The Self-Designing High-Reliability Organization: Aircraft Carrier Flight Operations at Sea

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> *A hundred things I have no control over could go wrong and wreck my career . . . but wherever I go from here, I'll never have a better job than this. . . . This is the best job in the world.* -- Carrier Commanding Officer

Recent studies of large, formal organizations that perform complex, inherently hazardous, and highly technical tasks under conditions of tight coupling and severe time pressure have generally concluded that most will fail spectacularly at some point, with attendant human and social costs of great severity.1 The notion that accidents in these systems are "normal," that is, to be expected given the conditions and risks of operation, appears to be as well grounded in experience as in theory. 2 Yet there is a small group of organizations in American society that appears to succeed under trying circumstances, performing daily a number of highly complex technical tasks in which they cannot afford to "fail." We are currently studying three unusually salient examples whereby devotion to a zero rate of error is almost matched by performance--utility grid management (Pacific Gas & Electric Company), air traffic control, and flight operations aboard U.S. Navy aircraft carriers.

Of all activities studied by our research group, flight operations at sea is the closest to the "edge of the envelope"--operating under the most extreme conditions in the least stable environment, and with the greatest tension between preserving safety and reliability and attaining maximum operational efficiency. 3 Both electrical utilities and air traffic control emphasize the importance of long training, careful selection, task and team stability, and cumulative experience. Yet the Navy demonstrably performs very well with a young and largely inexperienced crew, with a "management" staff of officers that turns over half its complement each year, and in a working environment that must rebuild itself from scratch approximately every eighteen months. Such performance strongly challenges our theoretical under standing of the Navy as an organization, its training and operational processes, and the problem of high-reliability organizations generally.

It will come as no surprise to this audience that the Navy has certain traditional ways of doing things that transcend specifics of missions, ships, and technology. Much of what we have to report interprets that which is "known" to naval carrier personnel, yet is seldom articulated or analyzed. 4 We have been struck by the degree to which a set of highly unusual formal and informal rules and relationships are taken for granted, implicitly and almost unconsciously incorporated into the organizational structure of the operational Navy.

Only those who have been privileged to participate in high-tempo flight operations aboard a modern aircraft carrier at sea can appreciate the complexity, strain, and inherent hazards that underlie seemingly routine day-to-day operations. That naval personnel ultimately accept these conditions as more or less routine is yet another example of how adaptable people are to even the most difficult and stressful of circumstances.

We have now spent considerable time aboard several aircraft carriers in port and at sea, though our team of non-Navy academics retains a certain distance that allows us to recognize and report on the astonishing and unique organizational structure and performance of carrier flight operations. 5 We do not presume that our limited exposure to a few aspects of operations has given us a comprehensive overview. Nevertheless, we have already been able to identify a set of causal factors that we believe are of central importance to understanding how such organizations operate.

In an era of constant budgetary pressure, the Navy shares with other organizations the need to defend those factors most critical to maintaining performance without, at the same time, sacrificing either operational reliability or safety. Following many conversations with naval personnel of all ranks, we are convinced that the rules and procedures that make up those factors are reasonably well known internally, but are written down only in part and generally not expressed in a form that can be readily conveyed outside the confines of the Navy.

The purpose of this article is to report some of our more relevant findings and observations to our gracious host, the Navy community; to describe air operations through the eyes of informed, yet detached observers; and to use our preliminary findings to reflect upon why carriers work as well as they do.

Self-Design and Self-Replication

> "So you want to understand an aircraft carrier? Well, just imagine that it's a busy day, and you shrink San Francisco Airport to only one short runway and one ramp and gate. Make planes take off and land at the same time, at half the present time interval, rock the runway from side to side, and require that everyone who leaves in the morning returns that same day. Make sure the equipment is so close to the edge of the envelope that it's fragile. Then turn off the radar to avoid detection, impose strict controls on radios, fuel the aircraft in place with their engines running, put an enemy in the air, and scatter live bombs and rockets around. Now wet the whole thing down with salt water and oil, and man it with 20-year-olds, half of whom have never seen an airplane close-up. Oh, and by the way, try not to kill anyone."
>
> -- Senior officer, Air Division

Today's aircraft carrier flight operations are as much a product of their history and continuity of operation as of their design. The complexity of operations aboard a large, modern carrier flying the latest aircraft is so great that *no one*, on or off the ship, can know the content and sequence of every task needed to make sure the aircraft fly safely, reliably, and on schedule. As with many organizations of similar size and complexity, tasks are broken down internally into smaller and more homogeneous units as well as task-oriented work groups. 6 In the case of the Navy, the decomposition rules are often ad hoc and circumstantial: some tasks are organized by technical function (navigation, weapons), some by unit (squadron), some by activity (handler, tower), and some by mission (combat, strike). Men may belong to and be evaluated by one unit (e.g., one of the squadrons), yet be assigned to another (e.g., aircraft maintenance).

In order to keep this network alive and coordinated, it must be kept connected and integrated horizontally (e.g., across squadrons), vertically (from maintenance and fuel up through operations), and across command structures (battle group--ship--air wing). As in all large organizations, the responsible officer or chief petty officer has to know what to do in each case, how to get it done, whom to report to and why, and how to coordinate with all units that he depends upon or that depend upon him. This is complicated in the Navy case by the requirement for many personnel, particularly the more senior officers, to interact on a regular basis with those from several separate organizational hierarchies. Each has several different roles to play depending upon which of the structures is in effect at any given time. 7

Furthermore, these organizational structures also shift in time to adapt to varying circumstances. The evolution of the separate units (e.g., ship, air wing, command structures) and their integration during workup into a fully coordinated operational team, for example, have few, if any, applicable counterparts in civilian organizations. 8 There is also no civilian counterpart for the requirement to adapt to rapid shifts in role and authority in response to changing tactical circumstances during deployment.

No armchair designer, even one with extensive carrier service, could sit down and lay out all the relationships and interdependencies, let alone the criticality and time sequence of all the individual tasks. Both tasks and coordination have evolved through the incremental accumulation of experience to the point where there probably is no single person in the Navy who is familiar with them all. 9 Rather than going back to the *Langley*, * consider, for the moment, the year 1946, when the fleet retained the best and newest of its remaining carriers and had machines and crews finely tuned for the use of propeller-driven, gasoline-fueled, Mach 0.5 aircraft on a straight deck.

Over the next few years the straight flight deck was to be replaced with the angled deck, requiring a complete relearning of the procedures for launch and recovery and for "spotting" aircraft on and below the deck. The introduction of jet aircraft required another set of new procedures for launch, recovery, and spotting, and for maintenance, safety, handling, engine storage and support, aircraft servicing, and fueling. The introduction of the Fresnel-lens landing system and air traffic control radar put the approach and landing under centralized, positive, on-board control. As the years went by, the launch/approach speed, weight, capability, and complexity of the aircraft increased steadily, as did the capability and complexity of electronics of all kinds. There were no books on the integration of this new "hardware" into existing routines and no other place to practice it but at sea; it was all learned on the job. Moreover, little of the process was written down, so that the ship in operation is the only reliable "manual."

For a variety of reasons, no two aircraft carriers, even of the same class, are quite alike. Even if nominally the same, as are the recent *Nimitz*-class ships, each differs slightly in equipment and develops a unique personality during its shakedown cruise and first workup and deployment. 10 While it is true that each ship is made up of the same range of more or less standardized tasks at the micro level, the question of how to do the job right involves an understanding of the structure in which the job is embedded, and that is neither standardized across ships nor, in fact, written down systematically and formally anywhere. If they left the yards physically different, even such apparently simple matters as spotting aircraft properly on the deck have to be learned through a process of trial and error. 11

What is more, even the same formal assignment will vary according to time and place. Carriers differ; missions differ; requirements differ from Atlantic to Pacific, and from fleet to fleet; ships have different histories and traditions, and different equipment; and commanding officers and admirals retain the discretion to run their ships and groups in different ways and to emphasize different aspects. Increased standardization of carriers, aircraft loadings, missions, tasks, and organizational structure would be difficult to obtain, and perhaps not even wise. 12 There is a great deal to learn in the Navy, and much of it is only available on the spot.

Shore-based school training for officers and crew provides only basic instruction. 13 It includes a great deal about what needs to be done and the formal rules for doing it. Yet it only provides generalized guidelines and a standardized framework to smooth the transition to the real job of performing the same tasks on board as part of a complex system. NATOPS †and other written guidelines represent the book of historical errors. They provide boundaries to prevent certain actions known to have adverse outcomes, but little guidance as to how to promote optimal ones.

Operations manuals are full of details of specific tasks at the micro level but rarely discuss integration into the whole. There are other written rules and procedures, from training manuals through standard operating procedures (SOPs), that describe and standardize the process of integration. None of them explain how to make the whole system operate smoothly, let alone at the level of performance that we have observed. 14 It is in the real-world environment of workups and deployment, through the continual training and retraining of officers and crew, that the information needed for safe and efficient operation is developed, transmitted, and maintained. Without that continuity, and without sufficient operational time at sea, both effectiveness and safety would suffer.

Moreover, the organization is not stable over time. Every forty months or so there is an almost 100 percent turnover of crew, and all of the officers will have rotated through and gone on to other duty. Yet the ship remains functional at a high level. The Navy itself is, of course, the underlying structural determinant. Uniforms, ranks, rules and regulations, codes of conduct, and specialized languages provide a world of extensive codification of objects, events, situations, and appropriate conduct; members who deviate too far from the norm become "foreigners" within their own culture and soon find themselves outside the group, figuratively if not literally. 15

Behavioral and cultural norms, SOPs, and regulations are necessary, but they are far from sufficient to preserve operational structure and the character of the service. Our research team noted three mechanisms that act to maintain and transmit operational factors in the face of rapid turnover. First, and in some ways most important, is the pool of chief petty officers, many of whom have long service in their specialty and circulate around similar ships in the fleet. 16 Second, many of the officers and some of the crew will have at some time served on other carriers, albeit in other jobs, and bring to the ship some of the shared experience of the entire force. Third, the process of continual rotation and replacement, even while on deployment, maintains a continuity that is broken only during a major refit. These mechanisms are realized by an uninterrupted process of on-board training and retraining that makes the ship one huge, continuing school for its officers and men.

When operational continuity is broken or nonexistent, the effects are observable and dramatic. One member of our research group had the opportunity to observe a new *Nimitz*-class aircraft carrier as she emerged from the yard and remarked at how many things had to be learned before she could even begin to commence serious air operations. 17 Even for an older and more experienced ship coming out of an ordinary refit, the workup towards deployment is a long and arduous process. Many 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.

The importance of adequate workup time--for flight operations to be conducted safely at present levels of technical and operational complexity and at the tempo required for demonstrating effectiveness--cannot be overemphasized. During our research we followed one carrier in which the workup was 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; this placed an *enormous* strain on all hands. While the crew succeeded--the referees adapted compensating evaluation procedures--risks to ship's personnel and equipment were visibly higher. Moreover, officers and crew were openly unhappy with their own performance, with an attendant and continuing impact on morale. 18

The Paradox of High Turnover

"As soon as you learn 90% of your job, it's time to move on. That's the Navy way."
-- Junior officer

Because of the high turnover rate, a U.S. aircraft carrier will begin its workup with a large percentage of new hands in the crew, and with a high proportion of officers new to the ship. The U.S. Navy's tradition of training generalist officers (which distinguishes it from the other military services) assures that many of them will also be new to their specific jobs. Furthermore, tours of duty are not coordinated with ship sailing schedules; hence, the continual replacement of experienced with "green" personnel, in critical as well as routine jobs, continues even during periods of actual deployment.

Continual rotation creates the potential for confusion and uncertainty, even in relatively standardized military organizations. Lewis Sorley has characterized the effects of constant turnover in other military systems as "turbulence" and has identified it as the prime source of loss of unit cohesion. 19 A student of Army institutional practices has remarked that the constant introduction of new soldiers into a unit just reaching the level of competence needed to perform in an integrated manner can result in poor evaluations, restarting the training cycle, and keeping individuals perpetually frustrated by their poor job performance. 20

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. SOPs 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. 21 Cumulative learning and improvement are also achieved slowly and with difficulty, and individual innovations and gains are often lost to the system before they can be consolidated. 22

Yet we credit this practice with contributing greatly to the effectiveness of naval organizations. There are two general reasons for this paradox. First, the efforts that must be made to ease the resulting strain on the organization seem to have positive effects that go beyond the problem they directly address. And second, officers must develop authority and command respect from those senior enlisted specialists upon whom they depend and from whom they must learn the specifics of task performance.

The Navy's training cycle is perforce dictated by the schedule of its ships, not of its personnel. Because of high social costs of long sea-duty tours, the Navy has long had to deal with such continual turnover--it attempts as best it can to mitigate the negative effects. Most important is the institutionalization of continual, cyclic training as part of organizational and individual expectations. This is designed to bring new people "up to speed" with the current phase of the operational cycle, thus stabilizing the environment just before and during deployment; however, this is accomplished at the cost of pushing the turbulence down into individual units. Although the deployment cycle clearly distinguishes periods of "training" from those of "operations," it is a measure of competence and emphasis, not of procedural substance, that applies primarily to the ship as a unit, not its men as individuals.

The result is a relatively open system that exploits the process of training and retraining as a means for socialization and acculturation. At any given moment, all but the most junior of the officers and crew are acting as teacher as well as trainee. A typical lieutenant 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. 23 In addition to these informal officer-officer and officer-crew interactions, officers and crew alike are also likely to be engaged in one or more courses of formal study to master new skills in the interest of career advancement or rating.

As a result, the ship appears to us as one gigantic school, not in the sense of rote learning, but in the positive sense of a genuine search for acquisition and improvement of skills. One of the great enemies of high reliability is the usual "civilian" combination of stability, routinization, and lack of challenge and variety that predispose an organization to relax vigilance and sink into a dangerous complacency that can lead to carelessness and error. 24 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 can be the source of some confusion and uncertainty at times, but at its best leads to a constant scrutiny and rescrutiny of every detail, even for SOPs.

In general, the Navy has managed to change the rapid personnel turnover to an advantage through a number of mechanisms that have evolved by trial and error. SOPs and procedures, for example, are often unusually robust, which in turn contributes another increment to reliability. The continual movement of people rapidly diffuses organizational and technical innovation as well as "lessons learned," often in the form of "sea stories," throughout the organization. Technical innovation is eagerly sought where it will clearly increase both reliability and effectiveness, yet resisted when suggested purely for its own sake. Data is logged with grease pencils by operators who read sophisticated radar systems; indicators for the cables to arrest multimillion-dollar aircraft are set and checked mechanically, by hand. Things tend to be done in proven ways and changed only when some unit has demonstrated and documented an improvement in the field. The problem for the analyst and for the Navy is the separation of functional conservatism from pure tradition.

Authority Overlays

> "Here I'm responsible for the lives of my gang. In civilian life, I'm the kind of guy you wouldn't like to meet on a dark street."
>
> -- Deck petty officer

Our team noted with some surprise the adaptability and flexibility of what is, after all, a military organization in the day-to-day performance of its tasks. On paper, the ship is formally organized in a steep hierarchy by rank with clear chains of command, and means to enforce authority far beyond those of any civilian organization. We supposed it to be run by the book, with a constant series of formal orders, salutes, and yes-sirs. Often it is, but flight operations are not conducted that way.

Flight operations and planning are usually conducted as if the organization were relatively "flat" and collegial. This contributes greatly to the ability to seek the proper, immediate balance between the drive for safety and reliability and that for combat effectiveness. Events on the flight deck, for example, can happen too quickly to allow for appeals through a chain of command. Even the lowest rating on the deck has not only the authority but the obligation to suspend flight operations immediately, under the proper circumstances, without first clearing it with superiors. Although his judgment 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. 25

Coordinated planning for the next day's air operations requires a series of involved trade-offs between mission requirements and the demands of training, flight time, maintenance, ordnance, and aircraft handling. It is largely done by a process of ongoing and continuing argument and negotiation 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. 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.

This does not mean that formal rank and hierarchy are unimportant. In fact, they are the lubricant that makes the informal processes work. Unlike the situation in most civilian organizations, relative ranking in the hierarchy is largely stable and shaped by regular expectations, formal rules, and procedures. Although fitness reports and promotion review boards are not free of abuses or paradoxes, the shipboard situation tends to promote cooperative behavior, which tends to minimize the negative effects of jealousy and direct competition. 26 Although officers of the same rank are competitively rated, each stands to benefit if joint output is maximized and to suffer if the unit is not performing well. Thus, we rarely observe such strategies as the hoarding of information or deliberate undermining of the ability of others to perform their jobs that characterize so many civilian organizations, particularly in the public sector.

Redundancy

> "How does it work? On paper, it can't, and it don't. So you try it. After a while, you figure out how to do it right and keep doing it that way. Then we just get out there and train the guys to make it work. The ones that get it we make POs. ‡ The rest just slog through their time."
>
> -- Flight deck CPO

Operational redundancy--the ability to provide for the execution of a task if the primary unit fails or falters--is necessary for high-reliability organizations to manage activities that are sufficiently dangerous to cause serious consequences in the event of operational failures. 27 In classic organizational 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." 28 For a carrier at sea, several kinds of redundancy are necessary, even for normal peacetime operations, each of which creates its own kinds of stress.

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 in as is 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 trade-off between operational and safety reliability that must be made much closer to the edge of the envelope than would be the case for other kinds of organizations. Indeed, for a combat organization, the trade-off point is generally taken as a measure of overall competence. 29

Most interesting to our research is a third 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 in this area that the rather unique Navy way of doing things is the most interesting, theoretically as well as practically.

As an example of (a), almost everyone involved in bringing the aircraft [in for a landing] on board is part of a constant loop of conversation and verification taking place over several different channels at once. 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 monitor for deviations, reacting almost instantaneously to anything that does not fit their expectations of the correct routine. This constant flow of information about each safety-critical activity, monitored by many different listeners on several different communications nets, 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 (as to speed and weight), and each of four independent arresting-gear engines be set correctly. 30 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 (Pri-Fly [Primary Flight Control] and LSO [Landing Signal Officer]). § During our trip aboard *Enterprise* (CVN 65) in April 1987, she took her 250,000th arrested landing, representing about a million individual settings. 31 Because of the built-in redundancies and the personnel's cross-familiarity with each other's jobs, there had not been a *single* recorded instance of a reportable error in setting that resulted in the loss of an aircraft. 32

Fail-safe redundancy, (b), is achieved in a number of ways. 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 seagoing 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 backups are required, such as "stressing the survivor" and mobilizing organizational "reserves." 33

Stressing-the-survivor strategies require that each of the units normally operate below capacity so that if one fails or is unavailable, its tasks can be shifted to others without severely overloading them. Redundancy on the bridge is a good example. 34 Mobilizing reserves entails the creation of a "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 execute them in an emergency.

The Combat Direction Center (CDC, or just "Combat"), for example, is the center for fighting the ship. 35 Crucial decisions are thereby placed nominally in the hands of relatively junior officers in a single, comparatively vulnerable location. In this case we have noted several of the 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 backup somewhere--on the carrier or distributed among other elements of the battle group. 36

In an "ordinary" organization these parameters would likely be characterized in negative terms. Backup systems differ in pattern and structure from primary ones. Those with task responsibility are constantly under the critical eyes of others. Authority and responsibilities are distributed in different patterns and may shift in contingencies. In naval circumstances, where reliability is paramount, these are seen as positive and cooperative, for it is the task that is of primary importance.

Thus, those elements of Navy "culture" that have the greatest potential for creating confusion and uncertainty turn out to be major contributors to organizational reliability and robustness under stress. We believe this to be an example of adaptive organizational evolution to circumstance, for it responds very well to the functional necessities of modern operations. In the days of great, compact flotillas, loss of navigational or deck or gun capability by one ship could be compensated for by shifting or sharing with another. There is only one carrier in a battle group and only a handful of other ships spread over many hundreds of square miles. Each, and most particularly the carrier, must internalize its own processes and modalities for redundancy.

Some Preliminary Conclusions

> "The job of this ship is to shoot the airplanes off the pointy end and catch them back on the blunt end. The rest is detail."
> -- Carrier commanding officer

Even though our research is far from complete, particularly with regard to comparisons with other organizations, several interesting observations and lessons have already been recorded.

First, the remarkable degree of personal and organizational flexibility we have observed is essential for performing operational tasks that continue to increase in complexity as technology advances. "Ordinary" organizational theory would characterize aircraft carrier operations as confusing and inefficient, especially for an organization with a strong and steep formal management hierarchy (i.e., any "quasi-military" organization). However, the resulting redundancy and flexibility are, in fact, remarkably efficient in terms of making the best use of space-limited personnel.

Second, an effective fighting carrier is not a passive weapon that can be kept on a shelf until it is needed. She is a living unit possessed of dynamic processes of self-replication and self-reconstruction that can only be nurtured by retaining experienced personnel, particularly among the chiefs, and by giving her sufficient operational time at sea. This implies a certain minimum budgetary cost for maintaining a first-line carrier force at the levels of operational capability and safety demanded of the U.S. Navy.

The potential risk of attempting to operate at present levels under increasing budgetary constraints arises because the Navy is a "can-do" organization, visibly reluctant to say "we're not ready" until the situation is far into the red zone. 37 In time of war, the trade-off point between safety and effectiveness moves, and certain risks must be taken to get units deployed where and when they are needed. In peacetime, the potential costs of deploying units that are less than fully trained are not so easily tolerated. If reductions in at-sea and flying time are to be taken out of workups to preserve operational time on deployment, training and evaluation procedures will have to be adapted to reduce stress--perhaps by overlapping final readiness evaluations into the beginning of the deployment period.

Third, as long-term students of organizations, we are astounded at how little of the existing literature is applicable to the study of ships at sea. Consider, for example, the way in which the several units that make up a battle group (carrier, air wing, supply ships, escorts) are in a continual process of formation and reformation. Imagine any other organization performing effectively when it is periodically separated from and then rejoins the unit that performs its central technical function. 38 More importantly, most of the existing literature was developed for failure-tolerant, civilian organizations with definite and measurable outputs. The complementary body on public organizations assumes not only a tolerance for failure, but at best an ambiguous definition of what measures failure (or for that matter, success).

Fourth, we have been encouraged to reflect on the new large Soviet nuclear carrier now being fitted out in the Black Sea. 39 The Soviet Navy is completely without experience or tradition in large carrier operations. Their internal structure is more rigid and more formal than ours and with far less on-the-job training, especially for enlisted personnel. 40 It will be very interesting to watch their workup time, deck loading, and casualty rates. Of course, it is not clear that they will be trying to emulate U.S. carrier operations rather than the somewhat different style and objectives of the British or French. 41 In either case, we estimate a minimum of several workups (each taking perhaps two or three years) before they begin to approach the deck loads and sortie rates of comparable Western carriers and, unless they are remarkably lucky, there will be some loss of lives in the learning process. 42

Notes

1. See, for example, Charles Perrow, *Normal Accidents* (New York: Basic Books, 1984).
2. Examples that have attracted recent attention include Bhopal, Séveso, Three-Mile Island, and Chernobyl. All four meet Perrow's criteria for coupling, response time, and complexity. The essence of a "normal" accident is that the potentiality inheres in the design of the system and, despite attempts to fix "blame," is not primarily the result of individual misbehavior, malfeasance, or negligence.
3. By comparison, *civil* air traffic controllers deliberately stay far away from the edge. Fixed rules such as maintaining five-mile intervals are designed to err broadly in the direction of safety. Moreover, the turnover rate for controllers is relatively low (barring extraordinary events such as the recent [1981] strike); even equipment changes are few and far between.
4. From this point we refer to carrier personnel as "men," since as yet the Navy does not allow women to serve aboard combat vessels.
5. We have followed both the *USS Carl Vinson* (CVN 70) and the *USS Enterprise* (CVN 65), under a total of four different captains, through their training and workup from Alameda and San Diego, California, and across the Pacific into the South China Sea. In addition, one of us (Roberts) has been able to observe the initial sea trials of the *USS Theodore Roosevelt* (CVN 71).
6. In formal organizational terms, we refer to this as "decomposability." The basic notion was introduced by Herbert A. Simon in "The Architecture of Complexity," *Proceedings of the American Philosophical Society*, December 1962, pp. 467--82,

reprinted in Herbert A. Simon, *The Sciences of the Artificial* (Cambridge, Mass.: The MIT Press, 1981).

7. During our interviews, one senior officer on a flag staff suggested that the several different functional and hierarchical modes of organization might be viewed as a set of "overlays" that are superimposed upon the formal organization at different times, depending upon the task or circumstance at hand. Many of the officers must shift roles numerous times during the course of a single active day of flight operations.
8. The few examples that come to mind are large construction projects, e.g., nuclear power plants, the Alaskan pipeline, etc. However, these usually have considerable oversight from a separate firm whose sole task is to coordinate and schedule the work properly.
9. This point was brought home sharply by the effort to bring up the ZOG computer system on the *USS Carl Vinson*, which would have required that almost complete knowledge about all details of ship operations be known and entered if the system were to function as originally intended. In retrospect, this can be seen as a near-impossible requirement without the mounting of a considerable special effort to collect and organize the data.
10. Furthermore, a strong captain is capable of altering both the character of a ship and the way it operates, if he so chooses.
11. Given the size of modern jet aircraft and the number carried at full load, the matter of spotting is far from trivial. Inefficient spotting can greatly reduce the ability to move aircraft about quickly. Incorrect spotting can lead to serious interference with operations, or even to a "locked" deck, on which it becomes impossible to move aircraft at all. In a trial using the deck model in Flight Deck Control, one of us managed to lock the deck so thoroughly that an aircraft would have had to be pushed over the side to free the deck.
12. Some nonfunctional variations are being reduced. For example, all LSO platforms will soon be located at the same level and position relative to the arresting gear wires. However, it is nearly impossible to upgrade all of the ships at once when new equipment is introduced; therefore, each is at a different stage of modification and upgrade at any given point in time.
13. To some extent this situation is improving. Landing Signal Officers (LSOs), for example, now work with simulators. Although this is no substitute for experience when "eyeball" judgment is concerned, it helps.
14. As one senior chief remarked to us: " You have to know it, but it rarely helps when you really need it."
15. Roger Evered, "The Language of Organizations: The Case of the Navy," in Louis R. Pondy et al., eds., *Organizational Symbolism* (Greenwich, Conn.: JAI Press, 1983), pp. 125--44.
16. A very few stay on one ship for many years, but such "plankowners" are rare in the modern Navy.
17. For example, the first crew was unable to spot the deck effectively; Flight Deck Control had been laid out with the deck model at right angles to the flight deck axis, interfering with spatial visualization and obstructing the Aircraft Handling Officer's direct view of the deck from his only window.

18. The recent grounding of the *USS Enterprise* on Bishop Rock off San Diego may have been at least partially due to her participation in a difficult exercise combining the elements of what were usually two exercises. The effect on ship's morale was very visible. See Karlene H. Roberts, "Bishop Rock Dead Ahead: The Grounding of USS Enterprise," submitted to U.S. Naval Institute *Proceedings*. [Editors' note: To the best of our knowledge, this paper did not appear in *Proceedings*.]
19. Lewis Sorley, "Prevailing Criteria: A Critique," in Sam C. Sarkesian, ed., *Combat Effectiveness* (Beverly Hills, Calif.: Sage, 1980), pp. 57--93.
20. L. R. Giguet, "Coordinating Army Personnel Agencies Using Living Systems Theory: An Example," U.S. Army TRADOC, 1979, as quoted by Sorley at pp. 76--7.
21. The term "proficiency" is used in the special sense of Hubert L. Dreyfus and Stuart E. Dreyfus, *Mind over Machine* (New York: Free Press, 1986), who classify five steps of skill acquisition: novice, advanced beginner, competence, proficiency, and expertise. For most officers, mastery of a specific assignment means at most the acquisition of proficiency--the ability to identify situations and act upon them without having to systematically think through the procedural steps involved. The most advanced stage, expertise, involves moving past "problem solving" to "intuition" in decision making. Examples of relevance here include the flying skills of experienced pilots and the specific expertise of senior chief petty officers--in each case representing many years of continuous practice of a small range of specific skills.
22. 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'ns, which holds annual meetings where information is exchanged and formal papers are presented.
23. Often, officers near the end of their tours, with new assignments in hand, are also trying to learn as much as they can about their future tasks and responsibilities.
24. K. Weick, "The Role of Interpretation in High Reliability Systems," *California Management Review*, vol. 39, 1987, pp. 112--27.
25. Roberts observes that similar rules would operate to similar advantage on the navigation bridge, which of necessity operates under more formal and traditional rules.
26. Even when fitness report ratings are based solely on merit, they are necessarily subjective to some degree. It is inherently difficult to compare ratings taken on different ships, in different peer groups, by different superiors, even under the best of circumstances. But the general opinion among those we have interviewed is that direct abuses of the system are relatively rare. As with all hierarchical organizations, politics will begin to enter as one moves to higher rank, but it is thought to be a minor factor below the level of captain.

27. 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.
28. Martin Landau, "Redundancy, Rationality and the Problem of Duplication and Overlap," *Public Administration Review*, November--December 1973, pp. 316--51.
29. In this context, we note that the tempo and character of U.S. carrier operations are so qualitatively different from those of other navies--including the French, British, and prospective Russian--that the envelope itself can only be measured by our own expectations and capabilities.
30. The engines are in different compartments and are hand-set 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.
31. During heavy flight operations there may be anywhere from six hundred to a thousand settings of the engines in a single day. A typical deployment will have eight to ten thousand arrested landings ("traps"), involving thirty to forty thousand settings over a six-to-eight-month period.
32. Although the probabilities are low, the possibility does exist. A minor error may simply result in too much runout, cable damage, or some damage to the aircraft. But an engine set for too heavy a weight can pull a tailhook out, leading to aircraft loss; setting for too low an aircraft weight can result in its "trickling" over the end of the angled deck and into the sea. Experienced air bos'ns and chiefs estimate that perhaps six or seven such serious errors have occurred throughout the entire U.S. fleet over the past twenty years. Our estimate for the rate of uncorrected wrong settings with serious consequences is therefore about one in a million--roughly comparable to the probability of a mid-air collision in a domestic commercial airline flight. Setting errors that are corrected are "nonreportable" incidents and therefore not documented. We also note that on the *USS Carl Vinson*, a much newer ship with a still unbroken memory, no reportable incident of any kind could be recalled in the first seventy thousand traps since its commissioning.
33. Allan W. Lerner, "There Is More Than One Way to Be Redundant," *Administration & Society*, November 1986, pp. 334--59.
34. This was brought home to us during a general quarters drill in which the bridge took simulated casualties.
35. During the period of observation, CDC was also the center for fighting the battle group, a task that will be increasingly 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), antiair warfare control consoles, and perhaps air operations and carrier air traffic control center (CATCC); other warfare modules, such as those for antisubmarine or antisurface warfare, may also be included or be in physically adjacent spaces.

36. For example, control of fighter aircraft can be done from the carrier, from an E-2 [airborne early warning aircraft], or from one of several other ships in the group.
37. Evered lists qualities of "responsiveness to authority," "being ready," "can do," and "not fazed by sudden contingencies" as among the more "obvious" character traits of naval officer culture. These are transmitted by training programs, ceremonies, and historical models. The latter is particularly important for the "can do" aspect of the officer culture.
38. Not only are the ship and its air wing parted, but the wing itself is split into component squadrons that train under different functional commands.
39. No definite name for this thousand-foot-plus, angled-deck, sixty to seventy-thousand-ton nuclear-powered carrier has been ascertained at this time. [Editors' note: The year after this article was published, what would have become the Soviet Union's first nuclear-powered carrier, *Ulyanovsk*, was laid down at the Nikolaev yard in the Crimea (but was never completed). Two conventionally powered carriers of a new class with approximately the dimensions mentioned were, however, fitting out in the Black Sea at the time: *Tbilisi*--later *Leonid Brezhnev*, now *Admiral Flota Sovietskogo Soyuza Kuznetsov*--and *Riga* (thereafter Varyag).]
40. See Bruce W. Watson and Susan M. Watson, The Soviet Navy: Strengths and Liabilities (Boulder, Colo.: Westview, 1986).
41. Although it is currently believed that arresting gear and catapults will be fitted--and the deck mock-up at Saki airfield in the Crimea is so equipped--ski-ramps for a total loading of sixty to seventy short-takeoff-and-landing aircraft appear more likely in the short term, with possible future retrofit of catapults into pre-existing deck slots at some future date. See, for example, Norman Polmar, *Guide to the Soviet Navy*, 4th ed. (Annapolis, Md.: Naval Institute Press, 1986), pp. 164--5.
42. As a group, we doubt they will be able to approach the operating conditions and efficiency of U.S. carriers in this century, if at all, even if they master the associated naval and aircraft technologies.

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*The first U.S. Navy aircraft carrier, commissioned as CV 1 (after conversion from a collier) in 1922. Langley was sunk by the Japanese in 1942. [Return]
†Naval Air Training and Operation Procedures Standardization.

‡Petty officers, the middle ranks of U.S. Navy enlisted personnel, specializing in a "rate" (such as Aviation Boatswain's Mate). "CPOs," or chief petty officers, occupy the three highest enlisted pay grades (aside from Master Chief Petty Officer of the Navy).

§Located in the island structure, and on the flight deck, respectively.

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