division (ACOR) of that agency. The enflight chart you suggest might be made from the same reproduction material as the preflight chart but printing the features of main enflight interest in brighter colors and showing the detail of secondary interest in subdued colors.

Dr. Magorian: We have a strong desire for more quantitative data on maps: more contours, vegetation heights, swamp and marsh conditions, and so forth. The question of appropriate symbolism with sufficient contrast and detail for each user-system needs considerable further study. The distinction between qualitative and quantitative symbols needs to be clarified.

Mr. Yanosky: Although my reference to the qualitative and quantitative symbol categories was rather cursory, I feel as you do, Dr. Magorian, that much work needs to be done in this field. This is one of the many subjects that would be included in the map design research program I recommended. Mr. Arthur H. Robinson, Professor of Geography, University of Wisconsin, has done some fine work along this line in his book "Elements of Cartography."

CAN THE GRAPHIC ARTS ADEQUATELY SUPPORT THE VISUAL PRESENTATION NEEDS OF NAVIGATIONAL SYSTEMS?

Deforest D. Choha
Technologist, Lithographic Division
Naval Oceanographic Office

Can we in the Graphic Arts manufacture multiple reproductions for use in navigational displays? Can we successfully meet the definition requirements for display systems? What about future possibilities?

The Graphic Arts is involved with diverse methods of imprinting symbols on materials which present visual information. We may do this with printing presses or cathode-ray tubes impinging light on photographic materials, or perhaps use pen and quill on parchment. We record information in visible graphical forms that can be easily utilized. We, at times, do this so well that it may be difficult to distinguish our graphic art from the fine arts. We may further relate the art to our visual world by noting that when a temporary electrical signal is converted to a spatial pattern its permanence assures it a place in the graphic arts.

We envelope all the diverse techniques used in the science of imagery and include most of the scientific disciplines. With all these attributes, we appear to be eminently qualified to produce multiple reproductions for use in navigational displays.

The printing arm of the graphic arts is its largest single element and is considered the largest industry in the Washington area, and depending upon the statistical base used it is one of the five-to-ten largest industries in the United States. This giant industry produced approximately twenty billion dollars worth of gross printing in 1965.

Consider for a moment the sophistication of the art of printing. Millions of copies of a printed page can be produced within a few short hours. The industry prints a diversity of products such as: books, magazines, periodicals, catalogues, billboard posters, advertising mail; and more to our interest, aeronautical charts and maps, the tools of air navigation. The versatility of the art is vast and ranges from symbolization imprinting of red hot soda bottles, copies of pictures in full color taken by a piece of equipment squatting alone on the moon, designs on the wallpaper in our homes, or the patterns on the clothes we wear. There are few materials known to man that have not been used for some form of printing impressions. Printing is the means for producing copious quantities of visual materials at great speeds. Witness our huge magazine and newspaper presses which print thousands of impressions per hour onto a web of paper. These presses not only print, but in combination with other processing equipment, slit, fold, collate, and bind five-foot-wide (plus) signatures in a single continuous operation. We at the Naval Oceanographic Office, using a battery of high-speed single and two-color 60" presses, printed some 32,000,000 impressions during fiscal 1966. Other government charting and mapping agencies added another billion imprintings to this already impressive total.

You would believe that an industry with all of these communicative abilities could adequately support the graphic needs of all the different types of visual navigational cockpit display systems. We are sure that it can, but the fact is that it has not. To fully understand the reasons for this "has not" we should first explore the cockpit display requirement.

A generalized definition of a Cockpit Navigation Display System might be stated broadly as a piece of equipment endowed with the ability to know where it is at any given time, and to be able to convey this information to a person or persons using it. Generally, airborne navigation situation display systems can be separated into three groups: raster scan conversions (electronic transmission), direct view (roller map), and optical display. We can graphically support the black-and-white requirements of the raster scan system, and because the direct view type uses existing charts it too can be supported both graphically and logistically. If we are to support optical displays, the third type, we should know what their characteristics are. An optical projection type display should have the following:

1. It must have an output that gives an understandable facsimile of the real estate below, one that is suitable for geographic orientation.

2. It must be light in weight and compact in size so it will comply with the weight and size limitations of our airborne vehicles.

3. It must have a memory to be able to locate itself when given a few impulse commands.

4. It must be conducive for continuing logistic support.

The navigation display system should be designed to make direct use of existing standard aeronautical chart and topographic map series in some form. This is essential because production of special graphics is too complex, costly, and time consuming to provide timely support for the display system. Additionally, we must consider using our existing chart data bank, not only because it is a readily available reference material, but also because it epitomizes one of the finest informational storage mediums available for our use. Because we are interested in the ability of the art to support these optical navigational displays, it would seem prudent to: (1) investigate the graphic arts composition of a chart; (2) the availability of some old and new materials; (3) investigate the possibility of using several unconventional techniques which may be suitable for the production of graphic input for navigational displays.

Using the navigational charts printed by the Naval Oceanographic Office as representative samples we note that our air navigation charts are printed with multiple colors. The most complex chart we at the Naval Oceanographic Office produce requires a press run for each of its nine colors. The sequence of production operations required to transfer the line separations received from the cartographic divisions, through the many reproduction phases, require the services of many highly skilled craftsmen. These men transfer images appearing on cartographically prepared line color separations, engraved by hand and machine, to either photographic intermediates or directly to metal printing plates. Each printing plate carries a separate record which is used for a single color printing. Color shadings on charts and maps are normally produced by the use of halftone screens or line-tint screens. The finest dot screen used, by the Naval Oceanographic Office, for chart printing is a 200-line-per-inch screen, having a definition of approximately four lines per millimeter. These screens control the strength of color in designated areas. We routinely achieve a resolution of eight lines per millimeter on our charts when we print a .005-inch line--the narrowest width line used that is commensurate with good cartographic practices.

Conventional pressure-printing systems (most charts and maps printed in the United States use Lithography) approach their limits of resolution when they print a 500-line-per-inch screen or a .002-inch dot or line. The factors limiting the resolution are the plate grain, paper surface, mechanical slippage, and the physics of image transfer from surface to surface.

Resolution numbers, although not firmly established as a quality measuring tool, at least serve as a universal understandable base. It should be noted that the resolution capabilities of any system are greater when the system uses a high-contrast image as its target. The figures quoted here are for the high-contrast portions of a chart.

The exact resolution of a multi-layered chart printed in nine colors is, of course, difficult to ascertain.

Photographic researchers at the Eastman Kodak Company and Batelle Memorial Institute concluded that an eight-line-per-millimeter resolution capability for a reproduction system would be excellent. This resolution may be considered as optimum for comfortable viewing over long periods. Our printed charts, as we have seen, meet this comfort index admirably.

If we now consider that the graphic construction of a chart is made up of multi-layers of colored tints and inked solids made by printing halftone dots and solid lines, as well as solid type matter printed one on top of the other, it becomes obvious that each square inch of a nine-color chart must contain millions of bits of information. This information must somehow be massaged, compressed, or altered for optical display use.

To preclude giving the pilot anything less than that which he is now using, a reproduction system must be designed to first reduce, then enlarge back to scale, and to display a chart image which will retain the same comfort index as our available paper charts.

The most reasonable method of preparing graphics for use in optical display systems appears, at this time to be a photographic one, because the state of this segment of the graphic arts is highly developed. In the interest of inter-service standardization of format, size considerations, and assuming that chart legibility is based on color, then logically, we should require the graphic arts craftsman to prepare a miniaturized color transparency reduced photographically by a minimum order of magnitude approaching ten. The definition and resolution appearing at these reduced sizes is not easily obtained with off-the-shelf photographic materials and existing flat field, fully color-corrected, copying lenses. The multi-layered construction of color film reduces its possible resolving power many times; 100 lines per millimeter appears to be a fair resolution limit for a duplicating color film suitable for chart copying. A color film to be used for chart copying should have other qualitative characteristics such as edge sharpness and color saturation --these are equally important characteristics but difficult if not impossible to measure. The resolving ability of a film can never exceed the resolving power of the taking lens; in fact it is much less. Two factors are in effect at the time of exposure, these degrade the resolving power of any lens-film combination. A much simplified explanation of this secondary inequity follows: (1) Colored films have a relatively thick three-layer construction (cyan, magenta, and yellow layers). Light passing through each layer is scattered and diffused because of the crystalline structure of the emulsions. (2) A photographic lens when transmitting all the colors of the spectrum through its lens components, because of the different length of the light waves transmitted, cannot reconstruct the full color image in a precise plane of focus.

These two lens-film factors in combination lower the definition and resolving ability of the final product. A useful rule-of-thumb formula used to predict the theoretical limits of this combination is:

$$\frac{1}{R_{(f)}} + \frac{1}{R_{(l)}} = \frac{1}{R_{(c)}}$$

where: $R_{(f)}$ = Resolving power of the film
$R_{(l)}$ = Resolving power of the lens
$R_{(c)}$ = Resolving power of the combination

If we chose a system goal of eight lines per millimeter on the viewing screen of an optical projector and assume a 15% loss of resolution in the optical system due to the lens/film combination and the viewing screen loss; and assume further, a magnification factor of ten for the system; then our transparency input should exhibit approximately a 95-line-per-millimeter resolution to display an image resolution within the comfort zone noted previously. Again, using the formula, a lens would have to resolve 2000 lines per millimeter throughout the full color spectrum when used in combination with a film possessing a 100-line-per-millimeter capability. A lens that can successfully shrink a 60-inch chart to a 6-inch image and meet these requirements may be impossible to design.

We can, of course, lessen the stringency of the lens requirement by raising the resolving ability of the film. For example, a combination of a 200-line-per-millimeter film and a 200-line-per-millimeter lens would theoretically provide a 100-line-per-millimeter transparency. A 100-line-per-millimeter transparency, possessing the other objective merits of well balanced color, good edge sharpness and full density of color, should project a fine display image that is well within the quality comfort zone noted previously.

A possible alternative method of solving the resolution requirement would be to use an indirect color-separation method. The use of microfilm for reduction, storage, and retrieval has become a highly sophisticated art. Approximately 200 lines per millimeter can be easily obtained with black-and-white film using existing equipment and lenses. This alternative method would require three separation black-and-white records. Each record would represent, in black and white, one of the complimentary colors to be printed on the transparency. The lens-film degradation factor could be eliminated by placing the black-and-white separation in physical contact with the color film and exposing the film with an appropriately colored light. Using the indirect technique, however, would make the operation much more complex. It would require stringent control of each phase of production to assure final physical registration and color balance, and would undoubtedly raise the production cost and increase the calendar time needed for preparation of the transparencies. The Technicolor Corporation of Los Angeles, California, has successfully used a similar technique for the color separation of motion picture film for many years. The Technicolor method, although using an indirect separation technique, differs in the final phases of production where a dye-imbibing process is used to make the final motion picture print film.

The graphic industry has recently witnessed the introduction of several new processes for creating visible images. Several of these modes of reproduction offer potential for high-definition graphics.

Electrostatic printing has merit. Materials used to capture a latent image can be made receptive to the full color spectrum which is of interest. This process uses a pressureless system of printing. Light weight equipment can imprint finely ground, dry, toner particles on practically any material. However, most of the reproduction equipment now in use is limited to black-and-white printing with a medium quality output that is not indicative of its full resolution potential. A contact method of printing using an electrostatic process can be demonstrated which will produce resolution equal or better than conventional printing processes. It may be possible to modify this technique of printing by cross coupling it to an electronic color-separation-scanner magnetic tape and an infinitely fine pencil of laser light to output high-definition full-color images.

Several large manufacturers are experimenting with plastics which have photographic properties. Quality images can be made to appear after proper exposure by using heat alone. One heat-developable film for black-and-white duplication is being marketed extensively throughout the country. This film, when exposed and processed, releases tiny bubbles of nitrogen gas on the emulsion. These bubbles, when subjected to heat, expand, burst and produce a form of reticulation on the surface of the film which tends to disperse the light in direct proportion to the amount of exposure. The resolution of this material is exceedingly high.

A continuous-tone printing method has recently been introduced by several commercial printing firms and shows much promise. Unlike conventional halftone printing which requires the insertion of a halftone screen between the taking lens and the film, this newer method uses a continuous-tone film as an intermediate step between the copy and the metal printing plate.

Using this method of printing the definition is no longer dependent on the coarseness or fineness of the halftone screen used, but is mostly limited to the grain of the metal printing plate. It appears that this technique can successfully print 20 lines per millimeter routinely, and better this with laboratory equipment.

Further experimentation should be conducted using grainless plates and plastic printing stock to determine the absolute limits of resolution available using this continuous-tone printing system. Many other modes of capturing high-quality images exist (Photopolymers, Holography, etc.). They have not been mentioned in detail since space precludes a full description of each technique.

To conclude: the graphic arts industry, as we have seen, ranges across a wide spectrum of scientific disciplines. However, there is no imaging science cutting laterally across the full scale of the exacting disciplines used in the graphic arts, and no large-scale effort to change the art to a science is being carried on at present. Our past graphic research efforts were expanded to automate the final phases of printing production; the successful results of these research efforts are evidenced throughout the industry by its ability to produce large quantities in short times. If the art is to adequately support a program for the production of optical display graphics we suggest a system analysis be made, using a team approach, to take a long hard look at the entire spectrum of the graphic arts, printing, photography, optics, in fact all of the so-called imaging sciences and arts. An attempt should then be made to merge several different aspects of the art or to develop new techniques or products, as found necessary, to produce modified charts with adequate characteristics for use in optical displays.

I hope we have established that the graphic arts is indeed a huge industry with a well developed capability and with scientific disciplines woven throughout its structure, one that is able to produce millions of copies of black-and-white newspaper pages, beautifully illustrated advertising pieces, functional cold type, color photographs of good-to-excellent quality, and a host of other useful outputs. It is, however, exceedingly doubtful that the graphic arts can today produce, in quantity, color transparencies of a navigational chart sufficiently reduced in size to meet the bulk, weight, space, and definition requirements of a display system by using available materials and equipment. It is doubtful that the segment of the industry supplying the raw materials and fulfilling the optical needs of our cartographic support community can furnish products that will yield the necessary definition, color, resolution and density, when used as input for an optical display system, with off-the-shelf research.

I truly hope that my limited investigation has possibly led me to the wrong conclusion: please tell me if it has.

DISCUSSION ABSTRACT

Dr. Pelton: In the color TV business, they found that a little bit of color with quite a bit of black goes a long way for a good color picture. I realize you're in a quite different game, but is it possible that the combination of high-resolution black with color might produce a better graphic?

Mr. Choha: Yes, this is an excellent approach, I think, for the eventual solution of our problem. We can produce most of the tints and colors with the three complementary colors (magenta, cyan, and yellow). The Oceanographic Office is now experimenting with a method of printing full-scale, full-color charts with four colors (adding black). Using this method we have successfully reproduced all of the necessary data required on one of our more sophisticated aeronautical chart series. The same arrangement might be used in a miniaturized printer to achieve a high-resolution chip. As you suggest, one could color-separate the chart into its three complementary records, print these back in continuous tone with a low-resolution process. The black component, however, could be committed to a high-resolution reproduction technique, and then reproduced with great fidelity.

Mr. Wolin: Are we supposed to gather from your report that some of us in the systems business are expecting the cartographic industry to do, at this time, something that is impossible, or unreasonable, in regard to our map displays?

Mr. Choha: No, I don't believe you've asked us to do anything that's impossible. I think we have to relate our problems to some of the photographic material makers and the lens makers and point out to them that there is an immediate market for higher resolution products. Then I think they'll come forth and produce exactly the things we need. The lens problem may possibly require government support, but the photographic products people can probably produce a high-resolution color film using their off-the-shelf research. We in the cartographic community may have boxed ourselves in, particularly in regard to aeronautical charts. We are continuously required to produce larger, more sophisticated charts; and, of course, these charts have more clutter. We then turn around and ask our operational people to use, for example, a 60-inch chart in a small cockpit. We're going to have to display the information on our charts in a more usable form. Yes! I think we can meet your requirements. It isn't an unreasonable demand. It just hasn't been done as yet.

Mr. Honick: I thought you would be interested to know that the problem of achieving high resolution and high contrast on color film has, in fact, been resolved.

I agree entirely with your specifications for the desirable materials, and until about three years ago the best results we were getting, using integral tri-pack materials, were about 70 lines per millimeter. But, the contrast range of these materials, which are designed for the amateur market, is wide in order to allow considerable latitude for exposure error. This was unsuitable for the recording of maps which are, in general, low-contrast objects. We concluded, as you did, that we needed a process color emulsion which was possessed of high contrast, low speed, and high resolution. And this has been produced by the European firm of Gevaert at Antwerp, Belgium. They call the material Scientia Color. It is a color negative film of low speed (approximately 1 ASA), high contrast (gamma 2.5), and high color saturation, with a resolution of 200 lines per millimeter.

This material has transformed the whole situation, and I think will change many of the conclusions that have been expressed today. It seemed to me that these developments were not generally known, and that many of the conclusions which have been reached have been based on an assessment of the potential of color film which was unduly pessimistic. Scientia Color has permitted us to get 200 lines per millimeter on a negative material, and to reproduce by contact printing and still produce transparencies with about 100 lines per millimeter on the positive print. This capability alters the whole logistics situation. It also illustrates the danger of premature standardization at a particular level of performance which is likely to be overtaken by technical advances.

Mr. Choha: We are aware of the Gevaert Scientia Color material, but were unable to procure some for test because of the "Buy America Act." We hope that you design people know how to circumvent this. There is one comment that I want to make. Our data bank is extensive. We have some 33,000 different charts at NAVOCEANO already printed and stored. As an interim measure, we could, if needed, reduce these onto an integral tri-pack color material, because it's such an elegantly simple way to miniaturize our existing chart data bank.

NAVIGATION DISPLAYS AND EVALUATION OF CONTACT-ANALOG SYSTEMS

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It is our mission at the Naval Missile Center to determine how the present Contact Analog Display can best aid the pilot in performing operational procedures and making tactical decisions. Before proceeding, let me digress to account for several of these terms.

A *Contact Analog (C-A) display* has two basic features. It presents symbolic representations of real-world elements, which move in proper scalar relationship to the actual vehicle; and these elements are anchored to their real-world referents. The vehicle is perceived and controlled in the vertical plane, and so is depicted on a vertical cathode-ray tube (CRT). The pilot can control the attitude and immediate location of his depicted vehicle using visual, movement, gravitational, and postural cues. The earth is perceived in the horizontal plane, and so is depicted on a horizontal CRT. The real-world cues might be symbols superimposed on and moving over charts and maps. The pilot is thus able to control and predict his future location. The planes of reference (the self and earth coordinate systems) as well as the displayed elements are both depicted in a totally integrated C-A instrumentation. This is important for orientation, but does not preclude the possibility of displayed information in one plane influencing the perception and interpretation of information in the other, but more about this later. It should be noted that the present C-A instrumentation has no such horizontal display component, but I presume it will be added at a future date.

Operational procedures may refer to local control of the vehicle and includes such factors as speed, altitude, steering, angle of attack, roll angle and roll rate, pitch angle and pitch rate, rate of climb and rate of descent. The vehicle's displays must let the pilot know about the present status of vehicle systems.

Making *tactical decisions* may refer to attacking enemy targets, and includes such factors as corridors of approach, defense implacements, knowledge of remote terrain and possible effects of adverse local conditions on targets, getting lost, and getting relocated. The displays should provide the right information with enough lead so the pilot can make the correct decision whenever a choice occurs, and should permit the pilot to "look ahead" and "look back."

A fundamental problem of local and remote control is that accurate orientation in the vertical or horizontal plane is necessary for interpretation of depicted information in those planes, and vice versa. This circular situation is usually resolved by cross-checking displays and reconciling them with real-world referents. I would like to make the point that disorientation in either the vertical or horizontal plane may be caused by the ambiguity between what is displayed and the way it is perceived, interpreted, and reacted to. If we could get at ways of minimizing the ambiguousness, we would be approaching a solution to these types of problems.

Yesterday, there was much discussion of the methods for obtaining and validating information requirements for maps and charts. In defining the information requirements, it is first necessary to have a definite set of terms by which distinction between information sources and orientation planes can be made. If your task as an experimenter is to measure operator behavior in response to vertical information, and the pilot is in fact responding to horizontal information, your results will be misleading to say the least. So a distinction must be made between vertical and horizontal orientation in order to distinguish between errors of orientation in contrast to errors of misread displays.

To illustrate the problem of ambiguity between vertical and horizontal information, I will ask CDR Lawson to assist me in the following demonstration:

1. Draw a five-pointed star in a 20-inch circle.

2. Make the points exactly equidistant.

3. Draw a two-inch figure 8 tangent about the 2nd, 3rd, 4th, and 5th points and return exactly to the first point.

4. Do not deviate from any line between points more than 1/4 inch.

5. Perform the above so as to finish the first leg in 40 seconds and the remaining legs in exactly 15 seconds each.

6. Do not look at a clock. Just count.

7. Do not look at the drawing surface, but rather look at the display being projected on the screen.

8. Oh yes, balance this stick on a finger of your free hand at the same time and don't permit it to fall.

The various constraints on this artificial task are essentially the same sort that the pilot must deal with in flying a sortie. He leaves home base, goes to exact locations, performs devious tasks only after arrival, maintains a time schedule, restricts deviations, returns exactly to where he began, while maintaining a balance between objects in different orientation planes. These things can and do become quite ambiguous and confusing even under much better feedback conditions.

The conditions which would make for better navigator performance and balancing behavior become apparent. Methods are needed which:

1. Provide an overall layout of the plot.

2. Provide look-ahead knowledge of spatial and deviation limits.

3. Provide immediate knowledge of rate of travel and change of direction.

4. Provide look-back information to see what's been accomplished.

5. Provide confirmation of control action.

6. Provide a comfortable time scale in which to accomplish the work.

There are numerous technicalities involved in dealing with these problems but the essence is the same regardless of the terms used to talk about them. You still must interpret your displays *and* remain oriented to control your vehicle while performing numerous housekeeping tasks, you must look ahead to plan and deal with changes of plans on short notice, and you must be able to see and confirm what you are doing and have done. When the pilot has sufficient information to do these things, he can more likely make the correct decision whenever a choice occurs.

Let me again mention that to achieve our complete stated mission, the effort would be well served with the addition of an integrated horizontal display (or a reasonable facsimile) to fully test and evaluate the integrated vertical C-A instrumentation. This would permit us to consider the joint or interacting effects of the one display and plane of orientation on the other, and avoid misstatement of C-A capabilities.

DESIRABLE DESIGN FEATURES PECULIAR TO A PROJECTED MOVING MAP DISPLAY

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Computing Devices of Canada Limited

INTRODUCTION

The concept of a projected moving-map display has, over the past few years, been the subject of many studies, discussions, and reports. To date, however, very few of these displays have actually flown and, in fact, very little information is actually based on practical results. As a representative of Computing Devices of Canada, a company with considerable experience in this field, I thought I might best utilize this opportunity by providing the conclusions that we have reached pertaining to certain desirable parameters peculiar to a Projected Map Display. I say peculiar, for I do not intend to enter into those problem areas common to all avionics equipment such as reliability and maintainability.

As a display designer and manufacturer, we must fill the gap between the cartographer and the user. Therefore the parameters to which I do refer pertain on the one hand to the raw materials and techniques available to us, and on the other to the display features we have found most suited to satisfying the user's requirement.

Obviously the scope of this undertaking will not permit detailed examination of any one particular facet; however, I hope that our findings in the various areas will prove of interest. For those who may be unfamiliar with ComDev's history in this field, I would first like to briefly describe the nature of the practical experience which we feel justifies our opinions.

The development of our Moving-Map Display system began with a concept originated by the Royal Aeronautical Establishment at Farnborough. Initial studies carried out by ComDev for RAE established the basic design parameters for a practicable system. Three developmental models of the Moving-Map Display were fabricated during the early part of 1963. All three equipments have undergone extensive demonstrations, bench trials, and flight trials. The first of these flight trials was conducted in two phases during the period from April 1963 to May 1964 by the Royal Air Force at Boscombe Down. For the first phase, the display was installed in a Hastings transport aircraft provided with true heading and doppler inputs, and subjected to 24 hours of in-flight evaluation in order to evaluate accuracy and assess human factors. The second phase consisted of 32 in-flight hours of system evaluation in a Javelin fighter to assess the suitability of the equipment as a pilot nav-aid in low-flying, high-speed, strike aircraft using air data inputs.

The next trials were carried out by the French Light Aviation Group in an Alouette III helicopter. It might be noted that the French, after 200 flying hours, have estimated that mission success in low-level support operations using the map was 90% compared to the normal 25 to 30% success rate without this equipment.

The third series of trials was again conducted in two phases, this time by the RCAF in the CF100 all-weather interceptor. The first phase carried out in 1965 consisted of 23 flights to determine navigators' and pilots' opinions on equipment handling when interfaced with inaccurate sensor inputs. The second phase using a doppler sensor has just recently been completed but no report has yet been released.

Constructive criticism contained in trial reports has resulted in numerous design improvements to the system.

DISPLAY TECHNIQUE

Computing Devices' basic technique

for Moving-Map Display is the use of a projected film strip. This technique was adopted in 1962, when the development program started, and has been retained throughout subsequent development. The main reasons for adopting the film strip technique rather than other competing techniques were that:

1. It allows maximum efficiency. That is, it provides maximum storage capacity in a minimum display indicator volume.

2. It permits use of a simple optical path.

3. It is compatible with a rugged physical design.

4. It simplifies the mechanization required for display.

5. Transparencies were commercially available in the desired format: 35mm or 70mm film strips.

The appearance of the Moving-Map Display is shown in Figure 1. The mechanization of the display is straightforward and is shown in Figure 2 as it was actually designed, in three physically distinct sections.

The rear section houses the projection lamp, one or more spares, and the necessary cooling elements. The center section contains a servo-driven turntable to permit orientation of the display. Mounted on this turntable are the projection lens, the film drive mechanism, and the film cassette which contains the film rolls and the position feedback elements. The film is driven from roll to roll for X or E-W motion, while the cassette itself is translated for Y or N-S motion. The front section contains the necessary servomechanism to position any auxiliary display elements and contains the projection screen itself.

ROLE

This particular type of display is directly tailored for the low-level, tactical fighter or helicopter operating without ultra sophisticated sensors and computery. While we have put considerable effort into studying the more complex area of combined displays, please bear in mind that our practical experience, and hence the basis for the points raised in this paper, are related to a fundamental map display.

As the desirability of design features is mainly a function of the general role of the display, the first step we should therefore take is to define this role. In the case of the Projected Moving-Map Display, we consider the role to be threefold. First, the display provides for effective communication from the computer to the operator. That is, it provides a dynamic display of present position and rate of change of position in the horizontal with respect to the aircraft environment. Secondly, the display permits the operator to orient his navigational information with the surrounding terrain. Finally, the function which I feel has been wrongly upstaged by the previous two in past system requirements--the provision of a simple and efficient feedback from operator to computer. The Moving-Map Display provides the facility for entering various types of fix data into the navigation computer to update the system, visual fixes in particular. For, no matter how sophisticated the sensors, for many years to come the updating requirement will prevail and when the pilot is operating VFR, the visual fix is the most accurate and the most psychologically satisfying method. That is, seeing is believing. The map display offers the only efficient method of relaying this information to the computer.

SELECTION OF PAPER MAPS, FILMS AND REPRODUCTION TECHNIQUE

The qualities of the display will naturally be determined to a great extent by the qualities of paper maps selected. We realize that, like any other display manufacturer, we must attempt to choose the best of what is currently available in this line for any particular aircraft role. Our trials and studies fully concur with the observations made by many others on this subject in that existing charts are definitely not tailored to the Projected Moving-Map Display. More specifically, the following complaints were typical of comments received.

1. Differentiation between line features is difficult because of lack of color contrast.

2. Certain information, such as contour lines, is difficult to interpret.

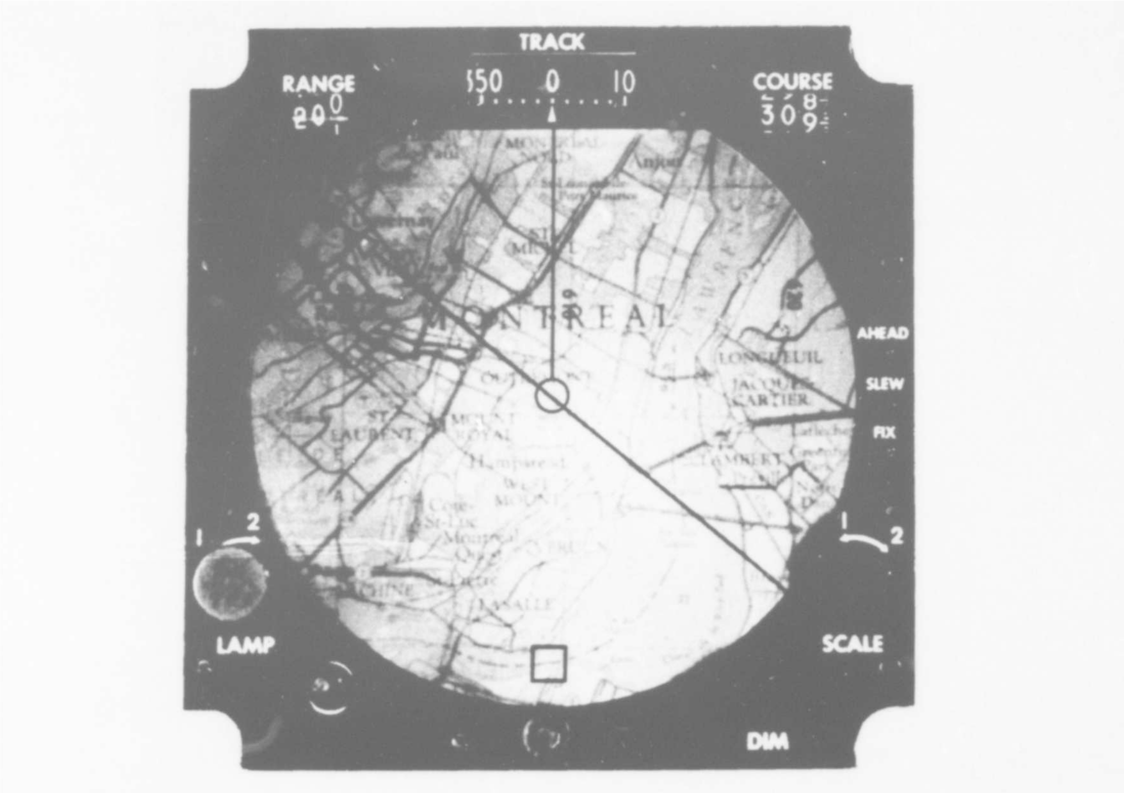

Figure 1. The appearance of the moving map display.

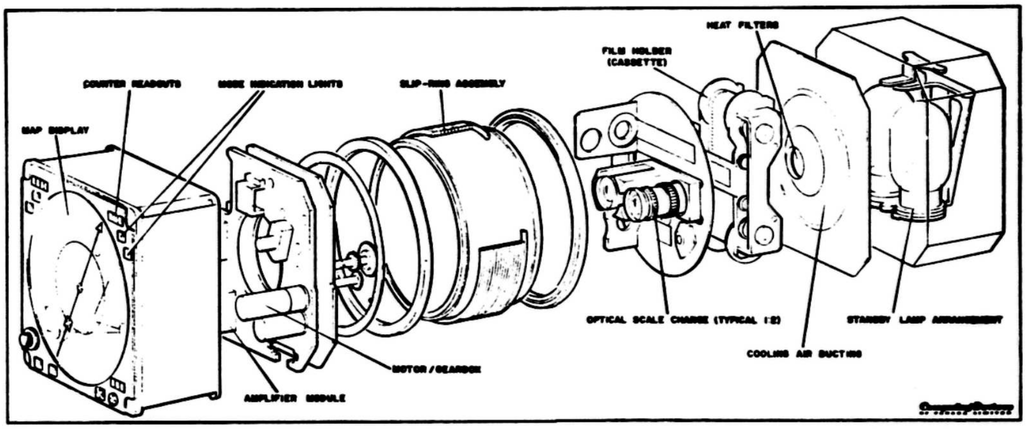

Figure 2. The mechanization of the moving map display.

3. In many built-up areas, too much map detail adds to confusion.

4. In the low-level role, insufficient absolute height information exists.

However, as I am sure that those concerned are already aware of these and similar inadequacies, I shall not pursue this aspect any further.

The format and type of transparency to be employed is also restricted by commercial availability. Kodachrome II 35mm positive film was used with excellent results in the initial three developmental methods. Unfortunately standard positive prints cannot be directly made from this film, so we continued testing various types of film to determine a suitable replacement. Our most successful results to date have been achieved using an intermediate negative, color print film combination. Although the advantages of a dimensionally stable base are recognized, the most suitable films for our purposes are not available upon a polyester base. We are led to believe that if the film requirement became large enough, this situation might change. However, environmental testing carried out to date on a system incorporating film on a cellulose triacetate base has proven its ability to meet those conditions specified in Military Specification MIL-E 5400 for Class I equipment. We have found film life to be limited only by the degree of fading considered acceptable. Although different films fade with different color tints, the degree of fading was found to be essentially the same for all films tested. Luckily, however, fading does not degrade film detail, only color. After 51 flights at Boscombe Down, the topographical detail was still completely readable even in the area immediately surrounding the airfield.

The two most suitable methods of producing positive map strips from the master negative are both contact printing processes. These are the continuous contact process and the step contact process. Although a step contact printer would provide a print of the highest degree of acuity, and within reasonable limits, of accuracy, we feel the printing process employed must be of the continuous contact type for the following reasons.

1. Due to perforation differences between suitable intermediate negative and positive print films, they are compatible with the continuous process but not the step process.

2. A special step printer would be required to eliminate frame separations in the copy. This would require a special aperture to make the length of film exposed and the length pulled down identical.

3. Although continuous printing is in current use, we have been unable to locate a suitable step contact facility.

In recommending the use of a continuous contact process, it is pointed out that this method suffers from two basic limitations, which are not present in the step contact method. The first is that the continuous contact printing method has no exact registration of the copy film with respect to the negative. The perforations of master and copy films are engaged by an involute tooth and drawn past the aperture against the tension of a jockey roller. The second is that since the film is in motion during exposure, deviations in perforation pitch from standard will result in slippage between the films at the aperture during exposure. Since the permissible deviations are quoted as ± 0.0005 inch in each film, it is assumed that all such slippages will be less than ± 0.0007 inch. This means that in a worst case, the finest line accommodated upon the copy will be 0.0007 inch thick. This will result in a 0.01-inch line thickness at the screen. This is a worst case: a more reasonable estimate may be of the order of a 0.003-inch line at the screen.

FILM FORMAT

The next problem is that of reproducing the paper charts on the film strip in such a manner that the aircraft's position in relationship to the earth is easily converted to the same position with respect to its location on the film.

Let us take a simple example to illustrate how this may be accomplished. To cover a large area of the globe on a strip of film requires the intermediate step of converting that area to a flat map. For minimum distortion, the map projection should be appropriate to the given area. For example, if the area is square, and located at intermediate latitudes, a Lambert conformal chart will provide best results. A continuous length of film is arranged to cover the given area of map by dividing the area into a number of east-west rows with north-south overlap between each row. Although a series of photographs are taken along each row, the map frame masters and copying camera are arranged so that the map detail is continuous along each row as shown schematically in Figure 3. Aircraft movement along each row therefore presents no problem, but if the route flown is across the row the display must obviously eventually reach the edge. When this occurs, the display is automatically slewed to the correct position on the next row.

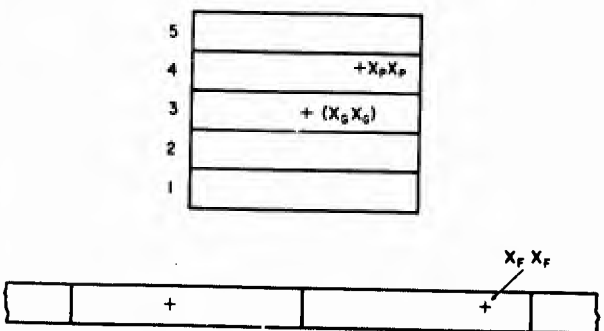

Figure 3. Arrangement of East-West rows in continuous film strip.

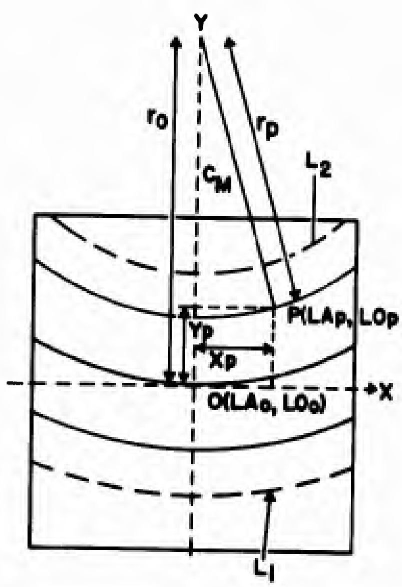

Figure 4. Expression of aircraft position in terms of film location.

What then is required of the computer in translating the aircraft's lat/long position into its location on the film strip? (See Figure 4.) First, the lat/long coordinates must be converted into the corresponding Lambert X and Y positions. While the

LAT/LONG TO LAMBERT X_P, Y_P CONVERSION

$$C_1 = \frac{\log \cos L_1 - \log \cos L_2}{\log \tan\left(\frac{90 - L_1}{2}\right) - \log \tan\left(\frac{90 - L_2}{2}\right)}$$

$$C_2 = \frac{R}{C_1} \cos L_1 \tan\left(\frac{\pi}{4} + \frac{L_1}{2}\right)$$

$$r_O = \frac{C_2}{\left[\tan\left(\frac{\pi}{4} + \frac{LA_O}{2}\right)\right]^{C_1}}$$

$$r_P = \frac{C_2}{\left[\tan\left(\frac{\pi}{4} + \frac{LA_P}{2}\right)\right]^{C_1}}$$

$$C_m = C_1 (LO_P - LO_O) \qquad X_P = r_P \sin C_m \qquad Y_P = r_O - r_P \cos C_m$$

computer could be required to solve all the equations listed, we would recommend that in addition to the longitude of grid center the three cone constants C_1, C_2 and r_o be programmed as initial conditions. Hence, the computer must solve the final four equations to produce the aircraft Lambert grid coordinates. The conversion from Lambert grid coordinates to film coordinates is then simply accomplished by first solving for the integer n, where n is equal to the Y displacement divided by the effective film strip width. To allow hysteresis in the frame advance cycle, n does not increase one integer until the solution slightly exceeds 1/2 and, conversely, does not decrease one integer until the solution is slightly less than 1/2. The film coordinates corresponding to the present position are given by:

$X_F = X_{Fo} + X_p + nL$ (the absolute distance of the grid center from the beginning of the film)

$X_F = Y_p - nW$

where X_F is equal to the distance in inches measured from the beginning of the film to the present position and Y_F is equal to the transverse distance in inches measured from a longitudinal line dividing the film strip in half.

A perfectly adequate approximate solution using analogue components has been developed, but it is essentially limited to the use of one or two scales. A digital solution, of course, does not suffer from this limitation.

VIEWABILITY

As one must first be able to clearly see a display in order to make full use of it, we must consider the various aspects of viewability to be of prime importance, image brightness in particular. Fortunately, the use of the film-strip technique permits the use of a simple, short, straight-line optical path from the projection lamp to the screen. Thus, by using a minimum of optical components, light losses may be minimized. In our original optical design, which has been incorporated in equipments for all flight trials to date, we managed to achieve a maximum operating screen luminance of about 3,000 foot-lamberts. This figure of 3,000 foot-lamberts was measured with the following conditions imposed: a magnification ratio of 24:1, transparent film in the gate, and operating the projection lamp at 80% of its rated value for extended lamp life. The following comments extracted from an actual report are typical of those pertaining to this system. "When the aircraft was flying 'down sun,' the display became completely or partially grey and made reading impossible." "In conditions of other than direct sunlight the range of brightness was barely adequate."

As soon as this inadequacy was realized a re-design cycle was initiated in the display optics. As a result, the operating luminance of the five-inch diameter display was increased to 5,200 foot-lamberts, a value found to be perfectly readable in bright sunlight conditions (above 10,000 foot-candles ambient). This readability extends to viewing angles of 35 degrees from the normal to the screen.

A schematic version of the projection system is shown in Figure 5. We have found that the most efficient, simplest, and smallest film illumination system is a projection bulb containing its own reflector, thus eliminating the condensing lens system. To reduce film cooling problems the reflector should be coated with dichroic layers designed to transmit a high percentage of infra-red radiation and to reflect visible light. This is particularly important for

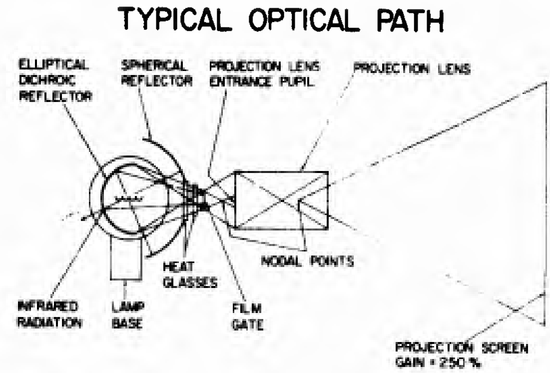

Figure 5. Schematic diagram of the projection system.

optical systems with small formats in which the film gate is usually the controlling aperture and brightness is directly dependent on the luminous flux density, or light concentration on the film. The efficiency of such a light source is surprisingly high: 50 percent compared to 30 percent for a classical condenser lens system. For format sizes up to 1/2 inch in diameter, short-focal-length lenses with large entrance pupils can be manufactured economically. Light passing through the film gate does not have to be bundled to enter a small lens opening, so that these lenses are compatible with a mirror light gathering system. Large-aperture, short-focal-length lenses can now be produced with essentially negligible distortion over a field of view up to 65 degrees. Assuming a coordinated design, proper selection of the projection lens for maximum aperture directly increases the display brightness. Screen materials having gains of 250% have been found to be optimum for map-projection displays. Even though screens with gains up to 500% are available on the market, they are not suitable for aircraft displays because of their highly directional characteristics.

A series of subjective tests were carried out to determine optimum photographic reduction and display magnification ratios. We are in complete agreement with the general consensus that, when standard paper maps intended to be read at distances varying between 10 and 18 inches are viewed from distances up to 30 inches, the displayed image must be over-magnified to some degree. In performing a tradeoff between display legibility and display diameter coverage for any given scale, we arrived at an optimum result of a magnification/reduction ratio of approximately 4:3. For a

5-in. diameter, 35mm display, we would intend to use a magnification factor of 16 and a corresponding reduction factor of 12, with a 7-in. diameter, 70mm display, the trade-off would suggest lowering these values to 14 and 10 respectively.

Contrast in the displayed image is another important factor in overall viewability. As contrast is partially a function of the type of screen used, we at ComDev experimented with a variety of screens. At this point we have not found a superior material to the dark plastic screen with a lenticular coating on the back which we have used from the outset. This particular screen offers excellent wide-angle viewing.

DISPLAY EFFICIENCY

Turning briefly to the subject of display efficiency, I have no doubt that the film-strip technique offers by far the greatest coverage capability for a given box size. For example, in a display eight inches square it is feasible to contain up to 30 feet of 70mm film. This amount represents 666 square inches of usable film, taking into consideration the amount of overlap required at both edges. At a reduction factor of 10:1 this is equivalent to a paper-map area of approximately 475 square feet. Even so, this feature, plus those of computer loading, initial condition input requirements, display diameter, and availability of charts, dictates a sensible approach to the choice of scales and the coverage provided at each scale. Based on these considerations, I personally question the operational advantage achieved in incorporating more than two scales, one for low-level work, the other for an enroute capability. To this should be added the capability of displaying fixed information frames to show emergency procedures, check lists, let-down charts, or any other data pertinent to a particular mission.

The RAF trials used 1:500,000 as the basic scale and this has been found most suitable. To achieve the maximum advantage intended in changing scale, we feel a scale ratio of approximately 4:1 is desirable. Thus we would recommend choosing the small scale chart from a 1:2,000,000 series, likely the JN series.

Our original models used a 2:1 optical scale change, but the disadvantages inherent in this technique caused us to abandon it and we would certainly not recommend it be employed in future systems.

ACCURACY

Let us now examine briefly the typical accuracy attainable using the multiple-copy, 70mm film-strip technique and sprocket feedback of film position. As mechanical accuracy will vary according to the particular system interface, I shall restrict this discussion to errors arising in the photographic process, the printing process, and the effects of environment on the film base. East-west errors along the length of the map strip must, of course, be considered separately from the north-south errors in placing information transversely across the map strip.

Table 1 lists sources and magnitudes of east-west errors. The main source of error in the east-west direction of the film is due to the errors of registration in placing the map information upon the film. These arise because the film is positioned in the display by a count of sprocket hole positions, whereas over short distances information is placed on the film on the basis of a linear correspondence between map and film. Since the perforations on the film are not always positioned perfectly, the map information displayed will be in error. The required map information is placed upon the master negative as a series of 18 perforation frames. As part of the process, the reduction factor is adjusted to make the adjoining frames

Table 1

Sources and Magnitudes of East-West Errors

Cause of Error	Magnitude (70 mm)
Master negative	±0.0015 in.
Pitch difference	±0.0004 in.
Aperture error	±0.0005 in.
Temperature effect	±0.00075 in.
Humidity effect	±0.00065 in.
Overall error	±0.0019 in.

butt perfectly so that, although the beginning and end of each frame will be in perfect registration, errors will arise in between. The maximum error is likely to occur after nine sprocket holes of the frame; therefore the probable error is equal to N9 times the ASA maximum permissible deviation from standard pitch.

In the continuous contact printing process, printing takes place past a 5/16-in. aperture in a curved surface. To accommodate the difference in length of master and copy films due to their different circular paths, the nominal pitch of the copy film is larger than that of the master.

Assuming that effective registration takes place due to the action of the sprocket tooth, it will occur for every perforation. Therefore, errors in registration due to deviations in standard pitch will be limited to a single perforation pitch. Since the films are carried past the aperture by the sprocket, registration is considered to have taken place at the aperture. Considering environmental changes, a typical expansion or contraction of .0004% per °F is quoted for safety-based film. Probable error is calculated assuming a possible range of temperature differences of ±100°F about the processing temperature of 70°F.

A typical expansion or contraction due to the effects of relative humidity is given as .07% per 10% RH. Probable error is calculated considering possible changes in RH of 50% about 50% RH.

Therefore errors introduced by these causes into the east-west direction of the film will be of the order of ±.002 inch in theory. Note that while the estimated overall error assumes no relationship between errors due to temperature and humidity effects, in practice there will be a tendency for these errors to cancel.

North-south errors are examined in a similar manner: their sources and magnitudes are shown in Table 2.

In attempting to make adjacent frames butt perfectly, the effective reduction ratio at which the master is shot is altered. A typical frame width of two inches will give rise to a probable error of approximately ±.001 inch at the film edge. In the presence of precise registration,

Table 2

Sources and Magnitudes of North-South Errors

Cause of Error	Magnitude (70 mm)
Magnification changes	±0.001 in.
Registration	±0.0006 in.
Skewness	±0.0002 in.
Temperature	±0.004 in.
Humidity	±0.0035 in.
Overall	±0.0054 in.

variations in the perforation width of ±.0004 inch will result in probable errors of ±.0006 inch. It is estimated that the effects of perforation skewness may give rise to errors of ±.0002 inch in the north-south direction. Temperature and humidity effects are calculated using the same assumptions as for the east-west case. Overall north-south errors therefore will be in the order of .0054 inch.

In addition, two further errors will arise as a result of the film cutting and perforation dimensions. In positioning of the film strip in the east-west direction feedback is achieved by a sprocket-driven synchro. In general, the perforations will be wider than the sprocket tooth and a dead zone will exist at a change in direction from east-west to west-east. Also the width of the film may vary by .004 inch. Since the spools must be machined to accommodate the widest possible film, there will be this amount of side play between film and spool when loaded with the narrowest film. Thus a side-to-side movement of the film in the cassette is possible and further error is introduced.

If we combine the mechanical errors inherent in a typical system to those just outlined we increase the calculated never-exceeded errors in X and Y to approximately .004 inch and .006 inch respectively.

Considering a magnification factor of 14 as previously discussed, we find that when operating on a scale of 1:500,000 in round figures we could expect a maximum display-system error of approximately 1/3 of a nautical mile. Related to the magnitude of sensor error, and mapping errors we consider this to be an adequate figure.

RELATED DISPLAYS AND CONTROLS

On the subject of related displays we would consider the following to be basic to any unit: (1) the fixed aircraft position symbol read relative to a topographical map background; (2) an aircraft track marker; and (3) a bearing pointer.

In addition, based on trade-offs involving cost, size, and weight, it would also be considered feasible and advantageous to include: (1) a rotatable compass rose; (2) a heading bug; and (3) peripheral digital readouts.

It is also possible to include by electro-mechanical means such features as a movable range cursor associated with the bearing pointer, or a movable light spot symbol. However, these quantities are outside the scope of the display application guidelines originally set.

I would like also to talk briefly about some aspects of the various control functions. The requirement for many control features such as a scale-change facility, or illumination-level control, or the capability of simply switching projection bulbs is fairly self-evident. For this reason I shall limit this discussion to the more controversial features specifically referred to in one or more of our trial reports. These include display orientation, manual slew characteristics, and present position offset.

Display Orientation

There seems little doubt that in most military applications the display is most efficiently employed when its vertical axis corresponds to the aircraft track. However, the capability for north orientation was also found desirable in terminal areas, above cloud, and to enable the reading of place names from the display. We initially provided this "North-up" facility as a momentary switch, but in light of comments received we have since provided this facility as a positive two-position selection.

Manual Slew Characteristics

An effective manual slew control must be incorporated if maximum efficiency is to be made of the display in the computer update role previously outlined. The type of control which we have found has received the most widespread acceptance is the omni-directional joystick. The direction of movement should, of course, always directly relate to the display movement despite its orientation, and the slew rate should be proportional to the amount of control deflection. I do not consider that maximum slew rates need exceed about one display diameter per second. Recommendations were unanimous that the slew control be mounted on an accessible control console, rather than on the display itself.

Present Position Offset

The recognized requirement of displaying angular data relative to the projected display dictates that the aircraft present position normally be depicted at the display center. To permit an increased forward viewing area along track, a control provision was made to enable offsetting the aircraft present position to the base of the screen. This facility was regarded as a useful extra rather than a mandatory function. If included, the offset capability must be inhibited in north orientation and otherwise clearly indicated to prevent confusion.

SUMMARY

The projected film-strip technique for a Moving-Map Display appears ideal for the low-level tactical role, especially when the aircraft does not contain sophisticated sensors and fixing aids. This technique provides greatest display efficiency and is consistent with a simple optical path and a simple, rugged mechanization.

Considering only what is currently available we would recommend the use of 1:500,000 pilotage charts and 1:2,000,000 JN charts as the basic paper maps. Using the suggested format to relate geographical position to film location, the master frames could best be photographed directly on to an intermediate negative film and hence copied on positive prints by the continuous contact process.

The display luminance must exceed 5,000 foot-lamberts at the screen for viewing in bright sunlight conditions. This factor, plus other optical and human factor considerations, dictate reduction and magnification ratios of approximately 11 and 15 respectively. A dark lenticular screen with a gain of 250% offers the best compromise between high gain and wide-angle viewing.

Display accuracies quoted as .08 inch maximum error at the screen are both realistic and adequate.

Related symbology and controls should be limited to those required to permit the display to carry out its three fundamental roles: effective communication between computer and operator, orientation of navigational information with surrounding terrain, and a means of simple, efficient computer update.

DISCUSSION ABSTRACT

Col. Kelsey: Do you have any facility for updating your film strips? One of the problems which will face our production agencies is that of revision; one needs the facility for correcting the individual frame in the display without having to do the whole thing again. Also it would be a great facility not to have to throw the whole strip away and start again if any error occurs in the production of the original negative.

Mr. Anderson: The film strip must be updated as a unit. However, we do believe that if the costs and time required to prepare and distribute the film maps are studied in detail it will be found that they are cheaper and quicker to update than paper maps. This should be true because film is more stable than paper and micro-techniques will cheapen storage and transportation of map products.

Mr. Erickson: Would you comment more fully on the nature of the improvement in performance found in the test trials conducted with the display? That is, just how did the display help the man do the job?

Mr. Anderson: Specifically, the French Army reported that the moving-map display improved their "nap-of-the-Earth" helicopter navigation mission success rate from 25% to 90%. A successful mission was defined as one in which the helicopter remained at nap-of-the-Earth altitudes throughout the mission without straying from a one-kilometer-wide corridor along the flight route. In general, there was an improvement because the navigation information display was presented to the pilot as a dynamic picture which required no interpretation. The French Army trial report expressed it this way: "All flights demonstrated that the Moving-Map concept was an excellent one when compared with one of the analog type presentations or readouts from Doppler indicators. These readouts always require interpretation, yet give no information whatsoever about the terrain over which the aircraft is flying. During low-altitude flying, particularly when involved in tactical maneuvers, the pilot need not worry about the navigation problem and can thus concentrate nearly entirely on pilotage and the mission to be accomplished."

Lt. Col. Robson: Have you collected any data on pilot reaction to viewing charts oriented to directions other than north?

Mr. Anderson: Yes. On all flight trials it was found mandatory to have both north orientation and track orientation. The selector switch (which was the momentary type on some of the trials) must be of the permanent type, so the pilot can set it to either type of orientation and leave it until he wishes to change.

THE DEVELOPMENT OF TOPOGRAPHICAL NAVIGATION DISPLAYS IN THE UNITED KINGDOM

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FIRST DEVELOPMENTS

The development of pictorial navigation displays in which aircraft ground position and track are superimposed on the projected image of a topographical map was initiated at the Royal Aircraft Establishment, Farnborough, in August 1959. Operational flight experience, dating from 1952, with roller strip maps driven from Doppler groundspeed data in an "along and across" planned track mode had demonstrated the advantages of a continuous, automatic plot of ground position. Tactical limitations were the necessity for preparing the full-scale map strip before a flight and the inflexibility of the plan which provided little freedom for changes of flight plan or diversions.

Optical projection displays were developed with the aim of storing a complete operational theater in one loading by microfilming maps in color, the film being driven in geographical coordinates. Tactical freedom of operation over the whole area stored in the instrument was therefore possible. Projection of a moving image on a circular screen surrounded by a degrees scale and the superposition of a central symbol representing the aircraft, together with a diametral arrow rotating in accordance with aircraft track, produced an illusion of greater realism than the roller map and also permitted extrapolation of the present position by laying track ahead over the topographical detail. Anticipation of features ahead and the ability to make good any desired feature shown within the field of the display was therefore simple.

An original experimental model built in 1959 is illustrated in Figures 1 and 2. The first concept was to store the microtransparencies on a transparent cylindrical drum driven by resolved groundspeed applied as axial rotation and axial translation.

The diameter of the cylinder was large enough (6 1/2") to accommodate the area required and the curvature sufficiently small over the area projected to be accepted by the optical projection system.

This instrument was flight tested in 1960 with encouraging results. The drum store has the advantages of providing a stable support for the film, preserving focus, and permitting precise traction. The map detail is also arranged with areas in their correct juxtaposition.

Storage capacity, however, is limited by the cylindrical area and the moving parts are bulky. The principle was therefore abandoned in favor of area storage on perforated, 35mm motion picture film stored on spools using the perforations for traction in one ordinate.

Engineered models of the second type were designed in 1960 and became available in 1961. The instrument is illustrated in Figures 3 and 4. This instrument had facilities for presenting the image either North stabilized or Track stabilized and was fitted with a dual lens turret providing an optical scale change from 1:500,000 to 1:1,000,000. Two lamps were provided with a changeover facility together with stepwise dimming. Using 100-watt lamps and a plastic Fresnel lens in front of the translucent screen as a field brightener, an image brightness of 700-1000 foot-lamberts was obtainable.

These instruments were operated from groundspeed derived from Doppler and track derived from a combination of Doppler drift and gyromagnetic compass heading, groundspeed being resolved by analogue computing into Northings and Eastings. Miniature D.C.

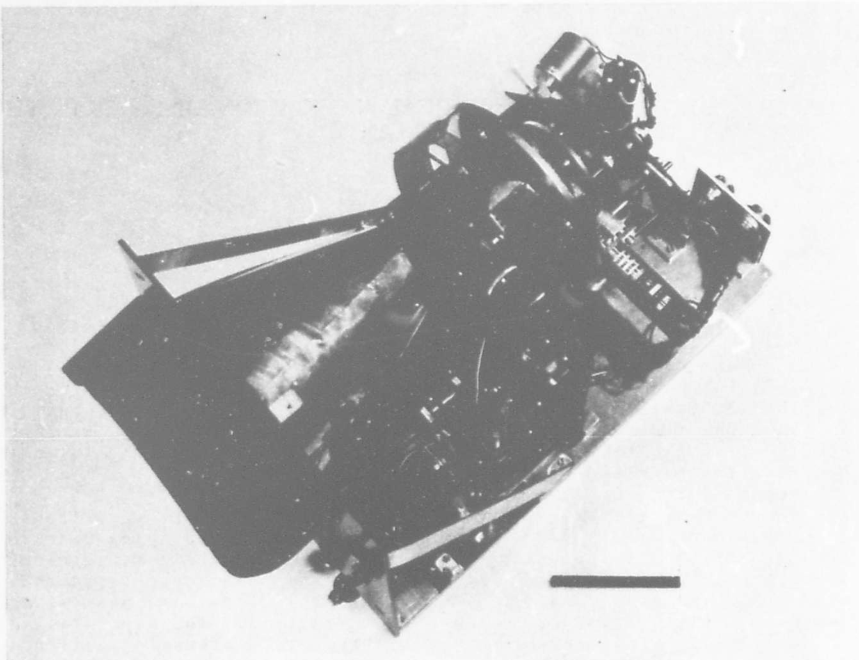

Figure 1. Topographical Navigation Display No. 1. 1959. Interior.

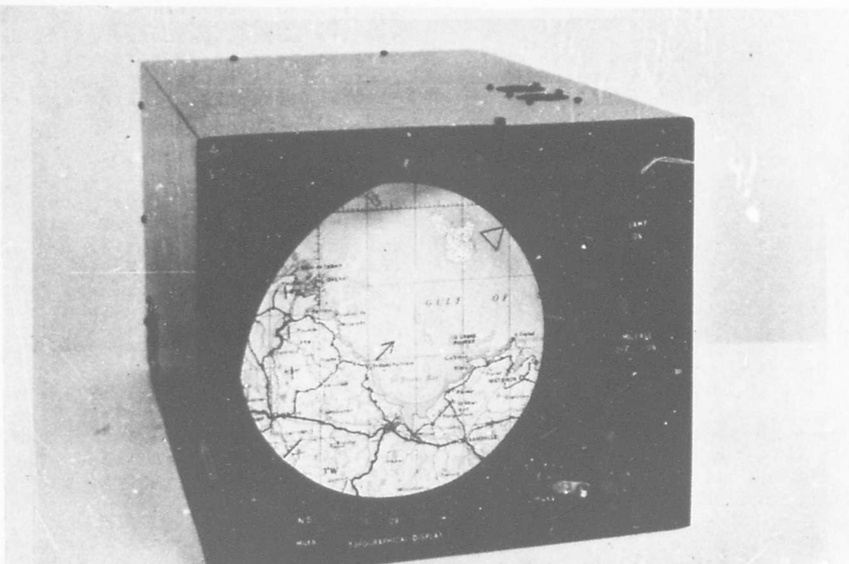

Figure 2. Topographical Navigation Display No. 1. 1959. Exterior.

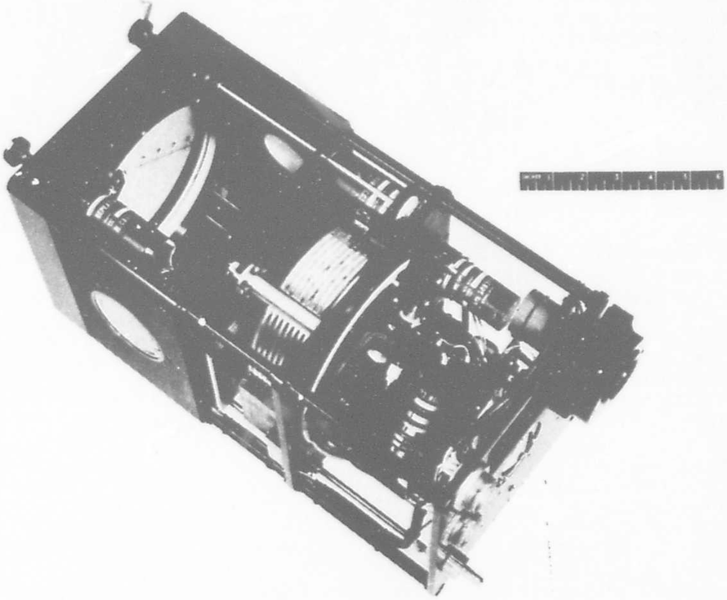

Figure 3. Topographical Display No. 2. 1960. Interior.

Figure 4. Topographical Display No. 2. 1960. Exterior.

stepping motors were used for the film traction system from the outset, the resolution (144 steps per nautical mile) being sufficiently high to give the appearance of smooth motion. These displays were driven as simple, open-loop devices, but the adaptability of step motors to operation from digital outputs was appreciated.

The storage capability on film strip is shown in Figure 5. Using a reduction factor of 19x, a published sheet of topographical map covering 2° of latitude can be accommodated on one 24mm x 36mm standard double frame on 35mm film. The area illustrated, covering 20° Lat. (1200 nautical miles) NS by approximately 53° Long. EW (approximately 2400 nm at 40N), is stored on 140 frames corresponding to 17 1/2 feet of film.

The maps used were standard RAF Topographical charts on Lambert's conformal projection.

Figure 5 illustrates the technique adopted to mechanize the frame change NS and to minimize the convergency effect of driving conical-projection maps in Cartesian coordinates. Successive frames were arranged with their central meridians vertical and parallel to one another. The published sheets were re-edited to provide an overlap EW and to arrange a consistent separation of the central meridians, so that the distance along the film required for a frame shift NS was a constant. A semi-automatic, fast-slewing facility was provided for this purpose.

Display development was initially aimed at a two-cockpit installation in which parallel displays were provided for both the pilot and the navigator, control of both being centered with the navigator. Some manual monitoring of the displays was therefore tolerable and complete automation of frame changing was not provided at this stage. Facilities for correction of the display to a fix were provided, the associated analogue computer being provided with a memory store of resolved mileage which could be discharged into the display after correction.

FLIGHT EXPERIENCE

Displays of the type described have been extensively evaluated in flight at high and low level both as a navigator aid and as a pilot aid. Similar models have been produced in quantity and have been used operationally.

Test flying, centered at the Royal Aircraft Establishment from 1961, confirmed the notable increase in information content of the display from

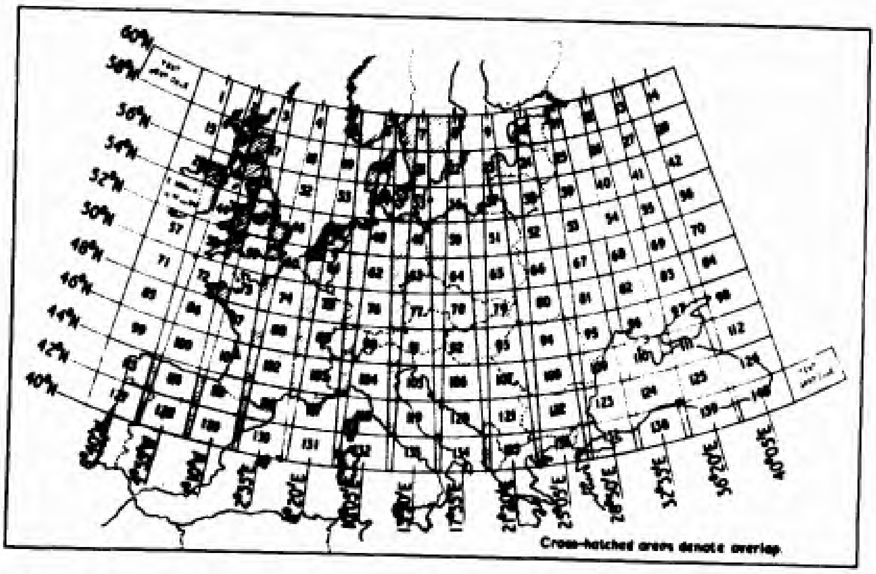

Figure 5. Map storage capacity of Topographical Display No. 2. 140 frames.

data sources hitherto used only to present latitude and longitude values.

The elimination of plotting, the reduction in work load and the continuous availability of a present position indication without time lag in a readily interpretable form in relation to all surrounding geographical features were all substantiated.

The ability to anticipate and to make good desired points was generally appreciated. Scale changing as a means of looking farther ahead proved to be a valuable facility, and at lower levels, the presence of hypsometric tints was favored.

Except at low level (250-500 ft), the standard 1:500,000 topographical charts employed were reasonably satisfactory for general navigation. At low level and in terminal areas, a larger scale such as 1:250,000 was preferred.

Both pilots and navigators preferred a North-stabilized presentation at heights above about 2,500 feet, but for pilot use at low level the preference for track-stabilized presentation was unanimous.

A separate, low-level trial was mounted for evaluation as a pilot aid in the front seat of a Canberra PR-7 aircraft. Dashboard installation was not practicable, but the display was mounted to the right of the pilot and facing upward as shown in Figure 6. The pilot was not required to adjust the instrument, which was monitored by a navigator in the rear. Experience was obtained in the height band 250-500 ft in this aircraft at speeds of up to 450 knots. Preliminary simulator tests had indicated that it was possible to interpret the display under these conditions, the time interval between the pilot being asked his position from the display and his reply being approximately 3 seconds.

This aircraft was flown by nine pilots, all of whom had low-level experience and three of whom were operational photographic reconnaissance unit pilots. There was a unanimous finding that the display could be usefully interpreted under these conditions. To quote one pilot, "The pilot could navigate with an accuracy which at low level could only be improved on when flying carefully preplanned routes over easily identifiable features. The ability, on sortie, to fly for an hour and twenty minutes over Germany (the pilot's first visit to Germany) at low level without any doubt about one's position to within one or two miles (and with a much less error after seeing landmarks), and being able to explore and divert in any direction at will, shows that there is great potential for this equipment in the role of a pilot navigation aid for high-speed flying."

The property of anticipation, operating in a track-stabilized mode, proved to be the most valuable feature of the display in the low-level trials. The mode of operation was generally to look ahead up the track line on the display for some feature, preferably of an across track character, its distance on the display being estimated by the graduations on the track line. The pilot, knowing his approximate groundspeed, would then watch for this feature approaching and would check as he passed over it.

It was however in the low-level case that the characteristics of the normal topographical maps used were most criticized. Many of the pilots

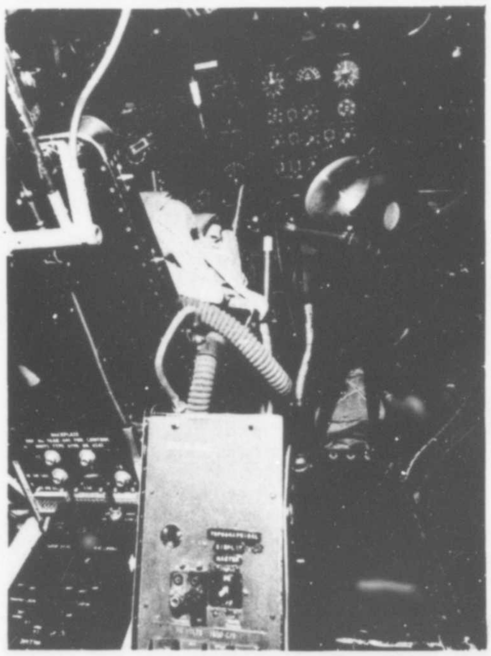

Figure 6. Experimental front installation of display in Canberra PR-7 aircraft.

indicated a requirement for "special" maps without being able to define precisely what they wanted beyond the fact that a larger scale than 1:500,000, such as 1:250,000, was desirable.

It was suggested that the low-level air map fulfills a different function from the traditional topographical map, which appears to be aimed at being as comprehensive a plan of terrestrial features as possible within the format. This generally presents far too much information in a given area for high-speed, low-level interpretation, and this becomes worse as the scale increases. A high degree of selectivity should be exercised in the preparation of low-level air maps, which should, it is suggested, aim only at the inclusion of those recognition features which are likely to be of value to the user at the height and speed range at which he is flying. Such features could, moreover, be encoded in a variable manner according to their ease of recognition. For example, railways are normally marked on topographical charts in a bold manner from which the user might suppose that they were always readily visible, except for tunnels. There are, nevertheless, many stretches where railways are not readily visible on account of shallow cuttings or trees. It would be possible to vary the intensity of the encoding symbol on the map to indicate the ease of recognition. The preparation of low-level maps on this principle requires a knowledge of the appearance of the terrain as seen by the low-level pilot, rather than a surface survey.

Separate flight appraisal by RAF Bomber Command Development Unit throughout 1961 as a navigator aid in bomber aircraft established the reliability and value of the presentation in this role. (Terminal areas at 1:250,000 were interpolated in the 1:500,000 cover provided with the approach and holding patterns marked on the maps.) The display was installed adjacent to a PPI radar display and was found to be valuable as a radar comparator in facilitating the interpretation of the radar display. From side-by-side comparison of the two displays, optical combination and superposition of both at compatible scales is a logical development.

CLOSED-LOOP DISPLAYS

The flight experience described with simple, open-loop displays integrating resolved groundspeed from sources such as Doppler have indicated that a high order of accuracy of traction of microtransparencies is possible, major discrepancies between the display and computer in an uncorrected system being due to convergency effects, rather than inaccuracy of traction. Given superior data sources together with complete correction of map projection effects, a pictorial display may therefore give an accurate representation of the position as calculated by the navigation system.

Discrepancies can then be regarded as system error and their correction by a fixing operation can also be used to correct the navigation system. In an advanced system where a digital computer is available as part of the navigation/attack system with inertial data sources, complete automation of the display with respect to map changes and coordinate correction can be realized by adopting a closed-loop system in which the map microtransparency is at all times related directly to the position calculated by the computer. Storage of targets, fix points, look-ahead facilities, etc., can readily be provided, and the visual display then affords a convenient means for the user to enter the computer. The resolution and response of the servo system must however be good enough to preserve the illusion of continuous motion.

In principle, it would be desirable to encode the microfilm, but in view of the problems of copying and subsequently reading with the necessary resolution, traction systems have been modified for closed-loop operation by gearing shaft encoders into the traction system as near to the film as possible, with a resolution of approximately one digit per tenth of a nautical mile on the 1:500,000 scale.

Displays of this type have been operated from a digital computer with automatic map changing, and considerable experience in programming methods has been obtained. A capacity of approximately 200 words has been found to be sufficient for the management of the visual display. The coupling of the pictorial display as a visual readout of the computer with its facilities for information retrieval, selection, and display provides a flexible and powerful medium that can clearly be applied to visual data other than maps, such as check lists, which can be stored on microfilm.

THE MICROPHOTOGRAPHY OF MAPS

Development of the technique of microfilming map areas in color has proceeded in parallel with development of the displays. In this application, in addition to the normal problems associated with microfilming, the requirements for an image of high resolution over a large field at a precise scale with minimum distortion impose severe demands upon both the copying objective and the film material.

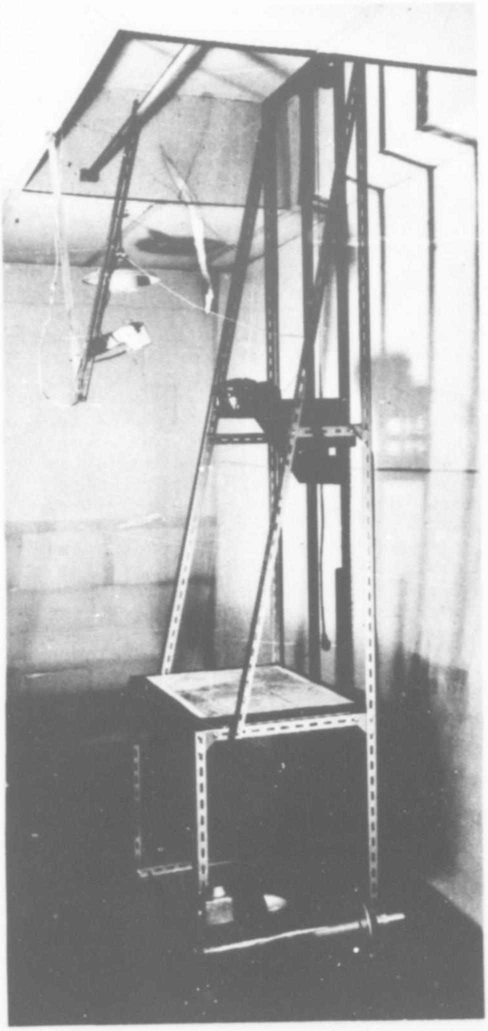

Figure 7. Microphotographic copying stand for map sheets.

At the commencement of the work in 1959, the resolution of available color film was the principal limiting factor, the best results being obtained with reversal positive color film of the integral tripack type, demanding professional processing which gave a resolution of about 55 lines/mm. Reproduction by duplication was not satisfactory and each film strip was an original. Efforts were therefore made to expedite the handling and copying of the maps as far as possible. The copying stand constructed for this purpose is illustrated in Figure 7. The maps are dry mounted in a hot press on cards and are aligned by datum marks on a suction easel. Copying is effected by electronic flash using a precision 35mm sequence camera with solenoid-operated shutter and motorized film transport. Using this stand it was possible to produce a strip of 140 frames similar to Figure 5 in 55 minutes, and production quantities were so produced.

Improvements in resolution of subtractive color films designed for amateur use during recent years, which achieve about 70 lines/mm have also been associated with an increase in contrast range in order to permit a greater margin for exposure error. This produces a lower contrast result unfavorable to the copying of maps, which are low-contrast subjects.

The recent development of European, slow, high-contrast, subtractive, color negative, film materials with a high resolution approaching 200 lines/mm has made it possible to produce film strips on color negative processed by the user in a single color development, and to reproduce by contact printing onto the same material, with acceptable resolution and with accentuation of original contrast and color saturation.

The establishment of a viable reproduction technique has greatly improved the logistic problem of producing and supplying film strips. A printing fixture developed for contact-printing complete film strips with a single exposure is illustrated in Figure 8. The cylindrical printing frame, eight feet in diameter, accepts a 25-ft strip wrapped around its circumference. The curvature assists contact between negative and positive film, but is slight enough to minimize longitudinal scale errors. The negative and positive films are backed by a rubber strip stretched over the back of both. Printing is effected by a single, central, strip-filament lamp in the center which is collimated by an annular plano-convex lens. A complete strip is printed in approximately 8 seconds.

A wide measure of control of color balance is possible with the color negative printing method by subtractive filtration of the printing light source.

Scale and distortion can be controlled in the microphotography of maps within 0.1%. The major source of error to date lies in scale variation of the originals when printed on paper. If the technique is to be widely used, the printing of a limited number of proof copies on a more stable base is desirable and appears to be technically feasible.

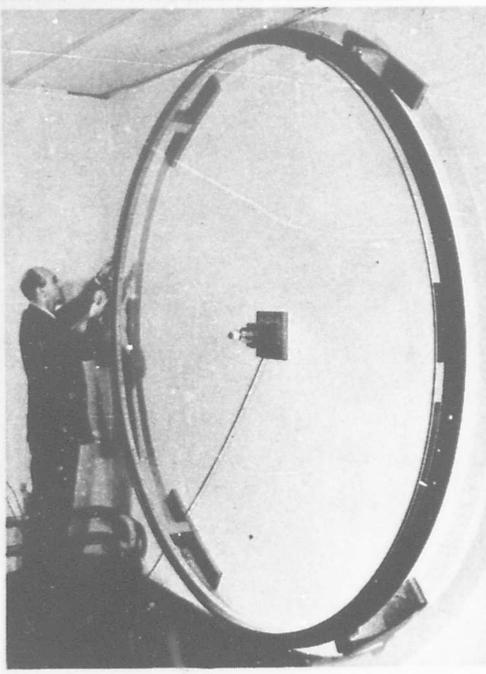

Figure 8. Printing fixture for 35-mm color negatives.

COMBINED MAP/CATHODE-RAY TUBE DISPLAYS

Combination of the projected map image with the image of a cathode-ray tube has been examined both with the aim of superposing a radar picture of the terrain on the topographical picture and of exploiting the flexibility of the CRT as a medium for writing symbols or information compatible with the map image such as markers, track demands, etc. The second facility aims at meeting a limitation of the projected microfilm type of display compared with devices using paper maps. This is the difficulty of editing or making ad hoc markings on the map material.

The problem is complicated by the fact that the phosphor persistence times required for radar and symbols differ. Using small bright CRTs of the type used in the head-up display, it is possible to project these using a subsidiary high-aperture objective with a magnification of about 3x and to mix with the projected map image on a translucent screen to give images of sufficient brightness to be readily distinguishable against the map image. This requires an image brightness on the face of the CRT of approximately 15,000 foot-lamberts on a two-inch diameter tube. Displays of this type have been constructed for closed-loop operation from a digital computer in which control of the electronically generated symbols is managed by the computer. CRTs of this high order of brightness having a persistence time suitable for radar display have not been available, and for radar/map mixing projection onto a translucent screen has been abandoned for bright field viewing systems using field lenses.

The system is illustrated schematically in Figure 9. A first projected image of the map microtransparency A'B' and the face of the cathode-ray tube are both imaged by the high-aperture transfer lens to their final viewing diameter in the plane of the field lens system A^2B^2 with a magnification of 2-3x. The field lens, A^2B^2 projects the effective aperture of the transfer lens in the plane of the user's eye with a magnification such that the exit pupil is approximately six inches in diameter, which permits binocular vision with a few inches permissible head freedom.

Since both the primary map image

and the CRT face are within the instrument, they are not affected by ambient light, and the system permits the use of a conventional CRT without brightness problems. The viewing angle and head freedom is, however, restricted. Since such a system is aimed at a pilot presentation where the user is restrained in an ejection seat, the limitation on head freedom may be regarded as acceptable. The system imposes optical design limitations since both the transfer lens and field lens systems tend to approach an equivalent aperture of F/1.

The interpretability of a forward looking radar trace at low level is greatly enhanced by superposition on the map image, at a compatible scale, while desynchronization of the two affords a direct indication of the navigation system error.

THE MODIFICATION OF GEOMETRICAL MAP PROJECTIONS DURING COPYING

The microphotography of maps by conventional methods taken one frame at a time produces reduced copies which are similar in geometry to the originals, assuming the copying lens to be free from distortion. Topographical charts are most commonly drawn either on Lambert's second modified conformal projection with two standard parallels or on transverse Mercator projection. In neither case is the Lat/Long grid rectilinear, and display traction applied in Cartesian coordinates produces errors unless corrections are applied in the associated computing. In view of the high cost and effort involved in preparing extensive cover of maps on any new projection, the facility which microfilming offers for modifying the map projection during copying is of interest.

Topographical maps drawn on a conical projection can be converted to a rectilinear grid and microfilmed by coupling angular motion of the map about its center of curvature of latitude past a slit aperture with linear motion of film past a slit in a continuous motion camera. The resulting transparency is not conformal in projection, but may be arranged to have scales which are not identical NS and

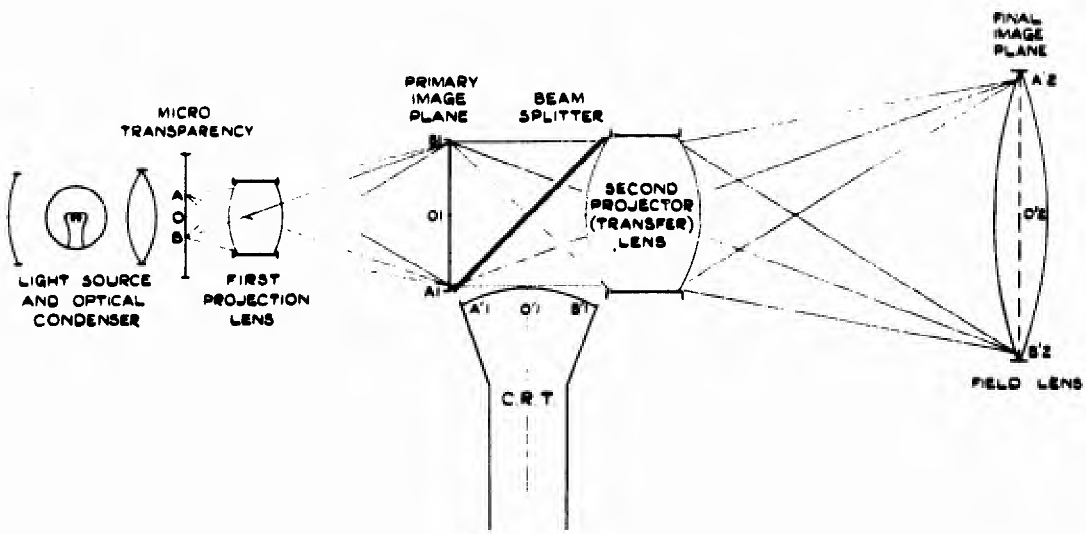

Figure 9. Schematic layout of combined topographical display.

EW, but are respectively constant in terms of latitude and longitude over a selected area. Meridians and latitudes are orthogonal. The traction of such microfilms in a navigation display may be simply arranged in Cartesian coordinates from navigational data sources having an output of aircraft motion in increments of latitude and longitude. Moreover, since the grid is rectilinear, maps may be joined EW indefinitely without discontinuity.

The errors involved in treating transverse Mercator sheets in the same way are insignificant for 1:250,000 scale. An example of a Lambert map treated in this manner is shown in Figure 10.

CONCLUSION

It has not been possible in the space available to give more than a brief outline of seven years' work. Sufficient progress in visual display and the associated microphotographic techniques, has, however, shown that the application of pictorial display to navigation, both military and civil, offers great promise. The development of visual readout devices and microphotographic methods are directly applicable both to the translation of computer information into meaningful terms and to the preparation, storage, and retrieval of cartographic data generally.

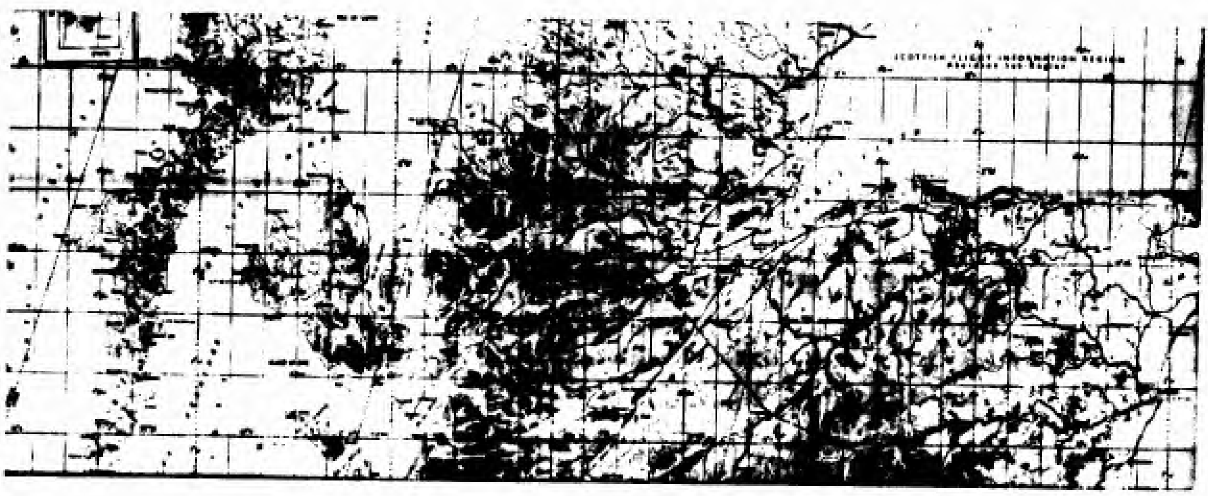

Figure 10. Rectified copy of Lambert's projection map made by continuous copying technique.

DISCUSSION ABSTRACT

Mr. Wolin: You have made it very clear that the existing cartographic materials were not suitable for your research and that special techniques had to be developed to produce the kind of materials you needed. Now, are these materials being produced by the cartographic agencies in your country, or are they so special that you, the systems engineer, have to produce them yourself?

Mr. Honick: The answer to that, sir, is that all of the material in the 1:500,000 scale series were standard R.A.F. topographical charts in the GSGS 4715 series which were current prior to the present series which are more similar to the ONC series. We were committed by our terms of reference to use a standard edition and were not in a position to demand any special material. I am very glad that you have asked this question because it confirms my own view as a user that, unfortunately, developments in the field of topographical maps from the point of view of my special interest have not been progressive. They have been retrograde. You have obviously been impressed by the relative brightness of color, contrast and the general boldness of printing in the projected transparencies that I showed, and I agree with you that, broadly speaking, that edition of maps was quite good from our point of view for general navigational purposes. We were, however, concerned to discover that the new and later editions which are being published are less suitable for this specialized task of microfilming than the older ones were. They are lower in contrast and are for all practical purposes almost monochromatic, so that there is little scope for optimizing during copying. They also embody a great deal of very fine print; the length-to-width ratio and intensity of the black of which is inferior to what we formerly had. My complaint is therefore that there appears to be no indication that the lessons of human engineering on the legibility of type, the importance of contrast and the virtues of color as an information medium are being exploited in their application to cartography. I find this situation regrettable, but that is my opinion from my experience of the material with which I have to work.

Mr. Fellinger: You described one system in which you used DC stepping motors. Was this used in conjunction with the doppler radar? And did you run into any heating problems with your stepping motors?

Mr. Honick: DC stepping motors were used in conjunction with doppler radar as the source of groundspeed. The analog computer employed received groundspeed from the doppler as a DC step transmission and the resolved outputs from the computer were also by step transmission at the rate of 144 steps per nautical mile. We did not experience heating problems with the receiver motors. It is true, of course, that miniature stepping motors do run hot, but they are designed to do so. The ones that we used were built in a size-11 configuration. These are relatively simple devices in which the rotor is a permanent magnet, there are no slip rings or brushes, which makes them basically a reliable component. We have had practically no failures with them in this application. With analog computing we were running from DC commutative inputs, but the stepping motor is one of the few devices that can be run direct from a digital output with the minimum of peripheral conversion equipment. A train of pulses can readily be sequenced, shaped, and amplified by solid-state circuitry and logic into a plurality and power level sufficient to run a receiver motor directly from them. If one does this simply with positive and negative polarity, omitting neutral, one obtains only six angular steps per revolution instead of 12, but this is adequate.

We have therefore retained the stepping motor drives in more recent closed-loop systems operated from a digital computer. Normal technique in this instance is to inject what are effectively velocity inputs into the display, but to look at the feedback devices at relatively infrequent intervals. The rate of growth of error of the display is sufficiently slow so that comparison of the feedback devices with the computer are required relatively infrequently, considering the calculating speeds of digital computers. For example, one can read the feedback devices once or twice per second--this is more than sufficient.

CARTOGRAPHIC SUPPORT FOR AIRBORNE NAVIGATION DISPLAY SYSTEMS

William R. Campbell
Requirements Analyst
Naval Oceanographic Office

I would like to enumerate the cartographic considerations and emphasize their importance in the design of and logistic support for airborne navigation displays. It should be remembered that the primary purpose of a navigation display is to present chart data in a readily usable format. Any navigation display which cannot do this in an optimum manner is deficient in design. Unfortunately, the cartographic aspects of display design have been given too little attention in the past to the extent that in some cases we are in danger of buying a "blank" window, in that the design requires chart graphics in a form that cannot readily be provided.

So that display designers may have a sort of check-off list, I will now give the more important cartographic design considerations that must be satisfied in any and all types of navigation displays, whether it be a direct view, optical projection, or raster scan type.

Standard charting series must be used. To use a data-processing term, the existing chart data-bank must be used. Any requirement to use specially designed graphics would be too complex, costly, and time consuming. I do not mean to infer that the normal paper charts have to be used. The compiled information can be published in a new format, such as a miniaturized film chip.

The graphics must be readable. Aeronautical charts are designed to be read at a maximum distance of approximately 20 inches. Any display with a viewing distance of more than 20 inches should have a magnification feature. Furthermore, the viewing angle should deviate as little as possible from the horizontal plane at the viewer's eye level. We call this "heads-up." This is most critical in low-altitude flight in a single or dual-tandem place aircraft.

The graphic must be in color. Otherwise, we would be giving the user something less than he now has in this respect. Color is very important in reducing the time required by the eye to locate a particular chart feature.

The chart portrayal must be mostly of an area ahead of the aircraft. Portrayal of the area behind the aircraft should only be that necessary for correlation of chart features and flight-path checkpoints. My recommendation would be two-thirds ahead, one-third behind. Aircraft position indication in the center of the scope has been prevalent in past systems.

There must be a choice of chart scale. The number of choices will, of course, vary with the flight mission. Standard aeronautical chart scales range from large-area coverage at 1:5,000,000, 1:2,000,000, and 1:1,000,000, to relatively small-area coverage at 1:500,000 and 1:250,000. A choice of four of these scales will normally suffice.

There must be a chart-projection correction capability. A chart projection is a systematic method of representing parallels of latitude and meridians of longitude of all or part of the earth's spheroid onto a plane surface. Each type of projection has distinctive features which make it preferable for certain uses, no one projection being best for all conditions. Some of the desirable properties of chart projections are: true shape of features, correct angular relationship, equal area, constant scale, great circles represented by straight lines, and rhumb lines represented by straight lines. The primary projections used for aeronautical charts are the Lambert Conformal Conic, the Mercator, the Transverse Mercator, and the Polar Stereographic. The aircraft navigation computer must be programmed to change the real-world navigation input into a map distorted-world readout on the display scope.

There must be a coding feature for updating aircraft position when shifting from one map frame to another. This should have both an automatic and manual capability. One map frame often will not match the preceding one either because of a change in reference parallels or chart scale.

Would you now believe that cartographic considerations are just as much a part of navigation display design as electronics and optics?

Next, let's open the Pandora's box on logistic support for navigation displays, at least from the cartographic support viewpoint. No matter how well a display system is engineered, if we can't provide the display graphics on a continuing timely basis, the whole display system becomes virtually useless. At present, the mapping and charting community can support the direct-view roller-map type display simply because standard aeronautical charts are used. One disadvantage of this display system is that it places the burden of cutting, stripping, and joining of charts on the already over-burdened pilot. The raster scan (closed circuit TV) display requires special graphics which would require an unreasonably high percentage of the Department of Defense production capability. Moreover, the present state-of-the-art restricts the presentation to one of black and white. With great reluctance, I have to say that the mapping and charting community cannot at this time provide full-color, miniaturized graphics on a production-line basis to support the optical-projection type of navigation display. The talent available and state-of-the-art in materials, optics, and processing equipment are conducive to developing this capability; however, little more than a token amount of research has been expended in this area thus far. A concerted effort would have to be made to develop a color miniaturization production capability within two years. This creates the "blank window" situation I referred to earlier.

Logistic support goes much further than producing aeronautical charts, whatever the form. It involves storage, distribution, maintenance and updating, which in turn involves data acquisition and collection, requirements determination and validation, and to complete the vicious cycle, chart production. The plain truth of the matter is that it takes too long for the mapping and charting community to respond to user requirements.

Having stated some of the problems, let's now consider some possible solutions. First of all, we must establish more effective communications between the interested parties; namely, the operational user, program planner and manager, system designer, instrument maker, and the mapping and charting community. I consider this symposium a big step in the right direction. Second, we must stop piece-meal improvement of the mapping and charting processes. Considerable effort is being expended in data acquisition and chart compilation (some prefer color separation) techniques. All too little effort is being made in improving data collection, chart reproduction, and distribution techniques.

I believe that we can put all of our required mapping and charting information in a shoe box or certainly in a file case. In doing this we would at the same time solve much of our storage and retrieval as well as distribution and security problems. One way of achieving this is to use the relatively new science of holography. Holography is the science of producing images with the pure coherent light emitted by a laser, the images being formed by a specially exposed photograph called a hologram. A hologram records the light-wave interference patterns made between laser light reflected from the subject onto a photographic film and laser light directed by a mirror onto the same film. When the light from the mirror is directed to the back of the film and the scattered light from the subject is recorded on the front of the film, the resulting interference patterns are produced in the emulsion of the film. Then, when a beam of ordinary white light is directed at the developed film, the emulsion layers filter out all color spectrums except the color of the laser beam used to illuminate the subject. When viewed at the proper angle, the hologram becomes a window through which you can see the original subject in the laser beam color and in three dimensions. Now, if instead of using a single-colored laser light, we combine red, blue, and yellow beams into a multi-colored beam, we should be able to make a hologram which can be viewed in full color and again, in three dimensions. Moreover, the image can be miniaturized and by varying the angles of the split-beam laser light, many images can be entrapped on the same piece of film. This is one way to put the world in a shoe box.

From our shoe box we should be able to quickly retrieve the desired graphic, and using our new reproduction system which we developed along with the cartographic hologram, we can print it on any material, at any size, as we need it. If we so desire we can use the hologram directly in the newly developed airborne navigation display which also has the capability of superimposing the mission plan and updated intelligence data on the display scope.

This is an example of the type of complete system that we need. Development will require the close cooperation of government and industry. We have no time to lose. I suggest that we roll up our sleeves and get on with the job.

DISCUSSION ABSTRACT

Mr. Wolin: I would like to compliment you on your courage in making this talk and endorse what you have said. O.K., question: Were you addressing this research and development problem to the cartographic industry or to the systems developer, or both?

Mr. Campbell: I was addressing it to everybody concerned. Cartographers don't profess to be that talented to solve all problems. We need help; we readily admit it and invite help from the fields of materials, hardware, optics, physics, and related sciences.

Mr. Sicking: In the original holography articles I seem to recall reading that, on any given picture, one could record theoretically an infinite number of different images, depending on the frequency of the original laser light and the playback light. In other words, theoretically on one film chip, you could produce the entire world series of charts as discrete charts. Also, any given area of the film strip contained a complete image. Now, I was wondering whether this is possible with white light playback.

Mr. Campbell: Of course, white light playback is a fairly recent development, within the last several months. I see no reason why it shouldn't be possible to use white light in a holograph reader. The secret is in the manner of using the taking laser. If it is bounced off of a mirror onto the back of the recording film, the resulting hologram can then be viewed with white light, at least theoretically. Your point about the fact that enumerable images can be recorded on the same piece of material simply by varying the angle of the taking laser is well taken. Viewing at the same angle, you get X picture, and when you change the angle to meet the second companion groupings of the taking and reference lasers, you get Y picture, and so on. This could conceivably lead to "putting the world in a shoe box" to which I referred in my paper.

Dr. Pelton: I don't think that I'm in disagreement with these comments on holography; it's certainly open for the future. On the other hand, we have some problems today, and why is it that you say we must stick with existing charts? We've said many times from the standpoint of the low-altitude pilot, they're not adequate, they won't do the job no matter what shape or form you put them in. We've got to have different charts. So I don't think that we can start with that premise and ever get where we want to go.

Mr. Campbell: Well, if I may elaborate on that point, I did not say we have to use the existing charts as they are now. I said we had to use our existing cartographic data bank. Now, you're referring to a possibility or even probability that we don't have the correct information on a particular chart for a particular mission. We are working on that for high-speed, low-level missions--for example, by sanitizing the chart, that is, removing some information such as place names, and even the latitude and longitude graticules. If you're doing visual navigation you're not using those, but that's still utilizing our existing chart data bank. We simply have to revise the way we make charts so that somewhere along the way, midpoint or three quarters of the way along the assembly of the basic information, we can cut it off, make a composite, and print it to have a special-purpose chart, then complete the rest of the processes and put out an all-purpose chart as we now do. We're working on that aspect.

CDR Heininger: I also want to strongly endorse your statements. We have favored the roller-map concept primarily because of the cartographic support, weight, space, and reliability. But the big problem is that it's going to take up to 12 hours to prepare a roller map for a mission, and this is the real problem.

Col. Herndon: I want to make a challenge. Speaking for the cartographers, I think I need make one point quite clear with regard to the requirement for low-level coverage for special purposes. Traditionally, ground surveys and later the use of photographs or photogrammetric applications have provided the horizontal and vertical description of the surface. These are the only ways that we have of getting the relative positioning to support the intense interest in low-level navigation. We're challenged by the necessity of converting from this traditional approach of looking at the surface from above to a system for looking at the surface in profile. A number of means has been proposed. It's been suggested that we use the vertical photograph and manipulate it with various camera systems. I recall one, the old land camera system, with which we tried to give a simulated picture of an essentially horizontal or profile view of the terrain. This didn't work--not well enough. The alternative to this is to take pictures at low level. From the military point of view, we do not yet have the access to, for example, the Sino-Soviet area. So, this approach is out. Even if you could fly such a low-level mission over an enemy area, it would lock you into a given channel and this is non-habit forming, because the enemy will soon realize that you're using that one channel and set up his defenses along that channel. So, you must have a means of making approaches along completely different channels. You need the flexibility. We have tried in many ways to find solutions to these problems. You're still using the ordinary cartographic product primarily because we have not yet found the solution to the kinds of problems that are being posed by the users. And now I come back to my point: I challenge the gentlemen in the room here, and ladies, to find some better means of converting from the kind of source materials upon which we must presently rely for the production of cartographic items to express the horizontal profiling view that seems to be required for the low-level approach.

SOME THOUGHTS ON MAP DISPLAYS

Stanley N. Roscoe
Manager, Display Systems Department
Hughes Aircraft Company

WHY MAP DISPLAYS?

Optical moving-map displays were conceived in 1949 as a superior means of presenting the aircraft position information made available by the new rho-theta radio navigation system then known as DME-Omni. Laboratory simulation experiments at the University of Illinois Aviation Psychology Laboratory and flight evaluations of experimental units by the former CAA during the early 1950s confirmed the optimistic hopes of the inventors and proponents.

In all of these tests no pilot ever became lost while flying with a map display. Private pilots and even non-pilots using map displays could navigate as well as experienced instrument pilots using conventional instruments. Perhaps even more surprising was the finding that pilots controlled airspeed, altitude, attitude, and heading significantly better under IFR conditions when using a map display, presumably because less attention was required for navigation tasks. This finding might also be interpreted as evidence supporting the concept of the hierarchical nature of the pilot's task since a map display presents information concerning the higher order sub-goals of flight suitable for establishing lower order indices of desired performance such as heading, altitude, and speed.

Based on these findings and special operational requirements associated with the SAGE air defense ground environment, the United States Air Force adopted an optical map display as part of the MA-1 aircraft and weapon control system in the F-106 all-weather interceptor. These systems have been in routine operational service throughout the 1960s. During these years the reliability and serviceability of map displays have become comparable to those of other basic aircraft displays. As a bonus, Air Defense Command pilots have saved several F-106s by making instrument let-downs and low-altitude IFR approaches following complete communication and navigation system failures by using the map display in its dead-reckoning mode.

While effective for its intended purposes, the map display in the F-106 performs only a few of the many functions of which such flexible devices are potentially capable. By using the map display as a means of displaying the results of certain MA-1 system self-test routines, it was discovered that the map display provides an extremely effective means for flight crews and maintenance personnel to communicate with their on-board computers.

The use of a map display to show self-test routines and to provide a means for the crew to talk to an on-board computer was more fully exploited in the map display and associated controls of the ASG-18 fire-control and navigation system originally intended for the F-108. The development of this advanced system was continued following the cancellation of the F-108, and it has been undergoing Air Force flight evaluation in the YF-12A at Edwards Air Force Base for the past three years. The use of the map display for the manual insertion of aircraft, target, destination, and TACAN station position coordinates has also proved to be a simple and effective way for the crew to talk to the ASG-18 system in flight.

Despite the success of map displays in interceptor aircraft, their potential value is even greater in tactical aircraft. During the development and flight testing of tactical radar and navigation systems, it has become evident that the full effectiveness of high-resolution surface-mapping radar is realized only when used in conjunction with a moving-map display.

The greatest single aid an operator can have in interpreting a radar ground map is knowing what he is looking at or, more precisely, the relative position of what he is looking for. Such knowledge can be achieved through intensive pre-flight study of charts, aerial photographs, radar imagery, etc., or by in-flight reference to such materials. The use of electronic markers on the radar display, showing the expected position of navigation checkpoints or pre-planned targets, may also be effective in limited applications. But by far the most effective aid to the operator is to present on a moving-map display the relative positions of the principal surface objects that should be visible and identifiable on the radar display. While a great deal of improvement in charting techniques is required to take full advantage of this mode of operation, impressive progress is being made by the USAF Aeronautical Chart and Information Center and the Naval Oceanographic Office.

In tactical aircraft, the value of a moving-map display as a primary cockpit navigation device is greatest when flying devious routes at extremely low altitudes. Under such circumstances, the range of visibility is severely limited even under ideal weather conditions. Even a slight departure from a pre-planned flight path can result in a missed checkpoint and possibly a disoriented crew. With the highly accurate self-contained navigation sensors now available, pre-planned point-to-point navigation is effective with standard flight instruments, but far greater tactical flexibility is afforded if the outputs of such sensors are presented directly to the crew in terms of continuous, instantaneous position on a moving-map display.

Thus, the display of stored information, used in conjunction with appropriate cockpit controls, appears to be a most effective device developed to date to assist an aircrew in performing the following functions:

1. Low-altitude tactical navigation, particularly at night or in poor weather and when departures from pre-planned routes are advantageous or required.
2. Interpretation of surface-mapping radar or other high-resolution, real-time, imagery-producing sensors.
3. Updating self-contained navigation systems by reference either to visual or radar position fixing.
4. Initiating and interpreting in-flight system self-test routines or performing the same tests on the ground.

In addition to these four principal functions, a number of incidental functions may be provided at little cost. Among these are the display of check lists and other procedural instructions, maintenance information, and terminal area traffic procedure diagrams.

MAP DISPLAY DESIGN ISSUES

Critical issues in the design of map displays fall into several major categories including: What shall be presented (the information content)? How it shall be presented (the rules for encoding information)? How the display shall be supported (questions of chart logistics)?

What Information Should Be Presented?

The information required on charts is highly mission-dependent. It seems to me obvious that the information required by the Air Defense Command in the F-106 or the YF-12 is quite different from that needed by the Tactical Air Command in the F-111A, which in turn is different from that most suitable for a heavy logistics transport such as the C5A. The emphasis that some place on the use of photographic copies of standard charts in map displays is unfortunate in my opinion. I fully realize that developing complete new chart series for various major classes of missions is an extremely expensive undertaking, but I believe that the improved results will warrant the expenditure.

In tactical aircraft, for example, the types of data that must be presented represent two distinct classes. The first class consists of relatively unchanging long-lead-time materials such as map presentations of theater areas, terminal areas, and aircraft and test procedures. The second class consists of tactical data which requires a quick reaction-time capability if it is to serve as a truly useful mission aid. Items such as current data on defensive deployments in tactical areas and readily available display of alternate attack and departure corridors offer a potential for invaluable assistance to the combat crew. This means a requirement for a storage capacity sufficient to hold the unchanging items and a technique that permits daily changes in the stored material.

How Information Should Be Presented

The optimum characteristics for electronically generated or optically projected charts differ greatly from those for charts printed on paper. These differences also warrant the preparation of special charts. Optimum charts for optical projection in the cockpit environment and for use in tactical operations differ from conventional flight charts in content, symbology, scale, print size, contrast, and color.

To be most effective the charts should be relatively uncluttered, bold in their lettering and other symbology, and of high resolution and contrast. Charts of at least two, and possibly as many as four, different scales should be provided: at least one to a relatively gross scale for enroute navigation and the other to a scale approximately four or five times as fine for local area operations such as position fixing, weapon delivery, traffic control, and landing. Each type should contain only information related specifically to its intended operational use, to avoid cluttering the chart and allow the use of a bold format. A single master chart to a third scale encompassing the entire operational area and showing the location and identity of all charts available in the display is also highly desirable.

Map displays create the greatest single source of light generated within the cockpit at night, even when dimmed to the same level as other displays. The total luminous flux emitted by the display can be reduced at least an order of magnitude by the use of negative black and white charts (white figures on a black background). This type of presentation can also be used with particular advantage in conjunction with color-coded dynamic symbols.

If the map display is to be most effective as a flight instrument or as an instrument for assisting the operator in the interpretation of high-resolution imagery from real-time surface-mapping sensors used in locating targets and navigation checkpoints, then the map presentation must be oriented relative to the aircraft's flight path or heading. When the momentary function of the display is to present alphanumeric information such as radio frequencies, runway headings, place names, or terrain elevations, then it is equally important that the printing be right side up to minimize operator reading errors. These combined requirements call for a dual mode of presentation providing either heading-up or north-up map orientation.

Another classic question is: what should move, the aircraft symbol or the map? Obviously there are advantages and disadvantages to both schemes. Ten years ago I was positive the aircraft should move against a fixed map as it does on practically all early map displays built during the 1950s. Now I am almost equally convinced that, on balance, having the chart move provides more really important advantages. The biggest single advantage is that it reduces the frequency with which charts must be changed by the crew. Even if charts were changed automatically, frequent chart changing is objectionable, and operating near the edge of a fixed chart restricts the field of view about the aircraft.

How Map Displays Should Be Supported

This is no doubt the most important topic to be considered by this symposium. Unfortunately it is a topic about which I have more questions than answers. For many reasons map display systems should be designed to employ microfilm charts rather than hard-copy paper charts or full-scale film transparencies. Microfilm is much easier to transport and handle, and a far greater chart capacity can be provided in a display employing microfilm.

The difficult questions have to do with where and how the charts are to be produced with timely updating and how they are to be distributed to their world-wide users with a minimal delay. For most aircraft/mission applications charts might be updated as infrequently as perhaps once a month. In this case they could be produced by a central agency and distributed in microfilm cassettes by air mail or military air transport. But consider the case of the tactical aircraft requirement to display such data as current defensive deployments on the map-display charts. Here a rapid reaction is required, and techniques thus far proposed for meeting this requirement are something less than attractive. Perhaps this symposium will provide some better answers than I have.

DISPLAY EFFECTIVENESS

The consideration of what constitutes an effective map display is vital. A tactical crew operating at low altitudes and high speeds in enemy territory simply does not have the time to physically manipulate currently available maps in the process of verifying aircraft position. The problem is almost as difficult for an all-weather interceptor pilot or a logistics transport crew. A truly effective map display should provide information at a glance with a bare minimum of operator interaction. This readily available information should be presented in a form which facilitates the correlation of displayed position with visual sightings and/or with sensor presentations. It is this provision of not only a single indicator of aircraft position, but the corroboration of one indication with a second or third which provides the navigational assurance that can significantly enhance the success of a mission.

DISCUSSION ABSTRACT

Mr. Abbott: When a white-on-black negative chart is used, does this depict symbolic content at some sacrifice to the shaded and tinted topographical content of the map?

Dr. Roscoe: It may to some extent. However, we have not experimented enough with the use of colors on black. I have seen some charts designed along these lines which are very promising. A great number of useful techniques for putting either white or colors on black can be brought to use. With some experimentation, I'm sure we can portray everything needed on the display, and still keep that light level in the cockpit down where it belongs.

Lt. Col. Howerton: In spite of specific requirements for navigation display devices for various types of aeronautical charts to meet high- and low-speed and high- and low-altitude performance needs, there remains a basic requirement for display of Flight Information Publications (FLIPs) information for use throughout the land mass portion of the world. Have you considered this basic "bread-and-butter" requirement?

Dr. Roscoe: Yes, microfilm chart strips provide an excellent storage medium for many types of auxiliary information which may be projected onto the display screen as needed.

Mr. Galipault: Do you think we should go back to the beginning of the problem of cartography, and gain a more explicit understanding of man-chart compatibility and interaction?

Dr. Roscoe: Well, I'm not sure what you mean by going back to the beginning. I assume you mean doing some more basic research, which is certainly desirable. But, I don't think we need to be too apologetic about the conclusions that have been drawn from experience. There has been a great deal of experience with these displays, with various types having been built by various companies in various countries. We have a pretty good understanding now of what the problems are and know what we have to do to solve them. The big problems have to do with charts, pure and simple. The optimum mechanical configuration of the display can be fairly well concluded; in fact, the consensus of the group here who have been working in this area shows that we've come to a common understanding of what we want in equipment. I think where the basic research right now is needed is in charts.

Col. Kelsey: I was certainly interested by your remarks, Dr. Roscoe; and Col. Herndon has deputed me to answer for the cartographic community. There's no doubt that both of us have got problems, but I don't think that it is any good, either you standing up there and saying charts have got to change, or Mr. Campbell earlier saying that the displays have got to change. Clearly, we both have got to think about this to find a solution. The cost and time it takes to produce and to maintain, and I stress the point, *to maintain*, the chart series have to be balanced against the cost and the effectiveness of the display system. To produce a new chart series for any substantial coverage takes anything between three to five years and then you have the problem of keeping it up to date. The overall cost is substantial and one has to balance this against the cost of the display systems. We in the cartographic field have many problems to study, and this symposium has been very valuable from this point of view. But I don't think it is any good either systems engineers or cartographers being positive and saying the other has got to change.

Dr. Roscoe: This is the first time I've ever heard any professional community ask for less work; but in all seriousness, I hope I didn't give the impression that I treat lightly the problem of preparing charts that are specialized for map displays. But let me point out to you that ACIC has done so for two different systems that we have built and, in the case of the MA-1 system, it is used throughout the United States. It is true that we don't have a complete series for the ASG-18, we just have those necessary for testing purposes. Both sets of charts were specially developed, tailored to the requirements of those two systems, and they, in fact, do their job very well. They meet their requirements to the great satisfaction of the users. Now somewhere in between, having inadequate charts on the one hand and breaking ourselves financially on the other hand, there is the compromise that represents the solution you're looking for.

Dr. Guttmann: I'd like to strongly confirm Dr. Roscoe's opinion about the status of the art in designing charts for display use. I must confess I'm extremely puzzled about the present status of this symposium. It almost looks like the instrument designers are to blame for stating requirements that have actually been created by the user. We have been asked to build these displays that require these charts. I would like to respectfully ask the Defense Intelligence Agency what is their interest in supporting the user?

Mr. Bloom: I just want to make a comment. We've heard a lot of pros and cons about the capability of the chart producers to respond to product requirements. Now, if the display people would really get down and define what their requirements are, I'm sure that we will respond.

EXPERIMENTAL USE OF SEVERAL BRIEFING METHODS AS AIDS TO TARGET DETECTION WITH HIGH-RESOLUTION RECONNAISSANCE DATA

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Human factors support to Advanced Development Program 665A by Aerospace Medical Research Laboratories (AMRL) at Wright-Patterson Air Force Base, Ohio, is concerned with the performance of human operators in airborne reconnaissance/strike subsystems. The nature of the task required of the operator in such a subsystem involves the effective utilization of any a priori information (navigation charts and like material) to orient the operator relative to the terrain area of interest, and aid his rapid identification of the desired target objects.

In the pursuit of the AMRL support goal to 665A, over the past three years, some 28 human engineering studies have been accomplished in-house by AMRL in conjunction with the 665A program to define and measure the various aspects (or human performance variables) that make up this operator task.

The a priori information (briefing material, charts, etc.) available to the operator in accomplishing this task was early recognized as one of the more important variables influencing his performance and four individual studies were carried out with a priori information to the operator as the primary variable or as an important secondary variable.

A review of the results of these four studies will be presented in this paper.

STUDY I

The perspective of human factors research in reconnaissance must include operator aids for the detection of targets. Realizing this, we decided that our first research should use commonly available Air Force flight materials. For the initial study, we selected Sectional Aeronautical Charts with the idea of varying their study and use by the subjects. This was represented by these four conditions:

1. Study of the chart of the area prior to the flight.
2. Use of the chart of the area during, but not prior to the flight.
3. Study of the chart prior to the flight and use of the chart during it.
4. Use of a list of target types, but no charts.

The apparatus used for presenting the radar imagery to the subjects and for scoring their responses was a display console with a 14 by 14 inch rear-projection screen and a 35mm data camera. The subject used an illuminated stylus to point at the targets and then pushed a button to trip the data camera.

The projector magnified the imagery 3.3 times and moved the imagery from the bottom to the top of the screen at a speed corresponding to 500 knots.

The imagery covered 400 nm from Baton Rouge, Louisiana, to Tallahassee, Florida, in length and approximately 38 nm in width and a scale of approximately 1:200,000. The film was divided into four 100-mile flights, each 12 minutes long. One hundred sixty-one targets were imaged including airfields, bridges, power lines, railroad yards, and tank farms. More than half the 161 targets were bridges, a target that has been dropped from our research because of their large numbers.

The charts were not altered in any way except to cut them to a size somewhat larger than the terrain displayed. Therefore, the subject had to search for the targets on the chart and on the imagery.

A surprising result was, the different approaches to briefing had no significant effect on performance. The mean detections for the four conditions were 54.8%, 55.2%, 56.0%, and 57.0%. Not even the false positive responses (calling a non-target a target) were significantly different 35.3%, 28.8%, 28.3%, and 27.7%.

False positives pose serious problems. Many irrelevant radar returns seem to resemble targets closely enough to elicit responses. Under the conditions of this study, even the use of the charts failed to reduce them. This could have been because the targets themselves were difficult and also that the subject felt he had to guess. One aspect of the chart/imagery relationship probably contributed to the false positive rate. Some targets appeared only on the imagery, some only on the chart.

STUDY II

The second study included variables of simulated velocity and briefing levels. The briefing materials consisted of a five-inch wide transparent film strip equal in length to the radar strip. Imprinted on the strip was the following information: (1) the distance flown in 8.5 nm increments; (2) the target type; (3) the flight distance to the target from the beginning of the flight; (4) the range to the target in nm from the left edge of the imagery; (5) a target cue mark indicating the position of the target on the imagery. This mark was on the transparent film. The simulated velocities were 600 knots, 1800 knots, and 3000 knots.

The side-looking radar (SLR) strip covered an area of terrain approximately 800 nm long and 25 nm wide. This original strip was divided into three strips imaging approximately 270 nm of terrain. To avoid any memory effects, no subject saw the same strip twice.

Twenty-one targets (airfields, dams) were imaged, seven on each strip. The three briefing levels and velocities were varied systematically so that each strip, briefing level, and velocity were equally represented. Briefing level I had no location information given. It was, in effect, a basic target recognition task. With just the fact given that airfields and dams were present and the task was to find all of them, the subjects averaged 3.0 (42.8%) detections per strip. The targets had been on the screen an average of 22 seconds before they were found. For this condition, the subjects also averaged 6.0 false positive responses, 66.9% of the responses for level I. These false targets were on the screen an average of 38 seconds before a response was made to them.

Briefing level II was the lower level of location information. By providing an indication of the distance of the targets along the flight path and the range to the target, the average detections increased to 4.3 (61.4%). The time to detect these targets increased, however, to 30 seconds.

Since the subject knew when a target was present, he responded only at that time. A false positive

TABLE 1

Response Summary: Study I

	Prior Use	Use During	Use Prior, During	No Chart
Percent Detection	54.8	55.2	56.0	57.0
Percent False Positive	35.3	28.8	28.3	27.7
Average Distance Traveled Before Detection	2.9	2.9	3.6	2.9
Average Distance Traveled Before False Positive Response	5.5	5.7	4.0	4.4

occurred when the target could not be found, and an erroneous guess was made. The average false positive responses decreased to 1.9 (30.4%) of the total responses for level II. These false targets were on the screen an average of 36 seconds before being found.

Briefing level III was the higher level of location information. In addition to the distance and range information, a target cue mark on the briefing screen was synchronized in location with the target. With this type of information, the average detections increased to 5.6 (80.0%). These targets were on the screen an average of 20 seconds before detection. The number of false positives decreased to an average of 1.1 or 16.8% of the total responses for level III. These false targets were on the screen an average of 33 seconds.

The addition of location information resulted in substantial increases in the number of targets detected and at the same time an equally substantial decrease in the number of false positives. This type of briefing seems to be a meaningful approach to enhancing target detection performance using SLR.

The slowest simulated ground speed, 600 knots, yielded an average of 4.6 (65.9%) targets detected and an average of 4.2 (47.8%) false positive responses. The average response time was 39 seconds for detection and 59 seconds for a false positive response. The intermediate velocity of 1800 knots reduced the average number of detections to 4.3 (61.4%) and the number of false positives to 2.5 (36.8%). The corresponding average response times were 19 and 28 seconds. The fastest velocity of 3000 knots reduced the average number of detections to 4.0 (57.8%) and the false positives to 2.3 (36.8%). The corresponding average response times were 14 and 18 seconds. It should be noted that the maximum times for the targets to be on the screen varied with the velocity: (1) 600 knots = 169 seconds; (2) 1800 knots = 56 seconds; (3) 3000 knots = 34 seconds. An increase in velocity, although detrimental to target detection, only reduced the average detections by .6 target (8.1%). The increase in velocity was, from another point of view, somewhat beneficial since it reduced false positive responses a net of 1.9 or 11%.

The analysis of variance for detections revealed that briefing levels were statistically significant at the .01 level. Although the main effects of velocity and strip and the interactive effect of velocity by strip were also both significant at the .01 level, comparing means shows that the effect of providing increments of information becomes the most important factor within the study.

A further investigation of the briefing levels, made by applying the Duncan Multiple Range Test, indicated that each increment of information produced a significant increase in the number of detections. Briefing level I in which no a priori information except target type was given, resulted in a mean detection of 3.0 per strip. Briefing level II, the first with

TABLE 2

Response Summary: Study II

	Percent Detections	Percent False Positives
Briefing Level		
I	42.8	66.9
II	61.4	30.4
III	80.0	16.8
Velocity		
600 Knots	65.9	47.8
1800 Knots	61.4	36.9
3000 Knots	57.8	36.8

a priori information given, increased the mean number of detections to 4.3. Therefore, the addition of location data, reducing the area to be scanned to a circle with a diameter of approximately two inches or five nautical miles, increased the mean number of detections by 18.6%. Briefing level III, which included the target cue mark added to that of briefing level II, increased the mean detections to 5.6 per strip. Thus, a net increase of 37.2% resulted from the addition of the highest level of briefing. Detection of all the targets was not expected because of the difficulty of finding some targets that are either very small or remain hidden in the radar clutter even when the observer is highly briefed. The a priori information did not include any knowledge of the flight path or the physical qualities of the particular target. Even so, a large increase was obtained.

The false positive is of serious concern for the reconnaissance/strike mission. It is especially important for mission efficiency and weapon economy. The two briefed conditions were structured so that the subject was required to search for a target only when the briefing material indicated that it was present. Therefore, a false positive response occurred when a subject mistook a non-target object for a target that he knew was displayed. Thus, for the two briefed conditions, the number of false positives was approximately equal to the total number of targets available minus the number of targets detected. For the unbriefed condition, the subject was told to find all the airfields and dams. Therefore, no inherent limitation was placed on the number of responses (correct or incorrect) that he should make.

The Friedman chi-square r test applied to the false positive data for briefing levels was significant at the .01 level. The mean false positive responses of 6.1 for briefing I totaled 66.9% of all responses at that level. However, for the same condition, only 42.8% of the targets were detected. With the addition of briefing (level II), a significant reversal in performance took place. With the restrictions on responses introduced by briefing, only 30.4% (mean of 1.9) of the total responses were false positives, while the number of detections increased to 61.4%. Furthermore, briefing III reduced the false positive rate to 16.8% (mean of 1.1) of the total and increased the number of detections to 80.0% of the total possible. These data showed that target detection performance increased almost 2:1 and false positive performance decreased more than 4:1.

The analysis of variance for detection time revealed that time to detect for the briefing levels differed significantly at the .01 level. Furthermore, the Duncan Multiple Range Test indicated that briefing II performance was significantly slower than I or III ($p < .01$). No significant difference was found between briefing I and III. The mean time to detect for increasing briefing levels are 22 seconds, 30 seconds, and 20 seconds. The target cue mark gave the precise location of the target on the imagery. Prior to the appearance of the target, the briefing material indicated that it would appear, then the cue mark followed. After judging the coordinates of the target from the briefing material, the subject began to search for it on the display. The time to detect it depended on the clarity of the target signature. Comparing briefing I, the detection time was for a search not directed by a precise notation of the target location. The approximate equality of the detection times for the two conditions is understandable when the number of targets detected is examined. When unbriefed, only the more easily detected targets, i.e., the more obvious target signatures, were detected (mean of 3.0 detections). With the target cue mark, the average number of detections increased to 5.6. Thus, more and less obvious targets were still detected within the same time reference. The significantly slower performance for briefing II can best be explained by the nature of the task involved. Here no cue mark was present, but a target was known to be present; thus, the subject had to refer to the briefing material several times to determine where to look on the radar imagery. Even though the target type and general location of the target was given, looking back and forth between the two displays took considerable time, thus, the target traveled a significantly greater distance down the screen before it was detected. An important consideration is, again, the significant increase in the number of targets detected over that in the unbriefed situation. Of most importance is the performance of briefing level III with significantly more targets detected in a time interval that was not significantly shorter than when unbriefed.

False positive responses exhibited a more stable time to respond. No significant differences were found for briefing levels with the Friedman two-way analysis of variance. However, the comparison of time for correct detections and time to respond to false positives indicated that, in every case, the latter time was longer. Thus, the observer searches for targets and then farther down the screen he responds to non-target returns. This is true only in the unbriefed situation. The briefed situation is somewhat different in that here the subject continued to search for a briefed target and, not being able to recognize its signature, finally chose an object that was not a target. These two factors help explain the extended time required for false positive responses.

The analysis of variance for detections showed that the number of detections at the different simulated aircraft speeds differed significantly ($p < .01$). Further analysis by the Duncan Multiple Range Test revealed that only the two extreme velocities differed significantly, with fewer detections at the highest speed. The number of detections was 4.6 for 600 knots, 4.3 for 900 knots, and 4.0 for 3000 knots, the respective percent detections were 65.7, 61.4, and 57.4. This maximum decrement of 8.3%, though statistically significant, is a very small effect compared to the large increase in number of detections that results from briefing. Targets are present on the 11-inch screen for 169 seconds at 600 knots, but at 3000 knots they are displayed for only 34 seconds. The fivefold increase in image speed did not produce a breakdown in the subject's performance, rather, at the higher speed, the subjects simply worked more rapidly.

Although the highest velocity produced a very small decrease in number of detections, it did not affect false positive responses significantly. Even though the absolute value of the obtained decrement was greater for number of false positives than for number of detections, the decrease was not statistically significant. The fivefold increase in image motion rate affected target detection and false positive responses differently. A possible reason for this is that the rapid image motion severely limits time for target search. False positives, on the other hand, may result from an attempt to find targets under the pressure of the time limitations.

The time to respond to targets and to false positives follow the same trend. Note that response time for both of them was much longer at 600 knots. This effect was statistically significant. The subjects were instructed to find and designate the targets quickly. One might expect differences to occur because of target availability times (169 seconds, 56 seconds, 34 seconds on the display), i.e., at higher speeds targets had to be found quickly or not at all. As in briefing, mean response times for false positive were longer than detection response times. This lends support to the concept that targets are found and then further search results in false positive responses. In addition, guesses are made when difficult targets are highly briefed and not immediately detected.

Besides correct detection and false positive responses, a third response is possible--misnaming of a target (classification error). No errors of this type were made by the subjects. This would be expected when the targets were briefed. The fact that no errors were made under the unbriefed condition is due to large differences in their target signatures.

Two methods of evaluating the practical implications of this kind of briefing and the different velocities are accuracy and completeness. Accuracy is the ratio of correct detections to the total number of responses, i.e., the probability that a response will be correct. Completeness is the ratio of the number of detections to the total number targets, i.e., is the fraction of targets that are detected. Both can be expressed as percentages.

Completeness has been discussed earlier. Briefing III yielded an accuracy of 80.0% and the 600 knot velocity yielded 65.9%. Therefore the maximum amount of briefing and the minimum velocity produced the most completeness for target detection.

A study of the target types and individual targets reveals something about target difficulty and how briefing aided detection. When only the target type was given, 13 of the targets were found by 50% or fewer of the subjects. Eight of these targets were airfields. When the first level of briefing was added, 10 of the targets were found by 50% or fewer of the subjects. Six of these were airfields. For maximum briefing only, two targets were found by less than 50% of the subjects--one airfield, one dam. This indicates a tendency for target difficulty to equalize with briefing.

Comparing the results of the first study and the second study, simple briefing materials are certainly indicated at least over the range of aircraft velocities investigated.

STUDY III

The third study in the series used Sectional Aeronautical Charts and Series 200 Charts in an attempt to answer these questions:

1. Will circling targets on the charts increase detections as expected?
2. Will different chart/imagery scale ratios produce significant differences?
3. Will the time before detection vary with different charts?
4. Will chart symbols produce differences?
5. Does the use of these two charts differ?

The strip of APS-73 (XH-4) radar imagery covered approximately 340 nautical miles by 25 nautical miles of terrain. At any one time the display depicted a 25 by 25 nautical mile area of terrain with a scale of 1:130,000. The strip extended from Peoria, Illinois, to Minden, Nebraska, with 150 miles missing around Ottumwa, Iowa. A simulated ground speed of 1800 knots was obtained by using an image speed on the display of 16.8 inches per minute. Each target remained on the screen for about 50 seconds.

Twenty-four targets (13 airfields, 4 dams, 3 railroad yards, 2 tank farms, and 2 ammunition storage areas) were on the film. These targets were each circled on the 1:500,000 and 1:200,000 scale charts.

Forty-two Strategic Air Command radar navigators participated in the experiment: 14 used the Series 200, 14 used the Sectional Charts, and 14 received no briefing except a list of target types. At the beginning of each session, the subject reviewed the chart he was to use. After he understood which targets to look for, the instructions appropriate for the test condition were read to him.

The 14 subjects in the control group (no charts) averaged 13.3 (of 24) correct target identifications. This is significantly lower than the average of 22.3 detections of the 14 subjects who used the Series 200 Charts and the mean of 22.5 detections for the 14 who used the Sectional Aeronautical Charts.

The average time that the subjects took to find these targets when no charts were used was 13 seconds. The average detection time when the Series 200 Charts were used was 16 seconds, and when the Sectional Charts were used the average was 19 seconds.

Even more impressive differences

TABLE 3

Response Summary: Study III

	No Chart		Series 200		Sectional Chart	
	Number	Percent	Number	Percent	Number	Percent
Average Detections	13.3	55.4	22.3	92.9	22.5	93.7
Average False Positives	22.4		1.0		.9	
Average Distance of Travel Before Detection	3.9		4.7		5.5	
Average Distance of Travel Before False Positive Response	5.2		7.5		8.7	

were found in the false positive responses under the different experimental conditions. Without charts, the subjects averaged 22.4 non-target responses. However, using the charts reduced the false positives to an average per subject of only 1.0 for the Series 200 and an average of .9 for the Sectional Charts. The average times to respond to these false positives were 18, 26, and 31 seconds, respectively.

The analysis of variance for target detections revealed that number of detections under the different experimental conditions differed significantly ($p < .01$). A further analysis by t-test indicated that the group that had no maps differed significantly in targets detected from both chart groups ($p < .01$). The chart groups found more targets. However, there was no significant difference in target detections between the two groups that used the charts.

The average number of false positives (22.4) per subject was vastly different for the group without maps; in fact, they responded to more false targets than real ones. The groups using charts with means of 1.0 (Series 200) and .9 (Sectionals) were effectively not different from each other.

The Kruskal-Wallis Test (Siegel, 1956) applied to the screen position at detection scores revealed an overall significant difference among groups ($p < .001$), i.e., they differed significantly in detection time and elapsed distance before detection. The Mann-Whitney U Test for individual comparisons gave these relationships: (1) the time to detect comparison between the control group and Series 200 group was not significant; (2) the Sectional Chart group took significantly longer than the no-chart group to find the targets ($p < .01$); (3) the Sectional Chart group also took significantly longer to find the targets than the Series 200 group ($p < .05$).

The Kruskal-Wallis Test was also applied as an overall test of significance for the time to respond to false positives. Significance at the .05 level was found. Again the Mann-Whitney U Test was used to investigate the differences between groups. Only the control group and Series 200 group yielded significance ($p < .05$), using the charts requiring more time.

The final statistical test involved a comparison of detection time and false positive time within groups. The Walsh Test gave these relationships: under all conditions [within the control ($p < .01$), Sectional ($p < .05$), and Series 200 groups ($p < .05$)] targets were found significantly faster than false positives.

Fifty-five percent of the targets were identified by the subjects who were not briefed. This percentage is higher than most found in preceding studies when the subjects were unbriefed. The imagery selected for this study was from a late model of high-resolution radar (APS-73, XH-4). It yielded a radar map that had increased resolution, better contrast, and brightness than the imagery of previous studies (McKechnie, 1966). The result was clearer definition of the radar images of the targets.

The charts provided information about the geographic location of a target and also the setting within its cultural and terrain background. The scale of the charts and amounts of detail on them were quite different. On the Sectional Aeronautical Chart (scale 1:500,000), both cultural and natural features are quite small. Symbols are used in lieu of an approximation of the object's radar return.

The details on the Series 200 Chart (scale 1:200,000) are more than twice as large as those on the Sectional Chart, and include image approximations of the objects. Another important difference is the absence of much of the cultural and terrain features. However, the important indicators are retained. Despite the differences between charts, each facilitated target detection equally. Thus, symbolic and relatively realistic portrayal of ground features were equally effective. Likewise, scale did not produce a differential effect on the number of detections. The beneficial effect of the charts for target detection is large and unquestionable, since the number of targets detected increased almost 40% with their use.

The distances that targets had traveled before detection were different for the three conditions. First, the charts slowed detection time. This result was expected since time must be spent looking at the charts. Less time was taken to find the targets without the charts, but fewer targets were found. Second, the Series 200 Chart required less time than the

Sectional Chart; the supposition being that the larger scale and reduced detail was easier to read and applicable information more quickly assimilated. Thus, the two charts differed with respect to time, but not detection.

For false positives, the same limitations on time to respond apply as above. Only the no-chart and Sectional Chart comparison approaches significance. False positives that occurred when subjects had been briefed were either guesses or responses to uncircled radar returns that looked like targets. In any case, the responses were made farther down the screen. These responses, which are to non-target radar returns, seem to follow the same pattern whether or not the operator was briefed.

The primary purpose of this study was to determine if annotated charts would aid target detection on SLR. The experimental results clearly indicate that annotated charts are of considerable value because they aid the observer in detecting more targets and mistaking fewer non-targets for targets. Both types of charts were equally beneficial in spite of the differences in scale and makeup. One important aspect of the study is the discovery that readily available navigation and radar charts may be easily annotated (circling targets) and will lead to excellent target detection performance. This seems to make unnecessary the use of complex equipment (electronic or other) to generate target detection aids for cathode-ray tube (CRT) or optical displays for targets of known location. This results in a saving in costs and reduces equipment reliability problems.

An unresolved question is that of the ease of handling the charts. It is not practical to carry complete sets of the charts on board an aircraft and charts are not necessarily published in convenient sizes. Further research needs to be initiated to determine whether a separate chart display should be incorporated and, if so, its position relative to the imagery, or whether the charts and imagery could be displayed on the same screen on a time-shared basis.

STUDY IV

It was the purpose of this study to simulate as many of the aspects of a mission to maintain surveillance of strategic-type targets from relatively high altitudes with high-resolution side-looking radar. A further purpose of the study was to determine the effects of three types of a priori information, presented in three different ways on the operator's ability to identify specific targets and accurately place display crosshairs on the desired aim point for each target.

Forty-eight combat crew navigators, from the Strategic Air Command, completed three repetitions each of the surveillance mission using 200 Series (USAF) Radar Target Charts, a specially prepared map on five-inch film transparency, or radar imagery that was obtained on a previous flight over the areas of the targets. The 200 Series Charts were hand-held; the map transparency and previous coverage radar imagery were displayed to the operator on a 4 by 4 inch back-lighted screen located on the deck of the radar display console, or displayed via a flying spot scanner on a 14 by 13 inch CRT display horizontally adjacent to the radar display.

A preliminary analysis of variance of the data pertinent to the subject matter here indicates the following results as is depicted in Table IV in the form of mean errors of target location and mean time for target identification and location.

1. The operators were significantly more accurate in placing the display crosshairs on the target aim point when the specially prepared map material was displayed to them as a priori information during their mission than when the previous coverage radar imagery was displayed.

2. The operators identified and located their targets most quickly when using only a hand-held 200 Series Chart and required a significantly greater amount of time for target identification and location when a priori information was displayed on the direct reading back-lighted screen on the display console deck.

From the preliminary results of this study, it appears safe to conclude that the type of information (chart, special map, or previous sensor coverage) to be presented to the

TABLE 4

Response Summary: Study IV

Accuracy: Placement of display crosshairs on target aim point.

Presentation Method	Mean Error
Hand-Held Chart	4.8 Units*
Auxiliary Display	3.9 Units
Side by Side Display	6.3 Units

Time: Display time for target aim point location.

Presentation Method	Mean Time
Hand-Held Chart	92.7 Units
Auxiliary Display	99.3 Units
Side by Side Display	100.7 Units

*Raw data "units" are used here to indicate relative performance and avoid classified information. "Units" are translatable to time and distance measures.

human operator does not affect his target identification and location performance as directly as the manner of presentation of the information. It may be the case, that more extensive investigation would define specific information content, quantity, format, or other variables, subsumed under "type" of information, as a major contributor to improved operator performance. It is apparent from the data of this study, the manner in which the operator obtains the specific information needed for his task, directly affects his performance. Therefore, a more effective contribution to improved operator performance is to be expected if future efforts are directed to determination of the more optimum way of presenting information to the human operator for the task he is to accomplish than to search for the optimum type of information to be presented.

SUMMARY AND CONCLUSIONS

A somewhat limited review of the results of four experimental studies of human performance in target detection with high-resolution side-looking radar has been presented here. It is assumed by the authors, and offered for consideration, that the results of these studies provide valuable insights into some of the many problems of aeronautical charting and information display. The studies cover use of standard aeronautical charts (Sectional and Series 200, USAF), specially prepared imagery, and previous coverage images of geographic areas of interest. The techniques of presenting the a priori (briefing) information to an operator included "hand-held," optically displayed, and CRT displayed. The following general conclusions are drawn from the results of the four studies:

1. A priori information does, in fact, aid target detection.

2. Image motion rates are not a limiting factor in the target detection task and briefing material (a priori information) is effective in reducing the performance degradation attributable to high rates of image motion.

3. No one type of a priori information, within the range of materials studied, is clearly or consistently more beneficial as briefing material.

4. The manner of presenting the a priori information to the operator directly affects his target detection performance and the manner in which the information is presented appears to be the most fruitful area for further investigations to improve operator target detection performance.

REFERENCES

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2. Siegel, S. *Nonparametric Statistics for the Behavioral Sciences.* New York: McGraw-Hill, 1956.

DISCUSSION ABSTRACT

Capt. Kilpatrick: You have reached a conclusion regarding the effects of image rate. Were your experiments designed such that conclusions regarding the effects of image exposure time could be made?

Mr. McKechnie: The three image velocities limited target availability to 169, 56, and 34 seconds. The average target detection time was less than half of each of these. Thus, the targets were found in the upper half of the screen. Since the detection decrement was small (0.6 target) and the targets were still found in the upper half of the screen, it seems that the subjects compensated well for the increasing time limitations.

Mr. Galipault: Was there an interaction between briefing level and velocity? I would also like to know what experimental design and how many subjects were used, and whether any pre-training was given.

Mr. McKechnie: The briefing x velocity interaction was significant at the .05 level. The first two briefing levels showed a slight decrement with a velocity increase; the third showed an increase for the first two velocities and a leveling off at the third velocity. A Lindquist Type-V model was used with 36 subjects. All subjects took part in a two-day training program to become familiar with side-looking radar imagery.

THE POSITIONING OF MAP NAVIGATION DISPLAYS IN AIRCRAFT COCKPITS: AN ANALYSIS OF REQUIREMENTS AND RESTRAINTS

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INTRODUCTION

This analysis of requirements and restraints relevant to positioning map navigation displays in aircraft cockpits will focus on high performance aircraft of the fighter, attack, and reconnaissance variety and on the ordinary visual map navigation task of detecting and recognizing checkpoints along a pre-planned course. The strictly visual case was selected because pilots contacted recently suggest that the visual mission may not safely be rejected as the primary operational mode. Hopefully this limitation will not obviate more general implications.

With this brief definition of the scope of this paper in mind, perhaps it is appropriate to take a look at a current navigation display. No doubt all of you are familiar with a marked and folded map. A typical example is shown in Figure 1. Such a navigation display is installed in an aircraft cockpit by attaching it to the pilot's knee board. This display does the job of aiding the pilot keep track of his position on the surface of the earth, a job he does by preparing and studying the map and then using it during a flight in conjunction with his view of the terrain to maintain the needed close contact with the ckeckpoints he has selected on or along the course. A map is used today because nothing as cheap and as available does a more adequate job. Notice also that this simple map-man navigation system has the advantage of only one moving part, the pilot, that can go wrong. This is a minimum for manned systems and makes maps on a knee board tough to beat. One could say that a map is cost-effective.

Tentative Requirements

The trick, then, is to develop a modern navigation display that improves on a folded-up map and to install it in the cockpit in a position more favorable than the pilot's knee board. What makes this tricky, aside from the general nonavailability of a good, inexpensive, reliable, display device, is the widespread failure of all of us concerned with the requirements for and design and standardization of cockpits and cockpit equipment to deal with the need for an improved map navigation display before it is upon us and it is too late to do much more than try to piece together a passable solution.

Non-Optimum Solutions

For example, the arrangement of cockpit displays shown in Figure 2 is a standard, the well-known "Basic Six." There is also a standard alternative, referred to as the "Basic T" shown in Figure 3. It can be seen that neither of these standard layouts contain provision for a navigation display. Navigation displays, however, frequently find their way into cockpits, often in the guise of tactical situation displays or map radar displays, which are not exactly map navigation displays of the type considered here. An interceptor currently in service is equipped with a tactical situation display positioned low in the cockpit, as shown in Figure 4. A fighter-bomber is equipped with a map radar display also positioned low in the cockpit, as shown in Figure 5. Another fighter-bomber with a crew of two pilots contains a radar display positioned in the top center of the front cockpit panel (Figure 6) and in the lower center of the rear cockpit display area (Figure 7). The cockpit design for an attack aircraft not yet in service provides for a map navigation display of a somewhat more advanced type located to one side of the center of the pilot's panel, as shown in Figure 8. There are others, of course, but perhaps these examples illustrate the problem.

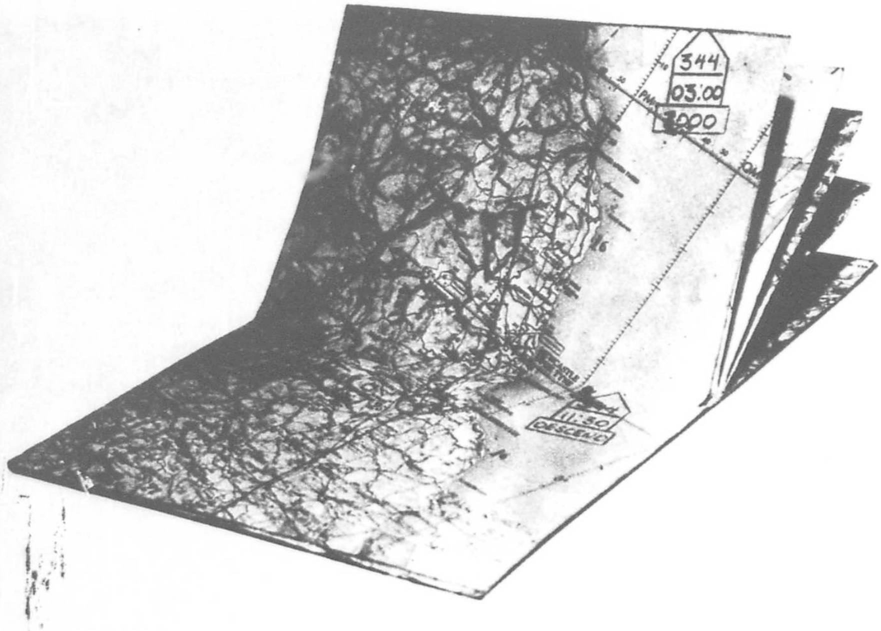

Figure 1. Current navigation display.

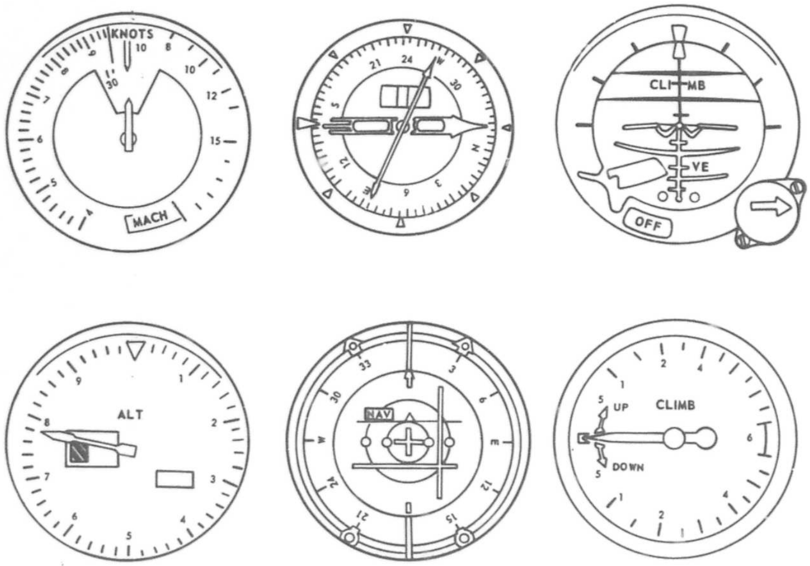

Figure 2. Basic-six cockpit display arrangement.

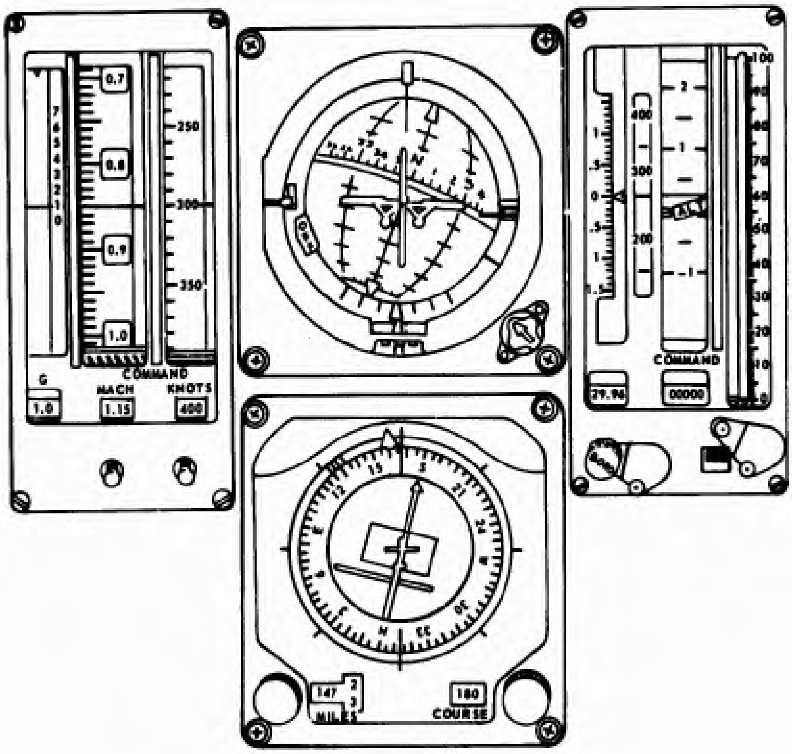

Figure 3. Basic-T cockpit display arrangement.

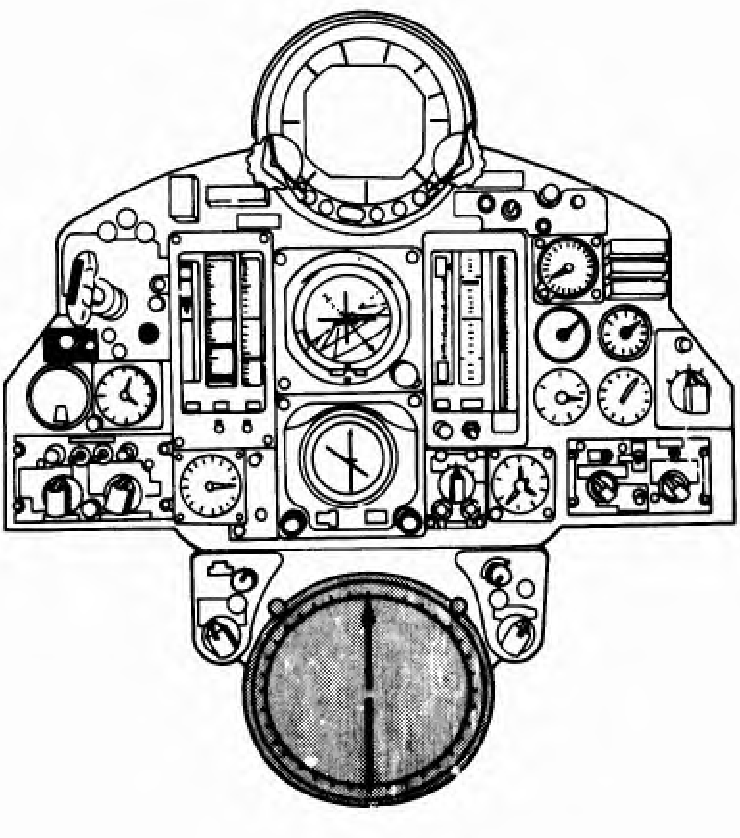

Figure 4. Tactical situation display in an interceptor cockpit.

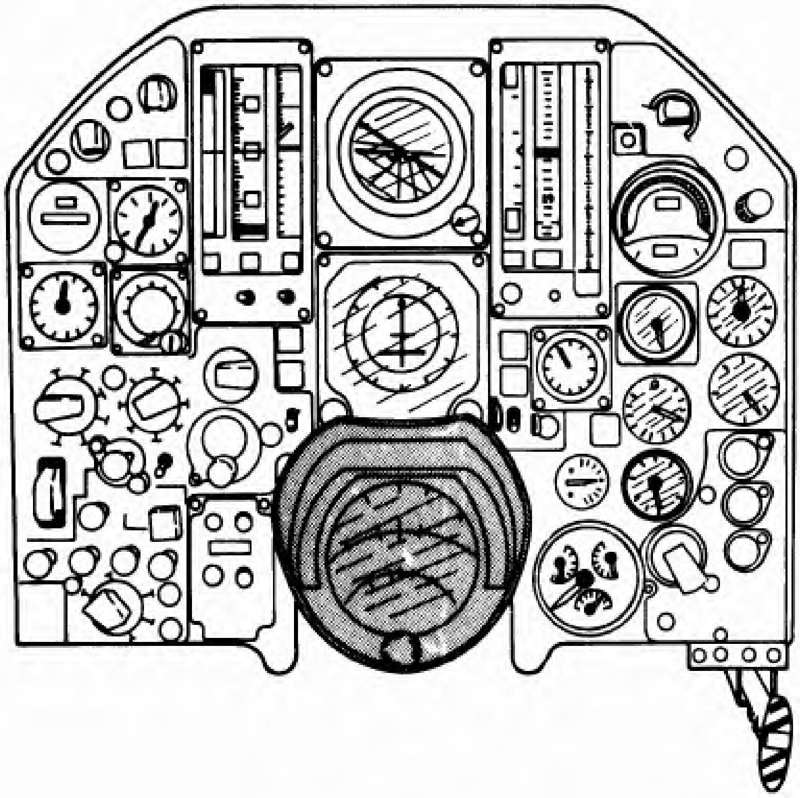

Figure 5. Map-Radar display in a fighter-bomber cockpit.

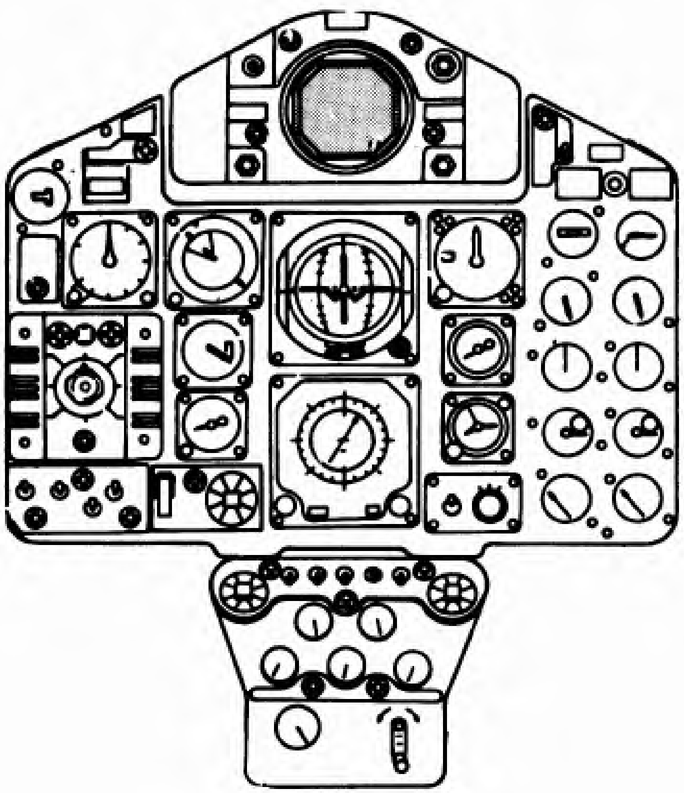

Figure 6. Radar display in the front cockpit of a fighter-bomber.

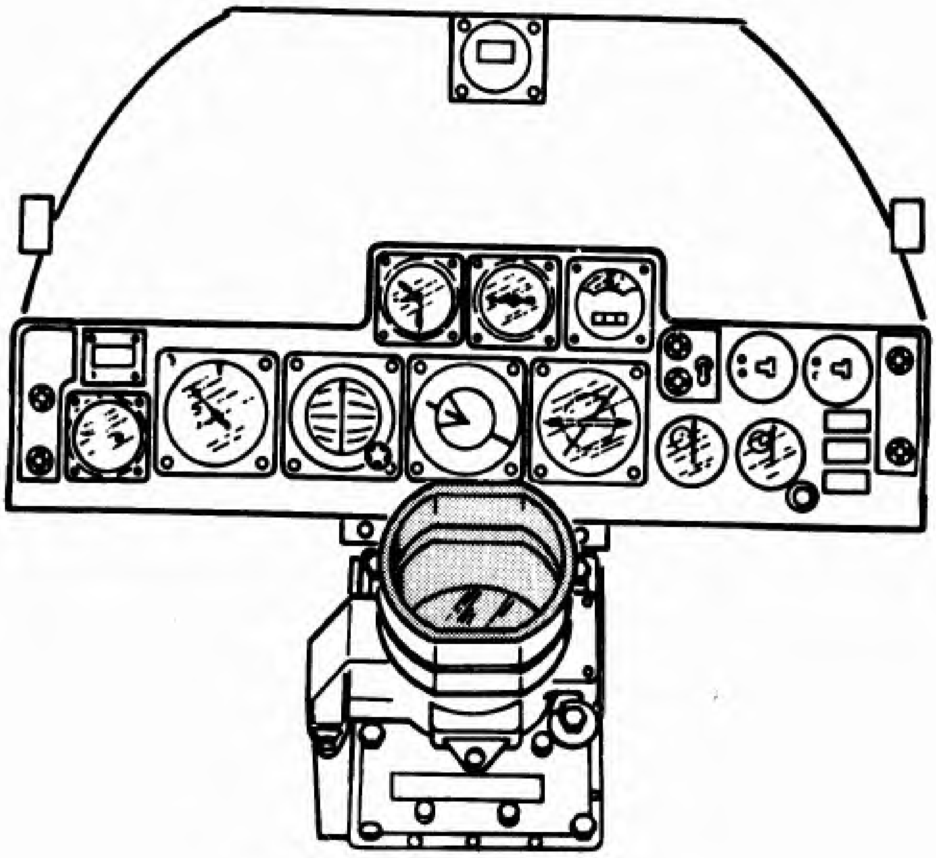

Figure 7. Radar display in the rear cockpit of a fighter-bomber.

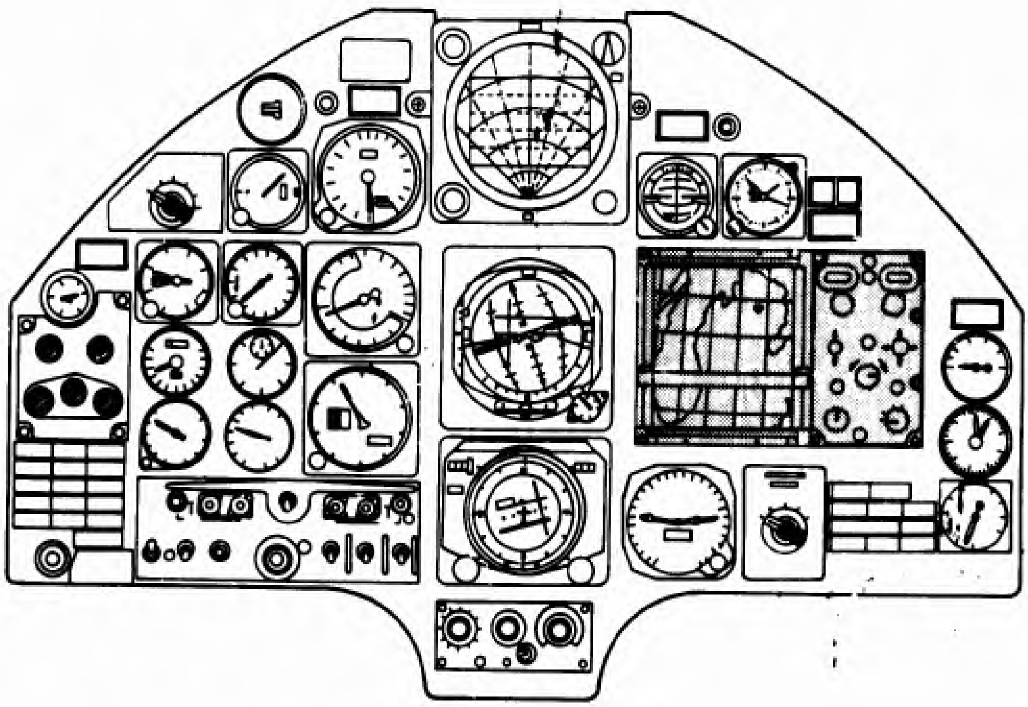

Figure 8. Map navigation display in an attack aircraft cockpit.

ANALYSIS AND DISCUSSION

The problem is that there seems to be little agreement on navigation displays themselves or on the appropriate location for them in a cockpit. Perhaps you will agree that it does not appear that navigation displays are taken seriously. Such treatment is far out of step with the seriousness with which many regard navigation displays. If this is in fact the case, there are at least two reasons. One reason is that traditionally radio aids have been used to solve the navigation problem. A second reason is related to the lack of space in aircraft cockpits, an old problem that easily could serve as a topic for a symposium all by itself. Since radio navigation aids do not effectively solve the visual map navigation problem and since there is little likelihood that provisions for radio aids will not be required, this leaves the space problem, or more directly the problem of fitting an effective map navigation display into an optimum position in a cockpit.

Alternative Display Locations

Considering for a moment the nature of a pilot's use of a visual map navigation display, in which there is a continuous in and out of the cockpit scanning between display and terrain, we can reject as inadequate any location not as near the top of the instrument panel as possible. The top center spot probably is the best of the top locations for the navigation display because it interfers less with other instruments now located on either side of the center, such as altitude, speed, and engine status displays in many cockpits. In addition, a top center location for the navigation display avoids the situation in which an off-center display could create an advantage or disadvantage with respect to visual access that conceivably could result in a preference for right- or left-handed approach turns. If such a preference developed in attack maneuvers, it could be detected by enemy defenders, with undesirable results, should the aircraft be called upon regularly to deliver air-to-ground weapons.

Restrictions and Limitations

The desired top center spot on the instrument panel, however, is prime display space and may not easily be won for the navigation display without a convincing story to back up its claim and perhaps some equipment innovations to eliminate the objections of rival displays. Objection to use of this space for a visual navigation display may be expected immediately on the basis of its being taken already by the primary attitude display, or if not this, because an intercept radar has been placed in the top center spot. Such objections have in the past held the top center position open for attitude or radar displays. This is entirely reasonable except for the fact that visual navigation is not normally employed when either the attitude or radar intercept displays are required, namely when on instruments or during an intercept when visual navigation is not appropriate. Although this is a rather sweeping assertion and not applicable in every case, it does suggest a possible rationale for solving the space problem by positioning a navigation display in the top center of the pilot's instrument panel in the same place as the attitude or intercept displays.

POTENTIAL SOLUTIONS

To solve the positioning problem in this manner requires that the optimum display spot be shared. The notion of display location sharing occurred to us several years ago, and with the help of some very able display designers, we were able to combine a map-type visual navigation display, a synthetic command-attitude display and multi-purpose sensor display all in one box. Such a device may be installed in the top center position on the instrument panel to optimize the visual situation for the pilot and to provide navigation, attitude, and sensor information for his use as he needs it.

Problems of Location Sharing

By sharing the cockpit location in this way, and thus solving the original display arrangement problem, it was soon apparent that another problem had been generated. And this is a painful fact of cockpit design, you can't push one place without having to pull in another. The pieces fit together too closely. One problem appeared when we considered the possibility that a pilot might want to use more than one display surface at the same time. A correlated problem of the same sort involves the reliability requirements of a multi-purpose display in which a single malfunction could degrade the display of three types of vital information instead of just one. The simultaneous-vs-successive problem has not yet been solved to everyone's satisfaction. And as far as solving the reliability problem goes, the solutions get expensive, whether the multi-purpose display is accompanied by standard backup displays or whether two multi-purpose units are employed to provide the needed additional capability and reliability.

Complex and Simple Possibilities

Of course there is no reason why a simpler device could not satisfy the need for a visual navigation display. Perhaps a swing-out or stowable self-contained or plug-in unit could be developed to be positioned by the pilot when required in the desirable top center position on the instrument panel, momentarily covering the display permanently mounted there. Such a device could furnish a mechanical alternative to the space-sharing electronic equipment described previously.

SUMMARY

The intention of this discussion is: (1) to point out again the fact that often beautifully executed equipment designs are not nearly as beautifully useful because of little things, like non-optimum positioning for ease of use; (2) to suggest a rationale for optimum positioning of a map navigation display; and (3) to mention an equipment alternative or two for a visual navigation display device. It seems the difficulty in the cockpit display arrangement business is not to lose heart too soon, but to press on and keep exercising one's creativity to the last, lest display location be compromised as a consequence of frustration with the problem, with the result that the visual map navigation display ends up in one or another of the non-optimum places reviewed today.

DISCUSSION ABSTRACT

Mr. Wolin: In other areas of aircraft instrument design, I have noticed that standardization has brought benefits to both military and civilian aviation. From your experience, Dr. Eddowes, do you believe that standardization of navigation displays is a desirable goal for us to pursue?

Dr. Eddowes: My answer is yes. I believe that unless we have standardization, the effects of providing navigation displays stand a good chance of being diluted, because the displays end up being hidden away behind the stick or under the seat or in some other place that has a hole big enough for them. My recommendation is that cockpit equipment standardization be broadened to include the notion of a modern navigation-type display so that it is no longer an auxiliary device that gets shuffled into the last available spot after all the rest of the things that can't be eliminated are accommodated. I am persuaded in my work with the folks who really design cockpits that they can do anything that they have to do. All one has to do is be very sure that they know what they have to do. The previous papers presented here and much of the discussion convinces me that there may be more than one standard required. Certainly a fighter or reconnaissance aircraft of the high performance variety requires a different suit of cockpit equipment than a very large transport or a light airplane or a helicopter. My comments urge that the difficulty we have in many of the present systems of shuffling aside and hiding our navigation displays be avoided through the employment of more creativity in arranging navigation equipment and the selection of more flexible and capable equipment for installation in the cockpit.

Mr. Angelos: What would your recommendation be for the optimum location of a pictorial map display in a large transport aircraft with a two-man cockpit?

Dr. Eddowes: I have had virtually no occasion to study the two-man transport cockpit and am in a relatively poor position to advise here. However, I'm inclined to recommend that a map navigation display be positioned directly in front of each pilot as near the top of the display panel as possible. I'd suggest in this case that alternate modes be provided to permit either pilot to use the map display mode as required while permitting either pilot to select another mode specifically relevant to his function at any given instant. This idea presumes that both men in the front cockpit are pilots and are required to exercise control over the aircraft at one time or another.

Mr. Russell: Placing a map display in the top center position indicates a greater need for this navigation information than for the primary attitude information necessary for basic flight control of the vehicle. Combining the map and attitude information presents an interesting human factors problem of an effective magnification of clutter by presenting information from different true planes in space on the same display plane. This may exceed the pilot's "saturation" level.

Dr. Eddowes: The problem you mention is so difficult that I would not suggest that it be considered seriously. Rather than try to develop a configuration for horizontal and vertical situation information to be presented at the same time on the same surface, I'd recommend that both types of information be made available for use, either one at a time on the same display surface, or simultaneously one type only on each of two surfaces, probably located one above the other in the top center of the front display panel.

Lt. Col. Howerton: A satisfactory navigation display device for the cockpit is long overdue. This recognition includes a proper optimum position on the instrument panel. This should be standardized, yet sufficiently flexible to satisfy the various needs of different aircraft performing different missions. Have you provided for the inclusion of basic flight information (FLIPs) used throughout the free world in your display considerations?

Dr. Eddowes: Yes, I have considered the presentation of basic flight information. Analytical studies carried out over the last three years or so have indicated that it is entirely reasonable to ask that a single multipurpose display be designed so that a pilot may select an aircraft attitude presentation, which also might include such additional information as altitude, speed and heading, as he determines that an attitude display is needed. My suggestion is that in this manner the positioning of neither map information nor flight information will be compromised. If only one display is provided the pilot may not call up attitude information and a navigation display at the same time. This is a significant problem that still awaits an inexpensive, simple, and workable solution. One way around it is to acknowledge that flight information is needed most when the terrain is not available for use as a reference and that the navigation display as considered here is needed most when visual reference to the terrain is available. Naturally, a proper navigation display would be very useful under IFR conditions also, which reaffirms the seriousness of the problem you have identified.

Mr. Galipault: What experimental evidence do you have to support your hypotheses about the positioning of map displays?

Dr. Eddowes: As far as I know there is no experimental evidence specifically supporting the idea as it was presented. Very likely there are studies which relate to it with varying closeness. Although I am personally convinced that the idea has merit, I would be the last one to recommend its adoption without first acquiring a convincing set of measurements of the performance improvements associated with use of such a map display under a wide array of work environment and mission conditions. Perhaps what I urge is that the new displays now available not be crammed into a cockpit anywhere they fit, with little or no consideration given to optimizing their arrangement.

SOME COMMENTS ON THE DISPLAY OF CARTOGRAPHIC INFORMATION FOR VERY LOW LEVEL FLIGHT[1]

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In this presentation, I would like to attempt to summarize the characteristics of the information available for geographic orientation during very low level flight, and to consider some characteristics of cartographic displays which would enable the pilot to use this information more effectively in navigating at low level.

Very low level flight is used to distinguish the clearances of up to 25 feet which characterize much of Army low-level flight from "low level" as used by the other services, where it typically refers to clearances of the order of hundreds of feet. In general, it is believed that this clearance difference should result in little or no differences in cartographic information requirements, although I suspect that the minimal clearance levels bring many of the problems of low-level navigation into much sharper focus. In addition, minimal clearance levels deserve special attention in cartographic research and development, since they represent the ultimate termination of the gradually lowering "lows" in low-level flight by the other services. It should also be noted that these minimal clearance levels do not belong exclusively to the Army, because a variety of research, training, and operational programs involving the other services frequently fly at these levels and these programs probably will increase in number in the future.

Low-level navigation involves a variety of information sources whose characteristics can be documented with reasonable confidence, both for the present and for the future. How these information sources will be combined and integrated together in systems for accomplishing navigation, however, is a major uncertainty. Such navigation systems could vary widely in effectiveness depending on the consideration they give to optimizing the integration of information sources for the accomplishment of low-level navigational procedures.

To keep our perspective, therefore, let's start off with the usual system design starting point. What are the objectives of a navigation system? Let's define the objectives in operator terms: Appropriate control actions by the crew which assure (a) arriving at a target (b) at the desired time with (c) appropriate awareness of aircraft-target spatial relationships. These control actions require indicators, or indicators combined with knowledge or data, which, respectively provide (a) indication of required heading changes to produce a groundtrack over the target; (b) a schedule status which indicates speed changes required to produce the desired time over target; and (c) bearing-range and/or time-to-go-to-target indicators to produce anticipatory knowledge of aircraft-target spatial relationships required for accurate weapon delivery or aircraft landing. In order to provide these "action" type indicators, the target must be specified; the position, heading and speed of the vehicle known; the route and desired schedule from present position to the target specified or known; and the anticipated effects of wind taken into consideration. These factors are, in turn, obtained from a variety of information sources, and by processing of data obtained from some of the sources.

These information sources can be grouped into broad categories: (a)

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[1]This presentation is in part based on work performed on Task LOWENTRY while with Division 6 (Aviation) of the Human Resources Research Office at Ft. Rucker, Alabama. The views presented do not necessarily reflect those of North American Aviation, Inc., the Human Resources Research Office, or the U. S. Army.

the external terrain or radio signals related to the external terrain; (b) maps or similar cartographic materials; (c) clocks; (d) aircraft status indicators, particularly heading and speed; (e) flight planning data; (f) the results of data processing on the above information sources; and (g) the crew and its skills and knowledges, including familiarity with the terrain and its characteristics.

When we attempt to define these categories in greater detail, the problem begins to get sticky. How is the target defined? How and how accurately are vehicle position, heading, and speed defined? How are the route, schedule, and wind effects defined and taken into consideration? The answers to these basic design questions in part must be based on certain assumptions about how the system will be employed, so let's use the toughest set of assumptions insofar as system design is concerned. Let's assume a friendly unit has been ambushed and is pinned down, and has requested airborne supporting fire. Each second this support is delayed may cost additional lives or injuries. Furthermore, an accuracy of 50 meters or less is required, and the time of strike must be established and coordinated with the ground unit at least three minutes before the strike to an accuracy of ± 5 seconds. In addition, we would like to be able to do this without radio aids. These assumptions are demanding of a low-level navigation system, but, unfortunately, are representative of a number of critical tactical missions that will be required into the foreseeable future. They boil down to immediate responsiveness and high accuracy, both in position and time at the target, and should be a major concern in any tactical low-level navigation system.

I won't attempt to develop further overall low-level navigation system requirements, but instead would like to use the remaining time on the use of, and desirable characteristics in the display of, cartographic information in such systems.

No matter how simple or sophisticated a navigation system, the basic crew task in navigation is the comparison of terrain information with cartographic information. Depending on the sophistication of the system, additional information within the aircraft that assists in this comparison may range from a compass, clock, and flight plan, to an automatically driven map display. Increased automation can reduce the number of procedural steps required in accomplishing this terrain-map comparison, and to a degree, equipment configurations that fall short of automation can also reduce them. We would like, basically, to compare terrain information with map information directly, without intervening steps.

Before proceeding, let's review the nature of the terrain information that is available at very low level. At first impression, it seems the road-stream-town patterns used for orientation at normal altitudes have been wiped out, and good orientation can only be a chance happening or the result of highly detailed flight planning. In large part, this is true, and the nature of the information provided by detailed flight planning deserves special attention. However, I would like to examine very low level terrain information on a more general basis.

Listed in Table 1 is a representative list of information available from the terrain. In summary, this information consists of objects, lines of position, vegetation, and relief data, or their electronic equivalent. The only item lacking from the usual list is patterns formed by combinations of features, which are largely blocked from view by intervening terrain or vegetation. Please note that I'm not implying these patterns aren't used in very low level navigation, but only that they can't usually be obtained directly by terrain viewing. Over the route being flown, these spatial patterns are highly important to low-level navigation, but information about them is in the form of temporal patterns, and must be converted to spatial patterns in order to be used with cartographic materials. This conversion is presently accomplished primarily by mission planning, but could also be provided by increased automation of navigation systems, particularly by map-display readouts.

The objects or features which are seen usually are located close to the path of the vehicle; consequently, considerable detail *can* be noted about them. At higher speeds, this level of notable detail may be reduced slightly, but will still be good except to the side close in to the aircraft. At very low levels, however, objects or features offset from the flight path only

TABLE 1

Information Available from Terrain at Low Level

A. Positively identified object or radio signal

1. Overflown
   a. Time

2. Offset
   a. Time
   b. Bearing
   c. Range

3. Distant
   a. Time
   b. Bearing

B. Tentatively identified object or radio signal

1. Overflown
   a. Time

2. Offset
   a. Time
   b. Bearing
   c. Range

3. Distant
   a. Time
   b. Bearing

C. Linear terrain line (e.g., road, stream, vegetation edge) or electronically defined line over the terrain

1. Overflown
   a. Time
   b. Relative angle of crossing
   c. Changes in feature to right or left

2. Offset
   a. Time of appearance and duration in view
   b. Range
   c. Bearing

D. Relief highs, lows, slopes, and patterns

1. Over high or low
   a. Time
   b. Relative direction with respect to predominant direction
2. Local relief patterns
3. Distant relief patterns
   a. Horizon profile

E. Patterns of characteristics in terrain, vegetation, or features which can have orientation value

F. Combinations which define a point or can define it by plotting or analysis

1. Intersection of two of the lines in C above
2. Position over a line with a bearing to an object or radio signal
3. Simultaneous bearing to two or more objects or radio signals
*4. Passage over a line, followed by passage after some time interval of a second line
*5. Passage over a line, followed by a bearing to an object after some time interval
*6. Bearing to an object, followed after some time interval of a second bearing to the same or a different object

**These represent the most common types of low-level orientation information, yet low-level navigation procedures do not provide for effective utilization of them.*

50 or 100 meters may not be seen due to masking; furthermore, beyond several hundred meters, detailed characteristics are usually difficult to determine.

Crossing a feature such as a road, stream, or vegetation edge is usually organized in terms of information collection. If crossing it can be anticipated, or if it is partially in view prior to crossing, it is scanned for potentially identifying features, and the direction considered most likely to provide useful information is selected for initial viewing. On crossing the feature, this direction is viewed initially, and then, if possible, a glance is obtained toward the opposite direction before it passes behind masking. In a multi-crewman aircraft, each man would be assigned a side and report what he saw. Assuming a road, desired information would be: (a) What angle is it crossed? (b) Does it continue straight? (c) If it curves, toward the forward or aft direction, how far away and how sharply? (d) Are there intersections, what type, toward forward or aft side of road; bridges; business, farm or residential buildings along it, and which side? (e) What is the contour situation, does the road go to horizon line over the closest ridge, or how many visible ridgelines does it cross before going over the horizon-defining ridge? (f) Is there indication of a town along the road?

The nature of the information available at very low level has, it is believed, several rather direct implications for the characteristics of cartographic materials, navigational procedures, and the design of navigational systems. (a) To be accurate in navigation to the levels dictated by tactical requirements, detailed topographic characteristics will have to be provided and used in system updating and checkpointing, and, in order to use these details effectively, a relatively high level of accuracy in knowledge of position needs to be maintained --either by frequent updating or equipment accuracy. (b) The information-containing aspects of relief and vegetation need to be provided, particularly since, on a time basis, they are the only information available during more than 90% of a flight. (c) In terms of frequency of occurrence of good orientation information, the lines-of-position type of information predominates over other types in most areas of the world by a substantial margin. Although current low-level navigation practice relies largely on certain line-of-position procedures, consideration of information available indicates that optimum low-level navigation systems and procedures will be those which adapt to the low-level environment the entire array of line-of-position navigation procedures practiced by the professional navigator in high altitude and marine applications.

The above indicated emphasis on using line-of-position information has certain basic system design implications. We need to be able to accurately determine visually the bearing to a feature and the relative angle of feature crossing, and, in turn, to associate this information with the cartographic display directly. This direct relating of information applies, of course, to other information sources within the aircraft. The one, two, or more data-conversion steps which characterize applying information sources to navigational decisions in most current aircraft must be circumvented in an effective and responsive low-level navigation system. Automation is one answer, but a compatible set of units and indicator bases of reference for the tactical low-level navigation situation would help substantially in less sophisticated aircraft. Units and bases of reference designed for civil airways flying can't help but make the tactical low-level navigation job tougher. However, changes in the right direction are occurring, and eventually cockpit design should catch up with the low-level job, be fully metric, and provide directly applicable navigational data inputs.

In terms of presentation of cartographic information for very low level flight, therefore, it could be concluded from the above discussion that a cartographic presentation is needed that emphasizes perception of feature detail, relief, and vegetation. In depicting relief, stream lines should be highly perceptible, and hilltops and ridgelines clearly defined. The edges of vegetation should be clearly defined. In specifying a desirable cartographic presentation for low-level navigation, the very real problems of time and cost of map preparation, distribution, and cockpit storage and display need to be considered, and proper weight given to their very considerable impact in determining the final product.

The comments which follow represent slightly more detailed thoughts related to the presentation of cartographic information for low-level navigation and operations. The basis for each of them is usually a number of complexly related factors, and I will not attempt to provide a detailed justifying rationale for each of them in this presentation.

1. In general, a smaller scale map is required as aircraft speed increases. For slower speeds, information requirements for aircraft navigation are almost identical with those of the combat foot soldier, and in air mobile tactics, the foot soldier's cartographic information requirements will shift closer to those of his aerial support. Almost all conceivable cartographic approaches toward improving perception of terrain-map relatedness for low-level flight should improve it also for the foot soldier. It is proposed that a research program could develop a single, multi-scale, map format that would satisfy the basic cartographic information requirements of all elements in a tactical operation from the individual foot soldier to commander or high-speed, fire-support aircraft. Such a format would have desirable implications for logistics and cockpit storage and display problems. This map format would require imbedding of large-scale details into the perceptual background of the smaller scale presentation. It might be possible by careful straightforward design without different illumination or other special effects, although requirements for the latter are probable. Such a format would have the desirable presentation feature of providing two different map scales from the same imagery source, which would have a number of advantages in providing low-level navigation cartographic information requirements.

2. Uniform detail, rather than emphasis of the outstanding structure, is required for low-level navigation. Most users will generally try to avoid the outstanding structure. Consequently, symbology similar to conventional topographic map symbols should be preferable. The "smoothing" of features as is common in small-scale maps should be avoided insofar as possible.

3. A "perceptual" format which is instantly apparent to the user should be used for the presentation of relief information, with supplementary conventional contour lines added to fill in necessary relief detail.

4. Stream lines and ridge lines which define relief lows and highs should be clearly defined.

5. A geometric progression (or perhaps a cycled linear progression) elevation encodement should be used, with spot or sector numeric data added. The 50-foot-high knoll in flat terrain should be as apparant as the 5,000-foot mountain in rougher terrain. From the very low level perspective, the 50-foot rise in flat terrain is probably more apparent than the mountain in rough terrain, and its cartographic presentation should be correspondingly apparent. Interval adjustment according to terrain roughness could be used if required. The first minimum-sized interval should probably go down to 15 to 25 feet for level terrain.

6. A clearly defined edge to vegetation should be used when such edges exist, but the interior of vegetation patches requires minimal indication. The vegetation-presentation format should be compatible with the relief-encodement format--one should not obliterate the other. The unsaturated screened green used on most older AMS CONUS topomaps should be avoided.

7. The cartographic data display or system should incorporate provisions for employing line-of-position navigation procedures in as direct a manner as possible. Such system design and data display should have a goal of reducing position error down to the relative error values associated with the cartographic materials employed.

8. A map display is required in order to provide effective immediate tactical responsiveness by aircraft. A map display, per se, can reduce equipment component accuracy requirements for many potential applications. Data is needed to quantify these two conclusions for entry into system definition trade-off studies.

9. Many automatic navigation systems have been found impossible to update under low-level flight conditions. The role of cartographic materials in low-level navigation system updating needs to be considered carefully in system designs and, preferably, this updating should be performed directly on the map display whenever available.

10. A cartographic medium that is easily updatable and changeable in the field is highly desirable.

In conclusion, I would like to indicate my conviction that the problems of low-level aerial navigation will be resolved most effectively by a systematic systems-oriented approach. Operational considerations, cockpit design and vehicle performance, navigation system design and map display, desirable map characteristics, map production and distribution logistics, other users, and even interservice and international coordination should probably all be taken into consideration in definition of the maps or cartographic materials for low-level navigation systems. New cartographic materials are probably essential to service-wide solution of the navigation problems of low-level flight, yet any commitments would be with us well into the future, and would have to provide for future requirements. My comments are in part based on an attempt to anticipate these future requirements, and many comments lack rigorous supporting data. They represent tentative conclusions about a variety of factors that should be considered in programs aimed at improving low-level navigation and the cartographic materials used in this type of navigation.

DISCUSSION ABSTRACT

Col. Herndon: Dr. Wright, in your studies, were there specified speed ranges that established parameters for your evaluation? Or expressed differently, what were the speeds involved in your specific studies?

Dr. Wright: I have worked with everything from about 40 knots to 600 knots and I was talking in this general complete speed range, I believe. Primarily, we were concerned with the 100-knot vicinity.

Col. Herndon: You said you mentioned the change in scale of charts as being related to speed, obviously. Did you formulate any brackets of relationships; for example, the 1:50,000 scale might be good up to a given speed of x, and then a 1:250,000 scale from speed x to y?

Dr. Wright: I looked for an answer to this question and I formulated a rule of thumb, which is: for 50 knots you need about a 1:50,000 scale; for 100 knots, a 1:100,000 scale; 200 knots, a 1:200,000 scale; and I think this ratio holds quite well if you try to get the maximum information for the least amount of clutter or package size in a cockpit. When you go to a map display, it might change somewhat.

Col. Herndon: Do I correctly interpret your opening remarks to indicate that you feel that the conventional map, which represents a vertical view of the surface, is the proper approach for low-level navigation as contrasted to the profile or oblique viewing representation?

Dr. Wright: I think you have to live with the facts of life, in that you can't avoid the requirement for a basic plan-view presentation. You'd like to be able to derive a horizon-type profile and other relief information as easily as possible from it, of course, but you have to live with a plan-view format.

Col. Herndon: Your suggestion to embed larger scale materials into a smaller scale base has been tried. The cartographers abhor this approach because apparently the users can never decide which part of the terrain should be sacrificed for the embedding. We have done similar things in earlier models in using representative symbology, for example, a symbol for a power plant at much exaggerated scale merely to emphasize the location of that power plant.

In addition, flip-up panels to give profile appearances and all sorts of gimmicks of that nature have been tried, but none have stayed very long. They've gradually reverted to the standard one-scale, plan-view approach.

Dr. Wright: What I had in mind here was, in effect, a variable magnification map-scale format where we could zoom in and out over a range of scales and obtain the information required at a particular speed. I agree with you, it is not a simple problem. I think it will require the best and fairly long-term efforts of the cartographic community and a variety of other people to attain this, and I'm not certain at all that it would be an achievable goal.

Col. Herndon: Are you thinking of a lens system of zooming as a feature of a display device as contrasted to an actual change in scale of the chart itself?

Dr. Wright: Yes, I think this would be desirable; particularly in the Army, where we have a wide variety of speed ranges over vehicles. We have a variety of charting requirements, and if we have one chart that could be applied over this entire speed range, we'd be in much better shape.

Col. Herndon: Mr. Chairman, I have brought today a number of samples of prototype charts that have been in development for some time. I brought them for an entirely different purpose, but after hearing the presentation by Dr. Wright, I think he might like to look at some of the efforts that have already been made to prepare materials that emphasize many of the features that he identified as needing attention for the low-level problem.

Dr. McGrath: Thank you, Colonel. During the coffee break I shall see that the prototypes are displayed to the symposium.

Col. Kelsey: Dr. Wright, I think you identified yet another of our cartographic problems by your interesting comment that the content on the map required for low-level flight is roughly the same as that required for the ground user. And I would like to emphasize to all our systems display gentlemen here that, all the time, the cartographers are being asked by both the airmen and the display manufacturers to cut out the clutter on the chart. I think we do need intense research into the amount of detail content which is required on the map or chart. I don't think, as far as the land users are concerned, this sort of research has been carried out. Certainly not in the U. K., and we hope to do so. That's the first point I'd like to make. The second point is that from very low level, your field of vision is very severely restricted as you have demonstrated and, therefore, again, more content is necessary on the chart in order that you've got some detail to relate to. And it all comes back to this problem of us deciding how much detail has to be shown on the chart.

Dr. Wright: I realize that in asking for a high level of detail I'm posing a very vexing problem which hits the pilot primarily--cartographic clutter in the presentation. I don't know the answer, but I'm convinced we need the detail. Somehow we've got to circumvent the clutter problem as we look at the map, but still have available the information we do need.

Mr. Voisin: Based on your research, you indicated a requirement for correlation between low-level pilot and footsoldier maps. The 250,000 scale JOG's presumably were designed for this function, yet a number of the particular requirements you cited seem less than fully satisfied by this series. Can you point out weaknesses? Does the 25,000 scale PICTOMAP satisfy the requirement more fully? Or is that scale too large?

Dr. Wright: First, I would like to point out that I think the JOG provides a substantial improvement for low-level orientation over previous 1:250,000 formats. As I recall the JOG, there are several things which I think could improve its low-level aerial use: (1) a relief presentation that could be used track oriented in any direction without change in perception of relief; (2) sharply defined vegetation edges; and (3) a road and stream presentation that can be detected with ease during one-half second glances under normal illumination levels and viewing distances. I think most maps suffer from lack of standard structure symbology having maximum discrimination and association values. The work begun in this direction should be completed, evaluated, and adopted. The 1:25,000 scale Pictomap has advantages when there is high familiarity with the area and a moment-by-moment pilotage navigation technique can be used over relatively small areas. For a target approach or checkpointing map, it is especially good; however, for enroute use it involves too much handling for manual use, and needs a very good automatic chart-changing capability for a map display. Relief information is not available in satisfactory form from it, and in a map display its limited range would frequently be a handicap. I think we would like to have something like the Pictomap for updating sophisticated navigation systems, although its 25 meters per millimeter scaling still does not provide the updating accuracy down to a few meters that we would like to have. Perhaps this indicates that using cartographic displays, per se, is not the feasible approach for attaining a high-accuracy updating capability, and that something like numeric annotation of coordinates of a standard corner of updating features might be a better approach. This 25,000 versus 250,000 scale question illustrates what I consider to be a serious deficiency in cartographic coverage for Army aviation requirements. The 25,000 scale is too large, and the 250,000 scale too small for the majority of information requirements. The 1:50,000 scale is still too large for most information requirements, which are best met by 1:100,000 or 1:125,000 scale maps at the speeds the Army flier. The 2:1 ratio in map scale coverage generally has best provided for user requirements. The two million, one million, half million, and quarter million scales provide well for higher altitude and higher speed user requirements. However, the lack of the 1:125,000 or 1:100,000 scale chart introduces a hole in the 2:1 ratio of scales exactly where it is needed by the Army aviator. If the 1:250,000 won't do, he must accept a 25-fold increase in bulk and sheet area and use the 1:50,000 scale map instead of taking a four-fold increase with the 1:125,000. I personally doubt that field-type topographic information can be obtained with better accuracy than is or can be provided by 1:100,000 scale maps, and I think some definitive field studies are needed to define just what field orientation capabilities are under various conditions and map scales. I think a properly designed 1:100,000 scale map could provide about 99% of the field performance of a 50,000 or 25,000 scale map. This map should have those features which are good point source fixes annotated with high accuracy coordinates, and most of the other labels in cluttered areas placed off to the side of the sheet with a reference index like those used for airfields on some aeronautical charts or city map street-locater indexes. With the extensive world-wide coverage at 1:100,000 or 1:125,000 scale, I would consider it likely that a 1:100,000 scale modified Pictomap series could minimize cartographic response time to "brushfires" and most effectively provide for lower speed aerial user requirements. Incidentally, I might note that this format might have possibilities for the multi-scale display format that I previously mentioned.

Mr. Wolin: We are having a communications problem, there's no question about it. In what language should the systems designer communicate his requirements to the cartographic community?

Dr. Wright: In good, plain English.

BRIEF COMMENTS ON PROBLEMS IN THE OPERATIONAL USE OF AERONAUTICAL CHARTS AND MAP DISPLAYS

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Operations Navigation 1 and 2 are responsible for RAF navigation policy associated with in-use aircraft. In particular OpsNav-1 specializes in non-radio/radar navigation equipment, aeronautical charts, and navigation techniques. A separate Operational Requirements branch deals with future aircraft navigation equipments.

ROYAL AIR FORCE OPERATIONS

In general, future RAF roles will involve the use of various flight profiles and navigation systems, which can be summarized as follows: Profiles of high and low altitude, high and low speed, single and multiple seaters, with and without sensors, fixed and rotary wing. The general approach to future navigation systems is in the development of an automatic head-up display using an inertial navigation system which is updated by either visual and/or radio/radar aids. The sophistication of the system used is, of course, to be dependent on the ultimate accuracy required.

One interesting aspect associated with present-day limited warfare and anti-insurgency operations is that there would appear to be little requirement for low-altitude and high-speed aircraft. This is substantiated to a large degree in operations in Vietnam and Borneo. Future operations are likely to be of a similar role for the next five to ten years. It is unlikely that rebel forces would have the facilities of modern SAM systems in the field. It is appreciated that this will not necessarily be the case in the built-up areas of the rebel strongholds. There is, of course, a separate requirement for these aircraft to penetrate sophisticated radar defences in other roles and for economy purposes, the aircraft must be capable of both roles.

AERONAUTICAL CHART REQUIREMENTS

When considering future requirements for aeronautical charts, the present coverage should be considered: Only 20% of the world is mapped at a scale of 1:250,000. Only 10% world coverage at 1:50,000. The majority of the small-scale mapping is relatively out of date and to be of maximum use to modern aircraft, must be brought up to date at frequent intervals. In consequence, RAF aeronautical chart policy considers up-to-date coverage its primary aim and ideal specifications and standardization as secondary. Furthermore, any concept of aeronautical charting must not be developed in isolation of the other forces' requirements. The only possible exception would be the maritime, strategic strike, and strategic transport forces; but this does not mean that they would require special charts. There are many factors which affect the production of aeronautical charts. The primary causes of delays and inadequate charting are usually financial and manning difficulties in the cartographic trades. Furthermore, when operating with Allies, standard chart products are required for efficient military operations, but international and bilateral agreements associated with aeronautical charts are often influenced by national policies with the resultant compromise and delays.

To assess the suitability of the present charting for current operations, aircrew opinion has played a major role and its limitations have been accepted. Other techniques of human factors research have not been applied specifically to investigate charts. The key to all new aeronautical charting lies in the proper training of aircrew prior to the introduction of new aeronautical chart products. It would certainly appear that in the past there has been a general lack of interest in the training of aircrews to interpret charts.

Map-Display Requirements

The main criterion in developing a map-display system is its simplicity of use and technical support. The major advantage of the system is that area coverage is available giving the aircrew maximum flexibility of routing within a specified area, which in the case of the P-1127 is 1,000 nautical miles square. The first-generation UK displays are mainly intended to be used as an updating and navigation aid for the aircraft navigation system. It is hoped that eventually a display system showing up-to-date tactical briefing information supplied at short notice will be developed.

Generally, the design of display systems should not require special charts to be produced. The display head should be as close to the head-up display as possible. This would ensure that there is minimum disorientation of the pilot when looking from one to the other. The display should not optically change the scale of the basic charting at the observer, since this will cause loss of detail at scales larger than 1:500,000.

The operational use of map-display systems is basically the same as an aeronautical chart. The success of a mission will still depend on competent pre-flight briefing, intelligence, and route study. Although this should be reduced to a minimum of time, perhaps too much emphasis has been placed on the requirements of rapid take-offs. The following other considerations associated with map displays should be remembered: (1) A small-scale chart will always be carried by the aircrew for aeronautical information and other pertinent details. (2) A separate complete set of prepared charts will be carried in case of the display failure. This will affect the preparation time and must be done if a high mission success rate under malfunction conditions is to be achieved. (3) Map-display systems should use current series as their basic material. It is possible to vary the colors of the present series by manipulating the reproduction material, but very little compilation work should be demanded by the system.

It is of the utmost importance that map-display charting requirements do not demand a disproportionate effort by charting agencies when compared with other users. It must be remembered that aeronautical charts and land maps will always be required for pre-flight briefing and for use in the field and until a computer system of chart making is fully developed, map specifications must satisfy a number of different user requirements. This is entirely due to the limitations of map production effort and finance.

The basis of present map-display development may be broken down into the following: (1) The use of the system as an updating display. (2) Elimination of track measurement and the consequent flexibility in tactical operations. (3) The look-ahead facility. (4) Possible development of map-matching systems associated with forward looking radar which may be considered a major advantage in low-level radar interpretation, although not as important for high-level radar interpretation.

Future Development of Map Displays

The second-generation displays should aim to show up-to-date briefing information and other aeronautical intelligence. This is of the greatest importance when the equipment is used for tactical operations. The size of the display head should be small to facilitate its positioning close to the head-up display. Four other factors should be considered: (1) The system should be capable of using both present and future charts as far as possible. (2) The display should not be at a different scale to that of the basic mapping. (3) Because display systems are used by relatively few people in comparison to the numbers using standard maps and charts, the designers of such systems should liaise closely with charting agencies and Ministry departments. (4) Although standardization of the film size is not possible at this early stage of display development, it should be the aim within a relatively small time scale.

Future Research Into Aeronautical Charting

From past experience it would appear that the following are the major factors requiring basic research in the development of aeronautical charts: (1) Identifying what information in an aeronautical chart is of prime importance to the aviator and what other detail on the chart he can accept if required by other users. (2) Methods of portrayal of terrain associated with terrain/human interaction. (3) The effects of chart scale on orientation problems. (4) Methods by which aeronautical features may be emphasized for ease of interpretation by aircrew. (5) In order to reduce the number of products, the various user requirements will have to be "compromised." This will have the advantage of economy, but guidance should be given as to where the best compromise lies. (6) The chart requirements for various roles when associated with automatic navigation systems. (7) The selection criteria of topographical features at various scales. It is important that these should be translated into instructions to cartographers.

It must be remembered that great progress has been made in obtaining internationally acceptable standard specification for aeronautical charts. Hence, if displays are to replace charts, the present Allied charting agreements must be respected. Finally, it is most important that in the development of moving-map displays, commercial implications do not override the operational requirements.

DISCUSSION ABSTRACT

Dr. Buckner: Currently in the U. K., are there any basic programs of research on charts? Can you give us your opinion of the role of such research and its value to the operational forces?

Sqn Leader Burton: There has been no research work within the U. K. relative to aeronautical charts specifically. However, a considerable amount of experimental flying and basic research has been undertaken to investigate the problems associated with target acquisition under various conditions of flight, visibility, and aeronautical charts. The results of the experiments have a considerable bearing in determining what can or cannot be seen from the air. To date, the trials have been confined to U. K. areas.

Basic research into aeronautical charts is long overdue. In the past, rather hit-or-miss techniques have been used. The use of questionnaires and their subsequent analysis, for example, could hardly be called "professional." With the rapid development of moving-map displays, urgent research is also required in this field.

A more controlled program of basic research, once established, could produce better charts more quickly and of greater value to the user. However, it must be stressed that there must be close cooperation between the user and the research team. Although the ideal answer to a particular problem might be suggested from the research data, important military, international, economic, or political implications may have been overlooked. In such cases where there is conflict between the ideal answer and other considerations, the research team should be in a position to suggest the best compromise solution after consultation with the user.

CHART REQUIREMENTS FOR LOW-ALTITUDE, HIGH-SPEED, MILITARY MISSIONS

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The specification of charts for use in planning and executing low-altitude, high-speed (LAHS) penetrations in well-defined regions is very complex, and available charts are not adequate. As the chart is effectively a portion of the penetration system, its design must be compatible with and considered in the design of the overall system. The LAHS military mission makes some special demands on chart accuracy. These, presented at a usable scale, result in a rather different chart than any current standard.

MISSION PLANNING CHARTS

The broad outlines of a method of analysis of terrain-mission interaction presently being developed are presented here. Detailed examples, conditions and countermeasures, however, are not discussed because of classification.

Terrain enters an analysis of the low-level mission in the concept of masking. Positive terrain mask, i.e., topography or vegetation obstructing the line of sight and fire from observer to target, was generalized from the ground tactical terrain effects: enfilade and defilade. The addition of ground clutter, effectively a constant elevation angle, to positive mask in radar lines of sight gives the effective mask angle, discussed by Stein, of our Laboratory, in 1959.

Early work results in mask angle distributions for sample terrains which represent the frequency of occurrence of these masks for any position of ground site and target aircraft. Although the relative invariance of the form of these distributions as slope and relief vary between terrains makes them attractive, their use in studying the interactions of actual flight paths and anti-aircraft sites is quite limited. Mask angles are still an important computational procedure, however, in military terrain analysis.

Where some site discipline can be inferred, sampled sites can be established for a given terrain. The exact positive mask angles, specified as the elevation angle and range to the masking object by azimuth angle, then determine the bounds on regions of effectiveness of any radar or optical detection system at the site against a target along any flight path.

The determination of realistic flight paths has also been developed. Deutschman and Groenewoud at our Laboratory on Project TINDEX I, a quantitative terrain analysis study for the Operation Research Directorate, Air Force Systems Command, have shown that a general statistical relationship exists among the mean clearance of an aircraft over the terrain and its minimum allowable clearance, speed, terrain-following system in use, and mean slope and relief of the terrain for homogeneous terrain samples. CAL has also developed quantitative measures for specific terrain profiles in connection with our continuing AF program of research and technique development in the field of low-altitude flight under AF Project 5199.

The masks around a specified site can be considered as (1) local, provided by woods and other obstacles near the site, and (2) topographic, provided by significant ridges, together with any vegetation along them.

The engagement of aircraft by small-arms fire presents a rather different mapping problem. It can be shown that the optimum location of a short-range, small-caliber anti-aircraft weapon subject to attack itself by the aircraft is at the end of a clearing. The route-planning chart must indicate vegetation with sufficient accuracy to show clearings and clumps of brush and trees large enough for machine-gun nests. The contouring should be close enough to estimate their field-of-fire from a dugout.

The amplified mask caused by woods close to a site is much greater than that caused by trees of the same size on distant ridges. The masked flight paths are found in valleys below the ridgetop or summit envelope, including vegetation.

Where masked areas extend sufficiently close to the site, a corridor exists for low-level missions to penetrate and destroy the weapon system. We investigated the concept of penetration corridors recently on CAL Projects LADS for the Office of Naval Research and PENVAL for the Air Force Systems Command.

Isolated hills near the site provide the most effective corridors in relatively flat terrain, such as the coastal lowlands of southeast Asia. Nearby deep valleys provide those for well-developed sites in more rolling terrains with level uplands found more commonly in the interiors of continents. In mountainous regions, deep valleys and high peaks tend to make good defensive sites quite rare.

Consideration of the above terrain effects leads to the concept of critical terrain for a given aircraft speed and clearance. Where the flyable, normally masked valleys exist sufficiently close together and are approximately the same depth as the clearance obtained by the penetrator, the terrain is termed "critical." The concept of "critical" terrain allows a preliminary estimation of aircraft capabilities required to fly through regions within the range of sites without engagement.

The dimensions of corridors provide information on the chart accuracy requirements and navigation requirements for low-level missions. Chart errors in the position of relief features may contribute errors in control and cause the aircraft to stray out of mask. Clearance or elevation errors prevent estimation of terrain-following performance or perhaps even the correct choice of corridor. Position accuracy of 100 meters appears adequate for high-speed aircraft. This is controlled by aircraft dimensions and control reaction time rather than topography and vegetation.

The development of accurate terrain-following radar systems has reduced the minimum obtainable average clearances during flight at high speeds in rough terrain to less than average visual capability, turbulence-limited. In general, minimum clearance accuracy requirements of 10 meters are typical for optimum high-speed flight over very rough terrain. The amplifications of local work discussed above require one-meter contouring around all potential sites in the terrain.

These requirements outlined above are close to current standards for 1:25,000 scale and are possible for 1:50,000. For cockpit use, even a full-time navigator has difficulty with roller-mounted or moving projections of this scale. A skeletal reduction emphasizing cultural and hydrologic features, checkpoints, IPs, etc., to an equivalent paper scale of some 1:250,000 would appear to be convenient. Whether the full detailed data for preflight route calculations should be compiled in chart form requires further study.

This applies with particular stringency to vegetation height data. At present even the photoreconnaissance data are not sufficiently accurate for determining the local mask. Interpretive methods for low-level oblique photography are required to supplement high-resolution vertical photography. We are making some progress in this methodology on a similar problem in jungle canopy photography for the Joint Environmental Effects Program. The canopy height is calculated by a computer least-squares routine from polar measurements relative to each photograph. The inherent errors in orientation of obliques thus can be reduced.

Some of the possible methods of vegetation-height data presentation include treetop contouring and green spot heights along ridges. Thus for mission planning purposes, it is reasonably clear that large scale (at least 1:50,000) charts are required with contouring intervals of the order of one meter. Much improved information on vegetation type and location and vegetation height is also needed for accurate mission planning. Now let us consider the problem of the charts needed to navigate during LAHS flight.

NAVIGATION CHARTS

Navigation in LAHS flight is accomplished primarily by dead-reckoning procedures, together with frequent updating of the position reference system by checkpointing, i.e., locating the aircraft relative to some recognizable feature on the ground. The checkpointing frequencies required depend, of course, on the DR system drift rates and the navigation accuracy required. Typically, a checkpoint is needed every 2-3 minutes with visual flight and possibly as infrequently as every 5-10 minutes for the (more sophisticated) systems of the future. The optimum penetration route (i.e., designed for minimum exposure) will typically skirt most populated areas (in fact, it will be planned to attempt to stay over wooded areas, avoiding large clearings as much as possible), thus it can be anticipated that for some portions of some missions, easily recognized cultural checkpoints may occur infrequently and when they do, they may be available for rather short intervals. It follows that it will be necessary to rely on hydrologic and topographic features to obtain position references on many occasions and for monitoring navigation system performance. In rough order of utility these features are: stream junctions, distinctive meander loops, islands in streams, high bands, cliffs, and finally, hills or peaks. The shapes of hilltops are changing rapidly at low altitude. Distinctive, continuously visible peaks are widely spaced.

We can thus conclude that from the standpoint of navigation, the primary types of information required on the map are: (1) information regarding the planned route; (2) checkpoints which can be acquired and accurately located from the aircraft; and (3) general terrain shape and hydrologic information with significant, recognizable terrain features readily interpreted. For the serious penetration mission (which is always highly preplanned) little else is needed or would be useful as long as the route is maintained. (Of course, intelligence information on the defensive environment would be added for each specific mission.)

I would like to illustrate this point: during LAHS turbulence testing in the U. K., the Royal Aircraft Establishment was making a series of visual flights in Southern England. A 3-mile corridor had been cleared for MACH 0.9 at 200 feet. Using the standard maps, the two-man crew consistently strayed out of their assigned corridor and had to go to higher clearances to get reoriented. As I got the story, one of the RAE people was complaining about this to a friend in the Navy Hydrographic office (where they make charts for use on ships). The friend happened to be a light plane enthusiast and appeared to understand the problem. They took a light plane and flew the route at 200 ft. but at a slow speed and "marked up" a map with what they could see from that altitude; he then made a map containing only that information. Using this map, the LAHS navigation task was greatly simplified.

The fact that the specially prepared map allowed much improved navigation for these LAHS flights indicates to me that we might well start from scratch in coming up with a suitable map for the LAHS case.

There are many factors which should be investigated regarding maps for LAHS flight. We need answers to questions such as:

(1) What is the best way to convey terrain shape information so the pilot looking out the window can quickly and accurately visualize what he can expect to see? How much information is needed? How should foliage be coded? What colors are best?

(2) Can this representation be used for flight in several directions across the terrain with equal effectiveness--or is a special map needed for each specific mission? Can a computer draw these maps for us from stored data?

(3) What checkpoints can be readily detected during LAHS flight and measured accurately? How long are they available? Is the utility of these checkpoints sensitive to the direction of flight? Which ones are best for radar, or perhaps for lasers? Are

there enough checkpoints compatible with the sensors in the penetrator so that a given mission can be accomplished?

(4) How do all of these factors vary as a function of various terrain types, weather conditions, seasons, etc., for various parts of the world?

(5) If research determines that some information is needed only on special occasions, can we print that information in invisible ink, brought out by ultra violet only when needed, or by some other such technique?

(6) What scale should be used? Should scale be a function of the type of terrain? Should blown-up views of checkpoints and specific terrain features be put in the margin of the strip map? Should this map go on a roller? Is it compatible with moving-map devices?

I am sure you can add many more questions to this brief list. If we followed the lead of the British naval officer, I think we could make some better LAHS maps: if we had the answers to some of the above questions, we could make some really good maps for LAHS flight.

In brief summary, let me make the following points:

(1) Present visual navigation capability during LAHS is relatively poor compared to what is now and will be needed in the future.

(2) The present maps are part of the reason.

(3) The map must be considered as a necessary part of the penetration system; thus it must be designed to be compatible with the rest of the system.

(4) Present maps are also a limiting factor in the mission planning operation.

(5) We might as well face facts and realize that, like airplanes, we cannot expect to make one map do *all* jobs satisfactorily: specialized maps are needed for the specialized task of LAHS penetration.

DISCUSSION ABSTRACT

Col. Kelsey: Well, gentlemen, here we have a most stringent requirement defined: to produce over enemy missile sites a 1:25,000 scale map with a one-meter contour interval. I just want to give you some idea of what this requirement involves. With the present state-of-the-art, to survey contours at one-meter vertical intervals would require photography taken from an aircraft flying at about 1,000 feet at about 100 knots directly over the missile site. It would also require ground control points to be surveyed every 200 or 300 meters on the ground with x, y, and z coordinates. Now this is not impossible, I appreciate, but I wouldn't like to be the aviator who was set that requirement. This is not to say that the art won't improve or that there could not be more feasible ways of doing this. But, if you state that accuracy requirement, then, to my understanding of the art, this is the sort of procedure necessary. If you can modify that requirement, then you may come back to other products which require less effort to produce, such as the PICTOMAP series, and it may well be that with a compromise one can get nearer your solution. So, that's the first point that I wanted to make: you must identify your requirement and come talk to those who would have to meet it to see what their problems would be.

The second point that I'd like to make concerns the experimental chart which Dr. Pelton showed. This was an excellent cooperation between individuals who had problems and were identifying them. And, unfortunately, we have to abandon further development on these lines because we just haven't got the facilities. (Incidentally, the Hydrographer at that stage did not reckon that it was his responsibility to do this sort of thing.) But, our standard JOG has most of the information that you want, and you can break down the components of these charts with very little effort. So, it may be that if you will discuss these problems with us, we can come up with a solution which is within our resources.

Dr. Pelton: I think we appreciate what you've said on both counts.

Dr. Magorian: Let me clarify one point. The accuracy requirement for one-meter contours is relative rather than absolute. That is, the point of putting the contours down is not to show the absolute elevation above sea level. I think this is an important point: the question of relative versus absolute accuracies. There is much work to be done on the depiction of information when you have the relative but not the absolute accuracy requirement. The relative information poses a cartographic problem, I certainly admit, but I think that a solution is possible.

One more comment on the low-altitude chart: the solution that you saw there, I think, is probably reasonably close to the kind of goal that Colonel Herndon was discussing in reference to the possible means of presenting profile-view information. I think that the extraordinary success of that chart was due to slope shading. The dark areas were not shaded with reference to a light source looking at the terrain in the conventional sense, but with reference to the inclination of the terrain surfaces. I think there are great potentialities in this method. In fact, it seems to me the most promising approach.

CDR Heininger: I think we're missing a good bet by not considering the use of graphics other than charts in navigation displays. For instance, aerial photographs or actual or predicted radar imagery, to the proper scale, could be used. In addition, we should not overlook the ability of the pilot to sketch his own chart for his particular needs, or to annotate his chart for display use. I think we should seriously consider these possibilities.

A PROTOTYPE AIR NAVIGATION CHART: SOME NEW CONCEPTS IN AERONAUTICAL CHARTING[1]

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The Federal Aviation Agency, which is responsible for providing standards of aircraft construction, pilot qualification, and general flying practices for civil aviation, is concerned also with the adequacy of aeronautical charts as navigational tools The increase of aircraft accidents has indicated to many authorities the need for a critical review of the chart as it relates to safety, and in pursuance of its responsibilities, the FAA in 1964 began a program of chart evaluation. One of the first chart series studied was the Sectionals, an examination of which revealed that a considerable quantity of information was carried on the face, with the result that the pilot found it difficult to obtain the information he needed. The numbers of colors used for hypsometric tints, the use of contours, the identification of cities and natural features by several styles and sizes of type, the presentation of much information that is of little value to the VFR pilot--all of these features combined to reduce the chart's legibility. After careful consideration of the chart's features relative to pilot requirements, charting experts and operational pilots in the FAA established new concepts of charting which were designed to improve the Sectionals. Recognizing the wealth of new cartographic ideas available from commercial mappers, the FAA furthermore solicited the assistance of private industries.

On July 1, 1965, a contract was let to Rand McNally and Company which called for the creation and printing of 1,000 copies of an experimental visual navigation chart at 1:500,000 scale, covering Southern California.

[1] Persons wishing a copy of this chart may obtain it from Mr. Clarence Johnson, AT-420, Rm 429, Federal Aviation Agency, 800 Independence Avenue, S.W., Washington, D. C., 20553.

Guidelines contained in the contract familiarized the contractor with the requirements of the VFR pilot, and enabled him to develop the kind of graphic desired.

One of the important principles continuously stressed in the guidelines was "the key consideration in selection and portrayal of all base detail is visual significance from the air." Another paragraph read as follows: "This chart is to be designed as an experimental chart combining topographic and aeronautical information. Great care must be exercised in the selection and accurate delineation of ground features that can be readily identified by the airman. Clutter to the placement of topographic and aeronautical overprint, names, and features must be avoided." Such guidance was accompanied by other material which effectively presented to the contractor the problems which a VFR pilot faces when he plots his course, and thus helped to assure that the chart designer had a correct appreciation of the job.

Also spelled out were specific requirements such as size (50" by 20"), front-to-back format (in other words two charts on one piece of paper), scale, projection, location of panels for legend information, and specific features which had to be shown, such as city insets at 1:250,000. One of the most important specifications called for shaded relief. Another requirement was to design a chart which could be produced by a single press run, thus limiting the number of basic colors to five. This is in contrast to Sectional Charts which employ up to nine colors and which require two press runs. Thus, in addition to an improved graphic device which would facilitate safe navigation, the FAA also desired a chart which could be produced at a savings in cost.

Apart from the general and exact

specifications that were contained in the contract, the contractor was requested to develop new graphic elements in order to fulfill the desired goal. As far as is known, the contract marks a "first" in aeronautical charting for it is an effort to create a graphic item designed exclusively for the VFR pilot, in contrast to earlier maps that represent superimpositions or modifications of existing map and chart material.

After having studied the terms of the contract, the Rand McNally Vice President in Charge of Cartography in consultation with other representatives of management decided that a team effort was required to create the chart. One man from the Cartographic Division was put in charge of technical production. The author of this paper was named Project Director chiefly because his location in Washington was important to the required liaison with FAA and other agencies, and because of his background in general geography. The Vice President of the Department of Art and Design was selected as the other team member, since it had been decided that the input of a graphic designer would be of value in the kind of chart that was contemplated. Furthermore, an outside expert in graphic design was employed as a consultant. While reliance on principles of art and graphic design is not unusual in the cartographic process, the emphasis placed on graphic designers very likely represents a certain departure from tradition. The opportunity to develop a chart of this kind from "scratch" as it were, is significant in itself, but the exploitation of the designer's point of view teamed with the cartographer's craft seemed to assure the development of truly a unique graphic product. In the contractor's view, the prototype chart, like any other chart or map, is essentially a graphic device whose content should reflect principles of good design. As a product whose function is visual communication, the chart therefore should be designed to relay information to the user in a way so that he will obtain the information sought quickly and with a minimum of confusion.

Two members of the team had experience in operational flying, and had valuable insight to the general problem. During the planning stages of the contract work, standard cartographic approaches were challenged and dropped if new practices proved more useful. Each symbol, piece of type, color, and other elements were examined carefully, and few items on the Sectionals survived to appear on the new prototype.

Of importance to the design of the chart was aerial observation of the chart area. Several flights afforded the team an opportunity to substantiate points of view expressed by the guidelines in the contract. Close scrutiny was given to the existing Sectional charts to determine whether items portrayed could in fact be discerned while in flight, and whether significant ground features were evident on the chart. During these observations, several pictures of the terrain were taken to allow the chart designers to gain lasting impressions of shapes, color, pattern, and other important visual aspects of the terrain and culture.

The time available for this paper will permit a discussion of only certain features of the prototype chart. In order to illustrate salient innovations, we will briefly cover shaded relief, hypsometric tints, typography, and symbology, concluding with some general remarks about the chart as a whole.

The first production task selected was the preparation of the shaded relief plate. This plate was started first for two chief reasons. First, all shaded relief had to be created anew, a process that required as much time as possible. Second, the placement of much of the typography could not be made until the plate could be used for reference. Thus, an air brush technique was employed to render the physiographic character of that part of the country. The color used was a dark green, selected because of its ability to harmonize with other color elements used on the chart, and because it gave an impression of actual terrain colors. The resulting shaded relief contrasted sharply with the relief depiction system (contours) employed on the Sectional charts.

To enhance the appearance of relief and to provide accurate information about the absolute elevation of specific areas, a hypsometric scheme was adopted. It was the contractor's belief that hypsometric values should be expressed in the color tan and screen values thereof. The reasoning employed was as follows. Because the total number of colors on the chart had to be kept at a minimum, a single color was sought that was versatile enough to show the desired elevation categories, themselves kept few in number since the essential character of relief was provided by shading. A shade of tan was selected. Since the dark green of the relief plate depicted the first elevation category (below sea level to 1000 feet) in a fashion deemed to be adequate, a screen value of tan was introduced to portray the second level, 1000-3000 feet. Two screen values of correspondingly smaller percentages were used for levels of 3000-7000 feet, and 7000-11,000 feet respectively. The color and character of the relief plate were applied to mountainous areas to act as a fourth hypsometric tint that was otherwise free of color. Contours were used only to divide the hypsometric tints.

In the opinion of the contractor, the existing chart suffers greatly because of the mass of printed detail on its face. In order to reduce the amount of black type and to improve chart legibility, typography was completely redesigned. Cities on the old chart are shown by type in different styles and sizes, approximating the population size of each town. Other printed information such as names of rivers, mountains, states, etc., are also equally detrimental to the chart appearance as designed. To improve typography for settled places, all cities, towns, and other settlements were identified by a single type style in two sizes only. The largest three or four cities on the prototype chart face received the larger size, while all others received the smaller. The city type furthermore was screened to reduce significantly the black appearance of the chart. Also, the effect desired was to create a "layer" of typography which is easily read yet which does not conflict with other information. In addition to the change in typography for settled places, other type styles were carefully selected to fit their intended purposes, and the placement of all type was carefully chosen to avoid superimposition and to promote legibility.

Symbology was also substantially redesigned. For example, on the Sectional chart, cities are shown by symbols whose sizes correspond to number of inhabitants. On the new chart, cities were shown by two symbols only: larger cities by a pattern which more or less corresponds with the extent of the built-up area, and smaller cities by an open circle. Virtually all other symbols were, in general, a departure from ones used formerly.

We have already discussed certain specific graphic elements. We will discuss briefly additional elements as they combine to effect a total graphic image. We have discussed the use of dark green to portray shaded relief. This color was also employed to depict several other elements, including grid, transportation, symbology (spot-heights, cities, and pictorial symbols used on the insets), all non-aeronautical type, and legend information. The resulting clarity of these items seemed to substantiate the efficiency of this color, while also demonstrating its compatibility with other colors used on the chart. The variation in screen values and line weights resulted further in a versatility of graphic depiction. The requirement to use no more than five colors made it desirable to find multiple uses for at least one color, and the dark green as employed seemed to meet that requirement.

With regard to non-city symbols, we wish to point out other innovations. The use of checkpoints in visual navigation is important, and these items therefore constitute a significant graphic feature. On current Sectionals checkpoints are identified by a small solid square as well as the written description of the particular item. These squares are easily confused with spot-heights which are shown by solid circles of approximately the same size. In an effort to improve legibility, checkpoints were shown by a simple check mark, with the base of the mark indicating the site of the feature. Wherever possible, in addition, the written description of the features was simplified to avoid lengthy descriptions. Thus, instead of saying "soda products plant," the experimental chart carries the word "plant." In other places the experimental chart substitutes "buildings" for "warehouses." In shortening the descriptions of checkpoints, the contractor was guided by a desire to reduce the amount of type and thereby improve legibility, while at the same time providing an accurate identification of these features.

On the Sectionals spot-heights, as stated earlier, are shown by solid circles. The experimental chart introduced solid triangles accompanied, of course, by the appropriate elevation. The use of triangles was designed to make these important elevations easily distinguishable from any other feature on the chart. Two sizes were employed. For each 30-minute square the highest absolute elevation carried the larger symbol, with the type size of the elevation also being larger than those for other spot-heights. Emphasizing the highest point conformed to a requirement of the contract to indicate minimum clearance for flight operations within each 30-minute square.

The symbology for airspace reservations was changed. The Sectional charts employ three variations of linear symbols to indicate three basic categories of areas. Prohibited areas are covered by parallel lines drawn at an angle. Restricted, warning, or danger areas are enclosed by a border of closely spaced parallel lines drawn at an angle. Caution or jet training areas are enclosed by a border symbol of widely spaced parallel lines. In the contractor's opinion this reliance on linear symbols adds to the general clutter of the chart, and in areas where these symbols are close together or are superimposed on other detail, the spaces are difficult to identify. The experimental chart substantiated a single saw-tooth pattern for all airspace reservations. The category of reservations is included along a border in a prominent place. Areas too small to be enclosed by such a symbol are covered completely by a solid triangle (actually a screen value) of the appropriate color, which was purple. In the contractor's opinion this device makes airspace reservations easy to see and induces no confusion in areas where other linear symbols are employed.

The identification of VOR and VORTAC facilities is accomplished on the Sectionals by rectangular boxes. The contractor felt that certain improvements could be made in the symbol used and in the placement of the type. In the case of VOR facilities, the Sectionals have the letters VOR placed at a break in the top of the appropriate box if that box is located outside of the appropriate compass rose; if the box is inside the rose the VOR is omitted. In any case the boxes identifying both VORs and VORTACs are the same size. Several changes in the VOR box were made. First, VOR was reduced further to a single letter V. This was done to simplify the type and to improve legibility. Regardless of whether the VOR box was in or out of the compass rose, the letter V was retained but its position with respect to the box was moved from the top to the left-hand side. At the same time the corners of all VOR boxes were rounded to distinguish them readily from VORTAC boxes. Within all aeronautical boxes the sequence of type was altered so that information sought by the pilot appeared first. Furthermore all type was placed flush left, and was not centered as is the case in the Sectionals.

For city insets, the contract called for the development of pictorial symbols. While three-dimensional symbols were called for, the contractor created instead a combination of three- and two-dimensional symbols. For tall buildings, radar domes, individual buildings, and certain other features which in fact on the ground have three dimensions, a kind of three-dimension symbol was developed, while for such flat features as golf courses and race tracks a two-dimensional symbol was prepared. In any case the symbols were designed to identify the appropriate feature clearly and unmistakably. For example, a golf course was shown by a solid dot with a pennant on top, and a ranch was shown by a steer's head.

Thus virtually every graphic feature on the new chart was redesigned with this principle in mind: to create a chart whose elements are combined in a fashion to present a clear yet accurate graphic item to the pilot. Certain symbols on the Sectional were, however, retained. The vignettes employed for controlled airspaces were not altered, and certain other aeronautical information was also retained.

Since the delivery of the chart to the FAA, administrative regulations have altered somewhat the probable destiny of the new item. Originally it was thought that many, if not all, of these graphic ideas would be adopted for a new series of Sectional charts. It is evident now that these ideas will have to be weighed against requirements of the Department of Defense and the Department of Commerce, and that a three-way mixture of these requirements would determine the appearance of a new series of Sectionals. Regardless of the ultimate use of these concepts in aeronautical charts, the contractor believes that many of the principles developed are of considerable value. The role of the expert in graphic design seems here to be clearly substantiated, and despite the trend in many categories of mapping and charting to rely on automated processes, it would appear that maps and charts of the future will better serve their purposes if the artist can participate in their development. There seems little doubt that for VFR charts, the product can benefit from the skills of the design expert.

DISCUSSION ABSTRACT

Dr. Gigas: Much of the discussion of the symposium has dealt with the miniaturization of existing charts to 35, 70, or 105mm to accommodate map-display systems. While many available charts probably cannot be readily converted to monochromatic display media, it would seem that much of the design of the Rand McNally prototype chart would lend itself to the requirements of single-color miniaturization. Could you comment on this?

Dr. Randall: In our opinion, good design automatically lends itself to miniaturization in one color. Although the prototype chart was designed for the civil VFR pilot, its basic features also could be adapted for display purposes. The use of only two styles and sizes of type; symbology that is simplified and, in part, pictorial; the use of a single color for more than one feature--these and other elements of the prototype make it suitable for display purposes. Furthermore, the principles employed in creating elements of the prototype could be used to great advantage in the preparation of charts other than those used for low-altitude, high-speed operations.

Mr. Borden: JANAIR research on geographic orientation has been directed toward the navigation problems of the military pilot, but we found in our early work that disoriented pilots also pose a major problem to general aviation. Do you think civil aviation would benefit from its own program of research similar to that of JANAIR?

Dr. Randall: The involvement of Rand McNally in navigation problems has been limited, but our experience with the FAA during the execution of the prototype chart convinced us that the requirements of civil aviation for improved graphic/navigational material are of a relatively high priority. We believe rather strongly that the adequacy of civil chart products should be investigated by a research program like that conducted by JANAIR.

NEW MAP FORMS

Lynn R. Wickland
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Army Map Service

My talk this morning is entitled "New Map Forms" and in talking about them I wish I could tell you that we had a computer attached to a lithographic press and were printing maps electronically. But, I cannot. Also, I wish I could show you samples of printed maps produced by electronic means. But, I cannot. However, the Army Map Service is continually searching for and developing new maps that are an improvement and that can be produced quickly to get them to the men in the field. Our fighting men cannot wait until we get mapping automated, but when and if we can automate mapping, we will.

PICTOMAP

During the Second World War, the Germans produced mosaics in color from black-and-white aerial photography. They made several negatives or positives, separated the features by hand, and then printed in color by the photogravure process. The 649th Engineer Topo Battalion also produced mosaics in color by offset printing. For the past several years the Army Map Service has been experimenting in the development of a map product which could be produced rapidly and which would eliminate the readability deficiency of the photomap. The development resulted in the PICTOMAP, a photomap-type product which stresses the use of photolithographic operations, rather than the conventional techniques used for preparation of standard maps. PICTOMAP is the acronym for Photographic Image Conversion by Tonal Masking Procedures.

The main difference in the PICTOMAP over the German or 649th mosaic is that the PICTOMAP is produced without application of hand work and without use of a halftone screen. The cartographers do produce the block-out masks and the overprint information such as type matter, contours, road fills, and other symbolization.

The PICTOMAP employs the photographic imagery of a standard photomosaic by converting the tones and features of the photography into interpretable colors and symbols. The basic components of the process consist of (1) three tonal separations photographically extracted from a photomosaic; (2) block-out masks; (3) drafted symbols and names data; and (4) the tonal separations are combined with the block-out masks at the platemaking stage and are printed in special tonal colors. The drafted symbols, grid, names, and marginal data are added in specific colors to produce the finished PICTOMAP, an example of which is shown in the fold-out.

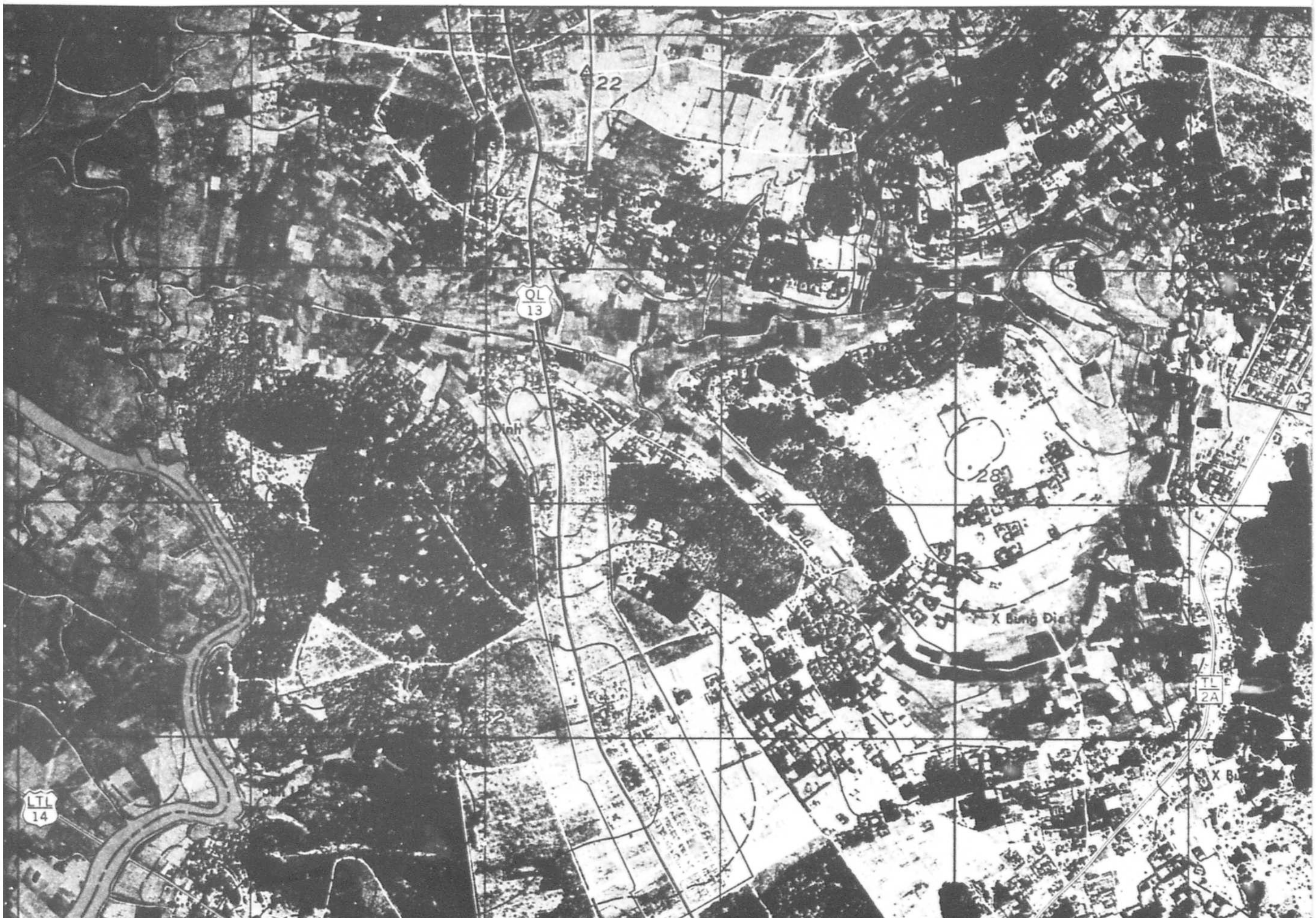
The main factors to consider in the production of PICTOMAPS are the following:

Quality of the photography. The photograph should have sharpness of detail at map scale and sufficient shadows for positive identification of map features.

Tonal range for the photography. The photography, after it is properly matched and assembled to form the base mosaic, should have contrasting tones. The highlights or land areas should be white, the middle tones should extend over the grassland and include all feature detail on the photography, and the shadows should be sharp and black and not extend into the grassland areas.

Map scale. The scale of the map plays a major role in determining the amount and readability of map features that are shown on the PICTOMAP. The shadows of the map features are the main key in photo interpretation. These shadows are taken directly from the mosaic, as one of the base tonal separations, and are emphasized on the PICTOMAP. Shadows accurately delineate many cultural features and lend a three-dimensional effect to buildings

A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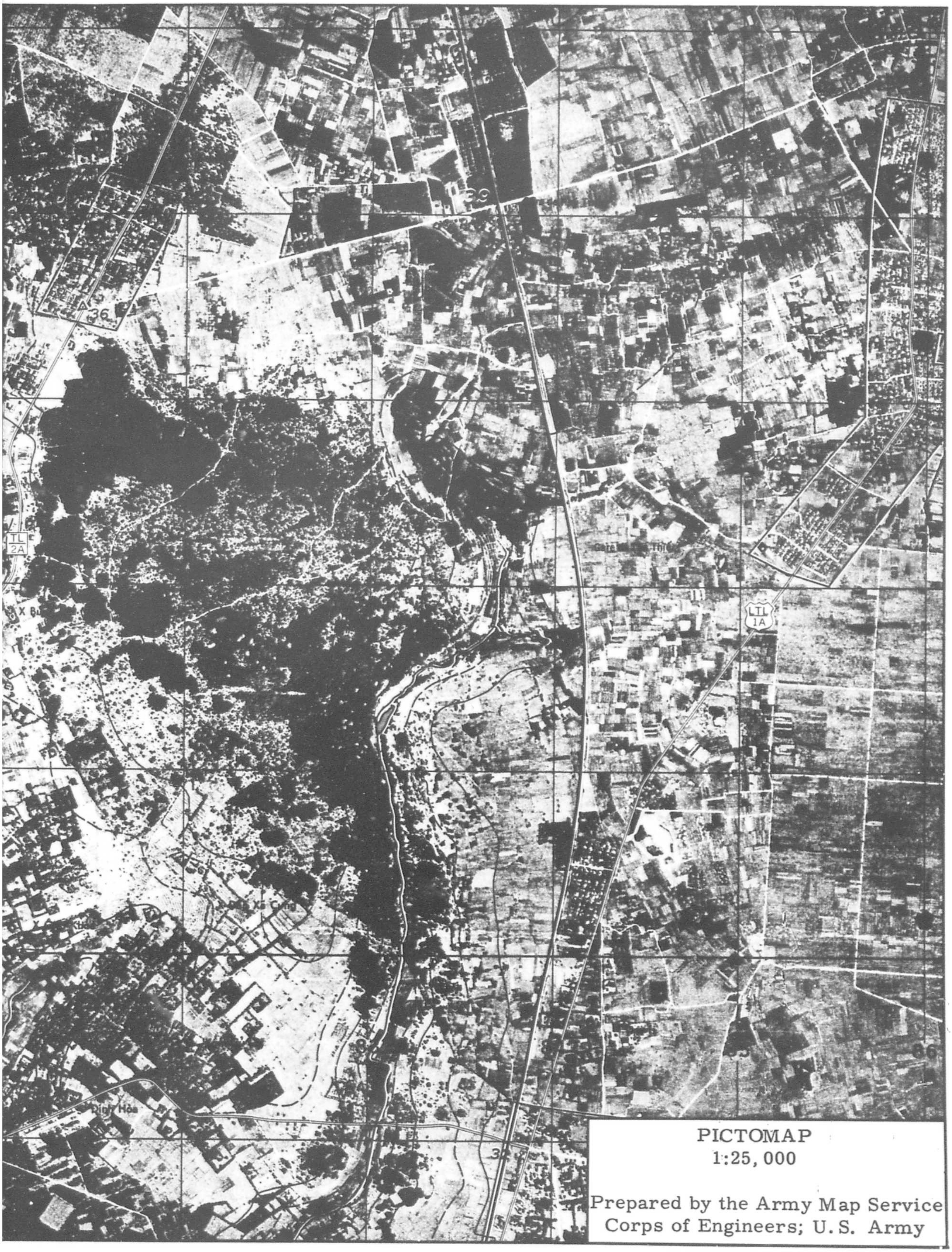

PICTOMAP
1:25,000

Prepared by the Army Map Service
Corps of Engineers; U.S. Army

701325

and vegetation, symbolizing and establishing the relative heights of these features.

Types of terrain and ground cover. In most areas of the world, nature is working for the PICTOMAP process. Terrain is made up of uncovered earth, grassland or low growth, and woodland. Therefore, in the normal tonal range on most mosaics, the uncovered earth generally appears in the light tones or highlight areas, the grassland and low growth occupy the middle tones, and the trees and woodland occupy both middle tones and dark shadow tones which set them apart from the low grasslands.

The various photolithographic techniques used in the production of the PICTOMAP necessitate the introduction of unique descriptive nomenclature:

Pictotone. The name given to various types of photolithographic copy which are derived from the base mosaic, and which contain the tonal values that produce the basic color tones for the PICTOMAP, for instance, Landtone, Vegetone, and Shadowtone.

Landtone. The copy that represents the uncovered earth and prints in a buff-like color tone.

Vegetone. The copy that represents densities of vegetation and prints in green tones.

Shadowtone. The copy that represents the darker shades and shadows which emphasize features by outlining and shading, and prints in a dark green or black.

JOINT OPERATIONS GRAPHIC

Another new map form is the "Joint Operations Graphic," a 1:250,000 scale map or chart with air data overprint which will be used by all the services. These JOGs, as we call them, were produced formerly by the Air Force in nine to eleven colors and by the United Kingdom in nine colors. Army Map Service has produced the same map or chart in five colors and in seven colors, thereby saving cost and time in printing. We are using the four-color process system from which we can produce all colors of the spectrum. These colors are yellow, magenta, cyan, and black. However, we can add a brown or an overprint purple for the air data or we can produce the purple with solid magenta and cyan ink when printing.

DIA has approved the AMS seven-color JOG at this time and it is expected that ultimately the five-color JOG will be accepted.

As with the PICTOMAPS, we are striving to produce the JOGs in fewer colors, thereby saving printing time which not only saves dollars for the Department of Defense, but makes it possible to get maps and/or charts to the men in the field much quicker.

AMS is also endeavoring to produce mosaics by the four-color process, using aerial color and printing in continuous tone. These mosaics would be in natural color with all of the detail shown in the color transparency.

DISCUSSION ABSTRACT

Mr. Shaffer: Would you please give us an idea of the amount of time required for the production of Pictomaps after you have received the aerial photographs.

Mr. Wickland: We started off in not dressing up the Pictomap too much, that is, from the cartographic standpoint. We can use the aerial photographs and be on metal in eight hours as far as the photomechanical process is concerned. The rest of the time depends on how long it takes the cartographer to set up his type, draft or scribe the roads, and make the fills for water. I don't have, on the tip of my tongue, just how much time was required, but we produced several hundred in just a few months from the aerial photography. You can do this very quickly, from the photomechanical standpoint or reproduction standpoint, once the mosaic is laid. And then if you decide not to put too much detail on it, the Pictomap can be completed within a day or two. Colonel Herndon just mentioned that in four months we produced 283 sheets for South Vietnam. So this gives you some idea--there is a tremendous savings in time. I might say that some people get confused and think that we're trying to push the Pictomap to have it take the place of Class-A mapping. I don't think this will ever come. I think that in certain situations the Pictomap would come first as a map substitute and then later on, if desired, the Class-A map could be produced.

Mr. Shaffer: I'd like to offer an additional comment on the Pictomap. Because of its rapid delivery, the Pictomap becomes very useful for depicting parts of the world where there are rapid changes, for example, in South East Asia where the arrival of the monsoons may result in rapid filling up of lakes, ponds, and overflowing of riverbanks.

Mr. Wickland: Yes, sir. We feel that mapping could be kept current within a matter of a few weeks, if the area is not too large. In fact, I might mention that the Geological Survey used this method for updating the Roanoke, Virginia, sheet and they did it very quickly from new aerial photography using the old base information.

Mr. Sicking: I'd just like to throw in a word of caution to the potential and actual systems designers. The Pictomap is, in truth, a beautiful display and is very rapidly produced from the photomechanical standpoint. But, the laying of the initial mosaic, which is a very large scale proposition, is not done rapidly. It is done like the compilation of any type of map over a very long period. The photography has to be rectified and controlled as it's laid. There are thousands of photographs that have to be put together and controlled to make a navigation-type chart. One should not just plan to throw a Pictomap into a display system because this gives a beautiful presentation. While it undoubtedly has a desirable place, in mapping target or terminal areas, one should consider the fact that there is an amazing amount of work in making a navigation chart from a Pictomap.

Mr. Wickland: That is a very good comment. In fact, I thought I made the point clear. I said after the mosaic is laid, then we could produce the photomechanical separations very quickly. And then it depends on how much time it takes the cartographer to produce his other materials.

Dr. Guttmann: Would you please explain what kind of aerial photography you need to overcome the difference in perspective from the center to the edge of the photographic image?

Mr. Wickland: What kind of photography?

Dr. Guttmann: Yes. Is it strip photography or just simple still photography?

Mr. Wickland: This photography is restituted. The tip and tilt is taken out as would be done for a normal mosaic. Also you can use the ortho-photo scope to correct the photography.

Mr. Borden: Are there any plans to establish Pictomap-producing units in operational areas such as Vietnam?

Mr. Wickland: Yes. Many topographic troops have already been trained for Pictomap production in the field. The Engineer School is teaching this technique to new students for topographic battalions or units.

CURRENT RESEARCH AND DEVELOPMENT TRENDS IN MAPPING, CHARTING, AND GEODESY

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The purpose of this paper is to discuss the latest trends in research and development for cartographic equipment, systems, and procedures for map production. First, I would like to describe the organization which was set up to insure that new equipment and new techniques are provided to satisfy military requirements for mapping, charting and geodesy. Second, I will discuss budget considerations in the research and development program. A third matter is the impact of military doctrinal changes on the types of services provided by the mapping, charting, and geodetic community. The fourth is current trends as far as the individual problem areas are concerned. Overall trends in these problem areas include the necessity for more precise measurements, faster response time, higher quality products, increased volume of products, as well as budget and manpower limitations.

DoD ORGANIZATION FOR MAPPING, CHARTING AND GEODESY: RESEARCH AND DEVELOPMENT

The Directorate for Mapping, Charting and Geodesy (DIAMC) is one of the four major line elements of the Defense Intelligence Agency. The Director for Mapping, Charting and Geodesy is Colonel Robert E. Herndon, Jr.; the Directorate is responsible for managing and budgeting for the mapping, charting and geodetic programs of the three military departments. The organization of DIAMC is shown in Figure 3 on page 15. The five offices in the Directorate were described by Colonel Herndon (p 16). The last of the five offices is the Advanced Systems Office. This office is responsible for seeing that new techniques and new equipment are provided as necessary to accomplish the mapping and charting mission. Some of its functions are

1. Establishing and approving R&D requirements.
2. Assigning relative importance to these requirements.
3. Preventing duplication between the Services.
4. Keeping current with the state-of-the-art in Government agencies and industry.
5. Advising the Director of Defense Research and Engineering (DDR&E) concerning the money and manpower necessary to satisfy the approved requirements.
6. Insuring that developed equipment actually satisfies the performance characteristics stated in the requirements.

Within the three Services of the Department of Defense there are approximately 300 people actively engaged in research and development work to satisfy these requirements. They are located in such organizations as GIMRADA (Geodesy, Intelligence, Mapping Research and Development Agency), Rome Air Development Center, U. S. Naval Oceanographic Office, Air Force Cambridge Research Laboratory, and the Air Force Aeronautical Systems Division. Their work is coordinated in several different ways to achieve the overall objectives: informally between the Military Departments, through the budgeting of research and development funds by the Director of Defense Research and Engineering, and by validation of requirements and management of the mapping, charting, and geodetic programs within DIA.

RESEARCH AND DEVELOPMENT BUDGETARY TRENDS

Research and development is sensitive to economic factors. We have gone in the space of a dozen years from being technology-limited to the present condition of being resources-limited. This change means that we cannot take advantage of all the ideas which are coming from the scientific world; we must use a selection process which will enable us to put certain ideas into the hardware stage which will combine effectiveness, efficiency and timeliness. This decision-making step will require the use of relevance factors, such as satisfying high priority military requirements, current budget limitations, and planned obsolescence of equipment currently in the inventory.

The research and development budget for mapping, charting and geodesy is around $50 million yearly, and like the DDR&E budget, is increasing slightly each year. The Army has the largest amount of these funds, almost 48%, with the Navy a close second. The Air Force has the smallest portion of this program; about one-fourth that of either the Army or the Navy.

IMPACT OF MILITARY DOCTRINE CHANGES

We are observing a number of changes in our national objectives and in the military strategy which supports these objectives, which has a leveling effect on the military budget. This affects the number of strategic weapons which will be employed in one case and in another it affects the degree of flexible response which is used when the nuclear deterrent cannot be employed. The first item, the decrease of our number of strategic weapons, means that we have to use them with increased accuracy. This is one of the major problems facing the mapping, charting, and geodetic community. The other major problem concerns the strategy of flexible response, where our military forces will be required to meet any degree of military non-nuclear aggression. Support of this strategy means that we must provide maps and charts with precise accuracies for areas all over the world, to support artillery fire, movement of ground troops, logistics, naval operations, and the like.

These two changes in military doctrine are reflected in changing military requirements for mapping, charting, and geodetic equipment. These are reflected in requirements for such items as an airborne gravity collection system, rapid combat mapping system, and a more precise hydrographic system.

TRENDS WITHIN MAPPING, CHARTING AND GEODESY

The overall trend in the cartographic process is towards very precise measuring machines, a reduction of manual steps in the cartographic process, a more rapid response in production of materials and automation of cartographic techniques.

In this broad category of Cartography, the trends are leading toward automation of the various processes employed in mapping. As some of you are aware, automation of the photogrammetric exercises is on the verge of being realized today. The automation of this step serves to point out the need for greatly reducing the number of hours required in preparing the necessary materials for annotation and reproduction. For example, systems have been designed for automatically placing names on a map (see Figure 1). This and other developments can someday, we feel, assist the human operator in the manual steps that are now required. When there is a mechanical step involved, one has the possibility of going to mechanical automation. However, when a thought process is involved, present-day technology limits us in what can be achieved.

Figure 2 addresses itself to the time required for the compilation and color separation of an average 1:50,000 scale map from new aerial photography.

During the time frame of 1960, using conventional techniques and instruments approximately 75% of the total map production time was used for the photogrammetric compilation processes, 18% for color separation and 7% for reproduction processes. A further analysis of these figures disclosed that approximately 77% of the total compilation time was used for stereo plotting. As a result, considerable thought was given to new approaches to mapping, stereo compilation, and associated equipment.

Map production, based on the preparation of an orthophotograph and dropped lines, was considered to be a sound approach to the problem, experiments were conducted to prove its feasibility, and an extrapolation was made as to the potential savings which could be realized. During the time frame 1965-67 using manually operated

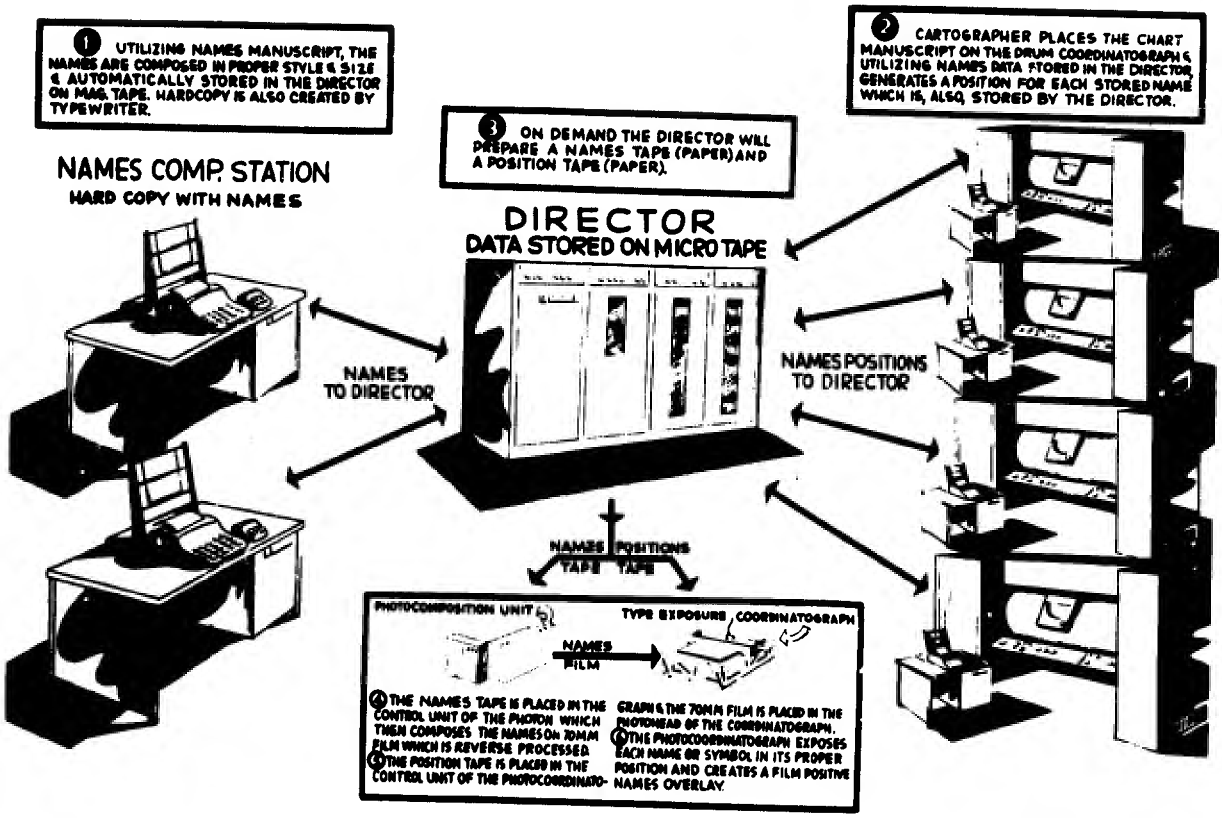

Figure 1. Schematic illustration of names and symbols preparation system.

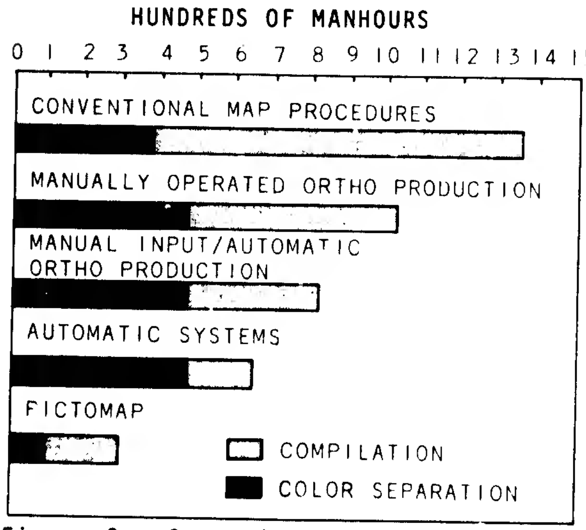

Figure 2. Comparison of time required for the compilation and color separation of an average 1:50,000 scale map from new aerial photography by different cartographic techniques.

stereo plotting equipment modified for orthophoto production, the instrument time can be reduced about 300 hours. You will also note that the color separation time has been increased approximately 100 hours. This increase is caused by the added burden of photo interpretation as color separation is being performed.

The last portion of Figure 2 shows what we expect to be able to accomplish during the time frame 1968-1970 with automatic systems compared with pictomap techniques. This portion of the graph is based on equipments and systems now in the research and development cycle and their expected production capabilities. Among these are the USQ-28 program for acquisition of mapping photography which is shown in Figure 3. In addition to the equipment shown in the figure, it includes:

1. Higher flying altitude (30-40,000 feet).

2. Higher resolution mapping cameras.

3. Higher resolution film.

4. Precise stabilized platforms.

5. Precise navigational systems.

6. Precise terrain clearance data.

7. Automatic stereo plotting equipment such as: Bunker-Ramo, UNIMACE; Bendix-Nistri, AS-11A; and Raytheon-WILD, Stereomat.

INTELLIGENCE DATA-HANDLING SYSTEM

Another example of DIAMC's action to insure modernization and commonality within the mapping, charting, and geodetic community is in the area of cartographic data-handling systems. One Service had prepared a work statement to have its operation examined by industry with the purpose of using automatic data-processing methods wherever practical. This work statement was reviewed by DIAMC and rejected because it did not consider the impact on the other Services. The work statement was rewritten to insure that the study would take into consideration and include the requirements of the other Services as appropriate. As a result of this action and subsequent studies to be conducted by or for the other Service, the Department of Defense will have a common file system where materials can be interchanged with the utmost efficiency, completeness, and timeliness.

General trends of the mapping and intelligence community are therefore being directed toward developing systems and concepts which breach the gap of thinking and doing. Recently instrumentation has been designed for storing topographic information in digital form and there is no reason that the complete contents of a map cannot be digitized in a similar manner. Instrumentation is presently available which can accept this information and reconstruct it into a graphic picture. We think it is now possible to perform a compilation exercise at some common scale, record this information on magnetic tape, or other medium, furnish additional input data to the tape with respect to scale factors, and then extract map images and content pertinent to that scale via automatic means, thereby reducing the number of times that an area must

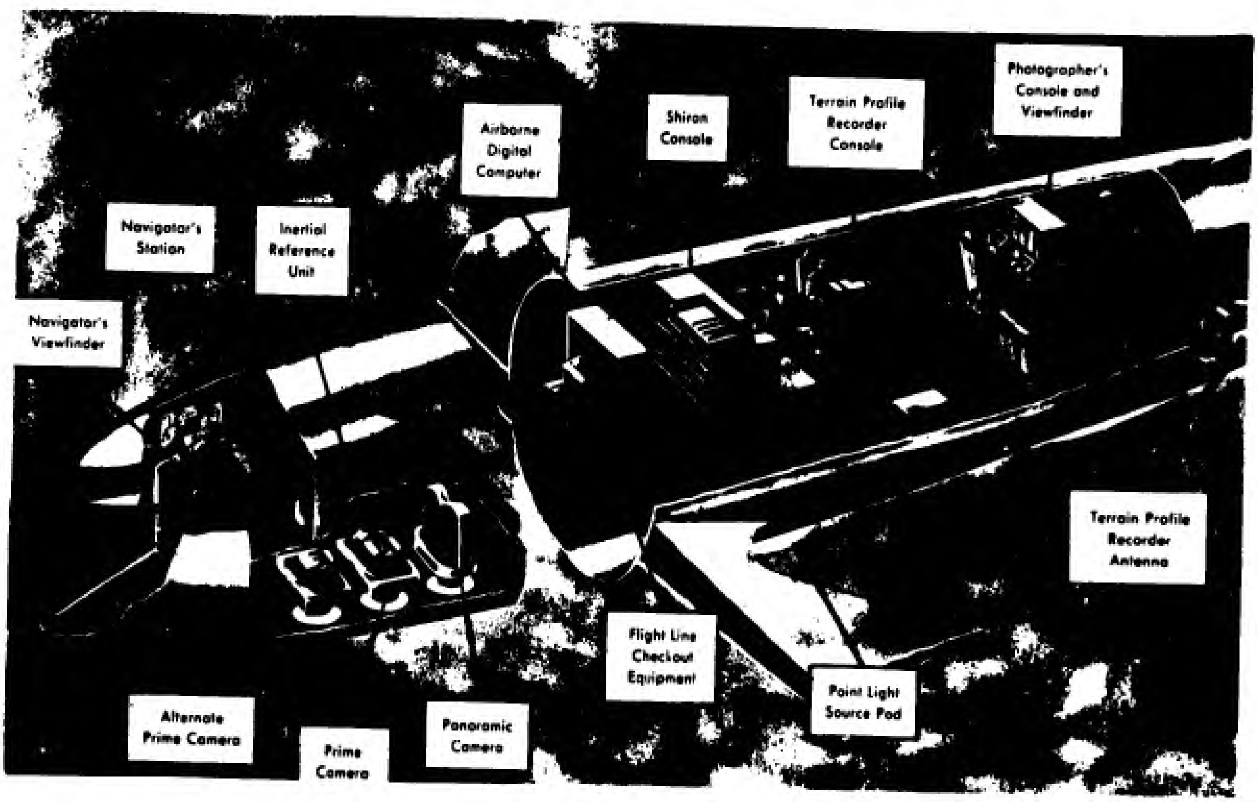

Figure 3. Schematic illustration of the USQ-28 mapping photography vehicle.

be re-created as under our presented practices. Information stored in such a manner can be readily updated as new data become available. As a by-product to this digital approach, we are finding that data in this form can be used for other purposes. For example, there is a requirement to be able to determine interference patterns from radiating electronic signals. Information must be available as to the topography from any given point so that interference patterns can be either changed or eliminated as necessary. The digital information of the topography now permits us to do this.

War gaming is another area where we can utilize these kinds of data in digital form. Also in the future is the possibility of transmitting digital information, either of abstract map data or continuous-tone photography, over long distances for subsequent readout and multiple-copy distribution.

CONCLUSION

In summary, current trends then for research and development of the cartographic effort are toward automating the processes and in general working toward the utilization of digitized data. These are some of the trends and some of the projects in research and development. We in DIAMC would like you to know that our doors are always open to anyone who wants to discuss new ideas and techniques which can be applied to advancing the discipline to which we are devoting our efforts.

DISCUSSION ABSTRACT

Dr. McGrath: I wonder if you could tell us how many of these proposed systems are actually being developed. Are these drawing-board objectives or do you have active programs going forward?

Mr. Schlager: We have a very dynamic R&D program for all of the functional areas of mapping, charting and geodesy. In some cases hardware exists or will soon be in the inventory. For example, we have digital recording devices, automated photogrammetric equipment, new mapping aircraft, automatic type-placement equipment, automated typesetting equipment and others. By utilizing some of these components we are developing systems concepts for automating the entire cartographic processes. Through these efforts we will define future requirements and problem areas. In summary I would say that we do have active programs addressing MC&G activities.

THE CONCEPT AND APPLICATION OF DIGITIZED TERRAIN

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In an age where everyone's scope of observation and interest is expanding, it is necessary to handle greater and greater amounts of data. It's no wonder so many businesses and institutions are eagerly seeking methods of storing, retrieving, and handling their large volumes of data. The map makers and map users are part of this eager group.

Before the computer age, no one really conceived how much information was on a map. For instance, we would say there was about an inch of road on a 1:250,000 scale map and that represented about four miles. Today, that same one inch of road is thought of in increments of one-hundredth of an inch, and each of these increments could have a coded address bit for the X coordinate and for the Y coordinate. In addition, we could have coded bits to identify the elevation, the number and width of lanes, and the structural characteristics at each of these X-Y points. Two to six hundred bits of information can now define the one-inch road in computer terms.

If we prepare a one-hundredth of an inch matrix to cover the average 1:250,000 scale map, we have approximately 6,000,000 X-Y intersections. Map information can then be coded and identified for retrieval by these X-Y coordinate intersections. With the myriad of man-made and physical features and 6,000,000 addresses for these data, it is easy to see that the map maker and map user are required to handle large volumes of data.

If you are thinking that the one-hundredth-inch matrix is more finite than necessary, remember that at 1:250,000 scale this only gives us an address location for information every 208 feet. The thing to remember is that whether the matrix be finer or coarser, we are handling large volumes of data. And to handle data volumes such as these, we must use computers and other electronic gear.

The easiest way to build a concept of numerical, or digital, mapping is to understand what Army Map Service (AMS), the inventor of numerical mapping, is doing and their thoughts for the future. The numerical terrain map has been a standard product at AMS for the past two years or so. Approximately 150 numerical terrain maps are in the AMS numerical library and the next five years of programming will put about another 1,000 sheets in the library. Notice I said numerical *terrain* maps. This means we are identifying the height information (the Z information) at the 6,000,000 previously mentioned addresses. How is this done?

The key piece of equipment around which today's system is built is called the Digital Graphics Recorder; an instrument with three arms, operating in precise unison over related planes. The first arm is situated over a table where the original input copy is traced. The second arm contains a pinpoint light source which is directed to a photo-electric cell in the third arm. In between the second and third arms are two glass plates with precision lines etched every one-hundredth of an inch. The glass plates are positioned so that the etched lines are at right angles to each other.

To begin the process of recording numerical terrain data, a metal plate, etched with the contours of the desired map, is placed on the tracing side of the recording instrument. The operator sets a dial for the contour elevation to be traced and then traces all contours of that value. As he traces along a contour line, the other arms pass over the etched glass plates and the number of one-hundredth-inch X increments and Y increments sensed by the photo-electric element is recorded on magnetic tape. The metal plate on the tracing table has a colored material in the etched contour lines which is removed during tracing; this precludes omission or duplication of a trace.

At this point, the numerical terrain is a heterogeneous lot of X-Y values at fixed values of Z. A computer program rearranges these data into the familiar and orderly reading scan (raster) form. On a 1:250,000 scale map this recording process gives us approximately one million points actually recorded from the contour lines. This leaves us about five million address points on our matrix which must be intelligently interpolated. This is accomplished with a computer program employing the planar method. As the computer follows along a scan line, it interpolates the values between the recorded values. It does this by examining the area around a given point and selecting two additional significant points of terrain. It establishes a plane through these three points and then establishes the next point along the scan line on this plane. The computer then moves to this point and begins the terrain selecting and plane determination process all over again. This may sound like a mammoth task, but a good computer makes rather short work of it.

This then is today's completed product, a 6,000,000 address matrix with a value for Z at each of these points. This is the product being used by the Electro Magnetic Compatibility Analysis Center (ECAC) in dealing with radio interference and propagation problems. An interesting and significant point about this numerical terrain map is that it allows a computer to provide answers to map problems. It doesn't have to display the total data graphically and have a human do his own problem solving as is done with ordinary map graphics. Enfilade, defilade, and profile data can be provided from parameters programmed into the computer.

From this current numerical map, we extend our manufacturing concept by considering known technologies as components of the existing system. First of all, automatic map-compilation devices already in existence provide a numerical output directly from stereo photography. This would give us numeric data simultaneous with map compilation and avoid tracing contours. Where tracing contours is still the best or only way to obtain the input data, it will be speeded with an automatic line-following type of graphics recorder. This device is already part of the AMS numerical mapping equipment. These devices will give us greater input flexibility and speed.

As storage media and compaction techniques are improved, they will be applicable to numerical mapping. Just about any improvement in the computer main-frame and peripheral gear, both hardware and software, will benefit numerical maps. The numerical map is in stride with a technology (computers) that is expanding rapidly. As computer technology grows, you can expect similar advances in numerical mapping.

In considering possible future uses for numerical maps, we must first extend our existing knowledge of numerical mapping and visualize what the feasible future numerical map could be. Then we marry this information with our knowledge of map uses and come up with possible applications. In developing a firm requirement, however, there must be a firm understanding between the cartographer and the actual user. When the cartographer understands the intended or potential use and the user understands the production capabilities and limitations, there is good reason to believe that a lot of map users should be doing their job more effectively.

So our first step is to forecast what the future numerical map could be. To state it simply, we want to know all of the physical and man-made cartographic information about selected X-Y positions on the earth. There will always be questions about the density of this X-Y network, its metric accuracy, and the content accuracy of information shown, but these are all questions of design and not equipment limitations. Just as it is with any product, the designer must frequently trade off some utility to save some dollars or resources. So our numerical map designer, and the user, will have to remember that increased metric accuracy means increased dollars and increased content means increased dollars through increased collection and upkeep. But the technology is available if the end justifies the means.

At present we have digitized values for Z at every one one-hundredths of an inch along a contour line. Through a computer program, we interpolate the Z points between the contours at one one-hundredth-inch intervals. All this gives us is the terrain, portrayed as accurately as the map from which it was taken and interpreted like an intelligent map user. But, if the end justifies the means, there is no reason to believe that we cannot record all other cartographic data regarding that X-Y point. Since we, the map makers, would not have to worry about map clutter on numerical maps, a lot more data could be packed into the tapes, ready for retrieval upon command. We would not have to worry about one feature obscuring the other either, since it is doubtful if any user would want to retrieve all of the data simultaneously. For instance, if there is a piece of culture at a given X-Y point, there is no reason why we cannot describe it in some engineering detail, such as how high is the building and what construction materials were used. Or, what is the surface characteristic of the road, its load capability, number of lanes, gradient, and curve. Or, if this point falls into a river or stream, we could record how deep it is here, which way and how fast it is flowing, and maybe even what the bottom characteristics are. Or, if this point falls in woodland, we could record how high the trees are and what kind they are. Or, back to our Z point, what is under it? Is it trafficable? As you can see, the possibilities are unlimited if the users require them.

Keeping our future numerical map in mind now, let us consider some applications which might lend themselves to it. A good place to start is line of sight applications, since one application of this is already in use at ECAC. With a numerical terrain map, a computer with a visual or graphic output device could tell you what is visible from a given point or, given certain parameters it could give you a best selection of points with an evaluation of how each point satisfied the given parameters. It can also provide the same information regarding the inter-visibility of points. This system is a natural for radio propagation and interference problems. Radar propagation and avoidance is likewise a good application. How about weapons blast and the radius of bomb destruction? Let us not overlook target acquisition and site selection for weapons with near-flat trajectories. And let us not forget the commonplace activity of just plain looking from one place to another, such as observation points and forward observation locations.

To extend the straight line idea a little further, consider defilade, that is, portrayal of all areas below or above certain heights. Low-altitude flight planning, and maybe even operations, could benefit from this numerical defilade information. A computer reading a numerical map could select the shortest route between two points at specified elevations. This same type of defilade information is required for selecting sites for dams and canals, and for inundation analyses. Natural and spill basins, water heights and volumes, and plug fill and volume requirements could be simplified through numerical data use. Flood plains, run-offs, and reservoir levels could also be determined more easily.

Computation of stockpile volumes, and earth volumes for erosion analysis and control would be an easier task with numerical map data.

Other civil engineering activities could also use numerical maps. Earthwork could be done by a computer using numerical map data. Cuts, fills, and haul directions could be computed directly from the numerical map data. Of course, as soon as anyone used our numerical map for this purpose, it would necessitate a map revision. It appears that this ability to manipulate earth data would greatly assist highway work. With terrain and drainage data in numerical form, a computer could provide a valuable assist in grade, slope, curve, cut, fill, bridge, tunnel, and drainage determinations. Pipeline work with its gradient versus pumping station requirements involves some of the same considerations.

Selecting military sites could be simplified with numerical map data. Airfields, with their Ground Control Approach radar and glide path problems; military camps with their cover and concealment, sewer, and drainage problems; all could be simplified with a computer using numerical mapping data. Selection of helicopter pads, storage, and test areas could likewise be more readily accomplished. And wouldn't war gaming take on greater reality with all of the aforementioned data in such a readily accessible form.

All of the uses I have mentioned assist the map user. But, I assure you, numerical map data could be used quite well by the map maker too. In fact, this is how Army Map Service got into the numerical map business. We were seeking a means of automating our model production. One of the interim steps in this automating process is a numerical map. By chance we found that this interim product for us was an end product for some map users.

First of all, existing automatic cartographic compilation devices such as the UNAMACE and the STEREOMAT produce numerical terrain data. It is hoped that we can produce more and more numerical data at this stage, i.e., vegetation, drainage, culture, etc., and that efficient means can be devised to assemble these data into some geographical format. These numerical compilations can be directed to a plotter with a scriber head and the scribing accomplished automatically. To go a step further, it is feasible to compile a geographic area once at large scale and then, by automated equipment, produce whatever scale and projection is desired. This automatic equipment would of course do the generalization and dropping out necessary for the smaller scales.

With our map data in large scale numerical form we have a rather ideal material for filing. I am not sure we would end up actually saving physical space, but we can certainly say what we are filing is more versatile. Any scale of map could be made from the basic file data by directing it to a scribing plotter and producing the color-separated scribed material. Users who wish the filed data for automated or computer use would simply receive a duplicate of our file material. Also, our filed data would be more accessible to other map data producers or users, since electrical transmission of digitized data can be done with more speed and fidelity than photographic images.

In brief summary, the numerical terrain map is currently in production at AMS and is being used operationally. By synthesizing related technologies, the production of numerical maps will be simplified and expanded and their application will likewise expand.

DISCUSSION ABSTRACT

Mr. Shaffer: You mentioned several applications of digital maps. I'd like to add that digital maps are also likely to be of great use in planning military operations of various sorts. In amphibious operations, for example, the characteristics of the beach, the slope of the off-shore sea bottom, the presence of shoals and other hazards could be recorded. There are many applications.

Mr. Gilbert: I agree that there are many applications. Large volumes of intelligence data are available, but they are in scattered files. Some are available in map form, but an even greater amount are in documents and card files. All of these data could be coded, digitized, and addressed to a matrix where they can then be handled in the form of a numerical map.

Mr. Russell: How many different types of information do you anticipate recording at each X-Y intersection on a digital map?

Mr. Gilbert: First of all let me assure you that I don't think we would be limited technically. Greater data volumes simply mean greater library and handling facilities are required. Programmers wince a little, too, at the thought of developing programs to retrieve and manipulate these data. Numerical maps might develop somewhat like our graphical maps, i.e., a numerical topographical map, a numerical hydrographic chart, a numerical aeronautical chart, etc. I rather feel, however, that the best solution is to file all of the information together, sort of a JOG numerical map. To answer your question directly, we anticipate recording all cartographic and intelligence information which is justified by the user.

Dr. McGrath: I have noted that in many proposed systems for data storage and retrieval the procedures for storage and retrieval are feasible and versatile once you get everything on tape. But, preparing the data for storage seems to be the bottleneck in most such systems. Have you considered that?

Mr. Gilbert: Absolutely! It can be a bottleneck if we fail to apply enough resources in this area and preclude a smooth work flow. Preparing our current numerical map is quite a task, and if you consider putting all map data and intelligence data into numerical form, you really have a task. For instance, the digital graphic recorder operation that I mentioned for recording height information takes 40 to 60 hours, the computer operation takes 10 to 12 hours, and miscellaneous preparation and checking operations take another 15 or 20 hours. All this effort is required to get one numerical terrain map on tape. Just like anything else, you have to expend resources to get a product. When you start talking about a cartographic data bank of any kind, you're talking about a lot of man-hours to get the information into the bank.

AUTOMATION, CYBERNETICS, MAPS, AND DISPLAYS

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Development Engineering Division
Army Map Service

To start with, the terms *automation* and *cybernetics* need to be set in proper context. First, automation is defined as an automatically controlled operation of an apparatus, process, or system by mechanical or electronic devices that take the place of human sense organs of observation, effort, and decision. Second, cybernetics is defined as the comparative study of the automatic control system formed by the nervous system and brain and by mechanical-electrical communication systems.

This discourse will relate automation, cybernetics, and maps to displays. After having defined the first two terms, the term map could stand a little clarification also. Webster's dictionary defines a map as "a representation, usually on a flat surface, of the whole or a part of an area." Because of the phrase "usually on a flat surface," this is a rather restrictive definition when maps, automation, cybernetics, and displays are lumped together. By deleting this phrase and adding the statement that a map is "a source of information" all the terms are in context and their interrelation can be discussed.

This paper will show that the electronic computer, using numerical map data, is a solution to the problem of navigation displays. This solution is predicated on the existence of an adequate numerical map library and the ability of computers to manipulate large quantities of data very rapidly.

Until very recently, maps have consisted of lines, symbols, colors, and letters printed on a flat surface such as paper. All of the various design characteristics were an attempt to portray information about the earth's surface in a compact but decipherable format. The only cybernetics involved in using the map data was on the human side in the nervous system and the brain. This situation had to be because nothing else could compete with these human attributes in the area of speed and flexibility of operation. The electronic computer has brought a new factor into the picture since it can compete successfully with the human brain and nervous system in many cases. In fact, in the storage and retrieval of exact data, the computer can far exceed human abilities in both speed and accuracy.

The goal of cybernetics in mapping and charting must be to determine what part of the human automatic control system which detects, evaluates, and utilizes map information can be assumed by an electronic computer system. It has already been demonstrated that a computer can generate accurate surface data from a numeric map. The next step is to instruct the computer to solve a specific problem by using this data, such as the sequence of vehicle control movements necessary to follow any given path across the terrain.

Once the computer has solved the problem of the sequence of movements to follow, automation can be instituted by including instrumentation to determine actual position along the path which would feed to a control device which would then activate movement of the vehicle controls to follow the correct path. This is the well-known feedback loop of: Where are we? Where should we be? What do we do to get there? The problem solution can be enhanced by including vehicle characteristics of maneuverability which would allow "look-ahead" as to just how faithfully the vehicle can follow the desired path without deviation. An analogy to this "anticipation" occurs millions of times a day on our highways. Consider the actions that an experienced driver takes in anticipation of the effects of centrifugal force on his car as he enters a curve on the highway. The good driver will attempt to minimize these effects by several means, one of which is flattening the curve by moving from the outer radius of the curve to the inner radius as he goes around the curve. Incidentally, this is one of the reasons spiral curves are used in highway design. The analogy, of course, lies in the driver's mental exercise to evaluate the car's maneuvering characteristics, speed, and road conditions in relation to the observed road curve and the catastrophe that occurs when the curve was sharper or more extensive than anticipated (over the cliff equals overshoot--worst case). Obviously, anticipation of action is something a human can find very difficult to achieve in many cases.

The degree of automation is variable, of course, and the case just cited is automated to a rather high degree since, theoretically, this control system could start, maneuver, and stop the vehicle without human intervention. The significant parts of this system involve measuring ability, correlation with known data, and reaction time. To the mapping community, the problem reduces to that of supplying the known data (topography) in a form and format usable by the system.

At present, opinion is that topographic data must be converted to numeric (digital) form at some time if it is to be used in automatic systems of any kind. Basically, this is dictated by the digital nature of electronic computers. Even if the ultimate use of the topographic data is by an analog computer, the production of the analog form of the data will probably be by use of the digital version. The Army Map Service has been producing the terrain part of topography in digital form since 1964 for use in electronic wave propagation and low-level aircraft performance tests and simulations in which computers play a vital part.

There have been several interesting proposals advanced on how to use digitized topographic data for display purposes, and the ones related to navigation displays will be elaborated on herein to show how automation could be applied.

For low-level flight navigation, the best reference could well be the horizon. With a digital terrain base and an electronic computer, it is possible to generate the horizon visible from an aircraft at a particular altitude and attitude. This horizon could be for 360° or any portion thereof as dictated by the detection instruments on the aircraft. As the aircraft moves horizontally or vertically, the horizon generated by the computer is appropriately changed to reflect the new position and attitude of the aircraft. The navigational possibilities revolve around the use of an aircraft scanning device such as side-looking radar (SLR) to detect the horizon. A simultaneous display of the computer horizon and the SLR horizon would give the aircraft pilot information by which he could correct his course by matching the displays. It would also be possible to allow the computer to match the SLR horizon with a computed horizon and display the corrective maneuvers to the pilot. Obviously featureless terrain, such as deserts and plains, would present a serious difficulty to this approach. Also quite obviously, the computing load can become very heavy under certain conditions. However, with good resolution in the radar and good terrain data, the correlation of the two images would provide a very positive position over the ground.

At high altitudes, horizon reference may become inaccurate, and the best solution could be reference to ground elevations or features. This process can be compared with ship navigation by soundings and islands. Incidentally, a ship navigating system based on bottom tracking has been suggested as very feasible along well-charted sea lanes. Again, displacement of a radar image from a computed image would furnish the pilot with the information on which to base corrective action.

To be useful, the computer and sensor displays must be generated at intervals commensurate with aircraft speed and some desirable positional accuracy. Some typical ground-coverage intervals might be as follows:

Aircraft Speed	Ground Covered in 10-second Display Interval
400 mph (500 ft/sec)	1 mile
800 mph	2.5 miles
1200 mph	3 miles
1800 mph	5 miles

From this chart, it can be seen that, even at high speed, a pilot could receive a position check at five-mile intervals without straining the computer or sensor capacity to generate the display too hard. Ten seconds' time in the "electronic world" is a veritable lifetime. Admittedly, the computer would have several other jobs to do, like keeping track of elapsed time of flight and the actual flight path in order to select the correct display from memory; however, it is not inconceivable for a computer to work in this kind of a time frame.

Data storage will be an area of concern for a while, perhaps; however, the following chart will show that it is not an insurmountable problem:

Area of Coverage		Resolution	Bits Required
7,500 sq mi	(125 x 75 mi)	±200 ft.	150×10^6
30,000 sq mi	(250 x 150 mi)	±400 ft.	150×10^6
120,000 sq mi	(500 x 300 mi)	±800 ft.	150×10^6

Even at relatively low resolution of data every 800 feet, the data for an area of 120,000 square miles could be stored in 150,000,000 bits. This many bits can be stored on 2,500 feet of magnetic tape (one reel) using present-day techniques, and indications are that an improvement in storage density of several orders of magnitude is achievable. For instance, a recent news item from IBM laboratories described a photographic film storage technique using color detection whereby millions of bits of information can be stored in an area the size of a matchhead.

Collecting and converting the map data to establish the digital topographic data bank is a task of major proportions; however, instrumentation exists already which should fill this data bank almost as rapidly as conventional map coverage is extended.

To summarize, navigation aids and displays must change to meet the requirements of higher speed and all-weather operation of aircraft. Traditional map and chart products apparently will not be adequate for future operations. Cybernetics, as the study of human and machine control systems, must be applied to the problem of redesigning maps, charts, and displays for institution of more automation in aircraft navigation. Electronic computers offer many opportunities to effect automatic control; however, use of computers imposes rather stringent requirements on the form and format of usable data, and this in turn imposes a responsibility on the cartographic community to change its product when necessary.

DISCUSSION ABSTRACT

Dr. Pelton: Just a brief comment. Your ideas are fine; it's nice to look to the future. But, we have taken a look at this problem of digital display generation, and have found that many serious compromises are going to be needed. Many of you probably know that we have an analog terrain storage system at the Cornell lab. At one point we were wondering whether the analog system is worth keeping, and whether a digital system could be substituted. Well, we found that if we used the whole 704 computer, a 32,000-word storage, and all of the tape banks to go with it, we could run at just about one-tenth real time. Now obviously, if you are thinking of putting a digital terrain data storage system in an airplane, with near real time readout, you've got to solve some mighty problems.

Mr. Aumen: I'm not proposing the solution right away, but I very definitely am throwing some ideas out for future application. Computers at present may be hard pressed to keep up with a digital terrain display, but the pace of progress in the computer industry will not slacken much. Consequently, what we can barely do on a 7090 computer today will be done on a shoebox-size computer tomorrow. In fact, this magnitude of change has already taken place in the past ten years. I think we need to look ahead *now* in order to avoid facing the type of problem in the future that we face today in the cartographic area.

Dr. McGrath: Do you feel confident enough in the future automation and digitization of terrain displays to recommend that designers who are working on future systems link up with you in developing their plans?

Mr. Aumen: I certainly do. In fact, one of the outputs from this digitized terrain data phase can be a rapid production of the custom map for which we've heard so many requirements this week. Every map display mentioned so far has required a different kind of map in order to be effective, and this is where the opportunity to use a digital base, with automated plotting, scribing, or photographic-exposing equipment, can really come into play. This is one goal we are striving for in the automation of our cartography. Cartographers have been used to graphics, and digitization is something entirely new. We don't know many of the questions, much less the answers, that will come up. However, I would say we are confident that this new format of map presentation is valuable and feasible.

Dr. Magorian: I think there is a great deal of work to be done in finding more efficient ways to store information in the digital computer memory. Your digitization program is simple and workable, but it uses a great deal more storage than is desirable. We have done some work on more efficient storage of contour data by careful packing of terrain process function parameters. It is already useful with the present generation of computers for mask data in penetration studies. The brute-force storage of everything is not the only answer.

Mr. Aumen: I can't argue with you. If you have any good ideas, we'd love to hear them. You used the right term, we brute-forced a solution. We were forced to produce something because somebody needed it very badly. ECAC could not do their job without digital terrain data, so we ground it out. The storage of 6,000,000 data points is probably a horrible way to solve the problem when the redundancy in terrain is considered. However, every time someone has proposed a fancy mathematical solution to the problem, we have found that the mathematical solution is taking more storage than the brute-force approach to achieve the same resolution. In other words, it often takes more space to store coefficients than simply to store all the numbers.

III

DISCUSSIONS AND REPORTS

GENERAL DISCUSSION

EDITOR'S NOTE: After the formal papers had been presented the symposium was open to general discussion. Participants were invited to comment on any of the topics relevant to the symposium objectives. The comments published below include those which were made on the floor of the symposium and those which were later sent to me in written form.

Col. Herndon: There was not opportunity following Dr. Randall's presentation to make one observation which I felt was pertinent to his paper. For some time in the United States, there has been duplication in the production of aeronautical charts of various types. There have been military versions and there have been civilian versions, each compiled separately to meet military and civilian requirements. There was established an Inter-Agency Cartographic Committee which has membership from the Federal Aviation Agency, the Coast and Geodetic Survey or ESSA, and the Department of Defense. The workings of that committee have now resolved the differences between the various products and the requirement for their use, and have agreed upon common aeronautical charts at the scale 1:500,000 and 1:1,000,000, and on certain of the flight information publications, including the low-altitude enroute charts, terminal charts, and some other charts. The committee is still working.

It's pertinent at this point to recognize, on behalf of Dr. Randall's efforts in the study contract which he had with the FAA, that many of the ideas which he found suitable for incorporation in his prototype chart are embodied in the product which is now agreed upon for production to meet both civil and military needs. There will be one basic compilation of the 1:500,000 and 1:1,000,000 charts. There will be two published versions: one military and one civilian. The civilian version will follow the concept which Dr. Randall expressed of printing head-to-toe or back-to-back for civil purposes, and will have a more detailed overprint of air information. The same reproduction materials will be used by the military to produce a single-sided sheet, in other words, not printed back-to-back. The back of the military version will be blank, and there will be a less detailed, more stable, air information overprint.

I wanted to recognize before this group the fact that Dr. Randall's ideas are quite good. Some of them could not be put into effect because of the conflict with established ICAO (International Civil Aviation Organization) requirements for expression of some of the items; but many of his ideas are still worthy of further consideration and possible application to follow-on products. The effort at the moment is to get these products into being in a single version in the United States.

Dr. Pelton: I left one question open in the comments I made this morning and I'm wondering if it is possible to resolve it now. If we need a better map for low-altitude navigation, who is responsible for and who is supposed to fund the research that must underlie the development of such cartographic products or display devices? Do the operational forces have to say they want such things before the R&D funds can be let loose? Can somebody clarify this situation?

Col. Herndon: Well, Dr. Pelton, I'll try. The established procedure places in the hands of the unified commands and the departments the responsibility for stating requirements to DIA for evaluation, validation, and either accomplishment within DIA or, more likely, the assignment of the development responsibilities to one of the three departmental agencies. Usually, but not always, these will be the cartographic production agencies.

Let's take two cases. In the case of the contractor who is working on a Department of Defense development project for a low-altitude device, the channel for the statement of that requirement is through the military department which has been assigned the developmental responsibility or has a contract for the development work. It cannot be made directly from the contractor to DIA. I believe the reason for this is clear. The ultimate responsibility for the application of whatever might be developed rests generally with the department that devised it; although DIA must assure that anything to be produced on a broad scale is applicable to other DoD requirements of a comparable nature. This is in the interest of cost effectiveness. So the department which is asking for the development must have control over the nature of the expression of the requirement to DIA, initially.

Let's take the second case of, shall we say, free-lance development. You have an idea and want to see if it can be put into a proposal which a department might consider for application to a weapons system. In this event, I do not want to shut the door. Although I am not in a position to have prototypes prepared for you or to give you any significant development support, I would certainly recommend that you come to us very early in the game. Develop the cartographic aspects at the same time that you're developing your concepts of the hardware. Please, don't establish the hardware in concrete, and then come to us and say, "I've got to have some fancy cartographic support." Under these conditions it cannot be provided either very quickly or very economically for the user. Obviously, we'd like to make maximum use of the things that have been developed and are now readily available in our repository. We'd also like to try to standardize on scales, symbology, and other aspects of the design. But let me make it very clear that we do not put any new development into the straightjacket of just those things that have already been done. You've seen enough evidence of that in just today's presentation on the R&D side. But we do want to try to get the same amount of lead time in the preparation of our cartographic, geodetic, and geophysical inputs as you want in the development of the hardware. And only by working in conjunction are we going to achieve the maximum, within given time and dollar limitations, in the development of any new system.

So come to us, call us, talk to us in any fashion that you like, and either within DIA where we have some modest cross-section of the relevant disciplines or in the departments that have much broader capabilities, we will make every effort to give you an understanding of the state-of-the-art, what we're able to provide today, what we think is feasible, and how it might be done. However, as I mentioned before, we have to do this "on our cuff," because we do not program for support of this type. It's not going to involve a full-fledged study, and it's not going to be the development of a prototype; it will be a discussion of your problem within any necessary restrictions against further dissemination of "privileged" commercial information. So, all I'm offering is a good working relationship in exchange for letting us know early enough what the cartographic inputs are likely to be. Then we can try to give you assistance on them, and make those inputs without unnecessary burdens to you or unwarranted burdens to the military in terms of costs, time, or production resources.

Dr. Randall: While the symposium was advertised as having application to the requirements of low-level, high-speed military operations, I was somewhat surprised to see the heavy emphasis placed on this one aspect of military aviation, with little organized discussion of the other requirements of military flying. As the conference progressed, it became evident that others attending also felt that undue weight had been placed on only one part of what should have been a broader area of discussion. It would seem that, without denying the considerable benefit of the present symposium, a conference should be planned that would consider the problem of creating adequate chart materials for all kinds of military aviation, assuming other than low-level, high-speed operations also have unmet charting requirements. A similar conference also should be planned to investigate the charting requirements of civil aviation.

A second point that bears mentioning concerns the capabilities of charts and chart makers vis á vis the requirements of chart-display producers. As was evident from remarks made at this symposium, many equipment producers seemed relatively unaware of chart capabilities. Although as a result of papers and discussions these producers gained a more realistic perspective about charts relative to display system requirements, it would appear that perhaps too much emphasis continues to be given the "requirement" for miniaturization of *existing* chart material. A more feasible approach might include the creation of charts designed exclusively for display units. In this connection it would appear evident that fresh ideas about and insights into the problems of chart design can be offered by small firms active in this field, and such organizations should be invited to participate in future exercises involving aeronautical chart design.

It would be very helpful if a follow-up conference addressed to military air charts and map displays could be scheduled within a couple of years in order to review the progress made along lines recommended at this first symposium.

Mr Honick: The concensus of evidence and opinion from the display developers is that the topographical navigation display is the solution to the problem of geographic disorientation. In the words of Dr. Roscoe, "the display is the most effective device to date for low-altitude tactical navigation." There can be few devices in which flight test results from many different sources have been so consistently successful. In no case has a user been in doubt of his position or become lost. If, therefore, the purpose of the symposium as stated in Captain Kilpatrick's keynote address was an effort which will lead in particular to the enhanced capability of pilots to know consistently where they are and what course to follow to reach the planned destination, the problem is one for which a technical solution exists and which has been extensively evaluated over the past five years.

The exploitation of such a solution demands the establishment of adequate microphotographic-cartographic-material production and supply agencies. Here again technical solutions have been demonstrated.

From this aspect, the trend of development in more recent series of topographical maps gives cause for concern. In color saturation, contrast, line thickness, type style, and frequency of annotation, maps are becoming progressively more difficult to microfilm in color. Since the qualities which facilitate microfilming are also those which are conducive to legibility, particularly under adverse conditions, this appears to indicate that human engineering and air-medical work is not being applied successfully. Part of the difficulty appears to be an attempt to make colored material for use in white light suitable for use also in practically monochromatic red by diluting the colors with gray. Since the two conditions are by definition incompatible, attempts to meet both can only cause a degradation of contrast in either. In monochromatic light, maximum contrast will be achieved in black and white and shades of gray, while in white light the exploitation of color gives a valuable additional channel of information.

It is apparent from the symposium that the preparation and dissemination of cartographic material on microfilm is now established and will develop. Optimization of the map material both for this purpose and for appreciation in an airborne environment appears to be the most significant task which has emerged from the proceedings.

Dr. Orlansky: The discussion of cockpit lighting centered around the fact that the Air Force employs low-intensity white lighting in its cockpits while the Navy uses red light. An attempt was made to argue the superiority of one system over the other. Each position was supported by a faithful member of each service, but faithfulness has very little to do with the correct use of available information. The fact of the matter is that, as far as its effect on dark adaptation is concerned, one method is as good as the other, and any argument to the contrary is based simply on ignorance. There is ample literature on this matter and the issue evoked lively discussions about 15 years ago.

The color of the lighting, as well as its intensity, must influence the ability of a pilot to read his charts, and if necessary, charts can be designed to be legible at relatively low light levels, e.g., 0.5 ml. Here again, the facts and solutions are well-known, and the major problem is to establish the operational conditions under which the pilot will have to read his charts. For two-manned aircraft, dark adaptation is not generally required for the navigator, because he is watching the radar scope. Despite arguments to the contrary, this is also generally the case for the pilot of a single-seated airplane, although there are some significant exceptions, such as spotting from the air at night in slow-speed aircraft not equipped with radar. Here, special maps may be required for use under low light levels. In any case, the solutions are quite straightforward once we specify (and are prepared to live with) the supposed operational situation.

Now, I would like to comment on another, more important, issue. Even if a substantial amount of money is provided to support new developments in chart making, I doubt that it will produce useful improvements unless we establish an evaluation facility. In the past, we have not lacked suggestions for new charts, navigation concepts, or equipment. These have ranged from being quite imaginative to quite worthless, but this has not always been an obvious, or even acceptable, judgment. The real question is to determine whether or not they are useful and, to a large extent, this question has been almost entirely ignored.

In order to assure real progress in this area, it seems to me that two steps must be taken: first, recognize the importance of objective evaluation of new ideas, and second, do something about this by establishing a facility responsible for conducting such analyses. In general, these analyses should be of three types: technological, cost-benefit, and performance evaluation with simulated or prototype equipment. The establishment of such a facility will help us decide which developments should be pushed, and will also develop a center with professional competence in the technological aspects of chart development and use.

Lt. Col. Barnes: I would like to submit a few observations concerning the communication problem between the chart users and the chart makers. As a former Strategic Air Command combat crew member, I was painfully aware of the problem and questioned one of the Aeronautical Chart and Information Center participants about this lack of effective communication. He told me that ACIC had no R&D budget and could only communicate at staff level concerning the evaluation of new charts. Also, from the floor at the symposium, it was inferred by several participants that the users really did not know what they wanted on the chart. My experience in this area indicates that the men using the charts may not individually be able to point up all of the deficiencies of a chart, but a group of such men, properly interrogated, can quite readily do this. Staff communication in this area tends to be one man's, or at most a small sample's, opinion and will not give the desired results.

A rather simple, inexpensive, and rapid solution to this problem that has been used at the U. S. Army Human Engineering Laboratories is the field questionnaire. This allows the user to express his opinion of the device and to provide the maker with answers to specific and general questions pertaining to the operational effectiveness of the device.

Dr. Eddowes: Although we are confident that substantial improvements in navigation performance will result from use of modern navigation displays, it is unwise to lose sight of the fact that many aircrewmen may not share our confidence and may, in fact, be reluctant to use the displays when they are made available in the cockpit. Because this is a possibility, at least two sorts of activities should be made a part of the development of new navigation equipment with the goal of insuring that usable systems are provided. One is a thorough public relations job on how to operate the systems with all potential users. A second is refinement of the equipment itself to be sure that the final configuration is absolutely as easy, fast, and accurate to use as possible. If such activities are not a part of the system development program, there is at least a chance that appearance of the equipment will be greeted with cries of, "Who needs it," or, "It's too much trouble."

If possible, every effort should be made to not forget that the appearance of new navigation systems is not likely to obviate current navigation equipment, including particularly the pilot's eyes. Positive visual identification of checkpoints and targets probably will be required even when navigation equipment becomes so good that visual sighting is no longer needed.

Improved navigation displays probably will not eliminate navigation errors. In thinking about navigation systems of the future it is worthwhile to remember that someone will be able to accomplish a task, no matter how difficult it is, and as we all recognize, there will invariably be someone who can't accomplish a task, no matter how easy it is.

Capt. Miller: This is one comment I

would like to get on the record on behalf of the user (the tactical fighter pilot). It involves the basic lack of communication between the designer of navigation displays and charts, and the pilots who eventually use these displays and charts. The cause of this lack of communication, I think, is the fact that the scientist and the pilot live in different worlds. They talk a different language. A scientist is a scientist because of certain abilities and desires, and a pilot is a pilot because of different abilities and desires. I would make a very bad scientist and, similarly, a scientist would make a poor fighter pilot. It is just as difficult, in fact impossible, for the scientist to put himself in the pilot's shoes as it is for the pilot to put himself in the scientist's shoes. Yet it is the task of the scientist to design display systems and charts for the pilot to use. The finest display system has no value at all if the pilot doesn't trust it enough to use it, or feels he doesn't really need it.

So, I urge the people designing navigation displays and charts to maintain a very close person-to-person contact with the pilots they hope will some day use these displays and charts. I can guarantee any map producer who comes to Luke AFB with a proposed map that I will draw a low-level mission on *his* map and take him up in an F-100 and show him, first hand, the problems a pilot encounters using his product.

Mr. Borden: My major interest in the area of aeronautical charts and map displays has been the development of methods to determine user requirements. Therefore, it was gratifying to see the enthusiasm that this subject generated at the symposium. The liveliest discussions in the general assembly seemed to follow papers on this topic, and, from all reports, the working group devoted to the development and validation of aircrew needs was among the liveliest of the working groups.

The conclusion that I reached after listening to the comments in the general assembly and the discussion in the working group was that the majority of participants agreed there is a need to develop more adequate methods of identifying aircrew requirements for use in the design of aeronautical charts and map displays. They disagreed, however, on the specific methods to employ in developing these requirements. I would like to propose that a follow-up symposium be held to discuss the relevant issues surrounding this area of methodological development. The purpose of that symposium would be to specify the kinds of research methods that could most profitably be employed to identify aircrew requirements for aeronautical charts and map displays, and to solve the "communication problem" we have heard so much about.

SUMMARY REPORT: DISCUSSION GROUP 1
THE DEVELOPMENT AND VALIDATION OF AIRCREW NEEDS FOR AERONAUTICAL CHARTS AND NAVIGATION DISPLAYS

METHODS OF VALIDATING REQUIREMENTS

There was much discussion within the group about the various methods of validating requirements. Much time was spent discussing the various roles of aircraft, both tactical and strategic, in order to fully understand the problems that we were attempting to clarify. It was considered that the validation requirements fell into two distinct groups:

Short-term Measures

These should take the form of a mixture of pilot opinion and performance measurement. It was thought that both these methods have their own limitations, but properly controlled each would be a very important factor in the final analysis. Furthermore, there should be a continuous process of evaluation subsequent to the introduction of any new aeronautical cartographic product.

Long-term Measures

When any new requirements are presented by users, a feasibility study should be conducted taking into consideration the operational and cartographic problems with any new design feature of the aeronautical chart. Following the development of a prototype it should be fully evaluated by the user, and both the operational and cartographic requirements should be reviewed prior to the sealing of the specification of a new product.

METHODS OF DETERMINING THE USER NEEDS

Although there was considerable discussion on this subject, no new methods of determining user needs were suggested. It was thought that no one method of analysis would suffice, and that a well controlled, multiple-analysis system would give the most reliable result. For the record, the methods considered by the group were as follows:

1. Use of questionnaires to be completed by aircrew.

2. A controlled debriefing following operations and training missions. Great care should be exercised with this method since this will no doubt be a considerable burden on aircrew following very tiring missions.

3. Performance measurement by use of simulators, terrain models, and film prediction systems as typified by JANAIR studies.

4. Performance of controlled missions by either automatic inflight recordings, tracking systems, or trained observers. It was appreciated that it is of course an extremely costly process, but was thought necessary as a back-up to the other three methods of analysis.

PROBLEM AREAS REQUIRING FURTHER STUDY

One of the most important factors raised within the discussion group was the apparent lack of knowledge of one another's problems which have become very significant during the symposium. Considering that we were all trying to achieve the same aim it was a sad reflection on our own abilities. It was agreed that there were two distinct problems: the lack of communication between users, system designers and cartographers; and a poor appreciation of the lag time between the identification of user needs and the implementation of improvements. Both these problem areas are organizational in nature and require rapid and efficient handling if we are going to give the users what they require on time.

GENERAL SOURCES OF RESEARCH DATA

The group discussed this item at length, and it became painfully obvious that although there were concentrations of data from various basic research on the subject under discussion, and possibly on fairly allied subjects, little coordination existed between collecting agencies. It was recommended that a specific channel should be established for the collection and collation of all information available relating to display systems and aeronautical charts. Some possible sources of information were (1) the Remote Area Conflict Information Center, Batelles Memorial Institute, Columbus, Ohio; (2) Counter Insurgency Information Service, Advanced Research Projects Agency, Washington, D. C.; (3) Ministry of Defence Science Library, Whitehall Gardens, London, England.

FUTURE NEEDS FOR RESEARCH

It was unanimously agreed that the following should be considered as a matter of priority if map displays and aeronautical charts are to meet the future requirements of the user:

a. A list of information centers should be compiled and distributed to all interested agencies.

b. Meetings to discuss navigational problems and systems and their effects on mapping requirements should be carried out at relevantly frequent intervals.

c. A program of basic research into all problems associated with aeronautical charts and map-display systems, with special emphasis on human factors research.

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SUMMARY REPORT: DISCUSSION GROUP 2
THE LOGISTICS OF CARTOGRAPHIC SYSTEMS AND IMPLICATIONS FOR THE DESIGN OF MAP-DISPLAY SYSTEMS

It was agreed that the term "logistics" would encompass all of the mapping and charting processes from chart production through reproduction and distribution into the hands of the operational user. It was further agreed that the basic discussion would be concerned with the display-graphic support interface as applied to roller-map displays which use standard paper charts and optical-projection displays which use some form of miniaturized chart graphics. The concluding major premise was that discussions would be directed toward the most immediate solutions to the cartographic support problems for the two basic types of displays now in production; and if time permitted, the discussion would be followed by a consideration of some long-range problems and possible solutions.

ROLLER-MAP DISPLAYS

Roller-map displays use continuous roll strip charts, including those necessary for overall area coverage for a particular mission. This includes the chart coverage necessary for enroute navigation, target acquisition, weapon delivery, and the geographic area coverage necessary for escape and recovery. At present, this type of display requires operational personnel, often the mission pilot, to cut, strip, and join together appropriate charts or portions thereof to cover entry, navigation, and exit along the planned mission routes. It has been found in practice that this chore requires up to 12 hours of effort. Discussions brought out that approximately 80% of the strip chart coverage would be fairly constant in a given mission area. The remaining 20% would vary on a day-to-day basis as dictated by the interdiction targets assigned.

After much spritely discussion, it was concluded that the present state-of-the-art was conducive to logistic support as follows:

A shipboard or advance-base reproduction capability could be developed whereby, using a slit or shutterless type camera, a master negative could be photographed of the tediously prepared paper strip chart of the planned mission route. From this master strip chart negative, any required number of duplicates could be produced by a contact printing system. An alternative solution would be to prepare beforehand the stabilized 80% area coverage back in the mapping and charting plant by a sequenced array of north-oriented charts covering a specified mission area. Needless to say, this would require mapping and charting community investigation and experimentation to produce efficiently these area-strip charts on a production-line basis.

OPTICAL-PROJECTION DISPLAYS

Optical-projection map displays require a miniaturized chart input which is magnified to the original or enlarged scale of the original chart on the navigation scope in the cockpit. Present deficiencies in the state-of-the-art are limitations in the optical lens and photographic color film. Typical lens capability is 200 lines per millimeter resolution in the center with fall-off on the edges to 100 lines per millimeter. Color film resolution is approximately 65 lines per millimeter. Color reduction ratio is approximately 10 times. Applying these to the resolution formula of:

$$\frac{1}{R_{optics}} + \frac{1}{R_{film}} = \frac{1}{R_{composite}}$$

The readout resolution on the scope, not counting any loss in projection, varies from five lines per millimeter in the center to four lines per millimeter at the edge. This is considered to be tolerable, but only marginally so.

The concensus of opinion was that the best interim solution for optical-projection cartographic support would be to photographically reduce an aeronautical chart or color proof thereof, 10 times on a 105 x 150 millimeter film. This film strip can then be inserted as the navigation chart input in the cockpit display. To complement this basic reference graphic, there would have to be a shipboard or advance-base capability to photographically reduce a chart overlay containing the latest intelligence and mission planning data. The overlay would be superimposed on the basic chart data when projected on the cockpit scope. It would be desirable to have a shipboard capability to enlarge and print out standard aeronautical charts from the miniaturized master. Unfortunately, this is beyond the state-of-the-art. To achieve this capability, black-and-white color separations would have to be made back in the plant which could then be printed, electrostatically or otherwise, in sequence and mechanically registered into a composite full-color chart on paper or other material. This system requires the obvious mapping and charting research and development effort and more basically, research on three-color or four-color processing. It was suggested that reduction in information content, saturation of colors, and type and symbol enhancement also be explored. On the other hand, over magnification on the display scope would partially achieve these objectives.

In response to a specific question it was agreed unanimously that government and not industry should provide the cartographic support for navigation displays.

A similar type symposium was recommended within a period not to exceed two years, and the Defense Intelligence Agency was suggested as the next host.

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SUMMARY REPORT: DISCUSSION GROUP 3
PROBLEMS IN ACHIEVING VERSATILITY OF, AND CARTOGRAPHIC SUPPORT FOR, DISPLAYS TO BE USED IN DIFFERENT FLIGHT MODES

The tone of our discussion group was set by a pair of Army helicopter pilots, one of whom served before the introduction of the Decca display in Viet Nam and the other of whom served both before and after its introduction. Hence, the bulk of our discussion was centered around displays for low-speed, low-altitude operations, including helicopters and counter-insurgency type aircraft such as the OV-10 and the Mohawk. The following points of interest were brought out during the discussions:

1. The importance of the chart as a system component was pointed out by the fact that paper strip maps have a varying, limited life in humid tropical environments since they absorb moisture and tear apart after a few missions. Printing charts on mylar largely corrects this. But, system effectiveness should not be sacrificed to simplify support logistics.

2. In order to save space and weight for payload, displays are used only in the lead helicopter. The consequence is that if the lead helicopter is destroyed or aborts, the group is left without a navigation display.

3. Existing roller displays lack the versatility to program new missions enroute.

4. Current chart standards present a natural limit to use of displays in pinpoint flying. Current practice is a line width of .020 inch; on a 1:25,000 chart this represents a distance of 40 feet and on a 1:50,000 chart a distance of 80 feet. The true geographic position of chart features is only known within about 80 feet at best. (Digitized chart data from aerial photos may improve on this in the future.) A small path which might be only five feet wide or so would appear on the large-scale charts as 40 or 80 feet wide, a veritable boulevard, and this condition is even worse on the smaller scales. Also, a road or stream with twists or bends which might be used for target identification may appear on the chart as a straight line since the bends are absorbed in the line width.

5. In particular, the need for a map display exists in the type of mission where the pilot's attention must be diverted from the navigation function for a period of time in order to perform a mission task, as on a strike mission for example.

We attempted to hypothesize a display that would be adaptable to various aircraft with a wide range of performance. The following characteristics were considered important·

1. The display should accept any of the present map scales so that charts can be selected suitable to the mission and would have a slow enough traverse rate in the display for good readability. For close air support, the display should use the same chart as the ground force uses.

2. Multisensor displays are required to permit the pilot to rapidly correlate data from the various sensors, such as radar and infra-red.

3. High reliability is necessary to build the pilot's faith in the device before the display will be accepted.

4. A dead-reckoning mode is a desirable feature in map displays.

The accuracy with which one can extract information from a map or map display will depend on:

1. Accuracy of map intelligence in gathering map data.

2. Effectiveness of cartographic techniques in putting the information on the map or map display.

3. The user's perceptual ability in interpreting the map's contents.

With the advances in cartographic technology, the ability to produce the geographic information on maps or map displays is progressing very well, but the ability to gather map intelligence, especially over unfriendly territory with pinpoint accuracy, and the resolution limitations of maps or map displays recognized by an observer may prove to be the major parameters as to how accurately one can pinpoint a target location with the use of maps or map displays. To circumvent some of these difficulties, one approach is to examine the degree of accuracy required of the map information in order to perform a certain task, and then utilize the current state-of-arts in meeting the needs. For example, the map accuracy requirement for enroute navigation is not as stringent as the requirement for locating a point target, since the checkpoints for enroute navigation are well defined, whereas for point-to-point reconnaissance they are not. Similarly, the navigational problem encountered by high-speed, low-altitude flight is much more serious than those of low-speed aircraft because of the heavy work load and short response time typified in the former situation. Therefore, the design problems of map displays must be tailored to various flight modes and the ability to switch from one to another within the characteristics of operational aircraft would be essential: from navigation to search; from one scale of map display to another; from one type of sensor to another, etc. The degrees of sophistication and complexity are, therefore, largely dictated by the aircraft performance and by the type of information needed for specified missions.

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SUMMARY REPORT: DISCUSSION GROUP 4
THE INTERFACE PROBLEM IN MAP-DISPLAY SYSTEM DEVELOPMENT

INTRODUCTION

Discussion of the interface problem in map-display development by the members of Group 4 focused on the man-machine interface to a considerable extent. Interfaces within map-display systems were identified between the display surface and an information-processing equipment complex and between the information-processing equipment complex and various sensor or information source equipments. These latter interfaces were not taken up by the group because the specializations of a majority of the group members were in the area of human factors and not in the development of equipment, such as computers, display generators, or sensors.

In discussing the man-machine interface problems in map-display development, the group identified 11 problems. For this summary these problems are grouped into two main categories: first, those related specifically to the displays themselves, and second, those related to display development. Within each main category the problems have been ordered into sub-classes of critical and non-critical. This scheme of organization of the material has been designed to suggest priority. A stronger designation of relative importance did not appear appropriate to the group, which generally believed that acceptable solutions to all of the problems identified here will be required before truly effective map-display systems can be developed.

A final section lists organizations represented in the group with research capabilities that may be utilized to assist in solving the various problems described in the following paragraphs.

DISPLAY-SPECIFIC PROBLEMS

Critical Areas

Safety and reliability. Although the issues of safety and reliability are frequently mentioned last, almost as an afterthought, they represent a problem of the greatest importance. Consequently, they are noted here first off. Unless a safe, and therefore reliable, map display can be developed, there is no point in pursuing the topic any further. Means must be found to make map displays as nearly absolutely safe and reliable as possible if such a device is to be used by aircrews. Since absolutes in this application may not be available, every effort must be made to devise ways to make it possible for the display user to assess decisively and continuously the functioning of the display system. In addition to a continuous self-check, the system must possess the capability of being usable in its failure modes, so that even with a relatively complete failure there will be a minimal map display available to the pilot for emergency navigation purposes.

Map content. There is every indication that determining map content will be a major problem. The significance of this problem stems from the fact that all issues of map content must be very carefully checked and tested for readability and efficiency of use and from the fact that map content includes such imponderables as color, symbology, information rate, and other meaty issues. In addition, the distinct possibility exists that map content will be found upon closer analysis to be determined by the characteristics of a number of specific missions, each of which will require the same sort of careful and exhaustive test-and-evaluation program, all of which adds to the difficulty and criticality of this problem area.

Display location. Unless the location of a map display is optimized for each cockpit installation, many of the advantages of the map display may be lost. The non-optimum location of many current navigation displays, in aircraft cockpits, furnishes evidence to support display location as a problem area. The performance advantages of all display equipment offering a possible solution to this problem should be measured and evaluated. Display location sharing by means of electronic equipment capable of presenting many kinds of needed information in the same spot successively, as well as simpler map-display equipment that may temporarily be positioned in an optimum location as required, also should be investigated.

Non-Critical Areas

All-weather flight. If a map display can be developed for any application, it should include the capability for use at night and/or under bad weather conditions. Since a map-display system is seen as improving on and obviating either dead reckoning or radio navigation, it must work as well as the navigation techniques under instrument and visual flight rule conditions. Therefore, the map display must be accurate enough to use during instrument approaches, for example. It must be accurate enough not only to represent the terrain over which the aircraft is flying, but must substitute for it when the terrain is not visible. Display accuracy of this quality is seen as a problem of substantial magnitude.

Map-display notation. Observation of experimental tests of map displays as well as analysis of requirements and the lore of map utilization suggest that the final design for any modern map display must include a capability for annotating the map. Flight instructions, weather, briefing data and other similar material are candidate information to be noted on the map display by the map user. Because aircrews have always marked maps and because it is unlikely that equipment designers will be omniscient enough to include all the needed capability in the map display, addition of this optional extra is needed as a catch-all.

Map scale. Although the map scale problem could reasonably be included within the general heading of map content, there is enough different about it to recommend its designation as a separate problem. As a result of considerable discussion, the group concluded that it is unlikely that a single map scale will be found to be adequate even for a single-mission-type application. Consequently, there appears to be no likelihood that display size can be optimized once and for all because of the addition of scale to the list of variables. Perhaps the best solution will be to determine optimum scale for each mission and then to adjust display size to take maximum advantage of the optimum scale and the other auxiliary scales also required. In any case, it can be seen that map scale must be carefully studied to insure that the man-machine interface is in fact optimized.

DISPLAY DEVELOPMENT PROBLEMS

Critical Areas

Standardization. There is no doubt that standardization is a highly desirable goal in the development of a map display. While many will agree that standardization is a problem, it is likely that few realize how great and how difficult standardization is to achieve. Considering the size of the problem a standardization program should already be in progress, and if one is not underway, it should be initiated at once. Such a program should be given the highest support and should be thought of as the start of a long-term process, eventually leading to the required standardization of map displays.

Coordination. One of the more significant functions of the present symposium has been to inform many participants of the activities of others working in the same general area. This suggests that much more enlightenment is possible and desirable in the development of a map display. Such a spreading of intelligence is needed in an effective map-display development program. It is evident that many problems may be avoided if all interested parties systematically, regularly, and seriously coordinate their work. Coordination of this sort is not easily obtained, but the potential payoff warrants the effort.

Exotic techniques. In studying the area surrounding development of map displays, the group discovered this question: Suppose that the map display that possesses the quality of persuading everyone at a glance has not yet appeared, and that the final decision isn't obvious now because the best alternative display hasn't been found, then what? This question suggests a problem of finding the way to a giant step forward to something new that will satisfy all the requirements for which we can only piece together solutions with the ideas, equipment, concepts, and technology of today. Working productively for pie in the sky prior to creation of the desired insight is the problem in this case. It is recommended, therefore, that determined effort on a long-range study of all avenues of approach to exotic solutions to the map-display problem be initiated. Electronically generated displays, photographically produced maps, and other similar notions should be investigated until it is clear that no stone has been left unturned in the search for the needed leap forward in advancement on the many problems of map displays as we know them.

Non-Critical Areas

Special chart requirements. According to information provided by a cartographic specialist in our group, current maps and charts have only begun to tap the fund of information available on very short notice for use in new map applications. This item focuses on the avoidance of unnecessary problems through taking advantage of current map-display information, the employment of which would add little or nothing to the costs of map-display development. In this case, it is recommended that map users and potential map users investigate thoroughly the possibilities of using map information available now before concluding that current maps will not do and then designing equipment that insures that they in fact won't do.

Display complexity. Much of the group's discussion of map displays was about relatively complex equipment for relatively high-performance aircraft. Low-performance aircraft, however, were not overlooked. Because of the significant improvements in navigation performance to be obtained from advanced map displays, it is important that inexpensive, uncomplicated map displays not be overlooked lest these performance advantages not be made available to the general aviation community. Thus the problem of not being caught up in the development of very high performance map displays to the point that simpler devices are ignored was identified. The goal of a series of modern map-navigation displays suitable for aircraft with performance capabilities varying from those of a Cessna 150 or a Piper 140 on up to the F-111 or a supersonic transport is strongly recommended to optimize not only the man-machine interfaces, but also to maximize the number of them optimized.

RESEARCH RESOURCES

Because many of the problems described above will require that substantial research be accomplished, no well refined solutions can be suggested with confidence at this time. Instead the research resources of the various government and industrial organizations represented within the group were identified to at least offer a means for solving these problems. The following organizations possess research capability and interest in the area of map display development:

U. S. Naval Missile Center, Human Engineering Branch

North American Aviation, Columbus Division

United Aircraft, Corporate Systems Center

Federal Aviation Agency, Atlantic City, N. J. and Oklahoma City, Okla. facilities

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SUMMARY REPORT: DISCUSSION GROUP 5
THE ASSESSMENT OF MAP-DISPLAY SYSTEMS

There are many possible circumstances resulting in a need to assess a map-display system. A procuring agency may want to evaluate a prototype system before the system enters production. Such an evaluation would be devoted mainly to verifying the performance of the system, but in addition the evaluation would search for design deficiencies that should be corrected in production and other minor changes that would improve performance. Possibly two or more competing systems might be presented for evaluation, and the potential purchaser would then want to evaluate the systems in comparison with one another, or in comparison with a previously used system. After a map-display system has been used for a period of time in one type of aircraft, changed conditions for its use may make it desirable to assess the performance of the system under the new conditions. Another possibility is that it may be desirable to introduce into a new type of aircraft a map-display system that has previously demonstrated its value in aircraft of another type. At that time the utility of the map-display system in the new aircraft might be assessed. Regardless of the circumstances preceding any kind of assessment of a map-display system, the purpose of the assessment is to evaluate how well the functional and design characteristics of the system satisfy the operational requirements of the user.

The assessment of map-display systems, in its most general aspects, resembles the assessment of other types of equipment. Consequently many of the problems associated with the assessment of map-display systems are problems similar to those encountered in other evaluations. Our discussion centered on two main topics: techniques for evaluating map-display systems, and criteria to be used in an assessment. These topics are of interest for evaluating other equipments as well. When details of the assessment process are considered, problems unique to the assessment of map-display systems begin to reveal themselves.

TECHNIQUES FOR EVALUATING MAP-DISPLAY SYSTEMS

There are three major ways of evaluating map-display systems; opinion sampling, theoretical or numerical analysis, and empirical tests in the laboratory, in flight, or in a simulator. The choice of which method or methods to use depends on what information is wanted about the system.

Opinion Sampling

A system that has entered service or is about to enter service is often evaluated by a poll. Personnel who have been using or testing the equipment fill out questionnaires to record their opinions on its performance. Based on the answers to the questionnaires, the ability of the system to satisfy the needs of its users is assessed. Often the responses will identify aspects of the system that should be improved. It is generally fairly easy to conduct an opinion poll, and the costs of a poll may be lower than a program of flight tests, particularly if the evaluators' operational experience with the system stems from flights performed for other purposes.

There are several problems associated with opinion sampling, and many of these problems are common to opinion surveys in general. The questionnaire must be designed carefully to avoid misleading or loaded questions. It must not be too long, or individual questions will not receive adequate attention. If too short, the questionnaire may overlook some important aspects of the operation and performance of the system. In the design of a questionnaire, the influence of engineers concerned with the technical performance of the system must be carefully balanced with the influence of psychologists who are mainly concerned with the design of the questionnaire and the human engineering of the system. Since several scientific disciplines are involved in designing a map-display system, a questionnaire to sample opinions about the system should preferably be prepared by a multidisciplinary team.

Probably the biggest difficulty with opinion sampling as a means of assessing map-display systems is that this technique measures the users' opinion of how well the system satisfies their needs or the popularity of the system with the users rather than the actual ability of the map-display system to satisfy the users' needs. Furthermore, normally an opinion poll queries only a sample drawn from the total population of actual or potential users. Members of the sample may influence one another's opinions. Often a group will contain a natural leader whose opinions are respected and adopted by many other members of the group. This effect reduces the effective size of the sample and causes a small number of opinion makers within the sample to wield an influence much greater than warranted by their numbers. Another problem involved in opinion sampling as a technique of assessing map-display systems is the reluctance of many members of the group being polled to accept change. Familiar procedures and familiar equipment are often favorably regarded simply because they are familiar, while a new and improved system is resisted because the untried and unfamiliar procedures for using it cause difficulties. A poll taken shortly after the new equipment was introduced might indicate that the new equipment was inferior to the old equipment. If the identical sample were polled at a later time to allow greater familiarity with the equipment, the same questionnaire might show that the new system was superior to the old equipment. Another closely related problem of opinion sampling is that a favorable general opinion is not always positively correlated with favorable numerical measurements of performance. The latter are presumably obtained from some other technique of assessment. Different techniques of assessment emphasize unequally the factors on which a map-display system can be evaluated. Opinion sampling lays stress on the users' favorable opinion of the system while slighting the engineering performance of the system. In contrast, a theoretical analysis of the system is likely to concentrate more attention on the ability of the system to satisfy certain performance criteria and less attention on the human aspects of the system. To reconcile conflicting conclusions from different techniques of assessment requires a very careful judgment of the relative importance of factors emphasized by the different techniques of assessment.

Theoretical or Numerical Analyses

Theoretical or numerical analysis as a means of assessing a map-display system involves the evaluation, individually or collectively, of the mechanical, optical, servomechanical, cartographic, electronic, and navigational portions of the system. This technique requires mainly pencil and pap r and competent analysts. It may be applied in a design review before construction commences on an experimental or prototype map-display system, or it may be used to confirm and explain the performance of a system as measured in flight tests. Theoretical analysis has the advantage of being relatively low in cost and easy to carry out, since it requires neither test equipment, nor flights over test ranges, nor even the existence of the system being assessed. Nevertheless, theoretical analysis presents a number of problems. It may fail to reveal design deficiencies that would be rapidly identified in flight tests. For example, a thermodynamic analysis of a map-display system might indicate that heat internally generated by the system should not be a problem, yet in an airplane the system that looked so good on paper may be plagued by breakdowns, caused by installing portions of the map-display system in confined spaces lacking the circulation of air envisioned by the theoretical analysis. In principle a theoretical analysis might have been able to predict the thermal difficulties, had the operating environment been adequately specified. Unfortunately, in practice it is rarely possible fully to specify the environment. Often a system must be designed before the details of its installation in aircraft are known, sometimes even before it is decided what aircraft will be equipped with the system.

It is likewise difficult to recognize or predict operating problems by means of a theoretical analysis. For example, personnel responsible for maintaining a map-display system may simply lack the intelligence or finesse in the use of test equipment necessary to achieve the performance of which the system is theoretically capable. A psychologist in the group performing the analysis may be able to identify some operational difficulties resulting from the interaction between man and the system (such as the preceding example) and estimate the degradation of the system's performance in the field caused by human factors. A group conducting a theoretical analysis of a map-display system should preferably be multidisciplinary in composition, with its members collectively possessing knowledge of the scientific disciplines required to design the map-display system, coupled with operational experience in the use of map-display systems or other aeronautical equipment.

The results of a theoretical analysis are a set of numbers describing the expected performance of the system--the horizontal accuracy of the cartographic materials, the response of servomechanisms, the expected error between the indicated position and true position, the time required to shift from one map or scale to another, the resolving power of the projection system, the mean time between failures, the error in navigational information supplied to the map-display system, etc. These numbers, compared to the design goals as given in the procurement specification or elsewhere, provide a basis for judging or assessing the map-display system. However, no matter how precisely these numbers have been calculated, the assessment of a system depends on how value judgments are formed on the basis of the theoretically calculated parameters of the system. Some subjectivity may enter if a single system is being evaluated, and if two different systems are being assessed, their comparison is all the more likely to be subjective. The systems may operate in slightly different ways. One might project a series of separate maps from film chips, and another, at a greater cost in volume, weight, and logistic difficulty, might display present position on a continuous strip map. In this example the time required to change film chips for the first system might be shorter than the time required by that system's specification, but the second system does not require film chips to be changed. In comparing these two systems a subjective judgment will have to be made, and the decision will depend on the relative importance attached to different parameters that are estimated or theoretically calculated. Even thoug the parameters describing the system may be known precisely, the problem still remains of interpreting these numbers.

Empirical Tests

One problem of flight tests results when many flight tests are repeated over the same terrain. Under these circumstances flight personnel may become very familiar with the ter rain. Flights to measure how much assistance the map-display system pro vides to the navigator may give misleading results, showing that the system is of only slight help because test personnel are too familiar with test areas and missions. Over unfami iar terrain the map-display system would be of far greater help to a nav gator. The characteristics of the te rain over which a map-display system is to operate also affect the value o the system. When the terrain has man distinguishable features such as rivers, mountains, lakes, cities, rai roads, road junctions and the like, position can be determined by pilotag Over terrain lacking in variety, such as desert, a map-display system will be much more useful than in varied terrain. To assess the utility of a map-display system, flight tests should be conducted over different types of terrain. This may be possib for potential civilian users such as the airlines, which can combine fligh tests of a map-display system with normal passenger and freight service. However, flight tests by military agencies usually are centered at one test site, and flight tests over many different types of terrain are likely to be more costly. In order to be certain that the results of flight tests are repeatable, a large number of flights is desirable. Unfortunately, the high cost of flight tests often prevents an adequate program of flight tests from being completed. Indeed, the high cost of flight testing is doubtless the greatest single problem associated with this techniqu of assessing a map-display system.

One way to reduce the cost of flight tests is to replace all or som of the flight tests by simulator flights. In a simulator the aircraft installation may be reproduced in great detail, or perhaps only the map display system and its controls arranged as they would be in a cockpit would be reproduced. Positional signals to the map-display from a naviga tion system such as an inertial navigator or a doppler would also have to be simulated. These signals might be provided either by recordings obtained during actual flights, or the desired signals corresponding to a given flight path might be calculated and then generated electronically. Motion of the aircraft can be simulated by motion pictures projected to represent the terrain that would be seen during a flight. This technique of assessment is well suited to measurements involving the navigator, such as the number of times he becomes disoriented during a flight, the amount of time the navigator spends to determine his position with and without the aid of the map-display systems, or the effect on the navigator's performance resulting from errors in the navigational inputs to the map-display system. Since a simulated flight can be repeated many times, these quantities can be measured to a high degree of confidence. This technique of assessment is not so well suited to measuring the performance and reliability of the map-display equipment, because in a simulator the environment is more benign than the environment in flight.

Each of the empirical techniques of assessing the performance of map-display systems has its own advantages and disadvantages. Depending on what system parameters are considered most important, a test program involving one or more empirical techniques, and possibly other techniques as well, can be planned.

ASSESSMENT CRITERIA

Regardless of how a map-display system is assessed, criteria should be available against which the system can be evaluated. The unavailability of adequate criteria is one of the biggest problems of assessing map-display systems. Ideally, the procurement specification should list criteria applicable to the assessment, and each criterion should be established rationally, as, for example, by theoretical analysis, by experience with other systems, by consideration of the missions in which the map-display system will be used, etc. In practice the procurement specification often omits important criteria. It appears that in many cases criteria do not exist, or cannot reasonably be expected to be given a procurement specification. The following are some examples of missing criteria:

The allowable number of disorientations per unit time. It is generally expected that the pilot of an aircraft equipped with a map display will become lost less frequently than he would without the system, but what constitutes an acceptable rate of disorientations? Because the frequency of becoming lost depends on terrain, flight altitude and speed, the accuracy of positional signals from the navigation system to the map-display system, and the skill of the map-display system's operator, all of which are outside the control of the engineers designing the map-display system, the allowable number of disorientations per unit time is not given in the procurement specification.

The distance from a preselected route. How should the allowable distance between the aircraft's instantaneous position and a preselected route be measured, by the root-mean-square distance or by the mean absolute value of the distance? For military missions, the deviation from a preselected route might be important only in the vicinity of targets, the home base, and check points enroute to the target. In contrast, safety considerations governing civil aviation require that a suitable lateral and longitudinal separation be maintained between aircraft at all times. Therefore the parameter of interest is the distance between an aircraft's actual position and its planned position (as a function of time) along a preselected route. Supersonic airplanes of the future will be constrained not only by considerations of safety, but because fuel costs increase so rapidly for any deviation from the planned route, which will normally be chosen so as to minimize costs, the lateral deviation of a supersonic airplane from its planned path is of greater importance than it would be for other aircraft.

The accuracy of locating targets of opportunity. In military applications of a map-display system it may be desirable for the pilot or tactical aerial observer to mark the positions of observed targets with the aid of a map-display system. A specified value for the desired accuracy seems to be generally unavailable to the designers of map-display systems.

Another problem of evaluating map-display systems is that tradeoff values for map-display systems and other forms of navigation are largely unknown. An agency or company procuring an aircraft may want to consider equipping the aircraft with a map-display system. In military aircraft space in the cockpit is usually at a premium. In order to install a map-display system, other equipment may have to be removed. The question is with which configuration of equipment is the aircraft more able to complete its missions? The deleted equipment may be navigational (Tacan, VOR, Loran, etc.), and other equipments such as communications gear and radars might also be removed. The ability of the crew to navigate the aircraft by conventional equipment (i.e., the equipment that would be removed in order to equip the aircraft with a map display) is unknown. Therefore, even if the performance of the proposed map-display system is known as a result of flight tests, there is still not enough information to make a decision on whether or not to replace some of the aircraft's equipment by a map-display system. A reference system needs to be established and its capabilities evaluated as a standard against which map-display systems can be compared. Pilotage and conventional maps or aeronautical charts form one system that might be selected and evaluated as a reference system.

Another problem relating to criteria for evaluating map-display systems is how to choose quantities that should be measured during laboratory tests, flight tests, or simulated flights. Some of these quantities are readily identifiable, since they appear in the procurement specification. Others are harder to identify, being omitted from the procurement specification because they are beyond the control of the designers of the map-display system. In the latter category, for example, is positional accuracy of the map-display system, which is a function of the accuracy of the cartographic material used in the system, the accuracy of the servomechanisms that cause relative motion of the map and the cursor representing instantaneous position, and the accuracy of the navigation system supplying signals to the instantaneous-position servomechanisms in the map-display system? A partial answer to the problem of selecting quantities i the latter category, is to identify errors of operational significance an physically measurable values that relate to the system's logistic and mai tenance requirements and operational performance. Numerical values for many of these quantities may perhaps have already been established as goal by the agency procuring the map-displ system or by the agency responsible for the performance of the aircraft. If not, a competent systems analyst should, by theoretical analysis and appropriate inquiries, be able to specify desired numerical values for these criteria. Then the actual numer ical values can be measured by laboratory, flight, or simulator tests, which should also make diagnostic mea surements of parameters affecting these numerical values. Some criteri cannot be specified quantitatively, yet they are so important that they deserve attention by personnel conduct ing the tests. Rather than to ignore these criteria completely, it is better to evaluate these criteria qualitatively, perhaps by an opinion poll of the test personnel.

In assessing a map-display syste the following list of criteria may be of some assistance. The criteria actu ally selected will depend on the type of aircraft, the missions for which i is intended, and the recommendations of the users and the procuring agency

Legibility and visibility. Unde this heading are included subheadings to cover legibility of printing and map symbols, clarit of markings on system controls and displays, adequacy of illumi nation, suitability of color con trast, scale and detail on carto graphic materials, adequacy of the area displayed relative to the needs of the mission, etc.

Accuracy. This includes both th overall or total positional erro and the contribution of the map-display system to the overall error. Note that in many military tactical applications and also i many civil aviation applications relative rather than absolute accuracy is significant.

Utility. The device should be studied to determine the extent of its ability to reduce the cockpit load directly related to navigation and position fixing.

For example, the customary mental and manual computations necessary to determine present position in relation to planned course, computations involving wind direction and velocity, progress along planned course, time (or distance) to go to target or emergency field, etc.

Flexibility. Display systems, in some instances, at least, will be designed for special applications. In all cases they should be assessed to determine the extent to which they can be utilized for missions other than their primary application. Few, if any, display systems are designed for installation in every type of aircraft or for use in the gamut of aircraft operations. Evaluation then should be made concerning its adaptability to each of the various missions, such as tactical support, high- and low-level bombing, photographic and mapping, resupply, search, and recovery. Consideration should be given to its ability to accept driving inputs from a variety of navigation systems.

Ability to update cartographic materials. For military applications, the ability to mark the location of friendly units and in flight to determine the locations of targets of opportunity is important. Not only the length of time required to correct cartographic materials, but also the accuracy with which new information can be entered in the field or by echelons further to the rear needs to be considered. Civil aviation is also concerned with updating cartographic materials to reflect changes in approach patterns to airports, radio frequencies for communication between air and ground, temporary changes in runways, etc. For both military and civil aviation, it is desirable to be able to record on the display last minute information such as planned flight path, computed headings, diversion points, and similar data.

Complexity. This heading includes two subheadings, first, the complexity of the system as regards manual operations and settings to be performed in flight, and second, the complexity of the system from the standpoint of the maintenance technician.

Reliability. This is conventionally specified as the mean time between failures.

Logistics. This includes the problems associated with the preparation, revision, and distribution to forward bases of cartographic materials, and the procurement and distribution of electronic, electromechanical, and optical components of a map-display system.

Compatibility. The precision with which information displayed can be correlated with charts in current production should be evaluated.

Training requirements. To utilize the full capabilities of any cockpit display, the crew must be properly trained to use it. The extent of the training required should, therefore, be considered. And, by the same token, field maintenance will preferably be accomplished by personnel already in the manning tables. If the display system can be repaired and maintained by staff personnel without the need for manufacturer's representatives, the additional training required by staff personnel and the number of additional personnel required to maintain the equipment should be estimated.

Installation problems. The adaptability of the system to various cockpit and the retrofit requirements are also of major importance. Display systems are generally designed with more or less specific aircraft in mind. It should, therefore, be profitable to consider the possibility of installing the gear in cockpits other than the one for which it might have been designed.

Cost effectiveness. This should include not only the total cost in dollars to equip each aircraft, but also the bulk and weight cost in terms of loss in useful load or alternative gear.

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SUMMARY REPORT: DISCUSSION GROUP 6
TECHNOLOGICAL POSSIBILITIES IN MAP-DISPLAY SYSTEMS AND THEIR RESEARCH AND DEVELOPMENT IMPLICATIONS

Assuming that the technology of navigation hardware will some day provide a system whose accuracy and reliability approaches perfection, the question arises as to whether there will then be any need for cross checks on flight progress and hence any need for a map display. The group generally concluded that as long as there is a man in the loop, the need for a check system will exist. This conclusion is modified in that the degree of need is directly related to the mission. That is, the routineness of the flight, the nature of the target or destination, the number of alternatives to be dealt with, and other such considerations will determine how much the crew must depend on real-world display correlation to successfully carry out the mission. The psychological effects of total reliance on an automatic system without visual cross checks would also have to be considered. The greatest impact may be that the nature of the display, that is, the things which need to be displayed, may change.

Changing needs also occur as a function of the particular aircraft-crew-mission combination being deployed. Except for certain logistic support and airlift missions the needs of the military pilot differ considerably from that of the commercial pilot. Tactical and strategic needs are usually different because of altitude, range, and more especially differences in crew makeup. Certainly the single-place fighter pilot cannot afford the luxury of the wealth of information that can be used by a navigator in a bomber aircraft.

The cartographic industry attempts to meet these differing requirements by portraying various amounts of detail at various scales. This results of course in certain compromises since the infinite variety of needs cannot be fully treated with the limited numbers of chart series it is practical to produce. Since the new trend in cartographic production is toward putting all information in digital form to speed up the information-handling process, it may well be feasible to build an airborne display fed from a digital data bank. By the use of selective filtering techniques the pilot would then be able to have his display tailored to his particular mission. In addition to being able to vary scale, detail, and color, he could also select the mode which would provide the greatest ease in correlating the map display with radar, infra-red, or other sensor displays, and the ground scene as it appears under different seasonal and lighting conditions. Not the least of the advantages of this digital display would be the relative speed and ease of updating. On the other hand, this level of sophistication would probably be denied the man who needs it most, the single-place tactical aircraft pilot. Also, magnetic tape and other digital data storage media are not famous for their permanence. Another approach which might give greater flexibility with a lesser degree of complexity might be to use the conventional film storage medium in connection with optical filtering techniques.

Insofar as display techniques and hardware are concerned, it appears that several approaches hold promise and that the technology to explore them is fairly well advanced. On the other hand, our understanding of what needs to be displayed is somewhat less advanced. If a total improvement to the navigation problem is to be realized then an attempt must be made to improve each element of the system; that is, the navigation components, display hardware, and the graphics. The present R&D effort on navigation components is quite extensive and should be adequate. Display equipment has been slower in its development, perhaps because of a certain reluctance to consider a map display as a really firm requirement. However, this situation is changing, and so more rapid progress should be seen in the near future. As for the graphic, the main R&D effort has been slanted toward improving production with little emphasis on improving the content. This task has been left up to the joint efforts of the cartographers and the users. Lacking any scientific basis for determining what content will provide for best pilot performance, these people have had to rely solely on a subjective approach for chart design. It appears that an increase in the R&D effort in this area to provide pilot performance criteria for selection of optimum designs for selected typical mission profiles is necessary.

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CLOSING REMARKS

Col. Robert E. Herndon, Jr., USAF
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I'm glad our human relations during the last three days have been so cordial. I feel the objectives of the symposium have certainly been achieved. As a result of the fine papers and discussions, I believe that we all have much better information about the interests, needs, problems, and to some extent the restrictions imposed on each of our interest areas.

There seems to have been an initial feeling that there has been little interest in providing the necessary cartographic support for improving air navigation systems. I hope this feeling has been dispelled.

I have no illusion that all requirements will be met to the full extent that each of you may, today, envision. I say this because those who have heard all of the papers and discussions will recognize that there are many conflicting points of view on how to present information and what to present.

The matter of language to be used in stating requirements was raised. Each discipline--each weapon system--has its own language. Procedures used for exploration of requirements permits me to say that it doesn't make any difference which technical language is used. The point is that the user input does not, and cannot, stop at the time of a written submission of requirements. The process of first validating a requirement and then developing a prototype, as well as the longer range improvement of a fully developed end-item, must all involve continuing contacts, discussions, and inputs of the requester and the ultimate users. Remember that developers usually are not the ultimate users and that the ultimate users may not fully agree with developers' ideas and solutions.

In addition to the exchange of information, this symposium has provided a challenge for better expression of requirements and a challenge for action to meet the requirements.

I will say most sincerely, this has been the most interesting, beneficial, and best-run symposium that I have ever attended. This reflects the sincere interest of all participants, dedicated efforts of speakers, and the extremely well planned and executed ground work by our Chairman. The speakers are especially to be congratulated, and thanked, for their efforts in our behalf. It is recognized that their presentations formed the bulk of our base for discussion and understanding of what constitutes the problems which we must address, and the present and future opportunities and means for their resolution.

I was impressed by the degree of exchange, and I intend to explore the possibilities of future repetition of this kind of healthy exchange.

In closing, I am grateful for the opportunity to express my appreciation to all participants for the kind of interest which was indicated by their travel and devotion of time to the objectives of the symposium. It is not possible to recognize all those individuals who accepted extra tasks to make our meeting more valuable. But I must single out for special recognition the presence of the British and Canadian participants, and their outstanding contributions.

This symposium was made possible by the sponsorship of the Office of Naval Research and the support of the JANAIR committee. I express to Captain Kilpatrick our deep gratitude for recognizing the need for this type of exchange and for bearing the financial burden, which was substantial. Thank you, Captain Kilpatrick, for providing this much-needed symposium.

I have saved for the last my

expression of admiration and gratitude to our Chairman, Jim McGrath, who developed, organized, and controlled the symposium proceedings. We have all greatly benefited from his skill and dedication.

I ask you to join me in a standing expression of gratitude to Dr. McGrath for a job extremely well done.

IV
APPENDIX

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This is a partial list of the organizations represented at the symposium. The mailing address, telephone number, and names of key personnel are given for each organization listed, and a short synopsis describes the organization's experience and capability in the fields of technology related to the development of map-display devices.

The directory is a roster of some of the government and industrial organizations who are currently engaged in activities relevant to map displays. The directory may serve as a practical guide for those who seek information on map displays, by providing a general index to the capabilities of various organizations to deal with different types of map-display problems and their ability to respond to the wide variety of technological requirements that are encountered in the development of map displays.

The directory is incomplete. A number of organizations represented at the symposium are not listed, nor are many others who have experience and capability in map-display technology but were not represented at the symposium. Nevertheless, the directory includes most of the organizations who have been dominant in this area of technology.

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ACIC has developed and produced map displays for the following:

Tactical Situation Display (TSD). Installed in ADC's F106 intercepter aircraft. Uses 35mm film strip which contains navigational data in the form of a map image which is projected onto a screen in front of the pilot.

Tactical Air Positioning System (TAPS). Installed in low-performance USAF aircraft and Army helicopters in South Vietnam. This is a hyperbolic navigation system which uses a specially prepared paper flight strip. Present position and track of the aircraft is recorded on the chart by a stylus trace which is generated by the TAPS signals received.

Pictorial Situation Indicator (PSI). ACIC developed and produced film strip for ASD's contractor, Gilfillan, Inc., to be used in PSI equipment for laboratory demonstration and for a flight test program to be conducted in 1967.

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GIMRADA is the principal field agency of the Corps of Engineers for research and development in geodesy, engineer intelligence, and mapping, for application to both field and base plant operations.

GIMRADA is engaged in the development of microfilm cameras and equipment for the production of micromaps for use in display systems, and has furnished micromaps for support of a number of display systems developments.

The agency is also engaged in developing equipment and techniques for producing and processing map data in digital form, for use in automatic cartography as well as fulfillment of map user demands.

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The Army Map Service (AMS) is the Army's mapping and geodetic (M&G) agency. As such, it has experience in these areas and it has the capability to mass produce M&G products. It maintains an aggressive program to develop new products and methods to satisfy expressed user requirements and to use its resources more effectively. This is evidenced by new map products, such as the Pictomap, the Numerical (digital) Map, the Plastic Relief Maps, and the photogrammetrically compiled Lunar Maps. Most of these products involved the development of new technologies and methods.

The AMS employees who guide and direct these activities are both civilian and military. They stand ready to serve as the communication link between the cartographer and the systems designer developing new aeronautical charts and map display systems.

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SYNOPSIS:

Astronautics is experienced in optical projection from film; CRT dynamic display superposition; map coding, storage and retrieval; and engineering for special environment equipment.

Astronautics was instrumental in developing the HSD for the F-111, Mark II.

AVION ELECTRONICS, INC.

11 Park Place
Paramus, New Jersey 07652
(201) 261-4100

KEY PERSONNEL:

P. Fetko, President.
W. L. Portugal, Director of Marketing
B. Lichtenstein, Director of Engineering
S. A. Staniloff, Marketing Manager, Display Systems
H. Hammerstein, Manager, Navigation & Display Laboratory

SYNOPSIS:

Avion Electronics, Inc., has been engaged for more than ten years in the development of pictorial presentations of navigation data for aircraft. This has included direct-view maps, closed-loop television, CRT and optical projection techniques.

In the commercial area, Avion has been dominant in the pictorial display development work for the FAA, and has produced a number of Rho Theta pictorial displays that are compatible with VOR/DME receiver outputs.

For military applications, Avion has developed a family of HDV (horizontal direct-view) displays for light fixed-wing and helicopter aircrafts. These include an ADV (automatic direct-view) display for the Loran-D system. A major current program is the HSD (horizontal situation display) for the Navy's ILAAS (Integrated Light Attack Avionics System).

BELL HELICOPTER COMPANY

Box 482
Fort Worth, Texas
(817) 282-7111, Ext. 347

KEY PERSONNEL:

Dr. Dora J. Dougherty, Chief, Human Factors

SYNOPSIS:

The ANIP-JANAIR rotary wing version of contact analog display system was conceived and evaluated by Bell Helicopter Co. As part of this program, both simulator and flight tests were conducted on pilots' capabilities for using a pictorial map display within the contact analog system.

BELOCK INSTRUMENT CORPORATION

112th St. & 14th Avenue
College Point, New York 11356
(212) 445-4200

KEY PERSONNEL:

B. Bullwinkel, General Manager, Information Display Systems
H. R. Epstein, Staff Engineer

SYNOPSIS:

Belock Instrument Corporation is currently engaged in design and construction of large screen dynamic display systems utilizing their recently developed Scopus series of high-speed projectors. The plotting projectors in this series utilize a flexible strip-film plotting medium with projector capacities to 2000 frames. Reference and spotting projectors are also available. The Scopus series is ideal for use in military command systems, air traffic control and business management problems. Display systems can be designed to interface directly with all types of digital or analog computers for graphical portrayal of information, text writing or situation analysis. Auxiliary equipment, such as character and vector generators can also be supplied.

Belock Instrument Corporation is also engaged in the development of high-resolution, single- and dual-axis electroluminescent displays. These displays are well suited for airborne or mobile command centers where space conditions and the equipment preclude the use of other display techniques.

BRITISH EMBASSY

Defense Research & Development Staff
3100 Massachusetts Ave.
Washington, D. C.
(202) 462-1340

KEY PERSONNEL:

Dr. W. B. Littler, Head of Staff
R. V. Whelpton, Director, Guided Weapons & Electronics
J. J. Gait, Assistant Director, Guided Weapons
Dr. A. N. Mosses, G.W.I. Section (Air Missiles)

SYNOPSIS:

The Embassy staff represents British organizations, such as the Royal Aircraft Establishment, Farnborough, which have actively studied the influence of map form on the success of aircraft navigation and target acquisition from low altitude.

CANADIAN MARCONI COMPANY

2440 Trenton Avenue
Montreal, Quebec, Canada

KEY PERSONNEL:

W. V. George, President
W. R. Bitcheno, Vice President, Commercial Products Division
K. C. M. Glegg, General Manager, Avionics Department
A. E. Kennedy, Sales Manager, Avionics Department

SYNOPSIS:

In 1952 the Canadian Marconi Company commenced development work on a reliable, self-contained, navigation system for aircraft. By 1958, the first FM/CW Doppler sensors were offered as production equipment, and since then the company has supplied more than 3000 Doppler sensors and over 2500 navigation computers to commercial and military users throughout the free world. Air France, Alitalia and KLM are three of the leading commercial airlines who use CMC Doppler sensors in their DC-8 and B-707 aircraft.

The CMA-668 Doppler sensor is representative of the third generation of sensors being developed by CMC. This equipment is characterized by small size, light weight, and high reliability. Circuits are solid-state throughout, including the transmitter, and wide use is made of microelectronics. A patented beam intersection technique obviates the sea-bias error which has limited the accuracy of previous Doppler systems when operating over water. In addition, Built-In-Test-Equipment and integral altimetry are also incorporated.

Work on the development of this family of sensors has been in progress at CMC for several years. In particular, the development of a supersonic Doppler was undertaken and successfully carried forward.

COMPUTING DEVICES OF CANADA

Box 508
Ottawa 4, Ontario, Canada
(613) 829-1800

KEY PERSONNEL:

R. I. Macnab, Marketing Specialist
D. W. Anderson, Display Systems Engineer
R. J. Struzina, Display Project Engineer

SYNOPSIS:

Computing Devices of Canada has built three developmental models of a projected moving-map display using 20 feet of 35mm, Kodachrome II, color positive, film strip. These three models have been tested in three major flight-trial programs in the Royal Air Force, the French Army Light Aviation Group, and the Royal Canadian Air Force. The first trial started in 1963 and the last was completed in 1965. Using this experience CDC is now bringing a 35mm moving-map display to production status.

CONCORD CONTROL INC.

1282 Soldiers Field Road
Boston, Massachusetts 02135
(617) 254-5106

KEY PERSONNEL:

J. O. McDonough, President
H. P. Grossimon, Vice President, Engineering
J. R. Fadiman, Sales Manager

SYNOPSIS:

Over the past seven years Concord Control Inc. of Boston, Massachusetts, has established a leading position as a manufacturer of equipment for automated cartography. The line of Concord equipment now includes precision plotters, manually controlled and semi-automatic line and point digitizers, text processors, precision automatic scanners, and a unique new system which provides on-line collaboration between a cartographer and a computer for compilation, analysis, generalization, and color separation. Since each of the Concord instruments has been developed to meet the specific needs of one or more of the map production agencies of the U. S. Department of Defense, they all provide an extraordinary degree of reliability under continuous multi-shift production operation. In addition, these instruments have been designed to provide line and image quality, accuracy, and sensitivity of a sufficiently high order to eliminate effectively the machine as a contributor to the errors of the finished map.

Concord Control has provided precision photo-coordinatograph systems for the automatic production of maps and charts to the U. S. Naval Oceanographic Office, the Aeronautical Chart and Information Center, and the Army Map Service. Two additional precision coordinatograph systems are under construction for the U. S. Naval Oceanographic Office, one for the Nautical Branch, and the other for the Aeronautical Branch. Complete automatic type placement systems constructed by Concord Control are in use by the Army Map Service and the Aeronautical Chart and Information Center. Concord graphic data digitizers are being used by the Army Map Service and Rome Air Development Center for tracing and recording contour lines from topographic maps and putting this information into digital form.

DECCA NAVIGATOR COMPANY LTD

9 Albert Embankment
London, SEI, England
Reliance 8111, Telex 28588 (London)

KEY PERSONNEL:

G. E. King
T. S. Kitching
M. Pearson

SYNOPSIS:

The Decca Navigator System is a

ground-based radio hyperbolic position-fixing system. The Decca Navigator Company started commercial operation in 1946 and the system is now used by more than fifteen thousand ships and aircraft of many nations for both civil and military applications.

Decca chains at present cover approximately six million square miles of the earth's surface including Europe, the eastern seaboard of North America, India and the Persian Gulf. Further chains are under construction or being planned. Many temporary chains are in use throughout the world for hydrographic and geophysical surveys and technical applications.

The Decca Navigator Company pioneered the presentation of navigational information on a pictorial display known as a Flight Log (in aircraft) and the Track Plotter (in ships). The Company has its own charting section which supplies the many different types of charts for Flight Logs and Track Plotters in use throughout the world.

As a development of the Flight Log, Decca produces the Roller Map as a pictorial display of navigational information derived from self-contained systems such as Doppler and Inertial. Flight Logs and Track Plotters normally use charts prepared by the Decca Navigator Company. Roller Maps use standard aeronautical chart.

DIRECTORATE OF MILITARY SURVEY (U. K.)

Ministry of Defence
Old War Office Building
London, S. W. 1, England

KEY PERSONNEL:

Brigadier B. St. G. Irwin, Director
Col. J. Kelsey, Colonel in Charge of Survey
I. D. Dawson, Liaison Officer in USA

SYNOPSIS:

The Directorate is responsible for the production of military land maps and air charts for the Royal Air Force and Civil Aviation. It publishes charts to meet a wide variety of requirements at a wide range of scales and has been involved for a number of years in designing charts suitable for navigational displays.

EASTMAN KODAK COMPANY

343 State Street
Rochester, New York 14650

KEY PERSONNEL:

W. S. Vaughn, Chairman, Board of Directors
Dr. L. K. Eilers, President
M. W. Gabel, Executive Vice President

SYNOPSIS:

Eastman Kodak Company is primarily a manufacturer of sensitized materials, chemicals, equipment and systems to fulfill and serve requirements in various fields of photography. Certain of these components are vital to successful development and operation of map-display equipment and systems. Kodak has had substantial experience in the application of photographic technology in satisfaction of the needs in the fields of cartography, map display, and related areas.

Kodak lithographic sensitized materials, chemicals, and equipment which are used broadly in the graphic arts industry are basic tools of map reproduction. Photographic emulsions coated on glass and dimensionally stable films satisfy the precise requirements of the mapping community. Extensive background in optics and projection systems together with experience in selection of the appropriate photographic materials combine to qualify Eastman Kodak Company engineers to handle map-display problems.

ENVIRONMENTAL SCIENCE SERVICES ADMINISTRATION

11800 Old Georgetown Road
Rockville, Maryland 20852
(301) 496-8189

KEY PERSONNEL:

Dr. R. M. White, Administrator

RADM. J. C. Tison, Jr., Director, Coast & Geodetic Survey
G. B. Littlepage, Jr., Assoc. Director, Office of Aeronautical Charting and Cartography

SYNOPSIS:

The mission of the Environmental Science Services Administration is to construct, produce, maintain and distribute aeronautical charts to satisfy all requirements of civil aviation for planning and conducting flight operations in the United States under both instrument and visual flight rules. It is also to provide charts for long-range intercontinental flights as required by civil aviation.

In addition the Environmental Science Services Administration conducts research to improve the presentation of data on the characteristics of the earth and electronic navigational systems to meet the changing requirements of aviation, to further improve the efficiency of our techniques and procedures in preparing graphic portrayals of the airspace environment, and provide ways to produce better charts more quickly and at less cost.

FEDERAL AVIATION ADMINISTRATION

National Aviation Facilities Experimental Center
Atlantic City, New Jersey 08405
(201) 641-8200, Ext. 2318

KEY PERSONNEL: (Test and Evaluation Division)

B. V. Dinerman, Acting Section Chief, Principal Engineer
H. D. Dunkei, Electronic Engineer
M. S. Plotka, Electronic Engineer

SYNOPSIS:

The National Aviation Facilities Experimental Center (NAFEC) has been concerned with civilian-oriented pilot and crew display and computation systems since 1958. The systems vary from small, discrete information systems to area navigation systems that are used in general and commercial aviation in both fixed wing and helicopter aircraft. Typical navigation devices and systems that have been tested are as follows:

1. Pictorial Displays (rho-theta)
2. Pictorial Displays and Course Line Computer (rho-theta, rho-rho-theta).
3. Computer Driven Panel Displays (theta, rho-theta, rho-rho-rho).

NAFEC is capable of precision laboratory and airborne testing and evaluating of airborne navigation devices and systems. The laboratories and facilities include the following:

1. Airport Environment which is simultaneously operational and a test-bed facility. Its largest runway is 10,000 ft. by 200 ft.

2. Aircraft Environment which includes all types of aircraft flown by experienced pilots world-wide from NAFEC where they are maintained and instrumentation-modified as per project requirements.

3. Surveillance Radar Environment which includes the Radar Facility, the Airport Surveillance Radar Facility, the Airport Surface Detection Equipment Radar Facility and the Air Route Surveillance Radar Facility.

4. Navigation Aids Environment which includes VORTAC and DOPPLER VOR-1 Facilities.

5. Range Instrumentation Environment which includes Phototheodolites, the Terminal Area Instrumentation Radar (TAIR), the Extended Area Instrumentation Radar (EAIR) and the Range Control Facility (timing).

6. Simulation Environment which includes the F100A cockpit, two P3A, Piper Cherokee and Cessna 182 trainers and a Cartographic Service Unit.

7. Computation Environment which includes the IBM 1401 and 7090 Computer Systems with electric accounting machine, programming and computer operations services for data reduction and analysis.

8. Services Facilities Environ-

ment which includes Drafting and Reproduction, Mechanical Laboratory, Standards and Calibration Laboratory, Weather Information Facility, and Photographic Services Facility.

FEDERAL AVIATION AGENCY

Approach and Landing Branch,
RD-320
800 Independence Avenue, S. W.
Washington, D. C. 20553
(202) 962-7125

KEY PERSONNEL:

R. D. Munnikuysen, Chief, Approach and Landing Branch
L. N. Spinner, Chief, Airborne Systems Section
J. M. Del Balzo, Project Manager
W. M. Russell, Representative to Advisory Committee on Flight Information

SYNOPSIS:

The Approach and Landing Branch of the FAA has sponsored and managed considerable development and evaluation of pictorial navigation chart displays for use primarily with VORTAC navigation systems. Current projects include advancement of such displays. The branch also has a member on the FAA Advisory Committee on Flight Information. This committee reviews requirements and problem areas in flight information publications, including charts for civil use.

FERRANTI LTD.

Ferry Road
Edinburgh 5, Scotland
DAvidson's Main 2231

KEY PERSONNEL:

D. M. McCallum, Manager, Electronic Systems Department
T. S. Briggs, Product Manager, Displays
J. Braid
L. R. Miedzybrodzki

SYNOPSIS:

Ferranti has been actively engaged in the map-display field since 1960. Current products include projected displays for both military and civil aircraft. Map displays for land vehicles are also made. In addition a considerable amount of work has been done in the field of combined radar - ground-mapping/moving-map displays. Ferranti also has experience in the preparation of film strips for map displays and in the photographic manipulation of map projections for special purposes.

GALIPAULT & ASSOCIATES

Box 304
Worthington, Ohio 43085
(614) 885-1172

KEY PERSONNEL:

J. B. Galipault, Principal Researcher and Owner

SYNOPSIS:

G&A has conducted several studies dealing with pilot-aircraft compatibility during very low altitude flight (VLAF). Mr. Galipault has conducted two VLAF pilot training courses for 10 experimental test pilots (NAA & US NATC Patuxent River). G&A is and will continue to conduct empirical studies in VLAF navigation. These studies include evaluation of basic navigation procedures, devices, and cartographer depictions.

G&A has an interdisciplinary research team composed of Ph.D.'s and experts in aviation psychology, aviation medicine, aerodynamics, cartography, human factors, operations research, systems research, and pilot training. Descriptive brochures are available on request.

HARRIS-INTERTYPE CORPORATION

55 Public Square
Cleveland, Ohio 44113
(216) 861-7900

KEY PERSONNEL:

T. C. Noon, Vice President, Research & Engineering
W. C. Roberts, Director of Research
H. M. McConnell, Product Manager

SYNOPSIS:

The Harris-Intertype Corporation engages in electrophotographic imaging material research and development. It also engages in the development of electrophotographic printing machines.

Harris-Intertype has supplied U. S. Army Engineer GIMRADA with engineering test models of a one-color EP map printer, a five-color EP map printer and two operational test models of a five-color EP map printer.

HONEYWELL INC.

Systems and Research Division
2700 Ridgway Road
Minneapolis, Minnesota 55413
(612) 331-4141

KEY PERSONNEL:

Dr. L. G. Williams, Senior Principal Research Scientist
R. C. McLane, Research Staff Engineer

SYNOPSIS:

Honeywell has several research programs directed toward increasing the effectiveness of information transfer across the man-display interface.

In our program the process of extracting information from displays is being intensively studied. The basic tenet is that the observer acquires discreet items of information from displays by a sequence of visual fixations. These fixations, in turn, depend on what can be perceived in the extra-foveal visual field.

The observers' fixations are determined by a precise measurement technique as a function of the perceptual task, the color, lightness, size, and shape of the target information, and of various background parameters. An important program objective is to obtain data and develop a model for predicting search times for displays in general. Our application of this work is the creation of a technique for optimum coding of information. In a study just completed the technique was used to evaluate image-enhancement procedures that modify the luminances of displayed objects. In addition, training apparatus has been constructed for providing the observer with immediate feedback concerning various aspects of his fixation behavior. Two other programs are determining what basic display format is most effective for manned vehicle control and navigation. Contact analog or pictorial navigation displays and symbolic vertical and horizontal situation displays have been studied in man-in-the-loop dynamic simulator environments. In submarine, VTOL, and helicopter displays, scale factor, coordinate reference frame, quickening, other pilot aids have been studied to improve information transfer. A hybrid computer facility with extensive alpha-numeric and vector display repertoire offers an experimental tool of considerable power for these research studies.

HUGHES AIRCRAFT COMPANY

Signal Processing and Display Laboratory
Mail Station X-156
Culver City, California 90230
(213) 391-0711

KEY PERSONNEL:

E. E. Herman, Manager, Signal Processing and Display Lab.
S. N. Roscoe, Manager, Display Systems Dept.
C. T. Carroll, Manager, Display Development Dept.
L. M. Seeberger, Manager, Display Projects Staff

SYNOPSIS:

Since 1953, Display Systems Department has been active in the design, development, and production of airborne navigation, radar, and multisensor display equipment. In addition, since 1955 the Department has had continuing effort placed in the area of simulation and simulator hardware design and development.

Development of a complex airborne pictorial (map-type) navigation display was begun in 1953 under the direction of Dr. S. N. Roscoe. This effort resulted in the production of the MA-1 Horizontal Situation Display for the F-106 all-weather interceptor aircraft. To date almost 1000 of these units have been produced, and they have been in operational service with the Air Defense Command throughout the 1960s.

In 1957, development was started on an optical projection-type navigation and attack display for the An/ASG-18 weapon system. This display is called the Horizontal Tactics Indicator (HTI). It presents continuous computer-driven displays of present aircraft position, target position, and navigation point against a projected chart on a 10-inch diameter viewing screen. Any one of 256 charts contained in a film cassette may be randomly selected for viewing. This display has been undergoing flight evaluation tests in the YF-12A at Edwards Air Force Base for the past three years.

Recently the design and fabrication was completed for a navigation display for the Hughes Aircraft Company TARAN system being installed in Swiss Air Force aircraft. The unit provides a moving map, stationary symbol display and can operate in either a Heading-up or a North-up mode. Approximately 100 of these units have been manufactured, and they are currently going into operational service.

HUMAN FACTORS RESEARCH, INC.

Santa Barbara Research Park
6780 Cortona Drive
Goleta, California 93017
(805) 968-1071

KEY PERSONNEL:

Dr. R. R. Mackie, President
Dr. D. N. Buckner, Executive Vice President
Dr. J. J. McGrath, Vice President

SYNOPSIS:

HFR was organized in 1952 to provide services to government and industry in basic and applied research on human performance in complex systems. Since that time, research has been conducted for over 100 different clients in every major field of experimental and engineering psychology.

The company currently employs 50 people. The professional staff includes specialists in the fields of experimental and industrial psychology, engineering, physics, mathematics, physiology, sociology, and opinion measurement.

Some of the current research projects related to air navigation and map displays include experimental studies of: geographic orientation in aircraft pilots, image-interpretation performance, electronic information displays, optical interferometry display techniques, visual search and target acquisition, and training of complex performance skills.

INSTITUTE FOR DEFENSE ANALYSES

Army-Navy Drive
Arlington, Virginia 22202
(703) 558-1000

KEY PERSONNEL:

Dr. J. Orlansky

SYNOPSIS:

IDA performs analytical studies and evaluates current technology for the Director of Defense Research and Engineering, Department of Defense, and his staff and for the Advanced Research Projects Agency, Department of Defense. The general purpose of these studies is to make recommendations for new programs of research and development important for military security.

INTERNATIONAL AERADIO LTD.

Aeradio House, Hayes Road
Southall, Middlesex
England
Southall 2411

KEY PERSONNEL:

C. F. Burton, Superintendent, Flight Documentation

SYNOPSIS:

The Aerad Division of I.A.L. has been supplying to airlines, air charter companies, executive and private flyers, all forms of aeronautical charts and supporting documentation, since 1947. Its key personnel have been engaged in the same work in earlier organizations since 1930. The current service provided by the Division is in the form of the Aerad Flight Guide, subscribers to which receive up-dated charts, for the enroute, instrument approach, let-down, and landing phases of air operations, every week. The coverage available is world-wide. The Division is currently working with Ferranti's of Edinburgh in producing specially drawn charts for the moving-map display.

ITEK CORPORATION

Government Systems Division
10 Maguire Road
Lexington, Massachusetts 02173
(617) 862-6200

KEY PERSONNEL:

R. Naiman, Vice President
E. Morse, Manager, Operations Directorate
C. Chambers, Manager, Data Analysis Center
B. Aschenbrenner, Manager, Graphic Systems Information

SYNOPSIS:

Itek's Operations Directorate is concerned with the development of advanced reconnaissance and surveillance systems including electro-optical applications, image stabilization, low-light-level systems, and navigational and computer systems. It is concerned with the design and development of panoramic and high-resolution cameras, multi-bank spectral and IR sensors.

Itek's Graphic Information Directorate is concerned with the development of specialized photographic printing and processing equipment. This equipment includes stereo-viewing and image-projection systems, color printers and processors, moving photointerpreter displays, rectifiers, and cartographic data reduction.

Itek Data Analysis Center in Arlington, Virginia, is staffed with photointerpreters and photogrammetry experts.

ITT GILFILLAN INC.

1815 Venice Boulevard
Los Angeles, California 90006
(213) 381-3441

KEY PERSONNEL:

A. J. Brown, Chairman of the Board
E. S. Phillips, President

SYNOPSIS:

ITT Gilfillan Inc., primarily known as a radar manufacturer, has developed Horizontal Situation Indicators, i.e., airborne moving-map displays, for the Armed Forces and for NASA. These include displays for helicopters, fighter aircraft, and for V-STOL and SST-Research. Designs are based on advanced techniques for combined optical and cathode-ray-tube imagery and a new concept of navigational chart logistics in the form of microchart chips.

JEPPESEN & COMPANY

8025 East 40th Avenue
Denver, Colorado 80207
(303) 388-5301

KEY PERSONNEL:

C. F. Pizac, President
W. A. Rosenkrans, Senior Vice President
E. H. Moerer, Treasurer/Controller

J. R. Dickinson, Vice President, Plans & Programs Develop.
J. H. Davis, Vice President, Services Div.
M. J. Sommovigo, Manager, Washington Office
W. A. Prescott, Vice President, Gen'l Aviation Marketing

SYNOPSIS:

Jeppesen & Company has been engaged in the business of producing cartographic compilations, drafting, and publishing maps and aeronautical navigation charts and flight information for over 32 years. Jeppesen & Co. additionally has been involved in various production, research, and development projects directly related to several types of automatic airborne navigational displays. Jeppesen & Co. has provided charts, transparencies, and film especially tailored for research PD/CLC programs undertaken by both government and private electronic manufacturing firms during the past 12 years.

LATADY DEVELOPMENT COMPANY, INC.

38 West Nippon Street
Philadelphia, Pennsylvania 19119
(215) 248-1655

KEY PERSONNEL:

W. R. Latady, President
Gordon Kitching, Vice President
Richard Kuehner, Mechanical Engineer

SYNOPSIS:

Latady is the custom designer, developer and manufacturer of precision optical, mechanical, and photographic instruments. The Latady product line includes a high-precision micromap camera for making 70mm chips and attachments for 35mm, 105mm, 5 and 9-1/2 inch film. Latady also manufactures versatile stereoscopes for photo interpretation and high-resolution lenses for the micromap camera.

Latady maintains a service field group for performance in the disciplines of Oceanography and highway surveillance. This group is versed in stereophotography and strip photographic techniques (shutterless camera) for obtaining data under unusual conditions. Field projects have been conducted both nationally and internationally.

LEAR SIEGLER INC.

Instrument Division
4141 Eastern S. E.
Grand Rapids, Michigan 49508
(616) 241-7788

KEY PERSONNEL:

T. Hainsworth, Department Head, Control-Display Systems
A. Ranford, Project Engineer, Map Displays, CDS
M. Olinger, Principal Staff Engineer, IFCS
J. Fellinger, Section Head, CDS

SYNOPSIS:

Lear Siegler is presently building twelve prototype map displays for the U. S. Coast Guard/FAA LORAN navigation system. This display is a cartridge-type fixed map with moving bug. A permanent trace of aircraft track is available by perforating maps every 10 seconds during mission. This display can be removed from holder and either held in hand or stored while operating. It is used primarily for over-water search-and-rescue missions and utilizes any standard air navigation chart. The chart edge is encoded for map indexing and automatic update when changing maps (handled by associated computer).

Lear Siegler has developed a film projection display for space simulator use; utilizing a moving-map concept. It is in operation at USAF-FDL Wright-Patterson AFB, Dayton, Ohio.

Lear Siegler has developed a cartridge-type map display with capability of storing and automatically selecting up to 12 different charts. It has the capability for integral electroluminescent (EL) lighting.

MINNESOTA MINING AND MANUFACTURING COMPANY

2301 Hudson Road
St. Paul, Minnesota
(612) 733-5796

KEY PERSONNEL:

M. R. Marquardt, Supervisor, Office of Contract Research Liaison
J. B. Gergen, Manager, Special Graphic Systems

SYNOPSIS:

The 3M Company manufactures more than 35,000 industrial and consumer products, many of which are standard items of daily use in the cartographic field. These products include *Dynacolor* films, *Wallensak* optical equipment and lenses, pre-sensitized lithographic printing plates, various magnetic recording tapes, and microfilm (including the 3M brand ADP aperture card).

Some recent 3M developments of particular interest to the cartographic/navigation-display community include a dry-process, rapid-access, *Dry Silver Film* for duplicating high-resolution transparencies from aerial negatives, a corresponding *Dry Silver Paper* for the rapid printing of high-quality enlargements from aerial negatives, and a wide-width, single-unit, *Printer-Processor* for use with the *Dry Silver Paper*.

Development of the 3M *Electrocolor Printer* for ultra-high quality color photographic reproduction is also of interest as an advancement in map-display technology.

NAVAL AIR DEVELOPMENT CENTER

Johnsville, Pennsylvania
(215) 675-7000

KEY PERSONNEL:

Capt. B. L. Towle, Commanding Officer & Director
Dr. H. Krutter, Technical Director

SYNOPSIS:

Currently NADC serves as technical manager for IHAS and ILAAS avionics systems, both of which utilize direct-view, multi-mode, moving-map display equipment. NADC has the capability of in-house research and development in areas of new display techniques, cockpit technology, simulation, and human factors.

NAVAL MISSILE CENTER, PT. MUGU

Human Factors Engineering Branch
Pt. Mugu, California 93041
(805) 488-3511, Ext. 8981

KEY PERSONNEL:

LCDR R. J. Wherry, Jr., Head, Human Factors Engineering Branch
O. Powers
Dr. K. Cross
P. Abbott

SYNOPSIS:

The Human Factors Branch is proceeding to install and perform preliminary test and evaluation on the JANAIR vertical (GE) display and Bell Helicopter 6DF Simulator. Basic sensitivity (thresholds) for various display elements will first be determined, subsequently flight missions will be simulated, using navigation and flight control systems. One aspect of these simulated exercises will involve the human interface efficiency in transitioning between navigation and flight control instruments. In some instances disorientation may be anticipated due to time-critical sampling and sharing of displays, in combination with ambiguous signals. Our interest will be in minimizing inadvertent ambiguities of this sort.

NAVAL OCEANOGRAPHIC OFFICE

Washington, D. C. 20390

KEY PERSONNEL:

RADM. O. D. Waters, Commander
Dr. C. C. Bates, Scientific & Technical Director
W. R. Nunn, Jr., Director,

Aeronautical Div.
W. R. Campbell, Chief, Aeronautical Requirements Analysis Br.
H. M. Abraham, Project Manager, Aeronautical Requirements Analysis Br.
C. V. McFadden, Director, Lithographic Div.
D. D. Choha, Technologist, Lithographic Div.

SYNOPSIS:

In addition to its mission in Oceanography, the U. S. Naval Oceanographic Office (NAVOCEANO) serves as the Navy's mapping and charting agency. As a part of this latter responsibility, NAVOCEANO conducts research and development projects to provide systems and techniques for the rapid collection, analysis, and application of data for navigation purposes.

In support of the Naval Air Systems Command, NAVOCEANO has initiated exploration into the aeronautical charting/airborne navigation display interface problems for the optical projection and roller-map type of horizontal situation displays.

Efforts to date included development of production techniques for making quality miniaturized graphics in color, preparation of a handbook on the cartographic considerations in navigation display design, and modification of chart compilation practices to permit easier production of special purpose charts.

NAVOCEANO, typical of the Department of Defense mapping and charting community, has a considerable wealth of knowledge and experience in cartographic engineering and the graphic sciences which can be used effectively to provide cartographic support for present and proposed navigation display systems.

NAVAL ORDNANCE TEST STATION

China Lake, California 93555
(714) 377-7411

KEY PERSONNEL:

E. Park, Head (Code 3516)
R. Erickson, Research Physicist (Code 3515)
Carol Burge, Mathematician (Code 3515)

SYNOPSIS:

The U. S. Naval Ordnance Test Station maintains the capability for flight testing of navigational systems, terrain clearance radars and associated displays. At present it is engaged in the analysis of display requirements for a major Navy missile system.

N. A. A. AUTONETICS

3370 E. Miraloma Avenue
Anaheim, California 92803
(714) 772-8111

KEY PERSONNEL:

Dr. R. H. Wright, Research Specialist, Human Factors
Dr. H. L. Snyder, Group Scientist, Human Factors
J. S. Sweeney, Manager, Display Systems
M. G. Kroger, Vice President, Information Systems

SYNOPSIS:

Autonetics' capabilities are in three major areas. One is the evaluation, in controlled laboratory simulation and flight test studies, of the effectiveness of various navigation information display techniques. The Human Factors Department has a unique VFR simulation facility in which a 60° x 160° field of view can be dynamically presented to the subject; it also has a large supply of 70mm, low altitude, color motion picture films for use in the facility.

A second capability is in the design and development of navigation display systems. The Display Systems Department is currently building a prototype of a device which will present a two-dimensional perspective view of navigation data taken automatically from contour maps.

A third capability is in the design and development of information processing systems. The Information Systems Division has demonstrated the feasibility of generating maps when more than half of the data upon which maps are normally based is missing.

simulators; research in the extraction of information from sensor system displays.

OFFICE OF NAVAL RESEARCH

Psychological Sciences Division
Washington, D. C. 20360

KEY PERSONNEL: (Engineering Psychology Branch)

Dr. J. W. Miller, Head, Engineering Psychology Branch
M. J. Farr, Asst. Head, Engineering Psychology Branch

SYNOPSIS:

The Engineering Psychology Branch of the Office of Naval Research has a contract program which includes many facets of human factors. In the past, several contracts have been devoted to problems related to displays and, in particular, to aircraft displays. Currently, we have one or two contracts related to the display of information which might ultimately contribute to the state-of-the-art on maps and briefing aids.

PHOTICS RESEARCH CORPORATION

Box 337
Montgomeryville, Pennsylvania 18936
(215) 368-0330

KEY PERSONNEL:

G. H. Hamlin, Jr., President
G. H. Landis, Vice President, Engineering
R. A. Bruner, Vice President, Operations

SYNOPSIS:

Photics Research specializes in compilation of maps to established specifications; studies leading to the development of new map specifications for special purposes; photo miniaturization of graphics in color and black-and-white for information storage and retrieval systems; development and preparation of analog devices for storage of terrain data for use in simulators; research in the extraction of information from sensor system displays.

RAND McNALLY & COMPANY

Box 7600
Chicago, Illinois 60650
(312) 267-6868

Rm 1104, National Press Building
Washington, D. C.
(202) 628-2608

KEY PERSONNEL:

R. L. Voisin, Vice President, Cartography
T. S. Hermes, General Marketing Manager
R. R. Randall, Manager, Washington Office

SYNOPSIS:

Rand McNally & Company has developed specifications for VFR and IFR chart preparation, design, compilation and duplication. Facilities exist for chart design, compilation, photographic and lithographic reproduction, and also distribution. Present activities include maintenance of VFR (high and low altitude) charts for the U. S. Air Force and preparation of 1:500,000 scale charts for civil and military use.

ROYAL AIRCRAFT ESTABLISHMENT

Farnborough, Hants, England
Aldershot (Hants) 24461

KEY PERSONNEL:

H. G. R. Robinson, Head, Instrument & Electrical Engineering Dept.
Dr. G. E. Roberts, Head, Bombing & Navigation Systems Div.
K. R. Honick, Head, Topographical Display Sect.

SYNOPSIS:

The Royal Aircraft Establishment is the principal British Government center for aeronautical and allied equipment research and development responsible to the Ministry of Aviation for satisfying the needs of the Defence Department.

The first pictorial navigation display in the U. K. was conceived, developed, constructed, and flight tested by the Instrument and Electrical Engineering Department; and development is still proceeding. Experimental resources are supported by design and production facilities sufficient for the production of engineering prototypes. Further development and production is undertaken by industry. The department has also been responsible for development of the microphotographic techniques required for film-strip production and possesses experimental production capability in this field. It is not, however, responsible for quantity production.

SPERRY GYROSCOPE COMPANY

Great Neck, New York 11020
(516) 574-1025

KEY PERSONNEL:

S. A. Conigliaro, Vice President for Systems Management

SYNOPSIS:

Sperry Gyroscope Company has been engaged in developing the first ILAAS (Integrated Light Attack Avionics System). This system incorporates the most advanced pilot aids yet devised. During a flight, the pilot can put the position of his destination into a computer and then receive a continuous indication of his location and desired course on a "horizontal situation display" in his cockpit.

When attacking a ground site, the pilot can use a cockpit "vertical situation display" showing terrain profiles. This helps him maintain minimal altitude above the ground and avoid obstructions on low-level flights in all weather.

ILAAS also includes a "Head Up Display" in which a representation of the landing area is projected on a transparent screen at the level of the pilot's eyes. This "HUD" allows him to follow instrument signals while his eyes are in normal visual flight position. He receives piloting cues, including target and landing perspectives, and thus can operate and land more efficiently in all weather.

STANFORD RESEARCH INSTITUTE

333 Ravenswood Avenue
Menlo Park, California 94025
(415) 326-6200

KEY PERSONNEL:

T. E. Stanley, Manager, Systems Analysis Dept.
Dr. K. Kryter, Director, Sensory Sciences, Research Center
Dr. P. E. Merritt, Manager, Information and Control Laboratories

SYNOPSIS:

Stanford Research Institute performs theoretical and experimental research for commercial, military, and governmental clients. The Institute also develops experimental or prototype equipment, but does not accept production contracts. SRI has capabilities in graphics, digital maps, psychology and human factors, air traffic, navigation, data handling, computer-aided simulation of military operations, military field experimentation, operational analysis, systems analysis, electronics, servomechanisms and control theory, optics, and mathematics. To support research in these fields SRI has model shops, computer facilities, and chemical, optical, electronic and graphic laboratories.

Research has included all the standard printing processes (letterpress, wet and dry lithography, gravure, intaglio, silk screen) and unique multi-color electrostatic printing processes. Diazo, electrophotographic and diffusion-transfer processes have been investigated. Special inks have been developed for studies of printability, and most notably for imprinting magnetic characters on commercial checks. Checks are now handled all over the world by this system which SRI developed. SRI has digital maps for parts of Okinawa, Korea, Vietnam, Iran, Germany and

California, the latter two giving vegetation and elevation. Psychological studies have included visual detection of signals in the presence of noise, and mathematical modeling of human perceptual and motor behavior. The Institute has an extensive data bank on air traffic all over the world.

UNITED AIR LINES, INC.

O'Hare International Airport
Chicago, Illinois 60666
(312) 625-1400, Ext. 2292

KEY PERSONNEL:

M. V. Cochran, Manager, Navigational Aids
T. G. Angelos, Staff Engineer, Navigational Aids

SYNOPSIS:

United Air Lines is investigating pictorial map-display devices with the objective of determining operational benefits for air carrier applications. Although not engaged in cartographic work, we are investigating chart-display methods of presenting to the pilot a realistic "picture" of terrain and obstructions, particularly in terminal airport areas.

UNITED AIRCRAFT CORPORATION

1690 New Britain Avenue
Farmington, Connecticut
(203) 677-9731

KEY PERSONNEL:

C. W. Williams, Manager, Information Systems Planning
R. W. Sweetnam, Technical Director, Human Factors
H. F. Wienberg, Marketing Specialist

SYNOPSIS:

The United Aircraft Corporate System Center maintains a staff and the appropriate disciplines necessary to perform problem solving in system analysis, requirements definition and validation, hardware and computer programming specifications, as related to acquisition, compilation, cartographic analysis, mapping and charting problems. The corporation utilizes automation equipment of many types including computation, reproduction, and analysis equipment to solve problem-oriented system requirements. The experience and capability included integrated aircraft display research, computer controlled graphics, digital transmission and display of weather maps, cartographic requirements and system analysis, data compaction, correlation, curve smoothing, data-bank and data-base analysis, display devices, digital mapping systems, guidance, control and navigation systems. Included in their experience are such systems as 433L, digital mapping system, graphic data handling of cartographic information, lexical processing and cartographic experiments in color separation.

USAF 6570th AEROSPACE MEDICAL RESEARCH LABORATORIES

Wright-Patterson Air Force Base
Ohio

KEY PERSONNEL:

Col. R. A. Yerg, Commander

SYNOPSIS:

The 6570th Aerospace Medical Research Laboratories plans, formulates, and executes the AMD (AFSC) program of exploratory development and assists in timely systems applications in the assigned technical and functional sub-areas of life support and human performance in the aerospace operational environment. This includes environmental effects, techniques, and equipment for well-being, protection, and performance enhancement in the following sub-areas: mechanical accelerating and related forces and energies; altitude; thermal; toxic hazards; bionics; human engineering and training; and nutritional support. Conducts in-house research to advance the state-of-art knowledge.

WEEMS & PLATH, INC.

48 Maryland Avenue
Annapolis, Maryland
(301) 263-6700

KEY PERSONNEL:

G. D. Dunlap, President
J. Larsen, Consultant
H. H. Shufeldt, Consultant

SYNOPSIS:

Weems & Plath, Inc., and its predecessor, Weems System of Navigation, has been involved in the development of many special-purpose navigation charts for air and marine use. These included the development of the Weems System of Navigation skeleton charts, using the most suitable projection for various bands of latitude. Development work has also been carried on for approach and landing charts, state aeronautical charts, and special relief maps. One of our consultants, John Larsen, while serving as chief navigator of TWA, was also instrumental in the development of the present series of Aircraft Position Charts produced by the Coast and Geodetic Survey. These have progressed from a Mercator with limited aeronautical data to a series of charts constructed on various projections suitable for aircraft flying in specific areas. The company has also been instrumental in the development of plotting charts and of the star altitude curves which presented pre-computed celestial lines of position in chart form.

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~~This~~ The document records the proceedings of a symposium on aeronautical charts and map displays. The meeting was attended by over 200 experts in the fields of technology related to the development and use of map-display systems for manned aircraft. The emphasis of the symposium was on the problems encountered in incorporating aeronautical charts and other kinds of earth-reference materials into map displays.

This document includes the manuscripts of 24 technical papers, abstracts of the discussions which followed the papers, summary reports of six special discussion-groups, directories of the participants, and a bibliographical appendix.

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