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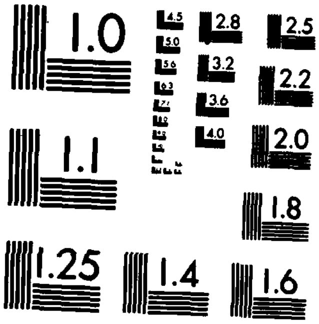
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AN ANALYSIS OF CONSTRAINTS TO
COORDINATED TACTICAL CREW
INTERACTION IN THE P-3C AIRCRAFT

THESIS

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AFIT/GLM/LSM/84S-32

AN ANALYSIS OF CONSTRAINTS TO COORDINATED TACTICAL CREW INTERACTION IN THE P-3C AIRCRAFT

THESIS

Presented to the Faculty of the School of Systems and Logistics
of the Air Force Institute of Technology
Air University
In Partial Fulfillment of the
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Master of Science in Logistics Management

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Preface

The purpose of this research effort is to provide an exploratory study of several key factors which impact team performance on the P-3C maritime patrol aircraft. In the evolution of the P-3C, designers took full advantage of state-of-the-art information processing technology, but apparently neglected to focus as diligently on the effective integration of tactical crew members with the weapons system platform. Several factors impacting team performance are analyzed including individual workload, communication and interaction among individuals, and coordination of individual effort. Current P-3C shortfalls, advantages of allied tactical crew station design, and relevant research findings are analyzed to identify the need for a more integrated tactical crew station arrangement for future maritime patrol aircraft.

For his perseverance and diligence in overcoming long lines of communication to provide guidance and advice, I am deeply indebted to my thesis advisor CDR Joseph S. Stewart II. I would also like to thank Dr. Guy S. Shane for providing research points of contact and his assistance in organizing and proofreading the numerous drafts. For their assistance in providing research relevant to human factors studies of the P-3C as well as allied ASW platforms, I deeply appreciate the responsiveness of the staff of the Naval Air Development Center, VP Programs Office; especially, Lcdr Ed Beach, USN; Maj Stan Toole, CF; Sqn Ldr Stu Heppenstahl, RAF; and Flt Lt Steve Gray, RAAF. Finally, I would like to thank my wife for her invaluable assistance in typing and editing, and for providing moral support.

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Abstract

The P-3C long range maritime patrol aircraft has evolved over the past thirty years into a very complex, multi-sensor weapons system platform. Increased effectiveness has been achieved by incorporating systems that rapidly process large amounts of data. However, crew members operate within relatively fixed cognitive limitations. Mission tasks are divided among the crew members who must work together to monitor, assess and control these complex information processing systems. Little emphasis has been placed on enhancing team performance through better communication and coordination among the team members. This research effort provides an exploratory study of factors which impact team performance. Areas analyzed include current P-3C human factors deficiencies that inhibit group interaction, a review of communication and group interaction literature relevant to the P-3C aircrew team environment, and an analysis of tactical crew station arrangements in allied maritime patrol aircraft. Although no theory of team performance exists, the preponderance of research indicates that team performance would be enhanced by allowing group interaction processes to

operate more freely (i.e., not constrained by rigid communication and organizational structures.) Future maritime patrol aircraft design must allow flexible crew communication and coordination strategies through an integrated tactical crew station arrangement.

AN ANALYSIS OF CONSTRAINTS TO COORDINATED TACTICAL CREW TEAM INTERACTION IN THE P-3C AIRCRAFT

I. Introduction

The Soviet submarine force represents a potential threat to the United States and its Armed Forces by virtue of its capability to launch nuclear ballistic missiles, to attack U.S. naval forces with long range surface-to-surface missiles or torpedoes, and to attack U.S. submarines with anti-submarine rockets or torpedoes. The United States Navy has responded to this continuing threat by expanding and modernizing its own anti-submarine warfare (ASW) capabilities and forces over the years. These ASW forces include sea-based weapon systems aboard such platforms as: destroyers, helicopters, S-3 aircraft and our own attack submarines. In addition to sea-based platforms the Navy also maintains a land-based force of long range patrol aircraft.

The Navy's current long range maritime patrol aircraft (MPA), the P-3 Orion, has the primary mission to detect, identify and track potentially hostile/high-interest ocean going vessels (both surface and sub-surface). Powered by turbo-prop engines for greater performance and efficiency, the P-3C is an all-weather aircraft that can fly extended distances and remain over a designated search area for prolonged periods. During its normal 8 to 10 hour missions, the P-3C uses the latest in acoustic and nonacoustic sensors, communication systems and navigation equipment.

The basic P-3 airframe, with numerous avionics system modifications to keep pace with ever expanding technological horizons, has proven reliable for over 30 years. (Appendix A provides a brief synopsis of the evolution of the P-3.) Today's P-3C uses sensor systems and onboard computer power to effect multi-fold increases in signal and data processing relative to the capability early in the preceding decade. Although ostensibly "designed and built to be operated as an integrated team effort" (46:9-1), past P-3C human factors analyses indicate substantial room for improvement in crew station design. It is the contention of this author that the P-3C was developed primarily around "hardware" solutions that attempted to enhance individual performance, and that the design does not incorporate fundamentals which recognize team dynamics.

Focusing on performance enhancements through computer processing technology has over-shadowed the much needed consideration of human beings as components of the weapons system. Each generation of sophistication has increased the potential for placing man in a position of sensory overload (45:18). Equipment is retrofitted, additional missions are assigned to aircraft, procedures are changed, and operating conditions vary (45:19), all without serious consideration of how this impacts operator and team performance. Current research in advanced cockpit design indicates that, "as presently conceived, the crew members' visual/motor channels will be badly overloaded in the performance of certain functions within required time limits" (14:5). Parallel developments in tactical crew member work station design also guarantee the reoccurring overload condition. Advanced technological designs have not incorporated sufficient consideration for certain human factors.

Naval Air Systems Command (NASC) is currently pursuing a planned development of advanced patrol aircraft system design criteria to avoid the problems and resultant costly fixes of the past (4:5-14). Under the direction of NASC, the Naval Air Development Center's (NADC), VP Program Office for P-3 Modernization is considering P-3C engine and airframe design changes for near and long term follow-on maritime patrol aircraft. One of the main objectives of their long-range criterion development is to produce a more effective ASW weapon system, one not limited by crew effectiveness or endurance, through early consideration and integration of the total system (4:12-5,6). A specific objective of the NADC VP Program Office is to "define operational requirements for future P-3 crew station design" (2). It is hoped that the research effort that follows will provide information useful to NADC in support of their objective.

Prior to delineating the realm of this research effort, a brief description of the responsibilities of each crew station is provided. The P-3C crew configuration normally consists of 12 men. The Pilot, Copilot, and Flight Engineer make up the flight station personnel and are responsible for maneuvering the aircraft to the positions indicated by the TACCO. The tactical crew members consist of the Tactical Coordinator (TACCO), the Navigator/Communicator (NAVCOMM), two Acoustic Sensor operators (SS1/2), and a Non-acoustic Sensor operator (SS3). The Inflight Technician (IFT) and the Ordnanceman fulfill the majority of their duties prior to take-off and often function as observers inflight. Although their inflight contributions often make the Ordnanceman and the IFT indispensable, they normally do not operate sensor systems and are therefore excluded from further discussion as tactical crew members.

The P-3C tactical crew is tasked to detect, localize, gather intelligence on and, when so directed, attack targets that pose a potential military threat. Satisfactory pursuit of mission tasking is realized through the two phases of contact development and contact refinement. (Appendix B provides a typical ASW evolution for those readers not familiar with ASW prosecutions.) Each crew member plays a vital role in contributing to overall mission performance.

The following is a brief summary of major inflight duties of the crew members. A more detailed listing of tactical crew responsibilities is provided in Appendix C. In prosecution of the ASW mission, the pilot coordinates ASW tactics with the TACCO and maneuvers the aircraft as directed on the appropriate flight instrument or tactical display. The pilot also coordinates tactical plot stabilization with the TACCO (46:9-3). (Plot stabilization refers to a procedure in which the aircraft's electronic position is "stabilized" relative to actual, expended search stores.) In addition to enroute navigation and communication duties, the NAVCOMM "shall be familiar with all ASW sensors and be prepared to direct the tactical crew should the need arise" (46:3-15) and "during target localization and attack phases of the (ASW) problem, the NAVCOMM will provide assistance as directed by the TACCO" (46:3-15). It is the responsibility of the acoustic sensor operators "to detect and classify contact data" and to act "in close conjunction with the TACCO" for the determination of sono target evaluation and appropriate buoy types and settings (46:3-17). The non-acoustic sensor operator (SS3) is responsible for determining the position of a submerged target using the Magnetic Anamoly Detector (MAD), detecting and analyzing signal emissions and radar targets of operational significance, and providing radar and electronic surveillance measures (ESM) information to the TACCO. During inclement weather, the SS-3 operator also provides radar safety-of-flight duties such as thunderstorm avoidance, identification of land masses, and separation from other aircraft (46:3-19). In addition to these areas of responsibilty, each crew member may be assigned additional duties by the TACCO or Patrol Plane Commander (PPC) and is required to "possess a familiarity with equipment used by other crewmen", in order to "facilitate crew coordination" (46:9-1).

Although either the PPC or TACCO may be designated as the Mission Commander (MC) and is ultimately responsible for the activities and effectiveness of the mission (46:9-3), the TACCO is responsible for the tactical portion of the flight mission and "shall coordinate the functions of the entire flight crew" (46:9-1). The TACCO ensures effective employment of the P-3C weapons system through crew management and coordination consonant with current tactical publications and procedures" (46:3-14). The TACCO coordinates all information received from other ASW crew members, decides on appropriate tactics, uses his search/weapon stores system to expend ordnance, informs tactical crew members of his decisions and actions, and focuses tactical crew members' efforts in the appropriate direction (46:10-11).

It should be obvious from the above descriptions that one of the most important elements to mission success is the proper coordination of crew members (23:1,2). As the ASW team leader, the TACCO is responsible for the integration of men, equipment, and information in the successful prosecution of hostile targets. He is the weapon systems manager.

II. Problem Specification

Years of extensive testing of military systems have shown that there is frequently a significant difference between the potential, or designed, performance of a system and its actual performance. This "performance gap" can be attributed largely to the performance of the human component in the system (31:76). There is a tendency to design today's technologically sophisticated weapons without considering the skills and capabilities of operating personnel to perform the more sophisticated tasks these weapons may require (31:80). Military utility of a weapon system is not simply an engineer's prediction based on an assumption of error-free human performance (31:80). It is the effectiveness of the platform when operated and maintained by its humans that determines actual levels of performance. Although the importance of human factors engineering to equipment design is generally accepted, it would seem that "some of the attention given to this area is more verbal than real" (7:85). For instance, a 1967 qualitative appraisal of human factors design of the Lockheed P-3 A-NEW Mod 3.1 Airborne ASW system indicated problems "which the operational forces will most likely have to adjust in the P-3C" (42:1). The authors of the study recognized early in the test planning that the hardware development had "a very long head start", which meant that any human factors discrepancies would be "viewed with alarm" due to extensive costs involved in any retrofit (42:1).

"Significant advancements in both operational efficiency of the Fleet and development of new hardware depend in large measure upon the knowledge of the functions of performance of ASW personnel" (10:1). ASW personnel are a priceless ingredient in increasing performance. Personnel are recruited, selected, and trained with great emphasis on attaining high levels of task proficiency. However, very little emphasis is placed on methods of integrating personnel working in groups or teams to increase collective performance. A systematic study is required to determine how to organize flight crew personnel to achieve higher levels of performance.

Problem Statement

The current U.S. Navy long range maritime patrol aircraft has developed into a complex weapon systems platform in response to equally sophisticated Soviet submarines and tactics. Unfortunately, incorporation of state-of-the-art information processing technology was not matched with the equally important considerations of integrating these systems with their human operators (24; 39; 58). Specifically, those small group processes which, when allowed to operate to their fullest, can result in performance output greater than the sum of the individual inputs of that group (26). Personnel factors are among the most sensitive factors in assessing system effectiveness. Personnel can make a system work or cause it to fail dependent upon their physical state or mental state. However, one cannot simply take measures of individual performance, add them together, and equate them with the performance of a group or team (10:encl 1-3). ASW team performance criteria are different from the criteria usually found in industrial or personnel research because of its dynamic nature. Emphasis is placed on speed and accuracy in tracking freely moving targets involving three separate environments (air, surface, sub-surface) under realistic conditions (10:encl 1-2,3). However, the ASW team is comprised of individuals, therefore, analysis of research relevant to group interaction should identify findings which are pertinent to defining operational requirements for tactical crew arrangement of future patrol aircraft.

Boundaries of Research

Due to the complexity of the weapons system acquisition process and the multitude of variables which impact individual performance, the following assumptions are made to deliniate the boundaries of the research analysis:

1. Airframe Availability. It is assumed that the airframe, avionics systems, and information processing sytems will be available in which the ASW team will be an integral part. It is further assumed that currently identified crew comfort related human factors deficiencies (5; 35; 66) will be remedied, and that future systems will not constrain ASW team arrangement in any manner.

2. Component Miniaturization. It is assumed that the trend of developing smaller, lighter components will continue thereby enhancing the capability to further arrange equipment and personnel without limitations from aircraft gross weight and balance requirements (27:ii).

3. Information Display and Control. It is assumed that current emphasis placed on the integration of individual operators with information display and control systems will continue in attempts to reduce operator workload in communicating with avionics, sensor, and weapon systems (14; 65).

4. Decision Support Systems. It is assumed that future aircraft computer systems will include decision aiding hardware and software programs which present alternative problem solutions for selection or modification by system operators. These systems can reduce operator workload and

allow better decision making under stressful conditions (36; 37; 49; 50; 68).

5. Integrated Sub-systems. It is assumed that future patrol aircraft will incorporate available technology to include fully integrated avionics, sensor, and weapons systems (40:3-4).

6. Tactical Crew Command Structure. Extensive inquiry indicates that research in multi-position command networks has produced inconclusive results to date. Related work in cognitive psychology has produced similar, contradictory results, although recent work is promising. Analysis of these activities is crucial to full understanding of P-3C crew function, however, the body of knowledge is not stable. Crew command and control network comparison is therefore omitted.

7. Extended/New Missions. Patrol aircraft have evolved from daylight spotting aircraft into complex weapons delivery platforms capable of attacking surface and submerged targets. It is assumed that future patrol aircraft will assume additional missions in addition to its primary ASW role (52:3; 33). Some of these new roles will involve inflight refueling to achieve extended mission length (66).

III. Methodology

An analysis of the literature was undertaken to identify research relevant to an exploratory study of factors and variables influencing team performance in complex tasks using a division of labor concept. Combinations of key terms listed in Table I were used to generate Defense Technical Information Center abstract listings as well as for manual searches through the Psychological Abstracts and the Social Sciences Citation Index for pertinent research published in scientific journals.

TABLE I

Key Search Terms

1. Military Aircraft
2. Navy Aircraft
3. Patrol Aircraft
4. P-3
5. Aviation Personnel
6. Flight Crew
7. Human Factors Engineering
8. Group Dynamics
9. Team Performance
10. Communications
11. Command and Control
12. Networks

Initial document reviews produced from a search strategy using key words one through seven revealed that Human Factors Engineers (HFE) define crew station design in the singular sense of a one operator - machine interface rather than a "crew" as a number of operators arranged as a group or team. Additionally, HFE research focused primarily on reduction of individual operator workload rather than on enhancing team performance through manipulation of group interaction processes. Subsequently, the search was expanded to include key words eight through twelve. With the exception of research on communication networks, the time frame of material analyzed was limited to those reports published after 1960 since state-of-the-art research was being incorporated into the P-3C baseline at that time.

Australian, British, and Canadian Exchange Officers attached to the VP Programs Office of the Naval Air Development Center were interviewed to discuss their countries' long range ASW aircraft crew station arrangements and crew interaction processes. Additionally, NADC maintains a P-3 library which was also searched for relevant research reports.

Literature was then arranged and analyzed according to that component or activity of the group being researched. The categories were: 1) individual factors which impacted group performance, 2) the flow of information between and among group members, 3) methods of organizing individual effort to group performance, and 4) other factors which contributed to "team" performance.

Chapters IV and V present the findings and conclusions of this exploratory effort as they apply to formulating recommendations and a research framework prior to developing operational requirements for future maritime patrol aircraft tactical crew station arrangement.

IV. Problem Analysis

This chapter provides a more detailed analysis of the problem areas identified in Chapter II. Problems will be addressed under four main areas; Operator Workload, Communication, Coordination, and Team Performace. Subsequent sections include 1) a summary of research findings for future MPA design, 2) a section on allied MPA design, and 3) a concluding discussion of findings relevant to future P-3C crew station arrangement to enhance team performance.

"ASW performance is a function of a series of operators interacting with specific sensors within one environment while seeking a target submarine in another environment with some over-all coordination . . ." (10:encl 1-3). The key word in that quote is "operators". These operators are 1) individuals who 2) interact in a 3) coordinated effort as members of a 4) team. These personnel attempt to achieve the highest possible performance by interacting with each other and the weapon systems platform through the various aircraft sub-systems.

The factors that contribute to individual, group, and team performance are among the most sensitive factors in assessing system effectiveness. Operators can make a system work or cause it to fail dependent upon their physical state (fatigue, sickness) or mental state (morale, training). This human element of weapon system design is usually addressed within the discipline known as human factors engineering (HFE). This field is responsible for integrating system hardware, software, environments, and procedures with human capabilities and thereby producing the highest achievable system performance.

Human factors specialists study system concepts to identify and remove sources of human error which could reduce system effectiveness. While the importance of human factors equipment design is generally well recognized (7:85), human factors are usually on the losing end of the balance sheet when it comes to cutting costs. This is frequently due to the inability to adequately "prove" the importance of proper man-machine integration in terms of numerical justification such as a percentage contribution to increased performance. The initial consideration of the human factors engineer is the proper allocation of tasks between the operator and the computerized aircraft sub-systems.

U.S. P-3C Considerations

Operator Workload. Two major considerations are involved in the task allocation process; positional workload and system effectiveness. Increased workload can detract from system effectiveness, and increased system effectiveness can require increased workload (48:v). Thus, indiscriminate applications of automation may have a deleterious effect on crew performance.

Human factors specialists have shown that man can be and often is placed in a position of sensory overload to the decrement of system performance. The introduction of computer technology into the airborne platforms has further compounded potential overload situations since high-speed computers permit the treatment of a much wider variety of sensor data than was previously possible. Today's automated equipment and elaborate software programs will assist crew members in monitoring and controlling the system, only if the man-machine interaction occurs within the information processing limitations of humans (28; 29).

Equipment designs which take advantage of human capabilities and account for human limitations enhance total system performance. If these factors are not considered in the design, system performance will inevitably suffer and the purpose for which the equipment was designed is jeopardized. Consideration of these limitations is even more significant today because "ever increasing technological advances are resulting in increasingly complex systems that are pushing human functions to their limits" (7:119).

Technological advances in the past several decades have resulted in the development of weapon systems platforms which far overreach the capabilities of man to operate them. Today's aircrew members operate under a high task load combined with a severely restricted time frame in which to perform required functions.

"Operational efficiency of the Fleet and development of new hardware depend in large measure upon the knowledge of the functions of performance of ASW personnel" (10). My research has shown that performance at the individual level can be degraded through systems which; create undesirable environmental conditions, use inadequate display and control designs, and require excessive data integration by the operator.

Environmental conditions must allow the crew member to operate in physical comfort. In an operational test and evaluation of the P-3C, human factors tests that reviewed each crew station for "adequacy of design by questionnaires, interviews and direct observation" (11:4-31), found that "the overall noise level in the airplane is excessive" (11:5-81). An ambient noise level of 75-80 decibels was recorded at the NAV/COMM and TACCO area, which effectively prohibits normal off-ICS conversation. The ambient noise level at the SS1/2 station "reduces the operators' aural listening capability and induces fatigue" (11:5-82). Excessive noise and vibration throughout the aircraft "frequently caused operator nausea and consequently reduced crew efficiency" (11:5-82). Crew member comments indicated that they felt that comfort and equipment integration were important factors that did not receive adequate design consideration.

Processor and display and control advances have created an information overload of such magnitude that operators have become unable to cope with the high rate and volume of information produced by their avionics systems (64). As a result system operators too often find themselves unable to make optimal decisions within the time available. The primary response to this problem has been more application of the same technology - the addition of more and more computer-based systems to provide still more informational analyses for processing by the aircrew member. This approach is doomed to worsen the situation because it provides the operator with more displays to read, more controls to manipulate, and more information to ponder, without providing any more time in which to do even the original tasks. The increasing demands placed upon crew members by newer and more complex systems and platforms thus make it necessary to reanalyze our approach to crew station design problems.

Another problem common to many weapon system platforms is the requirement that operators must integrate information from several different sensor sources to formulate a composite image of a tactical situation. This places an undue burden on the operators who must assess information from several sources (i.e., RADAR, ESM, IR, etc.) This problem is further compounded when multiple images are depicted in varying formats and different scales on displays with various presentation styles, update rates, etc. Thus, crew station design becomes a critical factor in total system design, since even the most modern aircraft equipped with the latest in automated sensors and processors can become inefficient or ineffective through a display and control configuration which burdens the operator. Experience on the P-3C has shown that the higher the automation the more complex is the procedure of communicating with the computer system. The workload saving due to computerizing various functions is sometimes compromised by the actions necessary to extract the computer stored data or computation (12:12-15). Tactical crew members currently spend too much time pushing buttons and not enough time on tactical planning and decision making. The literature analyzed indicated several approaches to resolving some of the individual operator task overload problems. The solutions discussed below are based on a task sharing concept which involves off-loading tasks from a highly loaded crew member to a crew member with a relatively low task load.

Workload Distribution. Workload sharing techniques attempt to provide more flexibility in the way operator and machine tasks are assigned. The simpliest approach to workload sharing involves the use of additional crew members. Early studies of the P-3 crew complement pointed toward using additional crew members to handle increased work load brought on by new missions and faster processing systems. One such study (62:12) analyzed the impact of two TACCO crews versus one TACCO crews and found the two TACCO crew composition allowed for greater speed of solution in the search phase and an overall greater information processing capability. The two TACCO approach apparently was discarded in view of pending computer advances which were foreseen to resolve any TACCO workload problems.

Two of the more feasible workload sharing techniques identified are dual station and workload distribution (64:3.1.3.d). A dual station approach involves one or two crew members working at the same station, thus allowing one operator to perform the functions normally assigned to the station while the other operator is resting or attending to some other assigned function. Workload distribution refers to the capability to distribute tasks among stations during the mission (64:3.1.3.d). Both workload distribution and dual stations would achieve their flexibility through multipurpose crew stations, crew station redesignation, and in tasking as a result of workload distribution. This gain in flexibility would also require crew members to be skilled in more than one tactical discipline and be able to make rapid mental transitions in switching from one task to another and possibly back to a previous task (64:3.1.3.d). Since human operators do not possess a limitless capacity for performing additional tasks or a repetoire of different tasks, procedures and guidelines must be formulated concerning a rational approach to workload sharing and its utilization in future systems (29:1).

With multi-purpose displays tactical consoles would not be limited to performing only one function. Instead, all crew stations would be multi-functional and would possess a high degree of uniformity in capability and layout of display and control functions. The designation of a particular station to perform a certain mission role could be accomplished through software downloading (64:3.1.3.a).

It is the contention of this author that, in addition to achieving task load reductions through the above methods, coordination of individual crew member contribution to the group effort is another key factor to be considered in obtaining higher performance from the P-3 platform with the current crew complement. Thus, we need a broader approach than merely providing more systems to provide greater quantities of data and information; we need a systems approach which considers the interaction structure used by the individuals to form a coordinated group called a team.

An approach which focuses on the coordination of the crew member's activities as a group may provide new insight and a means for achieving greater system performance in future generation MPA. For instance a 1975 Canadian Air Force study (3:2,3) of the tasks performed by the TACCO of the current USN P-3C examined areas in which the advantages of a more integrated tactical crew compartment would contribute to improved performance of various tasks and the mission segments. The study concluded that of the 408 tasks analyzed, 106 would be enhanced by a more integrated tactical crew layout. The same study also indicated a related problem in that many crew tasks are currently being limited by the cognitive capacity of the operator, and as a result of the information processing structure and layout, overload conditions cannot be accommodated by off-loading part of the task to another operator. Since the TACCO is responsible for crew coordination in addition to his role of weapon/search stores management and employment, one would expect the TACCO to benefit the most from an integrated approach, however further analysis of interactions among individuals indicates potential benefits for other crew members as well.

Communications. The flow of information between man and machine as well as between members of the group is defined below as a critical element in group interactions, and, therefore, it is critical to effective and efficient weapon system employment. Information must be communicated to the decision center to provide the basis for decision making, and the resultant decision must be communicated from the decision center in order to influence other members of the group whose cooperation is required to carry out the decision. The communication aspect of interaction is considered so vital to group processes that it is discussed as a separate section for emphasis.

Webster (18:296) defines communication as a "message", "an exchange of information", or "a system for communicating". The following discussion of information flow will focus mainly on the "system" for communication which is called a communication network. A communication network is further defined as "the interaction required by a group to accomplish a task" (43:71). The P-3C uses three of the basic types of communication networks, the circle network, the wheel network and the all-channel network. The following network descriptions are paraphrased from a 1955 study by Guetzkow and Simon (17:240).

In the wheel network group tasks are divided among group members with one member acting as the decision maker or "hub" and the other group members act as information processors or "spokes" who send their information to the hub. The hub integrates the information provided by the spokes and provides direction and guidance to the spokes to solve the group's task. An advantage of the wheel network is that it minimizes effort spent on group organization. However, the wheel network also suboptimizes the group effort in that the problem solving talents of the spokes may be wasted (effectively blocks task sharing). This is the most common mode used in the P-3C, in that the sensor operators, pilot, and navigator (spokes) are providing inputs to the TACCO (hub) who in turn makes the tactical decisions and coordinates the spokes based on his decision.

The circle network involves the use of a relay system wherein group members have access to all information but communications are passed through adjacent group members. The circle net has an advantage in that it reduces the number of communication channels available. The disadvantage lies in the relay process itself. By passing the information through a second party, errors due to loss of accuracy and timeliness of information can occur. The circle network is used on the P-3C infrequently and as a direct result of display constraints. An example would be when the Navigator is attempting to assist the TACCO with tactical communications (i.e., communications with another ASW platform) and must obtain the information from the TACCO because he is unable to access the information directly.

When the communication structure is such that each member of the group has access to all available information, that group is said to have an all-channel network. The advantages of this structure are that there is no relay system and all members can access required information directly. A disadvantage is that too many opportunities for communication may exist, as is the case when an individual operator receives more information than he can process (resulting in an overload condition). Most P-3C crews use the ICS system so that all operators can hear all communications, so in that sense all operators have access to all verbal communications. This method is especially used during time-critical phases of an ASW prosecution where there is no time available to track down an operator who is not on the right channel. However, proliferation of this type of verbal communication can also represent a distraction and interfere with simultaneous performance of tracking or control tasks (21:5).

Early studies (22; 55; 28; 9; 38) of communication networks used 3 to 5 member groups performing simple tasks, such as determining a symbol or color common to each member of a group. These networks used verbal and written communications media and varied the network design by allowing certain members to communicate directly, indirectly or not at all. These initial studies reported contradictory results (55:211) as to which networks were optimal under given conditions.

In a study by Mears in 1974 (43:75), communication networking research was applied to a business situation involving complex tasks performed by the Systems and Procedures group. The group was initially organized as a free circle (all channel network) and later reorganized by management into an autocratic wheel network in an attempt to increase organizational efficiency. The group, under the all channel network was thought to be inefficient because of the relatively large amount of time spent answering inquiries from group members and duplication of effort. However, contrary to expectations, efficiency (output) actually decreased after the wheel network was installed (43:76).

The lack of concensus of the initial network studies and the outcome of Mears' research consistently indicated that; 1) the relative efficiency of a given communication structure is highly dependent upon the task being solved by the group, and 2) the communication network determines the type of problem solving systems that can develop within that structure. In general these studies involved members of equal skill and the group coordination function was dictated by the communication structure employed and the ability of the individual who was chosen or emerged as the group coordinator.

Guetzkow & Simon (1955) studied the effects of communication problems upon the operation of groups; specifically, 1) results of the restrictions placed on a group's ability to organize itself for such performance, and 2) what effects communication restrictions have upon performance of the task (17:233). Guetzkow and Simon hypothesized that the "imposition of certain restrictions on the communication channels available to a group affects the efficiency of the group's performance, not directly by limiting the potential efficiency of task performance with optimal organization in the given net, but indirectly by handicapping their ability to organize themselves for efficient task performance" (17:233).

They found that the assertion of a direct relationship between effective functioning and freedom in communication was "unwarranted" (17:250). In other words, a reduction in communication restrictions does not necessarily lead to a more effective or efficient organization. Complete freedom of communication can be more limiting than restricted communications (17:233-235). This would suggest that controls and procedures be established when using display concepts wherein any crew station has access to all available information.

Relatively recent communications analysis studies of ASW platforms indicate that further research of crew communications may result in increased system performance. A 1971 study of ICS communications in the P-3C showed a high correlation between flight evaluation scores and ICS (communication frequency) measurement results (13:v). Although previous studies indicated that increased ICS communication requirements were likely to degrade crew problem-solving efficiency (42:6,7), correlations in this study indicated that the TACCO in an effective crew communicated more with his sensor operators during the detection/localization phase than did the TACCO in an ineffective crew (13:17).

A 1973 study (56:iii) investigated communications as a component affecting inflight ASW helicopter mission success. That study found significant improvement in crews that were trained in more effective communications procedures over crews who used "normal" operating procedures. The authors of that study recommended additional communications research into the effects of variation in communication links on system effectiveness, and the relationship between communications and the decision making process (56:vi).

One can conclude from the above analysis that differences in team performance are to a large extent influenced by the task communication structures. The analysis so far has indicated that group performance is affected by individual factors as well as how the individuals of the group communicate. The flow of information through a system can be viewed as both a determinant of how well the group can be expected to perform (prediction) as well as a resultant indicator of how well the group actually performed.

Coordination. The previous section indicated the impact of communication structure on a group's "ability to organize for effective performance." Organizing (18:325,1033) refers to coordination of individual member effort or, more formally; coordination involves subtasks, accomplished through individual effort, which must be arranged in some systematic order of precedence to expeditiously solve a given task. This arrangement of individual effort is the method or strategy employed by the group to enhance efficient performance through workload distribution. Decisions are consciously or unknowingly made which reflect how the group will interact. As previously discussed much of how the group interacts will be decided by the environment and supporting systems which the group must use to complete their tasks.

Since effectiveness on a given group task is influenced by the amount of effort applied by individual group members, it is important that members coordinate their activities so that individual effort is minimally "wasted" (19:333). The ultimate potential of group effectiveness would result if all individual effort were fully usable in task accomplishment. Unused or duplicated effort is considered "process loss" or wasted effort. Additionally, process loss increases as group membership increases, because the job of getting all members functioning together in a coordinated manner becomes more difficult. Therefore, attempting to increase performance by helping group members coordinate their activities more effectively (strategies of organization) can be construed as working toward "minimizing inevitable process losses" (19:333). Strategy refers to collective choices made by group members about how to carry out a given task (19:334).

Group interaction can affect these coordinating strategies through implemention of pre-existing strategies or reformulation of existing performance strategies (19:335). Pre-existing strategies are the standard operating procedures and rules of thumb that the group develops and operates under to accomplish routine tasks. Reformulation of strategies involves group reaction and reorganization to unique tasks or routine tasks involving degraded support systems.

In the case of the P-3C crew, there is minimum time available to study the effects of pre-existing strategies and to accomplish strategy reformulation due to excessive task loading involved in interacting with the equipment. This is true at the individual operator as well as the team leader level. Additionally, crew organization or coordination of individual effort is not taught in the replacement training squadrons to crew members or crew leaders (TACCO). Crew coordination is learned to some extent from "pass-down" information from several instructor TACCOs, however, most TACCOs develop their organizing strategies from on-the-job, trial and error processes of what works best for a specific crew in a specific situation.

Team Performance. Individuals interacting through formal or informal communication structures and related by the common factor of working toward task resolution is one definition of a group. Individual ability and effort, communication structures, and coordination of individual effort are factors which have previously been shown to effect a group's ability to function effectively (41). Organizations often refer to some of their groups as teams or crews. Although the distinction is not precise, there are several factors which impact team interaction more heavily than group interaction.

Two or more individuals may constitute a group if they are related by some common factor. And a group may evolve into a team if they are associated by virtue of a complex task/activity which requires constant practice or training by the entire group to maintain proficiency at the task. One might say that a team is a group, but a group is not necessarily a team.

Since a team is also a group, the previous analysis of group processes, such as individual ability, communication structure, and coordination strategies remains applicable to team analysis. However, in attempting to further evaluate factors which impact team effectiveness, difficulties arise due to the inability of researchers to agree on the differentiation between individual tasks and team tasks (34:4). Team tasks are defined (34:4) as tasks which require extensive coordination, to the point that interactions must be constantly exercised for the individuals to maintain high levels of performance. The individual team members train and work together in order to evolve into a stable, cohesive unit that develops and refines routine patterns of interaction in response to non-routine complex tasks. Depending on the complexity of the mission, team development may require lengthy periods of time. The following discussion identifies factors necessary to achieve and maintain effective teams.

Stability. Rapidly changing teams are unable to evolve requisite specialized interaction or standard operating procedures. Excessive turnover of personnel may easily prevent teams from performing beyond the level predicted by the simple aggregation of individual ability and effort. In a military organization, transfers, discharges, rotations, and school assignments are examples of several administrative restraints placed on any particular crew or team. Under conditions of aircrew instability, operating performance of an aircrew can be significantly impaired, as was found in a 1967 study of crew performance in ASW platforms (67). The study found that aircrew instability produced "less valid detections, localizations, and attacks, as well as greater operator error, than occurs under conditions of enforced crew stability" (67:12,13).

In a 1982 study of team performance effectiveness, researchers experimentally analyzed conditions that sustain group cohesion and productivity and that prevent social fragmentation and individual performance deterioration (12:46). The analysis of "introduction" and "replacement" effects of new team members emphasized the critical importance of providing "a structured transition in the form of orientation and training regimens for both novitiate and established team participants to minimize the potentially disruptive effects of altering interpersonal and social dynamics of a microsociety" (12:48).

Another concept which effects individual effort is that of social facilitation. Early in the history of research on group performance (44:297), the concept of social facilitation was introduced to explain why productivity of individuals working in the presence of others is often greater than the productivity of individuals working alone. A 1975 study of team organization and performance (44:297) assessed the effect of social facilitation upon team performance and founa a generally consistent improvement in performance attributable to social facilitation. The study emphasized that social facilitation may operate in a division of labor structure characterized by increased task difficulty and duration, only if individuals are working in the presence of each other (44:300). It would appear that physically arranging team members in close proximity would enhance individual and therefore team performance through social facilitation and the ability to communicate verbally.

Team Communication. The significance of information interchange through direct verbal communication is applicable to man-machine system operations where a group of individuals is cooperating to accomplish a task requiring decisions and actions based on the integration of information from a variety of sensors. Direct verbal communication (32:1) is one of the most fundamental tools of group activities requiring cooperation and coordination. Interference with the verbal communication process has a high probability of severely degrading group performance.

Research on group dynamics has repeatedly emphasized the importance of communication of information to effective group performance. When communication structures prevent efficient information flow, information "blocking" is said to occur. Blocking is frequently caused by overloading formal channels of communication (54:16). Since information must flow in order for the group to function, informal channels are established to carry needed facts. These informal channels are sometimes slower and less accurate than formal channels, but eventually the required information reaches the appropriate individual. However, problems develop if the information is time sensitive to the point of being nearly useless if it arrives too late or is inaccurate.

Communication becomes a critical problem in time-stressed team decision making (60:42). The system of information flow must allow data to be communicated quickly and accurately. The adequacy of the communication system depends on its capacity for efficiently routing information and the manner in which it allows team members to adapt to the communication structure to achieve greater efficiency. Team members must know how the communication system is expected to operate. "Miscommunication" (15:92,93) arises when there are different assumptions between team members about the communication structure. When teams are stable miscommunications occur infrequently; conversely, teams with high turnover of members may continually suffer from severe failures of communication. Another example of problems associated with a communication system occurs in teams that depend heavily on a particular individual decision maker. If these key individuals become overloaded by information arriving faster than they can react, mission performance may degrade dramatically. In this instance the communication structure becomes "too efficient" and results in an overall performance decrement.

Decision Making. There are cognitive limitations (15:54) on the information processing and decision making capabilities of humans. These limitations result largely from conscious adaptations necessary to solve complex problems. Data and information must be reduced to a level which can be processed within the bounds of human understanding and memory and often with a dictated time constraint.

In making judgments involving multi-dimensional issues (15:55), individuals can focus on only a few of the possible dimensions. Large amounts of information often lead to inferior and less accurate understanding and to less appropriate decisions (15:56). When the decision must be made in a stressful situation, individuals tend to rely even further on similar past experiences and on relatively few pieces of the mass of information available. Through this process, the decision maker is able to more rapidly define the current problem and enact the appropriate reaction. In choosing not to consider some possibly relevant data, the decision maker sacrifices the best solution under optimal conditions for a solution that is adequate and immediate.

Leadership. Coordination of individual effort in groups and teams is directed by group concensus or through an autocratic process by the appointed group/team leader (1:11,12,14,18). The coordination structure usually evolves through trial and error process, i.e., that structure which works best for the individuals and the team. All military teams have one individual who is ultimately responsible and accountable for the performance of that team. In an airborne weapon system platform, that individual is identified as the mission commander. By virtue of this position, he is the ultimate decision authority on the aircraft. This individual's "leadership" skill and ability are likely to have considerable impact on team performance. Leadership in an organized group can be defined as "the general function of facilitating the movement of the group toward the accomplishment of its designated goals" (54:2). Although leadership is a multi-faceted concept, analysis will be limited to the impact of subordinate ability and communication structure on leader effectiveness in accomplishing team tasks.

Leader involvement in team interaction may vary from complete direction of individual activities to only monitoring their actions. The degree of involvement may depend on the communication opportunities available as well as the particular sub-tasks involved in the team task. A 1983 study (6) of team problem solving investigated the problem solving behavior of three-member teams (a leader and two coworkers) in complex a task. The study manipulated the leader's level of proficiency (high/low), the form of communication permitted among team members (full/restricted), and the extent to which the two coworkers' functions overlapped (6:5,6). Problem solving effectiveness and participants' ratings of team performance were examined as a function of these variables. The study found that leader proficiency significantly effected team performance. Regardless of communication or coworkers' function conditions, teams with proficient leaders solved problems more quickly and with fewer errors (6:15,16).

Another study of leader ability and performance (30:527) analyzed variables that might block the potential contribution of leader intelligence to team performance. The variables analyzed were; leader motivation, leader experience, leader-boss (superior) relations, and leader-group relations. The study also identified the group's task organization and the ability of subordinates as potential moderators of team performance. Research results indicated that; the ability of group members was a significant determinant of group productivity, the way in which group members cooperated or organized themselves was as important a determinant of group performance as member ability, and group organization significantly moderated the effects of leader ability on performance (30:530). The above studies seem to indicate that individual member ability and group organizational patterns are both critical factors to team success. Leadership ability is a necessary individual quality required of the team coordinator, he must be proficient in organizing and controlling the team activities of group members (19:333) as well as any reqiuired individual tasks.

Allied Long Range ASW Aircraft Solutions

Nimrod MR MK2. The British Royal Air Force uses the Nimrod as its long range, maritime patrol aircraft (25). In response to proposed sophisticated hardware and software implementations, a 1978 study determined the optimal crew complement of the Nimrod MK2 to be a team of 13 aircrew members to man the following stations: Pilot, Copilot, Flight Engineer, Tactical Navigator, Routine Radar, ESM/MAD, and Communications (see Figure 1). The Air Electronics Officer (53:21), a position that has no P-3 equivalent, is essentially the sensor systems manager and is primarily responsible for workload distribution among the six sensor

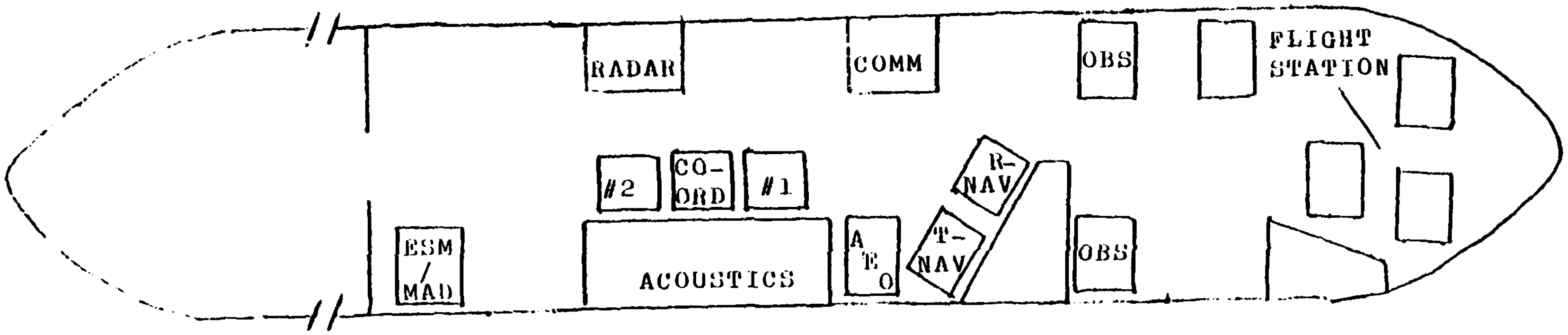


Figure 1. Nimrod MR MK2 Crew Station Arrangement (25)

system stations. Additionally, the AEO can assist with search stores system management when the Tactical Navigator (TacNav) is working on other tasks. The AEO is highly skilled in ASW operations since he must progress through all sensor positions prior to designation as an AEO. By virtue of their experience, many AEOs receive training in ASW tactics and become qualified for "Captaincy" (MC).

The crew complement study, in attempting to eliminate potential man-machine interface problems, analyzed leadership, management and decision making as variables which might enhance mission effectiveness and crew stability (53:1,2). It was determined that an additional free standing AEO/TacNav (53:23), responsible solely for crew management, would be under-utilized during most mission phases. Instead the study recommended that management and decision making functions be accomplished through a "primary responsibility matrix" wherein tasks were delegated among the Captain, TacNav and the AEO (53:19). The Captain is either the Pilot, TacNav, or AEO. Because the Pilots have no tactical displays other than computer steering information, pilot Captains frequently must delegate decision making to that individual with the appropriate information. The crew station arrangement, depicts how off-line conferences among the AEO, TacNav and Acoustic Sensor operators are enhanced by virtue of their general proximity to each other.

<u>Australian</u> <u>P-3C</u>. The Royal Australian Air Force (RAAF) version of the Lockheed P-3C is normally manned by ten crew members consisting of two Pilots, two Flight Engineers, a TACCO, a NAVCOMM, two Acoustic Sensor Operators, two Non-acoustic Sensor Operators, and a Lead Sensor Operator. (Crew seating arrangement in the Australian P-3C is identical to the U.S. platform therefore no figure is included.) All tactical crew members progress through a training syllabus and positional qualifications from Navigator/Communicator, Non-acoustic Sensor operator, to Acoustic Sensor operator, to Lead Sensor operator and, ultimately to TACCO (16). It is possible for an operator to accomplish this in their first squadron tour since their first tour is normally five to six years.

Similar to the British AEO, the Lead Sensor Operator is responsible for coordinating and interfacing the activities of the individual sensor operators with the TACCO. Additionally, the Lead Sensor Operator assists the SS3 during high task load scenarios. Australian ASW crews have no equivalent to the P-3C mission commander concept; decision making and crew management are functionally divided between the TACCO (mission tactics) and the senior pilot (aircraft safety).

<u>CP-140</u> <u>Aurora</u>. The Canadian Air Force is in the process of transitioning to the CP-140 as their long range maritime patrol aircraft (61). The CP-140 is externally identical to

the P-3C but internally takes a radically different approach to tactical crew arrangement (see Figure 2).

Efficiency benefits were achieved by placing operators conducting similar tasks or operators that frequently interact as close together as possible (bee730:5). Both Acoustic Sensor stations are adjacent, both Non-acoustic stations (NASO) are adjacent, and the Tactical Navigator (TacNav), since he frequently interacts with both the Navigator/Communicator (NavCom) and the senior Acoustic Operator (ASO-1), was placed adjacent to both NavCom and ASO-1.

The decision was made to incorporate an integrated tactical crew station design combined with an avionics suite that used common multi-purpose displays within the Lockheed P-3C airframe. The crew station arrangement includes nine crew stations: Pilot, Copilot, Flight Engineer, Tactical Navigator, Navigator/Communicator, two Acoustic Sensor Operators, and two Non-acoustic Sensor Operators. An additional Non-acoustic Operator serves as ordnanceman and permits a work/rest rotation cycle for the Non-acoustic Sensor Operators. (On particularly lengthy missions, an extra pilot and flight engineer are usually added to the crew.)

In researching their tactical crew station design, the Behavioral Sciences Division of the Defence and Civil Institute of Environmental Medicine emphasized close physical

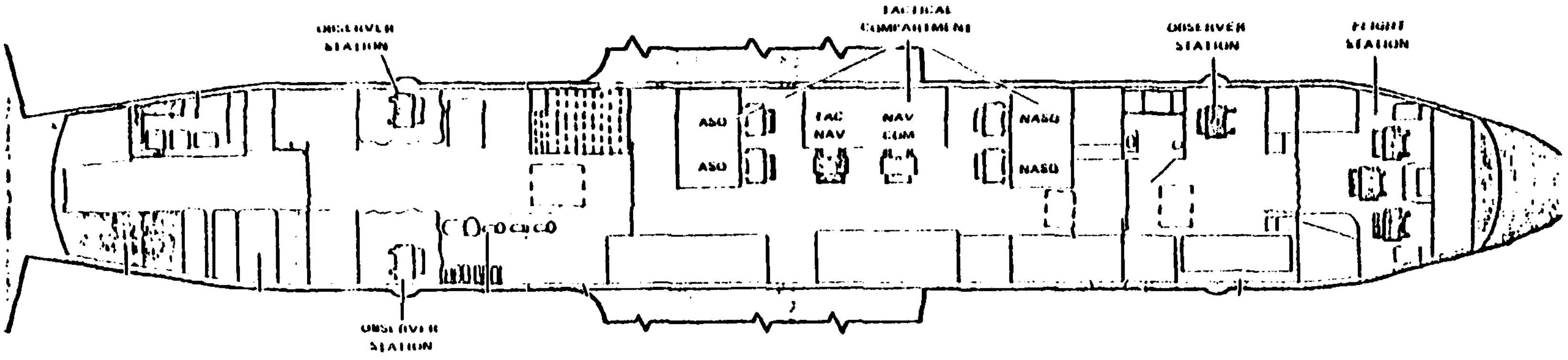
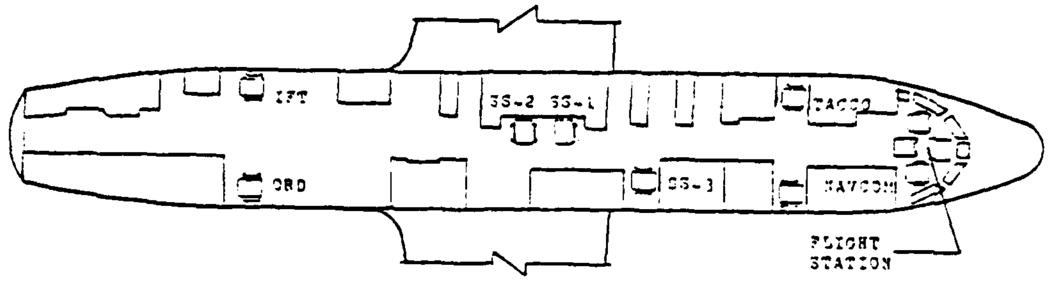


Figure 2. CP-140 Crew Station Arrangement (8)

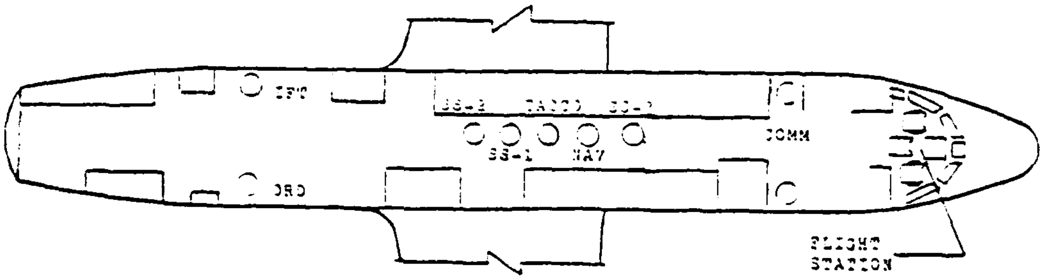
proximity and face-to-face communication among the tactical crew members (51:2,3). The advantages of an integrated crew compartment were believed to (51:2,3): promote a coordinated team approach to the LRPA operation; facilitate task sharing in circumstances when one crew member may be overloaded; facilitate consultation in cases of ambiquity or conflicting information; facilitate reversionary mode operation in the event of equipment failure; facilitate crew rotation; assist in maintaining attention during long periods of low activity by facilitating crew interaction; provide crew members with on-the-job exposure to tasks to which they may progress; facilitate crew proficiency training, and; enable senior crew members to monitor the performance of junior crew members.

The researchers stated that, "even though it would obviously be difficult (if not impossible) to quantify the foregoing advantages in terms of operational effectiveness (i.e., increased probability of detecting a target), they are, nevertheless valid considerations" (3:1).

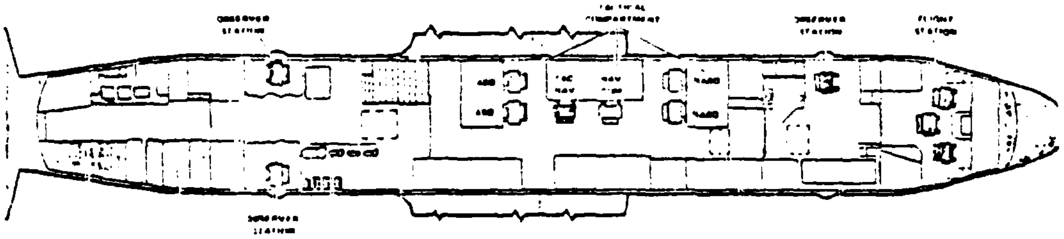
Allied Crew Station Arrangement. Figure 3 and Table II allow a comparison of crew positions among Allied long range ASW aircraft. Several differences become apparent in analyzing the crew complement of each of these aircraft. First, although the total number of crew members is approximately the same among all aircraft, the P-3C has the lowest number of tactical crew members (five). Second, both the British and the Australians use an additional crew member



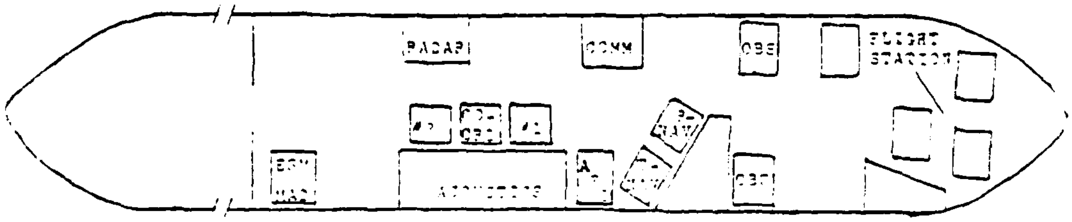
P-3C Crew Stations



P-3B Crew Stations



CP-140 Crew Stations



Nimrod MR MK2 Crew Stations

Figure 3. U.S. Allied Long Range ASW Aircraft Crew Station Arrangement (46; 47; 8; 25)

Table II

Positional Comparison of Long Range ASW Aircraft

United States		Australia	Great Britian	Canada
P-3C	P-3B	P-3C	Nimrod MK2	CP-140

Tactical Crew Members

Tacco	Tacco	Tacco	TacNav	TacNav
NavCom	TacNav	NavCom	Routine Nav	NavCom
*	*	Lead Sensor	AEO	*
Acoustic: SS-1 SS-2 *	Acoustic: SS-1 SS-2 *	Acoustic: SS-1 SS-2 *	Acoustic: Coord ASO-1 ASO-2	Acoustic: ASO-1 ASO-2 *
Non-Acoustic: SS-3 * *	Non-Acoustic: SS-3 * *	Non-Acoustic: SS-3 * *	Non-Acoustic: Radar ESM/MAD Extra-1	Non-Acoustic: NASO-1 NASO-2 Extra-1
sub-total: 5	5	6	9	7

Non-Tactical Crew Members

*	Comm	*	Comm	*
Ordnance	Ordnance	*	*	*
Technician	Technician	*	*	*
Engr - 2	Engr - 2	Engr - 2	Engr - 1	Engr - 1
Pilot - 3	Pilot - 3	Pilot - 2	Pilot - 2	Pilot - 2
sub-total: 7	7	4	4	5
total 12	13	10	13	12

* no equivalent position

responsible for sensor system coordination, thus reducing TACCO workload in this area. The Air Electronics Officer and the Lead Sensor Operator have no sensor equipment to operate and are therefore able to consider and recommend tactics to their tactical crew leaders. Third, the U.S. P-3C is the only platform to use positions for Ordnanceman and Inflight technicians. On other allied aircraft these duties are performed by those crew members with low workloads and varies depending on mission type and phase.

Although avionics systems were not compared, one might assume that the U.S. platform development has focused primarily on hardware/software solutions to increase overall performance. The U.S. VP Program is the only one wherein the TACCO does not progress up through the ranks as a sensor station operator. An advantage of this approach to TACCO qualification would be a better understanding of the sensor station operation and workload schedule. However, qualification as a TACCO would require a longer period of time and would likely extend longer than the normal three year U.S. VP squadron tour of duty.

Key Findings

Eight points, derived from the previous analyses and set forth below represent key issues which are pertinent to development of a tactical crew station arrangement in future patrol aircraft or any multi-man aircraft involving a division of labor concept and requiring coordination of individual effort to achieve a complex group task. The key issues are:

1. Systems which incorporate display and control and information integrating subsystems that operate well within operator cognitive limitations will enhance individual and team performance.

2. Workload distribution techniques will minimize the probability of overloading any one operator.

3. During non-routine task loading situations, flexible communication structures will enhance team performance by allowing teams to develop tailored problem solving strategies.

4. In the event of overloading or breakdown of a formal communication network, informal communication channels should be able to absorb much of the information flow to allow task progression with minimal performance decrement.

5. When stable, cohesive units are given sufficient time to evolve, performance will be enhanced through group processes such as social facilitation, development of standard operating procedures, etc.

6. Under conditions of severe time constraint and data/information overload, system operators are likely to make less than optimal decisions.

7. Team performance is tempered by individual task relevant skill and ability, communication structure, and leader ability to coordinate (organize) individual team member effort.

8. Excessive demand for team coordination will result in degraded performance of team leader individual tasks.

P-3C Tactical Crew Arrangement. Figure 4 depicts the P-3C crew station arrangement. It is immediately obvious from this depiction that direct, face-to-face communications between most of the crew is impossible without leaving one's station. The crew station arrangement of the P-3C does not optimize team performance. By dispersing the TACCO from his sensor operators, group interactions become constrained to operate within established formal communication structures and limitations are imposed on the extent to which the crew can organize for more effective and efficient performance. The present arrangement violates several of the key findings that enhance group interaction processes and team performance. In order for social facilitation to be most effective, operators should be in close visual proximity to one another. Within the present arrangement, opportunities for instruction of junior crew members are diminished. In being separated from his sensor operators, the TACCO's ability to supervisor is diminished. He cannot see how intensely the operators may be working and a simple request

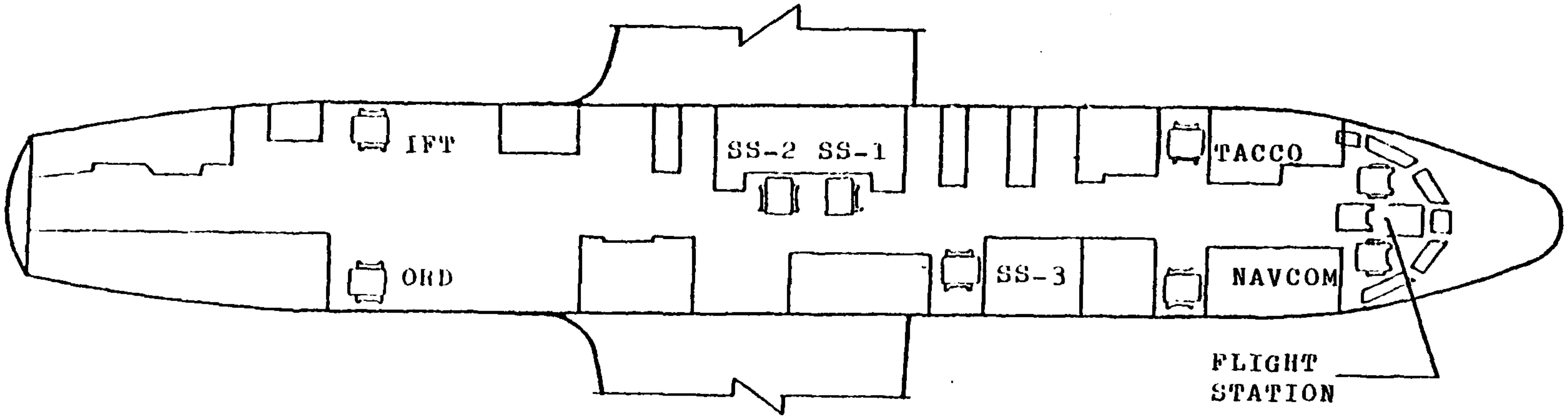


Figure 4. P-3C Crew Station Arrangement (46)

for amplifying information may become the "straw the breaks the camel's back". That request may push the sensor operator over the 100% workload he has been maintaining for the last hour. Crew members eventually learn at what points in a mission other operators become highly tasked, however, this takes time and assumes a stable crew environment.

Off-ICS verbal communication is effectively denied by the P-3C crew station arrangement. This requires that more information must be passed over the ICS, so much so that, during high group task loading, the ICS becomes a formal communication channel.

Early in P-3C conceptual design, it was assumed that, through training, the crew would learn to use the computer system to pass information thereby negating the use and importance of the ICS (59). In practice however, it has become apparent that the effort to input, extract and identify pertinent information from the computer system reduces crew concentration on their primary analysis and decision making tasks. The crew members naturally revert to aural communications channels which are easier to use.

Crews develop their own ICS "discipline" wherein they learn to use a succinct language to send and receive information over the ICS. For example, one TACCO may expect six or seven separate pieces of information in response to a question such as "status on attack barrier". Whereas another TACCO may only want two or three pieces of information.

There are fewer problems when crews are stable and have operated together frequently since they have time for all members to "learn" the language. However, when a crew member is ill and another operator fills in, the TACCO must inform the new crew member of his expectations or risk the chance of miscommunications during time-critical mission phases. Miscommunications result in errors and lost time. They must be resolved during training evolutions since time for discussion is usually not available when the mistake is made. Subjective information, such as a sensor operator's confidence in an acoustic signal bearing cannot be conveyed through the computer and even over the ICS. The TACCO can't see the operator's firm or less-than-positive expression when he states that the bearing is 230 degrees. Again, over time, voice inflections can become learned, but the learning process requires a highly stable crew environment.

The process of learning crew coordination is lengthy, just how long depends on the individual team and the strength (ability) of the TACCO to organize group effort. As crew members are replaced (leave the squadron, are assigned to another crew, etc.) the process of coordination of individual activity to evolve into a team begins again.

Current display and control system structure, although a vast improvement over earlier P-3 model aircraft, requires that the TACCO use two separate CRT displays and keyboards to converse with the central computer and, the ICS to request and receive information not available through the computer, inconvenient to obtain through the computer, or subjective in nature. The current display and control system involves minimal levels of commonality and therefore represents a limitation on the ability of the TACCO to distribute tasks among operators with lighter task loads. The TACCO as information coordinator is highly susceptable to task overloading because he is unable to offload even routine tasks because of information display constraints among all other stations. Although well trained in tactics, the PPC can provide the TACCO with little tactical decision making assistance due to the limited display capability available to flight station personnel. The NAVCOMM, who is training to qualify as a TACCO, has even less of a display than the pilots. Most often the pilots and NAVCOMMs assist the TACCO by monitoring assigned radio frequencies during coordinated operations with other ASW platforms. When another platform requests tactical information concerning the on-going evolution, the pilot or NAVCOMM more often than not, must obtain the information from the TACCO or have the TACCO pass the information himself. The end result is that TACCOs often find themselves so overwhelmed by "button pushing" tasks that they have little time to formulate and analyze decision alternatives which are vital to continued task performance.

The SS-3 operator, in a coordinated operations scenario involving multi-surface and sub-surface targets, has the greatest potential for task overload during critical mission phases. The SS-3 would be required to maintain safe standoff distances from potentially hostile surface targets, monitor and analyze ESM signals for potentially hostile fire control (targeting) radars, maintain tracking of friendly surface forces to avoid firing weapons in a direction that might endanger them, and all this while monitoring for magnetic anomolies from a submerged target. In an actual war scenario, there may be a serious capability degradation due to SS-3 task overloading.

Crew Adaptability. A major factor applicable to analysis of team performance that hasn't been discussed previously is the capacity of humans to adapt to their task environment (15:53). When given a task human operators, especially military personnel, will accomplish this task with all available tools, even though they may not be the best tools for the situation. This "can do" or "make do" adaptation of humans often hides potential areas for improved performance and decreased workload.

Summary. In summary, the current crew station arrangement paired with the present information communication system is working against team performance. The team leader is placed in a position such that his ability to coordinate the tactical crew is severely diminished. Crew coordination, or the organization of individual effort to accomplish the group task, requires a lengthy process which would likely be shorter given a better crew station arrangement.

V. Conclusions and Recommendations

"Complex information processing systems are increasing rapidly both in number and in importance for military systems" (60:39). A basic supposition is that information systems increase weapon effectiveness through increased data acquisition and precision. However, such complex systems also increase the processing demands on teams and increase the requirements for evaluating and integrating sensor data. "The importance of research on teams with command and control functions will continue to grow" (60:9) due to much higher information availability with new sensor systems, higher demand for information integration, and demand for faster, more accurate decision making. Accuracy of its total performance against time is the general criterion for an ASW system. And the personnel component, which is an integral part of this system, is of critical importance for it can either contribute to or detract from total system performance (67:11). Crew members must work together to monitor, assess, and control complex sensor and information processing systems. Specialized roles and functions are allocated to team members within organizational structures and communication networks "to effectively and efficiently integrate information and make decisions" (6:3).

Conclusions. The research findings and a comparison of Allied ASW platforms indicate that the P-3C tactical crew station arrangement is less than optimal. The current arrangement does not permit team performance enhancements through workload sharing, flexible communication and organization structures, or social facilitation. Based on a preponderance of research findings, team performance would be enchanced by allowing group interaction processes to freely operate. Social facilitation, informal communications channels, enhanced team leader and senior crew members ability to supervise and instruct, and workload distribution techniques would all serve to improve individual and team performance. Future U.S. maritime patrol aircraft design must include a more integrated tactical crew station arrangement to enhance team performance.

Many other variables and processes interact in determining the performance of a team including individual and team morale, retention rates, individual skills, individual and team incentives, individual and team objectives, experience levels, and variability of personal backgrounds. The development of a theoretical framework to predict team performance requires formulation of key concepts, hypothesizing causal relations, and testing predicted relationships (60:35). Human or machine experiments could be used to test hypotheses about performance determinants, specifically, particular command

and control structures, communications networks, and decision making processes (60:36).

Past team research has "primarily investigated individual performance in team settings rather than team training or performance per se" (60:9). If system performance is inadequate and if that system is composed of teams, it is necessary to evaluate the adequacy of the "team" performance (15:181). There is currently "no adequate theory of team performance" (60:35). Such a theory should describe the major factors affecting team performance and should enable interpretation or prediction of the effects of interventions in the team training and performance process (60:35). "New research should therefore investigate the utility of alternative modes of communication among humans and between humans and machines" (60:54).

Recommendations. It is recommended that future tactical crew station arrangement be approached from a team viewpoint. The tactical crew should be grouped in a common area to allow the TACCO maximum access to his sensor operators. The TACCO must be able to focus on mission planning and decision making. Common displays would facilitate both backup mode operations as well as equitable workload distribution among similarly skilled operators. The crew station design should be able to accomodate possible new missions. Recommendations for futher study include:

1. Determining optimum communication structures and coordination strategies for specific ASW missions and scenarios.

2. Developing a training curriculum to teach crew members and team leaders effective crew coordination strategies.

3. Analyzing the effects on team performance of replacing the Ordnance and IFT positions with sensor operators or providing the Ordnanceman and IFT with basic training at the non-acoustic sensor stations.

4. Analyzing the impact on team performance of greater information display capability at the NAVCOMM and copilot stations. Specifically, 1) ability of the NAVCOMM to accomplish TACCO functions, 2) impact of awareness of tactical scenario and ability to assist the TACCO with information integration and the formulation of decision alternative, 3) enhancements to the speed and accuracy of TACCO planning and decision making, and 4) impact on training cycle length from NAVCOMM to TACCO.

5. Comparing a theoretical optimal team command and control network to the currently dictated P-3C electronic data distribution network to 1) discover divergences between the two which contribute to inefficiences and 2) help define a construction of a future data distribution network which will compliment and enhance team performance by conforming to the optimal command structure.

Appendix A: Evolution of the P-3C Aircraft

There have been numerous changes within the Navy's land-based MPA force over the last 30 years. However, one aspect has remained constant: the repetitive process of introducing an aircraft to the fleet and then, over a long service life, continually adding new equipment to maintain pace with advancing technology to produce greater mission effectiveness.

In 1962 the Lockheed P-2 series patrol aircraft was replaced because the U. S. Navy needed a new platform to carry new sensors, weapons, and a larger crew to operate the equipment on long-range patrols (63:106). A new aircraft emerged beginning life as the P-3A and evolving over the years into the current P-3C Update II.5.

The P-3A incorporated 1960's state-of-the-art detection capability and the space required to accommodate new systems and an even larger crew. While the P-3A could monitor only four sonobuoys at one time, the P-3B, introduced in 1966 could monitor 8 sonobuoys simultaneously and utilized more powerful engines to allow for increased gross takeoff weights (63:106).

As a result of this new and improved equipment, the aircrew soon became inundated with more information than could be effectively used in rapidly solving an ASW problem. Although advancing technology posed this dilemma, technology also provided the solutions. To eliminate the excessive flow of data, the design for a high capacity digital computer and a more integrated weapon system evolved in the form of the P-3C.

The original concept for an integrated computer-controlled airborne ASW system was initiated in the late 1950s (11:3-1). The various software programs used in the P-3C have been under development since 1963 (11:3-2). In late 1968, Lockheed California Company was officially contracted to produce 24 P-3C aircraft (11:3-2).

The computer in the P-3C allowed most sensor information to be displayed real-time while providing continuous navigation and mission event recording. The computer freed the crew from performing simpler tasks and allowed an increase in the amount of time available for critical tactical decision-making (63:108).

By periodically updating production aircraft and enhancing the capability of those already in the fleet, the MPA force soon consisted of many differently configured aircraft with a large variation in capabilities. Presently, there are seven versions of the P-3 aircraft in operation and the number of Engineering Change Proposals (ECP's) submitted each year on the P-3C is still increasing, particularly for avionic subsystems, reflecting their complexity in comparison with the P-3A/B avionic subsystems (57:13). Because world-wide technology continues to improve, deficiencies in the P-3C weapon system during the 1980 to 1990 time-frame are being identified and a modernization program has been proposed to rectify the projected shortcomings (63:109).

Appendix B: ASW Mission

Tactical ASW consists of four stages: search, detection, localization, and tracking to attack criteria. The search phase begins after the aircraft arrives at the pre-designated search coordinates and employs the appropriate search tactics with associated sensors (visual, acoustic, nonacoustic, or a combination of these).

Detection of the target of interest occurs upon a positive confirmation of target emitters by sensor operators. Once this determination has been made, the localization phase begins wherein attempts are made to refine the target location (and confidence in the signal) through tactics suggested by the type of initial contact. This phase is designed to identify the threat and position of the target prior to commencing the tracking phase. The tracking phase is the process of determining target course and speed, closely following the target to gather intelligence data, and being in a position to quickly destroy the target if required.

Usually an ASW operation begins with deployment of relatively inexpensive multi-dimensional passive sensors to acquire initial contact on a target and estimate a rough Area of Probability (AOP). The AOP is progressively refined using higher cost directional sensors, either passive or active depending upon the mission, until localization or tracking is achieved. The transition from one phase to another can occur immediately or be a time consuming process depending on such external variables as size of initial search area, environmental background noise, target signal strength and target maneuvering.

Since the target is probably trying to avoid detection by whatever means possible, timely decision making and tactical reaction become increasingly critical as the aircrew progresses through the mission phases. The ASW problem becomes highly complex as the number of possible targets and friendly forces increases. With multiple targets, sensor operators become tasked to their limits. For instance, a non-acoustic sensor operator might be required to simultaneously analyze magnetic anomoly signals and ensure the aircraft does not enter established standoff distances from hostile targets. An example of increased workload from greater numbers of friendly forces occurs during coordinated operations where several ASW platforms (airborne, surface, or sub-surface) may be correlating information in prosecution of the same target. During these evolutions the TACCO may be responsible both for the management of his ASW team and possibly the conduct of the joint operation as well.

Appendix C: P-3C Tactical Crew Responsibilities

Table III.

P-3C Crew Complement

Flight Station	Tactical Crew
Pilot (PPC)	Tactical Coordinator (TACCO)
Copilot (2P)	Navigator/Communicator (NAVCOMM)
Flight Engineer (FE)	Acoustic Sensor Operator (SS1/2)
	Nonacoustic Sensor Operator (SS3)

Non-Sensor Operators

Ordnanceman (ORD)

In-flight Technician (IFT)

Of the full crew complement listed in Table III above, five positions, which require the highest degree of coordination for successful mission completion, make up the tactical crew nucleus. These crew members must achieve all readiness qualification exercises as a team in order to achieve and maintain peak crew proficiency, and will normally fly on the same crew from 1 to 3 years. The positions include the PPC, TACCO, NAVCOMM, SS-1, and SS-3. (Figure 1 depicts the P-3C crew station arrangement.) The following crew station descriptions were derived from the P-3C crew station NATOPS Manual (46:9-1 thru 5) and a Navy Post-graduate School Masters thesis (66:148-155) on In-flight Refueled P-3 aircraft.

Pilot

The pilot is the aircraft controller. He is responsible for positioning the aircraft and for all matters effecting safety of flight. The pilot may also function as a tactician, navigator, weapons manager, and system assessor.

As a tactician, he assists in the conduct of ASW tactics as directed by the TACCO and flies the aircraft to points as indicated on his tactical display. He must maintain a full understanding of the tactical picture and recommend tactics to assist the TACCO when appropriate. The pilot also contributes to plot stabilization by periodically maneuvering the aircraft to pass over reference points to synchronize the electronic presentation with real world events.

As an integral part of the weapon systems team, the pilot sets up the armament panels and enables ordnance release power as directed by the TACCO. When conducting visual attacks, he releases the appropriate weapon. When conducting blind attacks, such as over-the-horizon (OTH) targeting or on a submerged submarine, he positions the aircraft at the weapon release point as indicated by the

TACCO. Maximum coordination with the TACCO is required to ensure error-free weapon selection and release.

The pilot also functions as a system assessor. He closely watches all aircraft power systems to assess operating efficiency. Through coordination with the Copilot and FE, he continually assesses the status of all accessory equipment. He coordinates with the navigator to ensure that his navigation equipment is functioning properly and the aircraft position is correct and accurate.

The last major function the pilot performs is that of communicator. He utilizes the intercommunications system (ICS) to report external visual information to the TACCO, to confer with the navigator regarding updated position information and piloting maneuvers (heading, speed, and altitude changes), and to direct the crew during emergencies.

Tactical Coordinator

The TACCO employs appropriate tactics and procedures to most effectively carry out the mission of the aircraft and its crew. He initiates coordinated plans of action for all tactical crew members and continuously monitors, reviews, and revises the plan as the situation dictates. He decides on search store selection and release. Additionally, he ensures the accurate completion, collection, and disposition of required mission data.

A major function of the TACCO is the selection of search stores for release. Although the deployment of the search stores (sonobouys) is usually accomplished by the computer, the ordnanceman, when directed by the TACCO, can select and manually launch a bouy or eject a bouy through the free fall chute. The TACCO and pilot work together in the selection and release of all weapons.

Another major function of the TACCO is the coordination and integration of information provided by the tactical crew members. The TACCO uses the ICS to direct the efforts of the individuals and advise the sensor operators of the possibility of contact as well as informing them of planned tactics and sonobuoy pattern orientation. He also ensures that the proper external emissions conditions are maintained.

TACCO functions can be summarized by listing the areas in which he has prime responsibility: tactics - design, implementation, review, and update; coordination of crew member activities; sensor system management; weapon system management; and data processing system management.

Navigator/Communicator

The NAVCOMM maintains an accurate record of present and past positions, inserts navigation fly-to-points, updates geographical position, transmits tactical messages (as authorized by the Mission Commander), sets up radio equipment before and during flight, and maintains a record of the flight.

The NAVCOMM is responsible for navigating the aircraft to and from the specified operational area and transmitting aircraft position reports in accordance with appropriate directives. The NAVCOMM provides data link assistance as directed by the TACCO, monitors the navigation systems, and advises the TACCO in the event of any navigation/communication related equipment malfunctions.

Upon receiving designation of full qualification, the NAVCOMM immediately commences training to become a TACCO. As a result, in addition to his normal duties, he is often tasked to assist the TACCO whenever possible to gain ASW experience.

Acoustic Sensor Operators

The SS1 operator is the acoustic specialist in the P-3C. He manages and operates the passive and active acoustic hardware and software systems to accomplish data acquisition, interpretation and correlation, and target acoustic signal analysis and classification. He is assisted in this responsibility by the SS2 operator who performs the same functions. The SS1/2 operators also function as tacticians of sorts. They determine contact area of probability using comparative and hyperbolic fixing, and ensure pertinent contact or target data is extracted from signal processors for position and operating mode determination.

Especially significant is the fact that the tactical decisions made by the TACCO are based largely upon the contact classification and confidence of the SS1/2 in their identification. The decision to continue prosecuting a given contact is usually preceded by discussion between the acoustic operators and the TACCO. The outcome of this coordination can make the difference between a successful or unsuccessful mission.

The last major function of the SS1/2 operator is that of communicator. He utilizes the computer and the ICS system to report his equipment status to the TACCO, report contact and target information to the TACCO, and to confer and coordinate operations between and with all other operators onboard the aircraft.

Non-acoustic Sensor Operator

SS-3 controls and monitors the non-acoustic sensor systems on board the P-3C. He manages and operates the active and passive nonacoustic hardware and software systems to accomplish data acquisition, interpretation and correlation, and target analysis and classification.

The SS3 also operates as a tactician. He generates areas of probability from radar bearings and ESM intercepts, determines when contact classification (radar, ESM, IR) reliability has degenerated and suggests appropriate tactics, determines the intercept point of a contact with known course and speed, and manages tactical symbology to maintain a clear picture and understanding of the ongoing evolution.

The last major function of the SS3 is that of communicator. He utilizes the computer and the ICS to report equipment status to the TACCO, to report contact and target information to the TACCO, to coordinate weather avoidance maneuvers with the pilot, and to confer and coordinate operations between and with all other operators onboard the aircraft.

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The P-3C long range maritime patrol aircraft has evolved over the past thirty years into a very complex, multi-sensor weapons system platform. Increased effectiveness has been achieved by incorporating systems that rapidly process large amounts of data. However, crew members operate within relatively fixed cognitive limitations. Mission tasks are divided among the crew members who must work together to monitor, assess and control these complex information processing systems. Little emphasis has been placed on enhancing team performance through better communication and coodination among the team members. This research ffort provides an exploratory study of factors which impact team performance. Areas analyzed include current P-3C human factors deficiencies that inhibit group interaction, a review of communication and group interaction literature relevant to the P-3C aircrew team environment, and an analysis of tactical crew station arrangements in allied maritime patrol aircraft. Although no theory of team performance exists, the preponderance of research indicates that team performance would be enhanced by allowing group interaction processes to operate more freely (i.e., not constrained by rigid communication and organizational structures.) Future maritime patrol aircraft design must allow flexible crew communication and coordination strategies through an integrated tactical crew station arrangement.

18. Communications, Command and Control, Networks