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Complex, Large-Scale Military Systems and the Failure of Control

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I. Preface: U.S.S. Vincennes and Iran Air Flight 655

Patrolling the restricted waters of the Persian Gulf was a trying activity for most U.S. warships, designed, armed, and trained as they were for far-ranging 'blue water' operations. This was particularly true for the officers and crew of the USS Vincennes. One of the first of the Ticonderoga-class 'Aegis' cruisers, the Vincennes is a fast, lightly armored ship -- a cruiser built on a large destroyer hull -- specially optimized for fleet air defense. Although armed with various surface-to-surface guns and a variety of systems for close-in air defense, her real 'main battery' consisted of the Standard SM-2 anti-aircraft missiles stored deep in her magazines.

In her normal mission of providing air defense to an aircraft carrier battle group, the Vincennes' advanced Aegis fire-control system was capable of projecting a visible image of an air battle of many hundred square miles, tracking and distinguishing friendly and potentially hostile aircraft at ranges of tens of miles while engaging a variety of potential targets ranging from high-flying reconnaissance aircraft to high-speed cruise missiles. Bottled up in confined waters, this billion-dollar bundle of sophisticated and advanced technology was not much more able to defend herself from mines and Iranian speedboats than a destroyer, and was almost as vulnerable.

But the U.S. Navy, with its focus on broad-ocean task forces and quasi-strategic 'maritime strategies' had not built a coastal patrol navy, relying on its European allies to perform this function for them in NATO waters. So, on this morning of July 3, 1988, the Vincennes, like many of the U.S. ships on Persian Gulf patrol, was engaged in a sweep of the shallow waters of the Straits of Hormuz, a mission for which traditional Navy skills such as ship-handling and gunfire were more important than the high technology aboard. Also in the vicinity were two U.S. frigates, the USS Elmer Montgomery (FF 1082) and the USS Sides (FFG 14). With the memory of the attack on the USS Stark the previous year still fresh in every sailor's mind, all aircraft detection and warning systems were up and fully manned.[1]

On the previous day, several armed small boats of the Iranian Revolutionary Guard Corps (IRGC) had positioned themselves at the western approach to the Straits, and were challenging merchant vessels. Late that day, the Montgomery had come close enough to a ship attack in progress to fire warning shots at several of the IRGC boats.

Early in the morning of July 3, the Montgomery, the at the northern end of the Straits, reported another attack by seven small IRGC boats armed with machine guns and rockets. Shortly thereafter, another wave of thirteen such boats was reported, in three groups, one of which took a position of the Montgomery's port quarter. At 7:42 AM local time, the Vincennes was dispatched to the area to investigate the situation. At about 9:45 AM, one of her helicopters sent out to

'IFF' (identification, friend or foe?) system of World War II. When interrogated by a radar signal from a potential adversary, the transponder 'squawks' (gives off a specific response signal) in a pre-specified and fixed mode. The Iranian F-14s at Bandar Abbas are presumed to have been set to squawk in 'Mode II', a mode that would identify to the US ships that the aircraft in question were Iranian, and military. Iran Air Flight 655, however, was set to squawk in Mode III, a signal that identifies a flight as civilian. The code number, 6760 in this case, would distinguish that particular flight from others.

In the case of Iran Air Flight 655, the matter of life or death seems to have been settled by the 18 minute delay in departure. Because of this timing, the flight first appeared on the Vincennes radar at 10:17, just after she had opened fire on the IRGC patrol boats. At 10:19, the Vincennes began to issue warnings on the Military Air Distress frequency, and at 10:20 to begin warnings on the International (civil) Air Distress frequency as well. It was at this moment, with the aircraft unidentified and apparently closing on the Vincennes, that the TAO ordered the radical maneuver that created disorder and tension throughout the CIC. Over the next 3 minutes, with the ship in a radical maneuver, the CIC in confusion and disorder, and while continuing to engage the IRGC boats, the Vincennes issued a number of warning on both military and civil distress frequencies, (mistakenly) identified the Airbus 320 as a possible Iranian F-14, (mistakenly) reported hearing IFF squawks in Mode II, and (mistakenly) reported the aircraft as descending towards the ship when it was in fact still climbing according to its usual flight plan.[3]

Having informed Joint Task Force Command that a potentially hostile aircraft was at a distance of 28 nautical miles, and rapidly closing to within potential missile attack range, the Vincennes received permission to engage. Captain Rogers, the Commanding Officer (CO) held out for a minute or two more, by which time the still unidentified aircraft had closed to 15 miles and was still being reported as descending towards his ship. At about 10:24 AM, seven minutes into Iran Air Flight 655's flight, and eight minutes into Vincennes' fire fight, the CO fired two SM-2 Standard missiles at the unknown target.

A few seconds later, with the flight still on its assigned climb-out, and slightly to one side of, but well within air corridor Amber 59, it was intercepted by one or both of the missiles at a range of 8 nautical miles and an altitude of 13,500 feet. The Airbus 300, with some 290 people from six nations aboard, tumbled in flames into the Persian Gulf. None survived. The whole flight had taken less than seven minutes.

By noon of that day, Iranian helicopters and boats began the search of the area and the recovery of the bodies. It was not until later that day that the officers and men of the Vincennes would learn that what they had shot down was not an Iranian F-14, but a commercial, civil flight.

Some have even gone so far as to note that military systems as large-scale socio-technical systems are never that dissimilar in capabilities and structure from contemporary civil ones.[8] Indeed, the whole category of 'military technology' as separable from ordinary technology is a socially construction of academic professionals, for the technological principles at work have considerable commonality with those of contemporary civil technologies, however different the particularities of the military artifacts.[9]

Management vs. Control

The word 'control' is used in many different ways, carrying with them many different meanings, even in the disciplinary literature.[10] Among the more precise is that put forward by Martin Landau to differentiate it from more traditional techniques of 'management' according to the character and degree of knowledge involved.[11] In Landau's terms, any organization is fundamentally a seeker for knowledge -- empirically verified observations, theories, and models not only of its own behavior, but of that of its organizational environment. But knowledge without models is completely retrodictive. Since few decision circumstances ever repeat, organizations seeking to act on the basis of knowledge seek comprehensive models, which attempt to predict future outcomes based on present information.

It is the nature and interpretation of models that makes the control vs. management distinction a particularly critical one for the case of military systems. If one has perfect knowledge, correct information, and a verified, knowledge-based model that encompasses all possible variations, then one can indeed exercise 'control' over outcomes. That is, one can take the information in, interpret it, fit it into the model, compare the modeled output with the desired output, and either accept or correct the action to keep events on the pre-ordained course. All of which is predicated on being able to select not only an appropriate model, but the degree to which evolving circumstances correlate with the model's assumptions.

Management, on the other hand, involves decision-making under the acceptance of irreducible uncertainty, using heuristic models that are corrected on the fly, as necessary, as part of on-line trial and error learning. In life, there is always much more management than control. An outfielder drifting back under a fly ball in left field, a soccer goaltender watching the oncoming play, a batsman guarding a wicket, and a battlefield commander adjusting his troops according to the tide of battle are all 'managing' their particular critical environment, adjusting on the fly to try and get a favorable outcome.

Ironically, such systems were to move far more quickly than the nature of battle, or the weapons themselves, leading, in Vietnam, to a whole new class of failures of over-control.[16]

It is, however, no longer possible to distinguish between command and control systems and the weapons themselves. The electronics revolution is no longer distinct from weapons and weapons system development. Indeed, the latter more and more depend intimately upon electronics and internal data processing for their very function. This is one aspect in which technologies of control have become intrinsic, creating a whole new class of weapons and systems that are expressions of rather than tools of information and data processing systems.[17]

Yet, there remains still the fundamental, and extrinsic problem of exercising command and control over these smart weapons systems. And here, the rapid advance in technology continues to escalate the problem of weapons and system control at least as fast as it has increased the capability of the central command structure. Technological change in the modern military, even in some of the less-advanced countries, has increased both scale and geographical scope of operations far beyond the capabilities of previous form of command-and-control systems to act in real time. In an era of supersonic aircraft armed with high-speed missiles, quick-reacting radar-directed gun and missile batteries, and tank battles that may be won or lost on the first shot, there is simply not the time for centralized command systems to exercise real-time control over battlefield events.[18]

Faced with the problem of operating such a critical large-scale technological organization in situations where trial-and-error techniques are probably inapplicable owing to feedback and correction times being much longer than the time scale of the source events, commanders seem increasingly reluctant merely to advance and augment historical communications techniques, with their 'management' orientation. Instead, they are adapting the new and powerful technologies of information and data-processing to extend throughout their organizations a series of direct links for information and control, and placing at the center of the resulting web powerful, centralized command centers that are intended to exercise direct control from the top down to even the smallest of battlefield units.[19]

For these systems, as for all others, errors of various kinds will occur. However, as the technology in use grows in importance and scale, and comes to more tightly couple different units and different levels of command, the locus, nature, and scope of errors will change significantly.[20] Because of the increased coupling, misapprehensions and faulty performance are not so easily localized and repaired. And, to the extent that modalities of control come to dominate, the consequential deviations from modelled behavior can be far more profound. In some cases, the result may be a relatively complete collapse of the organization's performance, or its ability to further pursue its primary objectives or carry out its primary mission.

it cruising altitude while gradually gaining speed. Data and testimony from the USS Sides corroborate the flight path and the Mode III IFF squawk. Indeed, the Sides was to identify the unknown aircraft as non-hostile and turn its attention elsewhere only seconds before the Vincennes launched its missiles.[24]

The story told by those inside the Combat Information Center (CIC) aboard the Vincennes is quite different. From the first alerted contact, various personnel began to report a "Mode II" squawk, on a code (Code 1100) that was associated with Iranian F-14s. Although none of the data recorders reported any IFF response other than Mode III, Code 6760, those aboard the Vincennes continued to report Mode II, and to consistently mis-report the code of the Mode III signal. As the range closed, the Vincennes began to broadcast increasingly urgent warning messages to the unknown aircraft; at first, these were general challenges on both military (MAD) and international civil (IAD) distress nets. But as the notion that the aircraft was indeed an F-14 became fixed in the minds of the key operators, the challenges were made more specific -- on the MAD net only, and addressed to an unidentified 'Iranian F-14.' A quick thumb-through of a listing of commercial flights missed the clear listing for Flight 655, although it was on course and nearly on time.

A warning of possible 'COMAIR' a minute or two later was acknowledged by the CO, but essentially ignored. At this point, the ship was still engaging the Iranian surface boats. Moreover, the ship was heeling sharply as the Tactical Action Officer (TAO) ordered 30 degrees of rudder at high speed to unmask the aft gun mount; loose books and equipment flew about the CIC. With the TAO concentrating on the surface battle and his attention divided, the CO depended on the Anti-Air Warfare Commander (AAWC) to take care of the possible air threat. But the AAWC was new to his post, and generally regarded as inexperienced and a weak leader. De facto leadership fell upon the more junior (TIC), who by that time was almost literally shouting about the immediacy and seriousness of the threat.

To give Captain Rogers credit, he did allow the unknown aircraft to close to well within its possible missile firing range before asking for and receiving permission to intercept, and he did so only after repeating the challenge several more times. Only then, convinced that the threat to his ship is too serious to ignore, and under pressure to act quickly to avoid the earlier fate of the USS Stark, did he authorize the firing.

There are, then, three quite different narratives -- that of the memory perceptions of the officers and crew in the CIC, that recorded by the unforgiving instruments, and that described in report of the USS Sides, which was also monitoring the flight. But the Sides, after following the track for the same time, accepted it as a civil airliner, and turned its attention away prior to the Vincennes' order to fire. In precisely the same circumstances, the high-technology command and control system 'failed' to provide the means for a correct identification, while the low-technology one did not.

The Investigation Report

Navy hearing boards such as the one convened to review the events of July 3, 1988 are unique in focusing on the CO, owing to the long Navy tradition that it is the CO, and only the CO, who is responsible for anything and everything that happens on or to his ship. As often as not, judgement calls are made on the simple basis of what the hearing officers would have done in the same situation, given the same information.

This Navy tradition worked against the possibility of a comprehensive, systemic investigation into the circumstances preceding the missile firing.[28] For the question should not have been whether the CO was justified in taking the actions he did given the situation and the information he had, but how the situation had developed so badly and why the information being provided was so skewed from reality. These matters were in fact addressed by the investigation, but by no means to the degree or depth required to come up with a set of answers.

The Investigation Board was convened by Rear Admiral William M. Fogarty at Bahrain beginning on 6 July, while the events were still fresh in the minds of the participants. Formal hearings began a week later, and the entire procedure was completed and the report delivered to the Navy on 28 July.[29] Even in the cleansed form provided to the public, the report is rich in personal and technical detail. Perhaps the most striking feature is the degree to which the recollections of the participants as to the nature and assessment of the presumptive threat differ, and the variance between what was reported by the SPY-1A computers and what its human interpreters were reporting.

The record shows that the decision to fire was taken more or less calmly and deliberately on the basis of personal advice passed from junior officers to the senior Anti-Air Warfare Commander (AAWC), and from the AAWC to the CO -- in the face of a stream of contrary evidence from the electronics aboard. Faced with the problem of reconciling the manifest mistakes made in interpretation of technical evidence, the Hearing Board concluded that "stress, task-fixation, and unconscious distortion of data may have played a major role in this incident."[30] The report then went on to attribute the distortion to the relatively junior Tactical Information Coordinator (TIC) and Identification Supervisor (IDS), who became convinced that the track of Iran Air 655 was an F-14 after an IDS report of a momentary Mode II squawk. The Fogarty report states:

> After this report of the Mode II, TIC appears to have distorted data flow in an unconscious attempt to make available evidence fit a preconceived scenario ("scenario fulfillment").

This fulfillment including continuing to read the Iran Air flight as descending towards the Vincennes, even though the information being presented by the electronic suite was contradictory.

of the Navy, there was no culpable conduct displayed. The event was a very regrettable accident, but basically a by-product of the Iran-Iraq war.[31]

It should also be noted that the entire review process was treated as one investigating 'culpability,' as if personal malfeasance or neglect was the only issue. Having absolved the individuals of blame, the Navy, and, by and large, the press and Congress, then moved rapidly to the highest possible level of political analysis; if there was no personal malfeasance, and the *Aegis* system had worked perfectly, the result could only be attributed to the misfortunes of war.

The APA Panel

On October 6, 1988, a panel of five psychologists chosen through the American Psychological Association testified at a hearing of the House Armed Services Committee, accompanied by a great deal of media coverage.[32] Although a great deal of their testimony was directed towards the questions of decision-making under the stress of the circumstances, and at the failure of the Office of Naval Research and other Federal agencies to adequately support research into decision-making under stress, they also raised at the hearings the more general question of the techno-systemic environment within which the decisions were being made.

As the Fogarty report had done in its summary, the expert panel pointed out that in an era of increasing technical complexification, it will no longer do to continue to point only to 'operator error' as the source of malfunctions and disasters.[33] Rather, what happened aboard the *Vincennes* on July 3 could be seen as part of what one psychologist characterized as the 'glass cockpit' syndrome -- which in itself is a property of large-scale, highly sophisticated technical systems operating under conditions of high stress, high consequence, and high visibility.[34] Unfortunately, neither the Armed Services Committee, the Navy, or the Department of Defense seems to have had the least inclination to follow up this line of inquiry.

Facts and Factoids: Of Relevant and Irrelevant Argument

Before engaging in a further analysis of the performance of the *Vincennes* as a weapons system, it would be well to deal first with some other assumptions and beliefs about the incident that serve only to draw attention away from important matters.

Of these, the most public, and striking, is the attempt to attach some, or all, of the blame on the Iranians. Of course, we have no way of knowing what the pilot or crew of Iran Air Flight 655 did or did not know about the fire-fight going on below their assigned corridor, or why they (unluckily?) chose to fly to the north of the centerline instead of the south. Nor, given relations between the US and Iran, do we have any way of directly interviewing the staff and control tower at Bandar Abbas, to see what they knew. It is true that *if* Iran Air Flight 655 had been directed away major point is to find out why the risk, the potential for tragedy came about. Since our objective here is primarily to find out why the risk turned to reality, they are not relevant to our purpose. And neither, to a great extent, is the matter of stress.

Stress

The two primary factors identified in the hearings, the reports of the eminent psychologists, and most thoughtful journalistic analyses were the misreading of the commercial aircraft as descending when it was in fact ascending, and the persistent failure to correctly read out the IFF data being presented by the electronics suite in the CIC. Both of these are then attributed to the rather considerable stress at a time when the CIC was otherwise somewhat disrupted from the preceding abrupt maneuvers.

Subsumed under the category of stress as well is the institutional memory of the attack on the USS Stark the previous year. Within the Navy, the presumptive 'lessons learned' from the Stark incident were sufficiently strong, and the sufficiently unambiguous, that 'the USS Stark' is simply listed in the Investigative Report as one of the contributing causal factors without any further expansive discussion.

Stress was clearly a contributing factor, but its presence is in no way explanatory, and by no means exculpatory. Stress is, or should be, a central assumption of battle, alongside of confusion, uncertainty, and risk. To design our systems otherwise would be sheerest folly.[36] Based upon our long naval history, there is simply no evidence that the Vincennes was under a degree of stress greater than one would expect for a ship in combat, in strange waters. If the ship as a system is incapable of operating correctly under such circumstances, she is a failure as a weapons system, however well her machinery, electronics, and missiles perform.[37]

The Stark failed to identify the Iraqi aircraft as potentially hostile, and failed to properly arm and unmask its missile defense systems. But in what way did that contribute to the sequence of events aboard the Vincennes? The Stark was not prepared for hostile attack, not suspicious of enough of a potentially threatening flight profile, and not ready for combat soon enough in the chain of events. The Vincennes, however, was prepared, was suspicious, and was ready. Clearly it was not the specifics of the Stark incident that laid combat stress on the officers and crew of the Vincennes, but rather the memory of the consequences of any serious failure at all.

It is in this context that the matter of scenario fixation returns as a function of the shift from technologies that assist battle management to those that attempt to control the battle. Aboard the Sides, the officers and crew were free to experiment with scenarios, to use their data processing and information gathering equipment to assist with alternative descriptions of reality until they found one

Even when so expanded, 'pilot error', remains a portmanteau, subsuming two general categories of presumptive malfeasance: (a) failure to operate the equipment properly, or skillfully, or to follow various procedures and rules established to guarantee operational safety; (b) failure to rescue operations from an unanticipated or abnormal situation that was nevertheless within the presumed skill and capacity of the expert operator to rectify or remedy.

Following the terminology of Martin Landau, we refer to the first of these as a "Type I" error .. overlooking, ignoring, or mis-understanding the information presented even when it occurs within the envelope of the predicted or anticipated flow of events.[42] It should be noted that this class of error also includes 'anticipatable' equipment malfunction or stress over a wide range -- such as engine failures, electronic malfunctions, or high-stress operational periods such as take-offs or surface combat. Included in this class, therefore, is the failure to rectify or save a variety of situations that are presumed to lie within the range of an expert operator to correct or act upon because of his or her skill and expertise. The CO and officers of the USS Stark, for example, committed a Type I error in failing to put the ship on proper alert when an Iraqi aircraft was sighted.

The second we will call "Type II" errors .. accepting as true, accurate, or significant information that is misleading, incorrect, or irrelevant, or, by extension, projecting into a situation 'external' beliefs or assumptions about the nature of the situation or the state of the system. One example might be the failure to correctly set the flaps or landing gear into proper position during take-off, or to notice that de-iced wings have re-iced; persistent mis-identification of a potentially hostile aircraft heading towards a naval unit in a combat zone would be another. The actions of the Vincennes might well be so classified.

However, these historical classifications are increasingly inapt for large-scale technical systems, particularly those involving some degree of actual (physical) risk. The systematic progression and complexification of advanced technology has resulted in incidents that were once classified as "Type I" events progressively moving towards "Type II". Redundancies in equipment, presumptive higher reliability, and considerable sums spent on system design and large-scale integration result in the anticipation that such failures will be increasingly rare. One result is that pilots (operators) will acquire very little skill or experience with the acceptance and interpretation of signals of potential error. Lacking experience with complex systems whose informational modalities require formal interpretive training, the operators will find it very difficult not only to filter the information they are getting, but to discriminate between their intuitive or prejudicial judgements and those that the equipment is supposed to provide.[43]

The very complexity of the equipment will make it more difficult to ascertain what is going awry, why, and, at times, whether something is going badly or incorrectly at all. Where a pilot could once try to make a determination as to why his radio was not working, and what he could do about

VI. Technology and the Span of Command and Control

The Vincennes incident has provided us with a potentially valuable case, from which we may be able to draw some generalizations and conclusions about the future of long-range, highly-automated, control-oriented, high-technology weapons systems. It is this potential that makes it so regrettable that the Navy's investigation so systematically sought to identify and localize specific, non-systemic factors upon which the 'blame' (to the extent that it could be characterized as blame at all) could be placed.

In the days of wooden ships, command was relatively straightforward. Threats were clear and simple, developed at a reasonable pace and usually within sighting range, and were confined to the plane of the surface. A modern fighting ship fights in a three-dimensional environment that extends to hundreds of miles, facing threats that may develop with great rapidity, and with a demand to interpret and integrate many disparate sources of data and information. The 'threat environment' so defined is too complex to be the responsibility of the ship's CO, who must incorporate the threat into an even larger picture concerning the well-being of his ship, its relation to others, and communication with higher command. But combat decision-making is not a function that can be decentralized when threats and decisions develop rapidly. Aboard modern U.S. ships, the task of actually 'fighting the ship' is assigned to the TAO.

Over the past few years, I have had the privilege of being part of a research group that was allowed aboard several U.S. aircraft carriers, as part of a project on the organization and management of high-risk technological operations.[49] During that time, we have observed CDC (Combat Decision Center, formerly known, as on Aegis cruisers, as the CIC) operations at sea. Although we did not, and could not have, been in the CDC during real, or even potential hostilities, we have been present as observers during extensive and realistic training, and during combat exercises in Pacific waters that serve the dual role of final training and evaluation before the ship is qualified for combat and deployed.

Owing to the complexity of the combat environment for a carrier, which may at different times act almost alone, in concert with only a few escorts, or as part of a larger Battle Group, the tactical functions are all available and drilled aboard the ship itself. Thus, there are four main combat activities that need coordination and control; anti-air warfare (AAW), anti-surface warfare (ASuW), anti-submarine warfare (ASW), and offensive coordination (Strike). Of the four, the first two, anti-air and anti-surface warfare (primarily defensive) are closest in specification to those aboard the Vincennes, and will be used here for purposes of comparison.[50]

As on the Vincennes, AAW and ASuW coordination each center about a single person -- the TAO -- charged with performing the integrative tasks of assimilating different information from a variety of sources, assessing the current state of threat, and placing it into spatial and temporal

Moreover, the proceedings of the Investigative board show little sign of any primary role for 'bubble' formation aboard Aegis cruisers. Instead, the role of the multiple technical systems, which aboard a carrier serve primarily to feed information to the TAO seem to have been reversed. Aboard the Vincennes, the Aegis-directed, computer-operated anti-aircraft missile system is the primary system, with the CO primarily involved in deciding whether to activate its firing mode or not. In this situation, the TAO has become an input, not an integrator, and the CO an authority rather than an expert.

Instead of a closed decision-making system, based on the historical notion of the integrity and isolation of a ship at sea, the CIC on modern surface ships is increasingly a part of a larger web of information, control, and authority; instead of working with technologies whose characteristics are deeply and intimately familiar to those aboard, decision-makers much increasingly rely on abstract displays from systems whose inner workings are opaque to them. The locus of authority, and scale of consequence have rapidly expanded, while the responsibility remains at the operational level.

VII. High-Technology Military Systems: The Two-Edged Sword

Taken in context, the events surrounding Iran Air Flight 655 are illustrative of a series of disquieting trends within large-scale military command and control systems. The Sides, with less sophisticated equipment, a less comprehensive command and control system, and subject to larger direct risks if attacked (owing to its less sophisticated defensive systems), made a correct evaluation. But it was also a less valuable, less attractive target, under less pressure to act as part of the larger system of air defense in the Gulf. The Vincennes, despite its awesome capabilities, felt more threatened, more vulnerable, and under more pressure. Indeed, one might even say that the degree of pressure, the fear of threat, and the perceptions of vulnerability were exacerbated by the awareness of her CO of the Vincennes cost, her value and irreplaceability as the core of air defense, and the expectations of those who bought her, built her, and sent here into the Gulf.

Moreover, the nature of her equipment, and the crew's training to use it, put them very much in the mode of 'control' rather than management. Instead of being under constant pressure to interpret data and adjust systems to meet changing realities, the Vincennes was prepared and trained to activate an elaborate system of control in a situation where the only uncertainties would be those deliberately created by potential enemies trying to confuse their information and data collection system. Furthermore, the manifest confusion aboard the Vincennes is absolutely no excuse for her poor performance. Military systems that cannot function in the midst of confusion, or while under multi-threat attack are not only totally useless, they pose more dangers to their users than their opponents.

information was coming in, the CO and the CIC staff had no time to devise scenarios. Nor, given the increasing focus on systems of 'control,' were they trained in quick, heuristic scenario building. Therefore, they reacted directly to the threat as a threat, within the script they were already playing.

As we move to more expensive, more capable, weapons systems, the demand for systemic control to avoid error will surely increase. Until recently, this was true primarily of nuclear weapons systems, where the cost of a mistaken launch, or release of weapons, was so clear, and so dramatic, that almost literally heroic measures have been taken to prevent it.[55] Less well-known, but equally important, have been the continuing concerns over the ability to fire the system when necessary, in an atmosphere steeped with the precautions against inadvertent or incorrect action.

Heretofore, the distinction between nuclear and non-nuclear weapons was so great that the notion of systematically evaluating the potential for both kinds of error was rarely, if ever, extended beyond the traditional point of the training and testing of individuals, particularly those in command. But the advent of other 'conventional' systems as sophisticated, but without the terrible risk accompanies the nuclear systems implies that we will have to extend what we have learned to date. Moreover, many of these new conventional systems, such as SDI technologies and, as it turns out, Aegis and similar air defense systems, may well be geared for a quicker response time. Most will also be lacking the multiple levels of restraint that both available time and tremendous risk have imposed on strategic nuclear weapons.

Thus, the incident of Iran Air Flight 655, in context, serves as a sharp example of the perils of increasingly sophisticated, increasingly centralized, and increasingly expensive military C_3I systems. Whether they be bunkers under Cheyenne Mountain, AWACS flying over Western Europe, or forward command posts on either side of the inter-German border, these systems grow larger, more rigid, and more saturated with information and responsibility with every passing year. We are constantly reassured that the systems are workable, and only need more careful training of personnel to become error-free.

Even the Vincennes case is discounted, on the grounds that the Aegis system worked correctly. This is perhaps the most misleading statement of all, for without the Aegis system it is possible that the events described above would never have occurred. The Navy's complacency in the success of its hardware in the face of the failure of the Vincennes is analogous to saying that the operation was successful but the patient died. If the large-scale social-organizational-technical system fails to produce the right outcome, then it has failed as a system. Whether the proximate cause was human action or malfunction of the equipment is a matter of detail; substantive detail, to be sure, but detail none the less. It does not absolve us of the need to enquire further to discern whether the inability of the operators to avoid a mistake or recover a deteriorating situation occurred because of the structure and context of the large-scale technical system in which their decision was embedded.

15. The increasing attempts by Adolph Hitler to manage the front directly as WWII dragged on are the most famous, but Allied commanders were susceptible to the same temptation. See, for example, the several WWII histories of Liddell Hart, and the memoirs of, e.g. von Manstein and Rommel.

16. van Creveld, Command in War, 232ff. James William Gibson, The Perfect War (New York: Vintage, 1988) may be the single best book on how American managerial and technocratic assumptions led to a systemic defeat. For analysis of a more recent episode of over-control see: George C. Wilson, SuperCarrier (New York: MacMillan, 1986).

17. David Bellin and Gary Chapman, Computers in Battle: Will They Work? (New York: Harcourt Brace Jovanovich, 1987); Allan M. Din, ed., Arms and Artificial Intelligence: Weapons and Arms Control Applications of Advanced Computing (New York: Oxford University Press, 1987); Seymour J. Deitchman, Military Power and the Advance of Technology: General Purpose Military Forces for the 1980s and Beyond (Boulder: Westview Press, 1983).

18. See, for example, Zvi Lanir, Baruch Fischoff, and Stephen Johnson, "Military Risk-Taking: C3I and the Cognitive Function of Boldness in War," Journal of Strategic Studies, 11, No. 1 (March 1988), 96-114.

19. James W. Canan, "Sorting Out the AirLand Partnership," Air Force, April 1988, 50-59.

20. The term tight-coupling is most precisely delineated in this context in Charles Perrow, Normal Accidents (New York: Basic Books, 1984). The terminology is largely derived from James D. Thompson, Organizations in Action (New York: McGraw-Hill, 1967). See also K.E. Weick, "Educational Organizations: Loosely Coupled Systems," Administrative Science Quarterly, 21 (March 1976), 1-19.

21. I hesitate here to use the term 'systemic' failure, since to some that implies a failure of the Navy as a system, rather than the ship. Moreover, the ship as a system can only be understood as embedded in the larger context of the Persian Gulf command, which in turn is embedded in the still larger context of Fleet and Area commands, and so on. Other relatively complex large-scale technical systems may also share this property of systemic 'nesting,' which complicates description more than it does analysis.

22. This was much clearer in the perusal of the Fogarty report (Ref. 1) than it was in subsequent news stories.

23. The Aegis Display System data could not be extracted, precluding any positive confirmation of actions taken at the CO and TAO consoles.

24. To quote the Fogarty report directly: "The data from USS Vincennes tapes, information from USS Sides and reliable intelligence information, corroborate the fact that [Iran Air Flight 655] was on a normal commercial air flight plan profile, in the assigned airway, squawking Mode III 6760, on a continuous ascent in altitude from takeoff at Bandar Abbas to shoot down."

25. Washington Post, 30 April 1990. The Legion of Merit, the U.S. armed forces second highest award, was presented to Capt. Rogers and Lt. Cmdr. Lustig (the weapons officer) for 'meritorious conduct' and 'heroic achievement' on 3 July 1988. The citations did not mention the downing of the Iran Air flight at all.

26. Admiral Crowe was reported to have concluded that airport officials at Bandar Abbas "should not have allowed the flight to take off while a firefight was going on some miles away" (New York Times, 20 August 1988). Then Vice-President George Bush was quoted as saying: "I will never apologize for the United States -- I don't care what the facts are. For these and similar quotes, see, e.g., George Wilson, "The Risks of Shooting First" (Washington Post, 28 January 1989). To be fair to the Navy, their conclusion that Capt. Rogers was justified in firing in presumptive self-defense was widely shared on Capitol Hill. See, e.g., Congressional Quarterly, 9 July 1988, 1905ff.

27. As Karl Weick has put it: "An 'error' occurs when a person strays from a guide or prescribed course of action, through inadvertence and is blameworthy, whereas a 'mistake' occurs when there is a misconception, misidentification, or misunderstanding ("Technology as Equivoque: Sense-Making in New Technologies," paper prepared for a Conference on Technology, Carnegie-Mellon University, August 28-30, 1988).

43. Jens Rasmussen, Information Processing and Human-Machine Interaction: An Approach to Cognitive Engineering, (Amsterdam: North Holland, 1986).

44. See, for example, E. M. Roth, K. B. Bennett, and D. D. Woods, "Human Interaction with an 'Intelligent' Machine," International Journal of Man-Machine Studies, 27 (1987), 479-525.

45. Karl E. Weick, The Social Psychology of Organizing, 2nd ed. (Reading, Mass: Addison-Wesley, 1979). Similar ideas are increasingly current in the human-factors, man-machine interface literature. See, e.g., note 6, 45 above.

46. James Reason refers to embedding of representational errors as form of 'resident pathogen.' See: Human Error: Causes and Consequences (New York: Cambridge University Press, 1989).

47. For example, nuclear power plant operators must balance their interest in taking a plant down when they suspect something is not quite right against the cost to the utility of the loss of power.

48. Cf. Rasmussen "Human Error;" Reason, Human Error; Perrow, Complex Organizations; Weick, "Technology as Equivoque. One corollary of the system-embedded-error hypothesis is that this class of accident is a growing fraction of all accidents. Since the public, and many administrators and regulators (not to mention engineers) are demonstrably unwilling to accept the relative growth of this subset, such accidents are more often than not assigned to the category of 'human error,' even though, in reality, they should be assigned to a new class of systemic technical failures over which real operators, in real situations, have only the illusion that they are in control of events.

49. Rochlin, La Porte, and Roberts, op. cit.

50. Note that at times the Vincennes itself may serve as anti-air warfare coordinator for a larger group of ships, and therefore is at least as fully equipped (and probably with more modern equipment) as a carrier.

51. Karlene H. Roberts and Denise Rousseau, "Research In Nearly Failure-Free, High-Reliability Systems: 'Having the Bubble'," IEEE Transactions, 36 (1989), 132-139. See also Rochlin, La Porte, and Roberts, "Self Designing Organization."

52. Gene I. Rochlin, "Informal Organizational Networking as a Crisis-Avoidance Strategy: US Naval Flight Operations as a Case Study," Industrial Crisis Quarterly, 3 (1989), No. 2, 159-176.

53. Karl Weick, "Mental Models of High-Reliability Systems," Industrial Crisis Quarterly (in press).

54. For a discussion in the context of the U.S. Navy and the increasing complexity of its equipment, see: Eric Johns, "Perfect is the Enemy of Good Enough," Proceedings, October 1988, 37-48.

55. Bruce G. Blair, Strategic Command and Control (Washington, D.C.: Brookings, 1985) is a superb analysis of the status and quality of U.S. nuclear weapons command and control, discussing both positive and "negative" control modes.

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