TECHNOLOGY AND ADAPTIVE HIERARCHY: FORMAL AND INFORMAL ORGANIZATION FOR FLIGHT OPERATIONS IN THE U.S. NAVY

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INSTITUTE OF GOVERNMENTAL STUDIES
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Technology and Adaptive Hierarchy: Formal and Informal Organization for Flight Operations in the U.S. Navy [1]

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Abstract:

The high complexity and stringent technical demands of naval flight operations at sea have created a degree of adaptability and counter-hierarchical behavior that would be unusual in any organization, let alone a military one. On paper, modern military organizations are not only large and complex, but formal, authoritarian, and steeply hierarchical. In practice, they often share with many civilian organizations several modes of informal cooperation and networking. Empirical observation of aircraft carriers at sea during naval flight operations reveals the existence of several latent "alternative" modes of organization, each of which becomes activated according to current operational demands and exigencies. Hierarchical structures are incompatible with the demands of increased complexity, yet are not readily changeable in military organizations. We hypothesize that these alternative modes have been created to maintain flight safety and operational efficiency in an environment of high complexity, tight coupling, and manifestly high risk, with an organizational form ill-suited to the purpose, and that they are facilitated, rather than hindered, by the formality of military hierarchy. Organizational stress, however, remains high, and the generalizability or continued success of this strategy remains open to question.

Introduction:

Over the past few years, a small group of Berkeley academicians has had the unusual opportunity of closely observing flight operations at sea aboard large, modern, aircraft carriers.[2] We have noted with great amazement the adaptability and flexibility involved in the organization's day-to-day performance. The ship is formally organized in a steep hierarchy by rank, with clear chains of command and means to enforce authority far beyond that of civil organizations. But many aspects of flight operations are conducted via informal 'horizontal' networks cutting across the hierarchy. They are carried out via a process of ongoing and continuing arguments and negotiations among personnel from many units, in person and via phone, which tend to be resolved by direct order only when the rare impasse develops that requires an appeal to higher authority.[3]

There are sound operational reasons for conducting flight operations and planning as if the organization were in fact relatively "flat" and collegial. Traditional, hierarchical organizations are notorious for their relative inflexibility, the difficulty of coordinating units belonging to different "branches" of the organizational "tree", distortion and delay involved in passing information up and down organizational chains, and the tendency for individuals to hoard information to consolidate or advance their own hierarchical position.[4]

Such organizational pathologies are incompatible with the constant and pressing need to seek a proper, immediate balance between the drive for safety and reliability and that for combat effectiveness. The complexity of the equipment and the tightness of space aboard ship make it difficult to cope with uncertainties and minor errors without involving a large number of support units. Events on the flight deck can happen too quickly to allow for appeals through a chain of command to a formal authority.[5] Coordination of planning for the next day's air operations requires a series of involved tradeoffs between mission requirements and the demands of training, flight time, maintenance, ordnance, and aircraft handling as well as operational safety and pilot status. In each negotiation, most officers play a dual role, resisting excessive demands from others that would compromise the safety or future performance of their units, while maximizing demands on others for operational and logistic support.

Similar behavior occurs in other organizations attempting to cope with major technological change. In the civil sector, the organizational costs of such coping strategies would eventually result in formalization of the new channels, and/or transformation to a more appropriate form.[6] Neither avenue is readily available to military organizations, even though may of them are being asked to absorb major changes of ever-increasing complexity in weapons and systems at an unprecedented rate. Their dilemma is how to reconcile the nearly immutable formal organizational structures of militaries with the requirements of managing complex and sophisticated technologies.[7]

This puts a tremendous strain on modern military organizations. According to the literature and empirical evidence from the study of complex civil organizations similarly challenged by the incorporation of advanced technologies, the formal hierarchical structure that practically <u>defines</u> military organization is increasingly inappropriate to efficient management of its technologies. The lateral mechanism formed to cope are not only inconsistent with, but tend to undermine and weaken both formal authority and hierarchical structure.[8]

Moreover, maintaining the appearance of effectiveness and credibility has not been a minor or unimportant role in any era, let alone one in which the ultimate price of failure may be nuclear war. For military organizations to deter foreign governments and maintain legitimacy with their own, they must conduct the usual day-to-day operations, particularly those combat-related ones connected with 'readiness', with a high perceived effectiveness. Yet, in peacetime, they must also do so efficiently, and with minimal damage to or loss of equipment and personnel. Nowhere is this tension so obvious or the risks so clear as in the technical and organizational complexity of flight operations aboard a modern U.S. aircraft carrier.[9] Nor are naval personnel insensitive to the unusual stresses and complexities of naval flight operations -- they were not only receptive to, but encouraged, on-board research by a small group of academics interested in studying the modalities and structure of their operations.

This research therefore has two overlapping objectives. The rather unique constraints of the system under study make it an opportune instrument for examining the strains that the modern, complex, sophisticated technologies impose upon their operating organizations. It also serves as a prototypical 'high-technology' military system for the further study of the organizational demands and pressures that are likely to face other units, and other services, as many of the new military technologies still on order or in the conceptual phase are introduced.

Technology and Organization: Complexity, Error, and Risk

It is by now commonplace to observe that the structure of an efficient technology-managing organization is strongly affected by the nature and requirements of its core technology.[10] As a rule, the more sophisticated the technology, the more complex the range of organizational structure and behavior.[11] At times of rapid technological change, perceptible strains occur in organizations, imposing demands for structural adaptation. For most organizational exemplars, however, the requirements imposed tend to be fixed, or to vary over at most a small range. Given the low variance, organizational structures can either be re-designed, or organically evolve through a relatively stable process of trial-and-error.

The formal and hierarchical structure of military organizations is a functional adaptation to the exigencies of combat, where clear, rapid, and unambiguous lines of authority and responsibility are of primary concern. But hierarchical systems are most efficient when the core technology of an organization is relatively simple, and the mutual dependencies among units at different loci along the hierarchical 'tree' are relatively weak.[12] As tasks and technology get more complex, coordinating the activities of the several units involved becomes more frequent and more difficult -- to the point where 'reciprocal' forms of interdependence develop, so that several units may be unable to proceed with, let alone complete, their sub-tasks without complete coordination with those of others.[13]

Several propositions concerning the connection between technology and structure are of relevance to complexity, both technical and organizational, as defined here:[14]

- The greater the technical complexity, the greater the structural complexity. The structural response to technical diversity is organizational differentiation. [Scott]

- The more constrained the organization's resources or discretion, and the more critical the technology to operations, the more complex the organization will become in response. [Demchak]

- The greater the technical uncertainty, the lower the degree of formalization and the lower the degree of centralization. [Scott]

- The higher the degree of technical interdependence, the more resources that must be devoted to coordination. [Thompson]

- The more complex and unique the machinery, the greater the uncertainty and the resources or effort needed to obtain knowledge about potential outcomes. [Demchak]

Organizational complexity so defined has been the subject of considerable study, but almost never under the constraints and demands operative in the case of modern military systems.[15] Whether bureaucratic or profit-driven, civil organizations generally have a great deal of flexibility in structural innovation, which has been their primary adaptive strategy. Civil organizations are relatively free to differentiate, to decentralize, and to devote time and resources to coping strategies and coordination. Military organizations seek to react in similar ways, but are far more constrained with regard to human and financial resources, as well as organizational formalization and structure.

Most organizations also operate in an environment where process uncertainty is moderate and bounded, and the social consequences of 'errors' or 'failures" are limited in scope or impact. In the past few years, there has been an increasing interest in the study of those few organizations in which increasing complexity and uncertainty are conjoined with high social consequences of error. For some, it appears that inability to adapt creates a situation where failures will occur, as 'normal accidents.'[16] A few others, such as en-route air traffic control, utility grid management, or naval flight operations, seem to have developed organizational strategies that have thus far enabled them to cope remarkably well.[17]

For this type of organization, technologically-induced deviations from the assumed limits of performance and error can be internally quite disruptive. In most cases, however, disruptions to organizational performance tend to be relatively localized; external consequences tend to develop only slowly over time. Society "at large" will be affected only to the extent that the organization itself, or the product or service it is responsible for, are things that society values. These are the types of organizations, and social and organizational impacts, that have been the focus of most extant sociological and organizational studies.[18]

There are, however, organizations whose performance is tightly coupled to their technology, and who can be perceived to have failed almost immediately when an unanticipated error occurs; examples include the *Challenger*, *Three-Mile Island*, and Bhopal.[19] For some, such as *Challenger*, the general social consequences remain largely existential and perceptual. For others, such as Bhopal, consequences are real, and direct. Military organizations, operating in peacetime, cover roughly the same spectrum.

For naval flight operations, operating outside the range of prior assumption can be quite literally catastrophic. Pushing too hard could easily result in the loss of life, in the air or on the very dangerous flight deck, and/or the loss of one or more very expensive, and very scarce aircraft. At worst, a flight deck fire or explosion could cripple the carrier, taking it out of service for some considerable time. But inability to regularly sustain a high level of activity would greatly reduce the credibility of the force. Success, then, comes to be defined as being able to generate 'high-tempo' flight operations over some sustained period of time without serious incident or accident, and without thereby compromising the ability to do so again in a relatively short time.[20]

An organization operating manifestly high-hazard technology, cannot hope to somehow pass through an era of low challenge or low activity when seeking to gain credibility. It must be repeatedly successful over a long enough time for some of the major challenges to performance and 'excursions' from expectations to develop. Furthermore, for naval flight operations, as for many other military 'systems', the coping strategies available for dealing with the increasing complexity engendered by modern, sophisticated technologies are radically restricted compared to civil organizations. From our empirical observations aboard several aircraft carriers, we conclude that there is, nonetheless, a workable strategy -- devising a mode of organizational adaptation that allows the flexibility to conform quickly to shifting technical-operational requirements without disturbing the formal hierarchy.[21] What we cannot ascertain from a single study are such a strategy is generalizable, or whether it can be sustained in the face of rapid technical change.

The Organizational Context: A Sociological Exploration

Over the past year or so, our Berkeley research team has been seeking ways to describe naval flight operations and a few other "high reliability" organizations in more specific and formal terms, an exercise often frustrated by the realization that most of the literature in the field was developed from empirical research on organizations with a far greater tolerance for error.[22] Of the three organizations under study, the aircraft carrier is by far the most complex, the most hazardous to its own personnel and operational capability, and, as a military organization, the furthest removed from modern modes of organizational analysis.

A nuclear-powered aircraft carrier of the *Nimitz* class is an 1100-foot, 95,000 ton, socially and organizationally complex floating city of 6,000 men. On deployment as the center of its Battle Group of seven to nine ships, the carrier contains three quite distinct organizational structures. Battle Group Command ("Flag"), under the command of an Admiral, is aboard, in its own quarters, with a complement of about 25 officers and 20-30 enlisted. The ship itself, nominally just another of the units under Flag, has a complement of about 2,500 enlisted and 200 officers (including a company of Marines), organized under its Captain (the Commanding Officer, or CO). Within this general structure there are numerous functional sub-units (departments), such as navigation, engineering, nuclear power, air operations, management, supply, and so on, who must function both autonomously and in close coordination with the rest. Also aboard is the Air Wing, under the parallel command of the Air Wing Commander (CAG), with about 2,000 enlisted and 200-300 officers. Each of these units has its own organizational tasks, purpose and goals, all of which must be brought to bear in a coordinated fashion if flight operations are to take place.

Nor can flight operations be simply characterized as a technological task.[23] All three of the technological types developed by Thompson -- long-linked, mediating, and intensive -- are present.[24] But this distinction fails to capture the character of problem and response in sufficient detail. The approach used here builds on a sociological heuristic first put forth by Perrow for examining the interaction between technology and structure.[25] The chief modification consists of altering the independent variables to **"variance"** and **"unpredictability."** By the first I mean the scope and range of potential disturbances and unexpected events; the second subsumes both their sequence and their causality (i.e., the degree to which they present 'surprises' to the operators).[26] Both pertain to what we call 'error' -- manifest organizational failure to cope with or recover from severe, rapidly threatening stimuli. Thus, we remap Perrow's diagram as follows:

FIGURE 1

Character of Variation		High	Low
	Severe	Engineering Technical Knowledge	Non-Routine Exploratory Knowledge
	Moderate	Routine Manufacture Comprehensive Knowledge	Craftsmanship Experiential Knowledge

Predictability of Variation

Organizations dealing with predictable variances of limited range can be categorized as "routinized." They tend to be hierarchical, with clear separation of function between operations, management, and administration -- fully bureaucratic in the classic sense. Interdependencies among production, technical, and management cadres are likely to be low, problems sequential, and power distributed up the pyramid according to formal models of hierarchy. Operations can be fully pre-programmed and pre-planned, by delegation from the administrative/managerial level to the technical one, and by fiat to the production units. Automobile manufacturing is a classic example, and 'standardization' is the classic organizational adaptation.

For situations or processes in which variance is predictable, yet broad and varied in scope (computer software development, heavy machinery), the approach leans more toward the engineering model, in which discretion "on the shop floor" remains minimal. 'Planning' is the classic organizational adaptation; the cadre of problem-solvers at the technical level is large, and its role central. Because the range of variance is large, many alternatives must be considered; because it is formally predictable, these can be dealt with in terms of alternative strategies, programs, and plans; because no organization can afford to maintain an infinite set of alternatives, and there may be many choices of varying cost for any particular event, interdependence between technical and management levels is high, and reciprocal, but interaction between either level and operators is low.

Where variance is limited in scope, but largely unpredictable, preprogrammed schemata for problem search or organizational response must yield to 'craftsmanship', or experiential knowledge.[27] The importance of the technical cadre is low (owing to non-analyzability of problem search), and that of the production staff high. Interdependence between operations and management is higher because of the need to improvise solutions, but since such events are taken to be rare, reciprocal interdependence is problem-activated rather than structural. Negotiation between either group and the technical cadre is fairly low. Many small manufacturing firms fit into this category, with technical (engineering) staff being called in only to help solve implementation or equipment problems.[28]

When an organization must deal with frequent, severe, and largely unpredictable variance, it tends to move towards the non-bureaucratic model of the "R&D" organization, the university department, and the custom*p1969Xdesign shop. The operative mode is more or less democratic, bureaucratized only in non-essential functions (payroll, hiring), and largely non-hierarchical ("flat"). Planning tends to be general and strategic rather than production-specific or alternative-generating "tactical". Decisions proceed largely by consultation, discussion, and negotiation (the "collegial" mode). Interaction is high, and, depending upon the nature of the task and the technology involved, may involve "reciprocal" interdependence, in which no unit can perform its own task unless other units are simultaneously performing others.[29]

As military technology advanced, military organizations developed their own cadre of technical specialists, in parallel with the corresponding developments in civil industry.[30] This specialist cadre has grown rapidly in all modern military organizations.[31] At first, the issue was simply the proliferation of modern equipment. But as weapons systems grew more complex (and sometimes less numerous), there was a rapid increase in the **number** of tasks required, their **differentiation**, and their **interdependence** -- the operational definition of organizational complexity.[32] Thus, military organizations face the double problem of coping with increasing uncertainty in the face of growing complexity.[33]

The middle range of coping strategies -- standardization and planning -- are useful primarily for that category of unexpected event that is characterized by Demchak as 'knowable unknowns'; events that could, in principle, be anticipated -- with perfect knowledge.[34] The problems facing aircraft carrier flight operations are more general, extending to her second category of 'unknowable unknowns': operations under state-of-the-art technology involve contingencies and exigencies that are often not predictable from the present experiential knowledge base. In addition, tight schedules and the need to coordinate among the many specialties and tasks required foster reciprocal interdependence and tight coupling. Problems that may, when analyzed, turn out to present low variance may not be so recognized in practice; the tightness of coupling and limitation of time mean that many incipient deviations must be treated as potentially serious rather than 'waiting them out.'

Aboard the carrier, problems of all four type can occur, sometimes at the same time. The coping strategy for flight operations is to establish a series of informal 'networks' that connect those parties whose actions must be coordinated -- some for safety, some for efficiency, some to negotiate the trade between them. Moreover, each of these tends to have a different character according to the variance involved.[35] But as often as not, both the problem and the response net are evanescent; forming, with apparent spontaneity, in minutes as a crisis erupts and dissolving immediately it is resolved.

"Strike" planning, for example, is a primarily collegial ('liaison'/project team) exercise in which the allocation of aircraft and weapons for the next day's mission is put together every night by negotiation among representatives of the Air Wing, the Ship, and the Flag. Problems on the flight deck are often resolved by the 'craftsmanlike' experience of the deck Chief Petty Officers, but sometimes require the invocation of a negotiation network ('task force' or 'direct contact') that involves the Air Boss and the Flight Deck officer. Aircraft problems in the air are usually handled by a technical network involving both Ship and Wing personnel. And so on.

The gradually evolved solution in the case of naval flight operations is therefore to adapt and use <u>all</u> of these responsive modes, at different times, in different circumstances, and with different players, according to the situation at hand. When there is no stress, the structure remains hierarchical. When stress, and variance appear, or are threatened, one or more of the appropriate informal networks will be activated, by common consent, with no need for prior approval or formal recognition.

Indeed, if one runs through the contingencies and exigencies of daily 'high tempo' flight operations in a Battle Group Exercise, or on deployment in potentially dangerous waters, examples of each of the four paradigmatic organizational structures described in Figure 1 will appear almost every day, in different contexts and at different times. Moreover, the tightness of coupling and overlap of activity means that more than one may be operative simultaneously, but definitely <u>not</u> independently. The result is not so much a "collegial" atmosphere as a "university" one, in which many quasi-independent units must negotiate internally to get their own jobs done and externally with others to assure overall coordination and purpose.[36]

One of the more senior and experienced officers we interviewed described these as "authority overlays", using as a model the well-known procedure of overlaying transparencies to illustrate complex engineering or organizational diagrams one function at a time. Each officer on the ship has a formal allegiance to some particular department, and is placed neatly into some specialized sub-unit of the organization chart, linked to others both by command and by functional relationships. The ship, the Air Wing, and the Flag each have their own internal structure, and the official command and information links among them form the first, and formal, set of "overlays." Superimposed on these are the different 'quasi-permanent' informal networks responsible for primary tasks -- navigation, engineering, air operations, flight and hangar deck control, strike planning, and so on. And overlaid on <u>those</u> are the problem-solving networks that are activated only when things get outside of 'normal' boundaries.[37]

By the time we get to this level, the language of "overlays" is stretched too far. Since these networks gain or lose strength only as needed -- indeed are completely invisible in 'normal' operations -- yet must be flexed and drilled to make sure they will perform when required, it is perhaps better to think of them as <u>latent</u> structures. Since rank and deference give way to experience and problem-solving ability when they are active, they tend to dissolve rather more quickly when the need passes than they would in a civilian organization. But their need is governed not only by problem-solving requirements, but to provide a degree of redundancy to assure that more than one group or unit is monitoring the most critical activities.

<u>Redundancy and Structure</u>

Operational redundancy -- the ability to provide for the execution of a task if the primary unit fails or falters -- is a necessity for any organization managing activities sufficiently dangerous to cause serious consequences in the case of operational failures.[38] In classic organization theory, redundancy is provided by some combination of duplication [two units performing the same function] and overlap[two units with functional areas in common]. Its enemies are mechanistic management models that seek to eliminate these valuable modes in the name of "efficiency".[39] For a carrier at sea, several kinds of redundancy are necessary even for normal peacetime operations.

A primary form is technical redundancy, involving operations-critical units or components on board -- computers, radar antennas, etc. In any fighting ship, as much redundancy is built is as in practicable. This kind of redundancy is traditional, and well understood. Another form is supply redundancy. The ship must carry as many aircraft and spares as possible to keep its power projection and defensive capability at an effective level in the face of maintenance requirements, and possible operational or combat losses. Were deck and parts loading reduced, many of the dangers and tensions involved in scheduling and moving aircraft would be considerably lessened. Here is a clear case of a tradeoff between operational and safety reliability that must be made much closer to the edge of the envelope than would be the case than for other kinds of organizations.

The complexity of new, sophisticated technologies imposes direct burdens on the maintenance of both of these strategies. Newer equipment is frequently so large, or so expensive, or so integrated, that it cannot be functionally duplicated, however large the stock of spare parts. Moreover, the increasing cost, number, and differentiation of parts and repair skills has forced the carriers to depend increasingly on the flow of spares from land bases or supply ships and the 'swapping out' of modules for repair at specialized depots. This imposes corresponding costs on the organization.[40]

More directly related to our research, however, is a third and more indirect form, decision/management redundancy, which encompasses a number of organizational strategies to ensure that critical decisions are timely and correct. This has two primary aspects: (a) internal cross-checks on decisions, even at the micro level; and, (b) fail-safe redundancy in case one management unit should fail or be put out of operation. It is here that the multiplicity of formal and informal networks becomes most complex and difficult to dissect -- empirically as well as theoretically.

As an example of (a), almost everyone involved in bringing the aircraft on board is part of one of several constant loops of conversation and verification, taking place over several different channels at once.[41] This constant flow of information about each safety-critical activity is designed specifically to assure that any critical element that is out of place will be discovered or noticed by someone before it causes problems. Setting the arresting gear, for example, requires that each incoming aircraft be identified (for speed and weight), and each of four independent arresting gear engines set correctly.[42] At any given time, as many as a dozen people in different parts of the ship may be monitoring the net, and the settings are repeated in two different places.

Fail-safe redundancy, (b), is achieved in a number of ways. Formal duplication and overlap, the most familiar modes of error-detection, are used to some extent -- for example, in checking mission weapons loading. Nevertheless, there are limits to how they can be provided. Space and billets are tight at sea, even on a nuclear-powered carrier, and, unlike land-based organizations, the sea-going Navy cannot simply add extra departments and ratings. Shipboard constraints and demands require a considerable amount of redundancy at relatively small cost in personnel. In addition to the classic "enlightened waste" approach of tolerance for considerable duplication and overlap, other, more efficient strategies that use existing units with other primary tasks as back-ups are required, such as "stressing the survivor" and mobilizing organizational "reserves".[43]

Stressing the survivor strategies require that units operate below capacity, so that if one fails or is unavailable, its tasks can be shifted to others without severely overloading them. Mobilizing reserves entails the creation of a latent "shadow" unit able to pick up the task if necessary. It is relatively efficient in terms of both space and personnel, but places higher demands on the training and capability of individuals. What the Navy effects through the combination of generalist officers, high job mobility, constant negotiation, and perpetual training, is a mix that leans heavily on reserve mobilization with some elements of survivor stressing. Most of the officers, and a fair proportion of senior enlisted men, are familiar with several tasks other than the ones they normally perform, and could do them in an emergency.

The Combat Decision Center, for example, is the center for fighting the ship.[44] Crucial decisions are thereby placed in the hands of relatively junior officers in a single location. But we have also noted several of the compensating mechanisms described above. There is a considerable amount of senior oversight, even in calm periods. A number of people are "just watching", keeping track of each other's jobs or monitoring the situation from other locations. There is no one place on the ship that duplicates the organizational function of combat, yet each of the tasks has a back-up individual or network somewhere -- some on the carrier, some distributed among other networks of the Battle Group.

Thus, the provision of redundancy and the creation of informal and/or "latent" networking are not only complementary but interlocked strategies. Many of the networks whose existence owes primarily to one specific set of tasks or functions are also 'latently' able to advise, support, or even take over a different, but related set. Horizontal, functional networks are also intersected by vertical command chains. And since any individual acting in one structural context may also be a member of several other overlapping structures, both the means of detection and the means of activation are available.

Stresses and Costs

The combined burdens of introducing sophisticated new technologies into military organizations are too numerous to detail here, since they vary from service to service, from function to function, and sometimes from unit to unit. Nevertheless, there are several main categories identifiable even from this limited research:[45]

A. First Order, Direct Effects: These result from the costs of directly coping with the complexity and/or sophistication of the technology itself, including 'knowledge burdens' as well as parts, supply chains, increases in specialist ratings, 'tail to tooth ratios', inability to provide duplication, and fiscal costs.

B. Second Order Indirect Effects: These are the impacts on the organization that are caused by its attempts to cope with the technology and its 'first order' effects. Discussed at length above were the costs in human, organizational, and fiscal resources of: continuing to provide redundancy; creating new networks and maintaining old ones; and increased demands for schooling and training. There are undoubtedly others to be identified as the research proceeds.

C. 'Third Order' Indirect Effects: By 'third order' I mean those effects that arise owing to changes in overall perceptions as to the organization's motives, purposes, goals, and missions.[46] A shift to fewer, more expensive, but more capable tanks can cause a reassessment of the role and structure of an armored division. A shift to more capable aircraft can result in a perception, within the Navy or more generally, that it can perform additional, or more sophisticated missions. The assignment of these will of course place an additional burden on the organization; to the extent that functional or mission complexity thereby increases, the results will be as for "B" above.

The often-problematic relationship between technological change, technological sophistication, "complexity", and organizational structure is difficult to examine without taking into account all three of these levels. For, even when the character of the technology seems simplifying at the point of use (i.e., 'black boxing' electronics), the second and third order effects can overwhelm. In many cases, the need to conform to expectations and preserve prior levels of performance can drive the organization to divert resources in unexpected, and often complexifying, ways.[47]

All three levels are clearly affected in naval flight operations as new technologies (e.g. a new aircraft) are introduced. In an "ordinary" organization, many of the behavioral patterns we observe as the Navy tries to cope would likely be characterized in negative terms. Back-up systems differ in pattern and structure from primary ones. Those with task responsibility are constantly under the critical eye of others. Authority and responsibility are distributed in different patterns, and may shift in contingencies. Redundancy and overlap are provided by both formally structured and *ad-hoc* arrangements. This mix is not only "inefficient", but stressful.

In naval flight operations, where reliability is paramount, the organization relatively immutable, and the task of primary importance, it is not only accepted, but turned to benefit wherever possible. This is reinforced by a historical 'can-do' attitude, by pride in their ship and unit, and by a belief in the tradition of "generalist" officers and legendarily competent chiefs. In addition, at least for flight operations, there is also confidence in their ability to perform with a high level of safety and efficiency a job that no one else in the world even attempts at this level of sophistication.

The costs, however, are far from negligible. As the complexity of the technical systems and their associated tasks increases, more and more organizational resources -- space, time, and energy as well as money -- must be devoted to tasks and activities that are formally either non-existent or much more restricted in scope. The provision of redundancy, once achieved through relatively straightforward duplication of equipment, unit, or function, becomes a systemic, organizational task, adding to the work load.

An additional burden for the Navy is the continual rotation of naval personnel, even while at sea. Lewis Sorley has characterized the effects of constant turnover in other military systems as "turbulence", and identified it as prime source of loss of unit cohesion.[48] A student of Army institutional practices has remarked that the constant introduction of new soldiers into a unit just reaching the level of competence to perform in an integrated manner can result in poor evaluations, restarting the training cycle and keeping individuals perpetually frustrated at their "poor" job performance.[49]

Negative effects in the Navy case are similar. It takes time and effort to turn a collection of men, even men with the common training and common background of a tightly-knit peacetime military service, into a smoothly functioning operations and management team. Standard operating procedures (SOP) and other formal rules help, but the organization must learn to function with minimal dependence upon team stability and personal factors. Even an officer with special aptitude or proficiency at a specific task may never perform it at sea again. Cumulative learning and improvement are also made slow and difficult, and individual innovations and gains are often lost to the system before they can be consolidated.[50]

The Navy's training cycle is perforce dictated by the schedule of its ships, not its personnel. Because of high social costs of long tours of sea duty, the Navy has long had to deal with such continual turnover, and attempts as best it can to mitigate the negative effects.[51] Most important is the institutionalization of continual, cyclic training as part of organizational and individual expectations. At any given moment, all but the most junior of the officers and crew are acting as teacher as well as trainee. A typical Lt. Commander, for instance, simultaneously tries to master his present job, train his juniors, and learn about the next job he is likely to hold. If he has just come aboard, he is also engaged in trying to master or transfer all the cumulated knowledge about the specifics of task, ship, and personnel in a time rarely exceeding a few weeks.

As a result, the ship appears to us as one gigantic school, which in turn has certain benefits. One of the great enemies of high reliability is the usual "civilian" combination of stability, routinization, and lack of challenge and variety, which predispose an organization to relax vigilance and sink into a dangerous complacency that can lead to carelessness and error.[52] The shipboard environment on a carrier is never that stable. Traditional ways of doing things are both accepted and constantly challenged. Young officers rotate in with new ideas and approaches; old chiefs remain aboard to argue for tradition and experience. The resulting dynamic, at its best, leads to a constant scrutiny and re-scrutiny of every detail, even for SOPs. But it is also quite expensive in terms of time and energy, both of which are always scarce commodities.

The importance of providing adequate work-up time cannot be overemphasized. During our research, we followed one carrier through a work-up shortened by "only" two weeks for reasons of economy. As a result, the ship was forced to complete its training during the middle of a difficult and demanding mid-ocean exercise, with resulting enormous and visible strain on all hands. Although she succeeded, and although referees were willing to adapt evaluation procedures a bit to compensate, risks to ship's personnel, to the equipment, and to the Navy were visibly higher.

The direct burdens imposed upon the organization by technological change are therefore neither negligible nor unimportant. When one also takes into account the additional resource requirements, real-world limitations on the number of horizontal networks that can be created and effectively maintained, and the purely human limits as to the number of such networks one can effectively contribute to while still bearing a full duty load within the formal specifications of the organizational structure, there is every reason to be concerned about the future ability of military organizations to cope.

Conclusion: Adaptation and the Role of Formal Authority

High-technology civil industries with potential severe consequences have adopted a series of strategies to cope, some of which are workable, some not. In nuclear power plant operations, engineered reduction and control of small incidents has disguised the tight-coupling from operators and managers alike.[53] Other organizations choose to live with uncertainty and the other existential costs of collegial organization, and organize "flat" and informally, so that maximum resources can be brought to bear quickly on almost any problem. This may well be the case in air traffic control, where the ratio of managers to operators is very low, and the distance between them small, and "administrators" are kept remote from the floor to deal with the external environment. Many are also able to buffer themselves in a variety of other ways, choosing to avoid technologies that induce complexity or to defer or avoid some of the consequences by controlling their environments.[54] These and similar solutions may be available even to other high-technology-using military organizations -- provided they have the resources to buffer or absorb the extra costs or lay them off onto other organizations in their environment. But few of these solutions are suitable, or affordable, for the 'combat' military.

The evolved solution in the case of naval flight operations is to employ an ad-hoc mix of all four organizational structures: implementing them in different modes, at different times, in different circumstances, and with different players, according to the situation at hand. Superimposed on this all are both the formal networks and the overall hierarchical structure, which serve to prevent the dilution of authority or the muddying of responsibility and provide clear distinction between problem-solving and lines of command. This leads to the first proposition concerning organizations under constraint:

- **Where the organization is constrained by structure or resources from formally adapting to the pressures of technical diversity and increasing complexity, differentiation and lateral networking will nonetheless proceed, by informal modalities.**

Operation along the multiple nets is a skill perfectible only by realistic exercise and drill, which requires the devotion of considerable resources to 'realistic' operational training. This has been realized by the Navy, who give the aircraft carriers and their wings first call on fuel and parts as well as on a specialized cadre of trainers and evaluators.[55] Nevertheless, budgets are finite, as are training time and resources. But as the system grows in complexity, increasing the number of functions and networks that any individual must master, the end of the training cycle has been systematically displaced into the beginning of the deployment period. This itself is a source of strain and potential risk.

Effects like these are quite visible. The indirect costs of maintaining the double structure are not. The experiential 'shadow' organization composed of informal networks is handed down from generation to generation by oral tradition; nowhere is it completely described in SOPs or other formal documentation, so that neither budgetary nor time allotments are adequate.[56] Thus, there are unacknowledged as well as recognized increases in organizational complexity -- which is thereby growing more rapidly than is generally realized at the 'administrative' level where technological, staffing, and training decisions are made.

There are also internal costs. As complexity grows, so does the difficulty of exercising control within the organization. Each network that forms is nominally a control system, so that the presence of many informal nets greatly decentralizes operational control. The corollary is that whatever the formal makeup of the organization, centralized hierarchical control will be increasingly difficult to exercise if changes in its structure are such that members become more interdependent.[57] The military compensation for this is of course the formal chain, whose authority must be formally delegated or explicitly or implicitly ceded. But this does create both internal strain and potential conflict, particularly when the network is informal and the delegation implicit.

These observations present a series of puzzles to the observer whose analytic tools were developed and sharpened through the study of Sears Roebuck or Health Education and Welfare. Modern, high-technology military organizations are in a process of structural evolution that is not well studied or understood, but can have profound consequences for all of us, as well as for the organization itself. Naval flight operations provide an interesting case study, and a 'simple' one because of their high visibility, and because they are tested on a daily basis. Much more needs to be done on systems whose failures are not so visible, and not so well-tested.

If the system being operated were, say, a large, modern telecommunications net, the strategies outlined above would probably suffice. But for most military systems, and in particular for naval flight operations, high variance and low predictability force the organization repeatedly into the upper right hand corner of Figure 1. When operations are also tightly coupled (real-time urgency, low buffering), the result, is severe internal conflict in the organization.[58] Organizations operating in this domain seek to be centralized for immediate obedience and response, owing to their tight coupling; but they also seek to decentralize to optimize problem search and recognition because of their high variability. Perrow argues that the threat of emergencies tends to dominate, resulting in the invocation of centralized command structures in an emergency -- perhaps just at the point where the decentralized structures should have the greatest voice. And so it seems to have been also on the U.S.S. *Vincennes* in the Persian Gulf.

In the case of aircraft carrier flight operations as we have observed them, these conflicting tendencies are stabilized (rather than resolved) by the very formality of military hierarchy. Lines of authority are always clear, and the command system can always be invoked, literally 'at a word.' What is more, naval tradition fixes the locus of responsibility firmly -- traditionally on the Captain.[59] Thus, the dissolution of the organization into informal problem-solving networks cannot directly threaten either the structure or the authority of the underlying hierarchy, or give it reason to fear that it will not be able to reassert control if and when necessary. It is for this reason that I hypothesize that the formality and externally-determined structure of military hierarchy not only facilitates, but stabilizes the numerous informal networks.

This leads to the second proposition, in the form of a hypothesis perhaps more true of military organizations than of civil:[60]

- **The more the formal structure and lines of authority are <u>external to the technology</u>, the more stable the informal networks, and the more buffered the organization from pressures for formal structural change.**

The validity of our empirical results on non-combat carrier operations are somewhat ambiguous, since we did not (and could not) have observed her under actual battle conditions. However, an independent report by a journalist who was aboard the U.S.S. *John F. Kennedy* during the fateful December 1983 raid on Libya tends to strongly support <u>both</u> our own conclusions, taking the carrier as an independent system, and Perrow's, insofar as the command chain as a whole was concerned.[61] Inside, the ship remained "flat" and adaptive; outside, the command chain showed all the information and control pathologies that steep, formal hierarchies are infamous for.

The implications for future military systems, both in peacetime and in combat, therefore remain quite troubling. Although naval flight operations seem to be coping fairly well -- if external command structures allow them to -- there is little evidence that the adopted strategies are generalizable even to other military systems. Moreover, increasing information flows and facility of communications makes outside intervention ever more likely. It is also difficult to remain sanguine about the continued ability of even the aircraft carriers to cope. As technologies and threats grow more sophisticated, both organizational complexity and coupling will tend to increase. Military organizations, already considerably strained and relatively slow to adapt, are more likely than most to find themselves in 'non-adapted' configurations, and far more likely than most to have to respond to time-urgent, critical situations in whatever configuration they happen to be in.

As military and civil organizations shift from mere users of technologies to integrated socio-technological systems, the threat of similar failures in other, perhaps more dangerous, situations is quite real. Recent events in the Persian Gulf have sharpened our perceptions that complex military systems are all to subject to so-called "human" failures. But the humans in the Combat Information Centers on both the U.S.S. *Stark* and the U.S.S. *Vincennes* were part of the technical-organizational operating 'system,' not exogenous to it. Blaming the humans as individuals when an organization fails may help to preserve some cloak of organizational credibility; it does little to address the fundamental problems of operating a modern, highly technologized, tightly coupled, complex organization, under the stress of battle.

Appendix

The "Alert 5"

The best way to convey the degree of technical, operational, and organizational complexity that is imposed upon naval flight operations by the physical limitations of ship-board operations and the degree of tight coupling that is imposed is to take a single, fairly simple example. In this case, I have chosen the "Alert 5" -- anywhere from one to four F-14 fighter aircraft that are kept on deck, fueled and armed, with pilots in the cockpits, in real or presumptive high-threat environments. As the name suggests, these aircraft are on alert to launch at any time within five minutes of notification, regardless of the time or state of the flight deck.

In the case of land-based air forces, this would entail 'merely' the selection of a couple of aircraft, to be armed and fueled and kept near the runway or taxi strip, a couple of pilots (with second-seaters if necessary), and a crew to get them into the planes and assist them in start up. At sea, the demands are much more rigorous, which is why the degree of complexity far exceeds that of other, seemingly parallel, military situations.

Pilots and Planes

Most of us have been raised on the classic image of the pilot and his plane, in a personal relationship much like that of the cowboy and his horse, and of the maintenance crew that takes care of both. A charming image, but obsolete. Modern fighter aircraft are too expensive, too scarce, and require too much maintenance time, to be assigned to individual pilots. Instead, the aircraft of the Wing are maintained, refueled, and overhauled in the most efficient way possible; at any given moment when an aircraft is needed, the Wing Commander (or his delegate) will simply select from among those that are ready to go.

At sea, there is the further complication of physical positioning. Given the size of the aircraft and the crowding of airframes onto the carrier, mobility is very limited. If launches are being planned ahead, aircraft must be maneuvered into precisely pre-determined positions on the flight deck, and launched in careful sequence. And aircraft are moved from the hangar deck onto the elevators and up onto the flight deck according to their hangar deck locations. Although a pilot may be certain well in advance of his mission just which aircraft he will fly, he has no choice in the matter. A typical air group has several pilots (and aircrew, if needed) for each of 'its' aircraft.

Pilot availability is governed by other factors. In order to remain 'qualified' for operation on a sea-borne aircraft carrier, pilots must have a minimum number of take-offs and landings within a specified prior time frame. Furthermore, the requirements for night operations are even more stringent, so that a pilot is not considered 'night qualified' if he has been on leave for a week. He must perform a number of "quals" -- launches and takeoffs done specifically to re-hone his skills -- before he can scheduled for 'real' night-time operations. Moreover, after a mission, or after sitting in the cockpit for some number of hours manning an "alert" fighter or tanker, a minimum number of rest hours must be acquired before a pilot can safely be scheduled to fly again.

The Wing Commander needs to balance present demand for pilots against future possible demands, and between various kinds of missions, which involves considerable external negotiation. He must also ensure that all of his pilots have equal access to flight time. He must also balance his natural desire to match his pilots known skills with mission profiles against the need to demonstrate 'fairness' and to provide multi-mission training opportunities for all of his personnel. All of this will run through his mind as he chooses the "alert" pilots.

The Ship as Base

Some of restrictions and constraints imposed by shipboard operations were mentioned above -- the primary one being the physical limitations imposed by the difficulty of maneuvering large aircraft within the confining universe of hangar deck, elevators, and flight deck. But these limitations are extended further by the organizational and operational constraints that accompany them. Maintenance, like everything else having to do with the airframes, is strongly constrained both by the physical space and by the availability of personnel.

With regard to space, it is necessary for all shipboard aircraft (including helicopters) to have one or another variety of folding wings to decrease the necessary storage space. Indeed, space is so constrained that aircraft on deck normally must fold their wings almost immediately after landing, and before taxi-ing on the deck, and spread them only when they are on the catapult positioned for launch. On the other hand, there are some kinds of maintenance that <u>require</u> that the wings be spread for inspection or to do work on the airframe.

When that occurs, the maintenance crew, or other responsible party must formally request permission, and obtain not only a specified space on the hangar or flight deck, but a specified time slot in which to work. The permission-granting officer (usually flight deck control) must take into consideration not only the availability of both space and time, but the possible consequences to <u>other</u> operations if for some reasons the wings, once extended, cannot be easily folded again. Such events are rare, but highly consequential, and must be taken into account. Therefore, what often ensues is a conversation with higher or parallel authorities, perhaps ranging as high as the CO, before a decision is made.

With regard to personnel, the ship may seem enormous by some standards, but the 5,500 - 6,000 personnel aboard crowd it to the scuppers. And many billets must be filled with the people needed to keep the ship operating as a ship, 24 hours a day, seven days a week, for months. Only a limited number of maintenance personnel can be taken aboard. Although the hours they put in far exceed the demands on land-based military personnel in peacetime, there are limits. Maintenance of high-tech aircraft is a delicate and highly-specialized craft, requiring that the personnel not be over-tired or over-driven except for relatively brief bursts (surges).

Finally, there is the matter of parts. The 'maintenance kit' for a highly complex aircraft such as the F-14 nominally consists of many thousands of items, ranging from small bolts to complete jet engines. Even a super-carrier can carry only a limited inventory, so that at any given time some number of aircraft may be awaiting shipments in from remote depots.[1] If the carrier is deployed far from bases, it may even be necessary to defer some maintenance to prevent inventory depletion, since a carrier on active deployment must be ready to go into actual combat on very short notice. Therefore, there is once again the necessity to negotiate among the various ship departments how and when to draw the parts stock down, what the current status is, where and when resupply might be required, and so on.

Coordination of Ship and Wing

Since some of the maintenance personnel, and shops, belong to the ship, and others to the wing, considerable coordination between them is required. In practice, this is handled by reassigning command responsibilities, so that some ship personnel are effectively 'transferred' to the wing when it embarks. To compensate, the wing also brings aboard a quota of cooks and other support personnel who are transferred to ship units to pick up the additional load. Less trivially, the aircraft themselves are fueled, armed, cleaned, and moved around physically by units under the command of various ship officers (a separate division for each of these functions). Nothing will happen at all unless the closest coordination is maintained -- in fact, a senior wing Chief is regularly assigned to sit in Flight Deck Control to continuously negotiate wing needs with the ship officer in charge of the deck.

Since it may literally take hours to 'spot' aircraft on a flight deck for a complicated large mission launch, keeping an eye out for the position and readiness of the Alert 5 is no trivial matter. Each and every movement on the flight deck must be coordinated to allow a quick path for the alert aircraft, even if that means calling down to Flag and negotiating with the Admiral's staff about the type and sequence of event they have called for.

Coordination with Other Elements

Since the ship is assumed to be deployed, the Battle Group command ("Flag") will also be aboard, with the responsibility of planning missions both far in advance and for the next day. It is Flag, usually with the advice of his own staff and the CAG, who will determine the need for alert aircraft at any given time. But Flag may be planning a whole host of other activities that cause conflicts with alert readiness, or at least complicate it. Throughout the discussion above, it was implicitly assumed that once the fighters were on deck and manned, ready to go, the problems were essentially solved. But that is not the case. Alert aircraft cannot be kept on or near the catapults unless there is no other planned activity on

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1. A typical *Nimitz*-class carrier will have to carry kits for the many aircraft types -- a typical mix would be F-14 (fighter), A-7 and A-6 (attack), S-3 (anti-sub), EA-6B (ECM), E-2A (AWACS), and helicopters. Of these, only the A-6 an EA-6B have some limited compatibilities.

deck at the moment.[2] For example, they are located aft on the flight deck during launch operations. But all of those involved in air operations, from the Air Boss in the control tower down to the deck hands, must be able to relocate them for launch within the five minute window.[3]

Finally, it should be recalled that the ship is the Group's airfield and air resource, and that other warfare commanders (Surface, Submarine, Air, Strike) may be requesting air "assets" at any time for their own purposes. As a rule, attempts are made to negotiate the balance within and among the many units involved; rarely, an appeal has to be made to the Flag for resolution. Each time the balance is re-settled, the status and manning of the Alert aircraft must be reconsidered, taking into account most of the factors outlined above.

Conclusion

From the above, it can be seen that what might appear to be a simple, hierarchical command at a staff meeting (e.g., the Admiral asking that a pair of aircraft be put on Alert 5 from 0800 to 1400 the following day) will often set into train a complex series of tightly-coupled and interdependent activities, many of which will require a series of informal negotiations between units and entities at different hierarchical levels within the organization. Although such tight coupling is not always manifest (some days are pretty quiet, even at sea), the potentiality is always there. As a result, the cognizant and responsible officers must always assume first that it is present, and treat their day-to-day environment and interactions on that basis.

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2. This sometimes happens, e.g. during the time when a large number of aircraft have been launched and are out on another mission. In that case, the alert aircraft may be moved up on or near the forward catapults. They cannot be moved onto the waist catapults, because those are located smack in the middle of the "landing area".

3. Also, given the high fuel consumption of modern fighter aircraft, it is necessary to maintain an "alert tanker" as well -- to top up the aircraft once they have reached altitude and possibly to refuel them on their way back from a distant intercept.

NOTES

1. The author wishes to thank Prof. Todd R. La Porte and Prof. Karlene H. Roberts for their collaboration and cooperation throughout the research, and for the free exchange of ideas and data, and Prof. Chris C. Demchak for her insightful critique of the first draft of this paper.

2. Thanks to the cooperation of the Navy, and of the various ship's Captains and officers, we have been able to follow and observe two complete cycles of training aboard the U.S.S. *Carl Vinson* and U.S.S. *Enterprise*, both nuclear-powered aircraft carriers stationed at Alameda Naval Air Station.

3. As a general rule, the participants deem themselves to have 'failed' if authority must be invoked to resolve an impasse.

4. See, for example: Harold Wilensky, *Organizational Intelligence* (New York: Basic Books, 1967), 42ff.; Charles Perrow, *Complex Organizations: A Critical Essay*, Third Edition (New York: Random House, 1986), 29ff.

5. Even the lowest rating on the deck has not only the authority, but the obligation to suspend flight operations immediately, and without first clearing it with superiors, under the proper circumstances. Although his judgement may later be reviewed or even criticized, he will not be penalized for being wrong, and will often be publicly congratulated if he is right.

6. See, for example: Alfred D. Chandler, jr., *Strategy and Structure* (Cambridge MA: The MIT Press, 1962). A more theoretical discussion may be found in W. Richard Scott, *Organizations: Rational, Natural, and Open Systems* (Englewood Cliffs NJ: Prentice-Hall, 1981) at pp. 217ff.

7. This has been a recognized problem since the 1950s; see Morris Janowitz, "Changing Patters of Organizational Authority: The Military Establishment", *Administrative Science Quarterly*, vol. 3 (1959), 473-493.

8. Scott, *Organizations*, op. cit.

9. Gene I. Rochlin, Todd R. LaPorte, and Karlene H. Roberts, "The Self-Designing High-Reliability Organization: Aircraft Carrier Flight Operations at Sea", *Naval War College Review*, Autumn 1987, 76-90.

10. The term 'core technology', and many of the following concepts, are taken from James D. Thompson, *Organizations in Action* (New York: McGraw-Hill, 1967).

11. This argument has become "conventional wisdom", as most persuasively argued by John Kenneth Galbraith in *The New Industrial State* (New York: Signet, 1968). For a more organization-theoretic treatment of the same topic, see J. Serge Taylor, "Organizational Complexity in the New Industrial State: The Role of Technology", in Todd R. La Porte, ed. *Organized Social Complexity* (Princeton: Princeton University Press, 1975), 77-118.

12. Thompson, *Organizations in Action*, p. 132, finds them suitable for situations of no more than "modest" complexity.

13. The term is from Thompson, who establishes his argument around three levels of complexity: pooled (each party must contribute); sequential (they must do so in fixed order); and reciprocal (none can proceed independently). Airline operations with modern aircraft were in fact the prime illustration of 'reciprocal' interdependence in an organizational context.

14. These are taken from Scott, *Organizations*, Thompson, *Organizations in Action*, and Chris C. Demchak, *War, Technological Complexity, and the U.S. Army* (Ph.D. dissertation, Department of Political Science, University of California, Berkeley, 1987).

15. As pointed out by Scott, *Organizations*, p. 282: ".. virtually all of the empirical studies of supervision and control in organizations tend to focus attention on informal and endorsed power, often termed "leadership", to the neglect of formal and authorized systems of control."

16. Charles Perrow, *Normal Accidents: Living with High-Risk Technologies* (New York: Basic Books, 1984).

17. Rochlin, La Porte and Roberts, "Self-Designing Organization"; T.R. La Porte and P. Consolini, "High Reliability Organizations: Challenges to Organization Theory", paper presented at the American Political Science Association annual meeting, Washington D.C., September 1988; K. H. Roberts and G. Gargano, "Managing a High Reliability Organization: A Case for Interdependence", in M.A. Von Glinow and S. Mohrmon, eds., *Managing Complexity in High Technology Industries: Systems and People* (New York: Oxford University Press, 1988).

18. Todd R. La Porte, "On the Design and Management of Nearly Error-Free Organizational Control Systems", in D. Sills, C. Wolf, and V. Shelanski, eds., *The Accident and Three-Mile Island: The Human Dimensions* (Boulder CO: Westview Press, 1982).

19. The term tight-coupling is most precisely delineated in Perrow, *Normal Accidents*. See also K.E. Weick, "Educational Organizations: Loosely Coupled Systems," *Administrative Science Quarterly*, 21 (March 1976), 1-19. Where effects are indirect, or long delayed (e.g., contamination of subsurface water with industrial wastes), both social response and organizational strategy can be quite different. We deal here only with those cases where effects are direct, and proximate.

20. A typical response to an outsider's first direct observation of naval flight operations is that they are simply not possible. An operating large carrier is basically a medium-sized airport, shrunken down to the space of a couple of football fields. In some areas, error tolerance is essentially zero. These powerful, heavy aircraft must be shot into the air by catapults, and physically captured by hook and wire when they return. If catapult and engines do not function perfectly, the plane is immediately lost (and the crew have only a few seconds to react and eject before they accompany it). If the arresting gear wires, which bring the aircraft to a sudden, brief halt when it lands on the deck, are set incorrectly, the plane may 'dribble' off the end into the water, or have its tail torn off. And any kind of incident, from fire to brake failure, must necessarily happen in close proximity to other aircraft and the people who handle them.

Moreover, given the size, and power of modern aircraft, and the dangers they present both fore and aft from intakes and exhaust, the flight deck, where numerous aircraft are being moved around by hand, with engines running, during launch and recovery operations, seems very like a modern day inferno. That flight operations and maintenance can be supported at all within the limited confines of the ship seems remarkable enough; that the rate of serious accidents and deaths among the personnel who handle and move these aircraft about in the same close quarters, day in an day out, is as low as it has been seems even more remarkable.

21. Rochlin, La Porte, Roberts, "Self-Designing Organization".

22. Specifically, the organizations we are examining use human operators to successfully manage hazardous and complex technologies in real time.

23. Unfortunately for the strict application of either Perrow's analysis or Thompson's, naval flight operations are neither "industrial" or "non-industrial", for they have both a material and a social product.

24. Thompson, *Organizations in Action*. The terms are not so much descriptive of the technologies as they are of the respective roles of the three levels of the organization -- technical core (operators), managers, and administrators.

25. Charles Perrow, *Organizational Analysis: A Sociological View* (Belmont, CA: Wadsworth, 1970). Scott, *Organizations*, 37ff., has an interesting comparison of Perrow's typology with Thompson's.

26. The term is from Todd R. La Porte.

27. See, for example: Arthur L. Stinchcombe, "Bureaucratic and Craft Administration of Production: A Comparative Study", *Administrative Science Quarterly*, vol. 6 (March 1962), 463-482.

28. Thompson, *Organizations in Action*, 80ff. I spent several summers working for small manufacturing firms like this and can independently verify the accuracy of the model.

29. Thompson, *Organizations in Action*. Where interdependence is high and reciprocal, the coupling direct, and the time scale involved short, we approach the definition of "tight coupling" used by Perrow (*Organizational Analysis*).

30. The most trenchant analysis of the manpower implications is that of Martin Binkin, *Military Technology and Defense Manpower* (Washington, D.C.: The Brookings Institution, 1986).

31. Wilensky describes the evolving structure as more a "diamond bulging int he middle" than a pyramid (*Organizational Intelligence*, p. 47).

32. This definition comes from Todd R. La Porte, ed., *Organized Social Complexity* (Princeton: Princeton University Press, 1975), pp. 10 ff. As complexity is as difficult to formalize conceptually as 'technology' or 'structure'(see, for example, Langdon Winner, "Complexity and the Limits of Human Understanding", in La Porte, ibid, 40-60), the operationalized definition is adhered to throughout.

33. Thompson, *Organizations in Action*, p. 64ff., discusses the difficulties posed the Air Force by the rapidity of technological change even in the mid-1950s.

34. Demchak, *War, Technological Complexity, and the U.S. Army*.

35. Scott, *Organizations*, 217ff., discusses a range of "lateral connection" strategies for civil organizations that closely resemble these.

36. Indeed, it most closely resembles the characterization of a 'university' put forth by Perrow, which has collegial sub-units but is both authoritarian and hierarchical overall (*Complex Organizations*, p.28).

37. Strike planning, as the nexus at which so many formal and informal networks converge, is hardly ever in 'normal' conditions when operational tempos are high -- even in peacetime.

38. We note that the kinds of redundancy required to assure continued effectiveness in combat -- e.g., in situations where physical damage to ship or command chains is anticipated -- are qualitatively different from redundancy directed primarily to assuring the performance of safety-critical tasks. Elements of the former, however, are often major contributors to the latter.

39. Martin Landau, "Redundancy, Rationality and the Problem of Duplication and Overlap," *Public Administration Review*, 23 (Nov/Dec 1973), 316-351.

40. See Chris C. Demchak, "Complexity, Rogue Outcomes, and Weapons Systems", paper presented at the American Political Association Annual meeting, Washington D.C., September 1988.

41. At first, little of this chatter seems coherent, let alone substantive, to the outside observer. With experience, one discovers that seasoned personnel do not "listen" so much as they monitor for deviations, reacting almost instantaneously to anything that does not fit their expectations of the correct routine.

42. The engines are in different compartments, and set by hand by separate operating teams, so that collective failures in setting can only occur at the command level, i.e., in the Tower, where a number of other independent measures for cross-checking and redundancy are in place.

43. Allan W. Lerner, "There Is More Than One Way To Be Redundant", *Administration & Society*, 18, No. 3 (November 1986), 334-359.

44. During the period of observation, CDC was also the center for fighting the Battle Group, a task that will increasingly be supervised by the new Tactical Flag Command Centers (TFCC) as they are installed. Depending upon the physical arrangement of the ship, the CDC area contains the Combat Information Center (CIC), anti-air warfare control consoles, and perhaps air operations and ship air traffic control (CATCC); other warfare modules, such as those for anti-submarine or anti-surface warfare, may also be included or in physically adjacent spaces.

45. The concept of secondary impacts developed by La Porte, was extended to tertiary impacts by Daniel Metlay. See G.I. Rochlin, D. Metlay, and P. Windham, *Space Disposal of Nuclear Wastes: Socio-Political Aspects*, Vol. 2, Report to the Ames Research Center, NASA (Berkeley: Institute of Governmental Studies, University of California, Berkeley, December 1976).

46. This usage differs somewhat from that developed by La Porte et. al., where 'third order' effects referred to changing perceptions of the structure of society and the role of individuals in it.

47. Demchak "Complexity, Rogue Outcomes, and Weapons Systems".

48. Lewis Sorley, "Prevailing Criteria: A Critique", in Sam C. Sarkesian, ed., *Combat Effectiveness* (Beverly Hills: Sage Publications, 1980), 57-93.

49. L.R. Giguet, "Coordinating Army Personnel Agencies Using Living Systems Theory: An Example," U.S. Army TRADOC, 1979, as quoted by Sorley, 76-77.

50. We have observed several mechanisms used by the Navy to prevent such loss, including incentives for reporting successful innovation and formal procedures for their dissemination. The most general mechanism, however, is the informal dissemination of information by the movement of personnel, and through those responsible for refresher and other forms of at-sea training. A most remarkable combination of trainers and active personnel is the recently formed association of Air Bos'n's, which holds annual meetings at which information is exchanged and formal papers are presented.

51. Oscar Grusky has found that rapid rotation in the military weakens personal executive power but encourages the development of a general orientation towards organizational authority, which would be a functional adaptation for the Navy. See "The Effects of Succession: A Comparative Study of Military and Business Organization," in Oscar Grusky and George A. Miller, eds., *The Sociology of Organizations* (New York: The Free Press, 1970), 439-454.

52. K. Weick, "The Role of Interpretation in High Reliability Systems", *California Management Review*, 39, 1987, 112-127.

53. Perrow, *Normal Accidents*.

54. Taylor, "Organizational Complexity in the New Industrial State."

55. The lack of similar training and support for the surface warfare Navy received considerable attention after the attack on the U.S.S. *Stark*. See: Capt. John L. Byron, "The Surface Navy is Not Ready", *Proceedings*, 113/12/1018 (December 1987), 34-40.

56. When operational continuity is broken or non-existent, the effects are observable and dramatic. One of us has had the opportunity to observe a new *Nimitz* class aircraft carrier as she emerged from the yard, and has remarked at how many things had to be learned before she could even begin to commence serious air operations. Even for an older and more experienced ship coming out of an ordinary refit, the work-up towards deployment is a long and arduous process. Many operational weeks are spent just qualifying the deck for taking and handling individual aircraft, and many more at gradually increasing densities to perfect aircraft handling as well as the coordination needed for tight launch and recovery sequences. With safety and reliability as fixed boundary conditions, every moment of precious operational time before deployment is devoted to improving capability and efficiency.

57. Jennifer Nias, "The Sorcerer's Apprentice: Complexity in Educational Systems", in La Porte, *Organized Social Complexity*, 256-278.

58. Perrow, *Complex Organizations*, 150ff.

59. Under modern battle conditions, this traditional assignment has become more ambiguous even when operating in the classic detached ship mode (e.g. the *Vincennes*). Where the locus of responsibility lies when the error is made by the CAG, or at the Flag level, is less sure. George C. Wilson *SuperCarrier* (New York: MacMillan, 1986) graphically describes both the remoteness and lack of sensitivity to operational requirements of the command structure and the progressive deterioration of the ship's ability to launch an effective raid as the stress increased. He also notes the difficulty of assigning the traditional Navy accountability once the locus of decision is moved off the ship.

60. My thanks to Chris C. Demchak for sharpening this point during a series of illuminating discussions on military organization and hierarchy.

61. Wilson, *SuperCarrier*.