SPEED:
The Implications of Hull Speed for Tactical, Operational and Strategic Naval Operations

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Introduction 1
  Overview of Speed 1
  Organization of the Paper 3
  Metaphors, Models, Reality 3
    General Metaphors 4
    Models (Analytic Approach) 5
  Definitions and Terms of Reference for Speed 6
    Physical Speed 6
    Information and Cognitive Speed 7
    Domains of Analysis with a Focus on Speed 8
Speed in a Distributed, Networked Force: Exploitation of Options and DMER5 13
  Network/Networked Dynamics: Operational Implications of a Networked Force 13
    Generalized Scenario and Parameters for Analysis 15
    General Logical Flow of the Analysis 17
Models 19
  Koopman Search 19
  Queuing Analysis 22
  Surge Deployment Analysis 24
  Evasion Analysis 26
Analytical Results 28
  Baseline 28
    Off-board Vehicles 29
    Sensitivity analysis 29
    Maintenance of Situational Awareness/Access 29
    Mission Profile 30
Summary and Conclusions 31
  Summary 31
  Programmatic Implications 31
  Conclusions 33
Appendix A: Charts Used for the Analysis 35
Notes 43

Introduction

Overview of Speed

“Attack Effectively First”[1] almost screams for speed advantage in tactical positioning, decision making capability, information gathering and weapons delivery. In the naval context, this maxim of Hughes is driven by the compellingly constant results of naval engagements, from the time of Nelson to the present day. In Chapter 8 of *Fleet Tactics*, Hughes discusses speed as a necessary capability to enhance maneuver; clever maneuver being essential for positioning to win the “battle of the first salvo”. He goes on to discuss the downside of speed: expense. Speed costs: in weight, money, space, and stealth. He also points out that modern naval analysis has not made an effective case for the value of speed when considered in context of the numerous other performance trades required when designing and building modern warships.[2] Speed, as Hughes points out, is one of the constants in naval warfare, and many new technological capabilities and advanced operational concepts have speed at their core. These include hypersonic and speed-of-light weapons, high speed strategic sealift ships and the nascent development of innovative and cost effective high speed tactical hull forms and propulsion systems on the technology front. Conceptually, the tenets of Network Centric Warfare: Self-synchronization and Speed of Command are but two operationally oriented concepts that aim to achieve decisive warfare effects through technologically enabled speed. In light of these potential new capabilities, a deeper understanding the impact of speed in operational concepts is overdue.

Speed has been a long sought after capability in many endeavors and is generally thought to be a ‘universal good’. In the business world, speed is manifested in the concept of ‘first mover advantage’. In sports, the drive for speed as a competitive advantage is ubiquitous. Indeed, most sporting events have speed at the core of their activity; in many of those that do not, speed remains a key discriminator of success in the overall competition. In the military, the fighter pilot’s mantra, “Speed is Life,” and the surface warrior’s threat-driven need to automate multi-mach missile defense decisions are concrete examples of the goodness of speed as an operational attribute. Even the submariner’s drive to the ‘preferred firing position’ is driven by the need to address issues relating to speed differentials in undersea warfare. Many advanced military concepts in the late 1990s have explicitly and implicitly made speed a cornerstone of the imputed value they bring to military competition. Just how much speed is worth is an open question.

In the Naval context, the emphasis on speed is manifested in the concept of Network Centric Warfare, with its twin pillars of self-synchronization (a kind of speed advantage that allows lower echelons to coordinate complex warfighting activities without direction from above) and speed of command (explicitly striving for high rates of change in rapid, accurate, application of force against an enemy). In terms of physical platforms, the desire for speed is manifested in the ‘Streetfighter,’ a new concept for littoral warfare based on a small, high speed, surface combatant. The Streetfighter was envisioned as the key to ‘rebalancing’ a tactically unstable fleet, a fleet “top heavy” with large capital ships, susceptible to saturation missile attacks by aggressive anti-access forces.[3] The Streetfighter concept has found programmatic instantiation as the Littoral Combatant Ship (LCS), a member of the DD(X) Program ‘family of ships’. LCS platform concepts seek to attain the speed required for Network Centric Warfare and Assured Access in the Littorals, trading off weight, money, space and stealth by exploiting emerging technologies and advanced hull forms.

To date, a clear, concise, analytically rigorous discussion of the value of speed in the context of a Maritime Anti-Access threat has not taken place. The collective assessment, evidenced by stated requirements and speeches by Navy leadership – most based on the current state of the art in high speed ships – is that a speed of about 50 knots is sufficient. We will look at the requirement for speed primarily in the Assured Access context of the deployment, management, exploitation, refueling, repositioning, recovery, replacement and redeployment (DMER5) of off-board vehicles as well as other aspects of the value of speed in Information Age Warfare. Specifically, we will look closely at the value of speed at the Operational Level of War and below (1- to 2-star Carrier Strike Group (CSG)/Expeditionary Strike Group (ESG) Commander's level), with excursion to examine of the impact of speed at higher levels. Due to limitations of scope and the maturity of analytic tools, we will primarily look at speed impacts in the Physical Domain of warfare and will characterize broadly and qualitatively these impacts (as well as other considerations of speed) on the Information and Cognitive domains of warfare. We will also discuss the impact of speed within and across these domains of military competition.

Organization of the Paper

This paper is organized in 6 parts (including an appendix). Part 1, the introduction, provides a broad overview of speed and the general contexts in which we will provide assessment and analysis. Part 2 presents an abstract analysis and assessment of speed in a distributed, networked force. It contains a conceptual discussion of a distributed, networked naval force, how such a force must operate to be effective and, in particular, how various conceptions of speed are important to this type of force. Part 2 also defines the general littoral operations scenario and provides analytical questions of interest. Part 3 presents analytic background for the results presented in Part 4 and the conclusions of Part 5. We pay special attention to issues that generate combat advantage at the operational level of war, especially with forces that have LCS-type speed and maneuver capabilities. Part 6 is an appendix containing detailed data supporting the analysis.

Metaphors, Models, Reality

When broaching new subjects, inventing new operational concepts or applying new conceptual and analytic tools to problems, metaphors provide a useful tool for fixing an abstract idea or concept in the mind. Metaphors connect the new idea and context with concrete examples from previous experience, opening the door to understanding or to a new view of a problem. Metaphors and concepts, however, do not by themselves provide sufficient information to make design or investment decisions. To move beyond metaphor, we must also create useful models of the problem and concept in order to generate more detailed understanding of the dynamics of a new concept or process across many different contexts. We will use classic operations research models of naval warfare as well as models used in other areas of analysis (but nonetheless applicable to the general problem of high speed warfare in an anti-access environment) to move beyond metaphor and generate higher quality decision support. In this effort, some of the models will yield quantitative information; others will only yield logically derived qualitative or descriptive insights.

General Metaphors

Car Races: NASCAR/Formula 1/Drag

A general metaphor that is useful in thinking about the relevance of speed in different operational contexts can be found in the various forms of automobile racing: Drag, Formula 1, and NASCAR. Generally corresponding to tactical engagements, Drag Racing is about individual unit speed, from reaction time out of the gate to raw horsepower that gets competitors to the ¼ mile mark the fastest. The set of requisite competencies is relatively narrow and tie breakers for success are very clear and unambiguous. Contrast Drag Racing (tactical) with Grand Prix/Formula 1 racing, a form roughly analogous to the operational level of war. The interplay of factors is much more complex, requiring careful management of time (pit stop length) resources (fuel, tires, brakes) and risk (when to take a pit stop and what resources to replace), not to mention the much larger skill set required of the driver. That said, the end state is much the same: complete the course in the shortest time.[4] NASCAR racing provides yet another metaphor, one more relevant to strategic levels of competition. Though individual NASCAR races are won on the basis of speed, success in the overall NASCAR season is predicated on judicial use of resources, timing and risk in the context of each race as well as in the larger context of the annual scoring competition for NASCAR Racing Teams. Rules on mechanical configurations and capabilities of the vehicles are tightly constrained, resulting in the formation of draft lines, which become the major dynamic within which competition occurs on the track. In the NASCAR draft lines, alliances form and dissolve, cooperation and competition coexist with each driver competing to finish first (at least some of the time) and working to stay near the top (always).[5]

Industrial Age Speed vs. Information Age Speed

The metaphor of car races provides an interesting perspective on differences between classic Industrial Age Warfare and emerging Information Age Warfare. Success in Industrial Age Warfare was predicated on moving massed forces as fast as possible toward the objective, usually in single service or very limited joint capability packages and in the context of a well defined, understood and slowly changing enemy. In emerging Information Age competition, the initial focus has been much more on achieving order of magnitude increases in performance by tying together joint force packages with improved combat processes in a more systemic way than previously possible. Consequent to this focus on 'warfare as a system', issues such as properly identifying and articulating the warfighting goal, keeping options open for unexpected contingencies and guiding (rather than directing) forces have come to the fore as much more important than before. This systemic change in warfare is percolating up to the strategic level, causing changes in the dynamics of international competition. The parallels with automobile racing are obvious.

Industrial Age Warfare, though characterized at the tactical and operational level by constants of fog and friction, usually took place in the context of well-defined objectives, clearly discernable enemies and threats and a relatively isolated context (the battle field, generally free of third parties). As the Information Age unfolds, the constants of fog and friction still exist, but with much different character, and dynamics (and if we could measure them, probably greater magnitudes as well). Warfare in the Information Age appears to be much more about leveraging understanding to make better decisions faster – getting the right solution as fast as possible rather than identifying a solution, then executing as fast as possible. Getting the right solution as fast as possible requires a different set of personal, organizational and institutional skills and attributes; skills and attributes that are focused on learning: gathering information, integrating it into consistent and coherent chunks relevant to resolving the problem at hand and maintaining robust feedback from the evolving competitive environment. These demands lead to the increased importance of collaboration and cooperation and the need to retain options (strategic, operational, tactical and technological). In many ways, these statements are timeless statements of obvious warfighting truths. However, Industrial Age concepts relied very heavily on technological, stove-piped solutions that were generally well crafted, practiced routinely and changed very slowly over time. This condition reduced pressure to collaborate, cooperate and required only a limited set of options. In sum, a (the) most critical issue regarding speed in littoral combat is understanding the dynamic interplay between improved decision making, faster decisions and faster physical capabilities of all types. Understanding the operational value of physical speed is a crucial first step.

Models (Analytic Approach)

The overall objective of this analysis is to provide information that will allow decision makers to make objective judgments of the *value of speed* as current operational requirements evolve and new operational requirements are discovered. Our work here will take a classic Morse & Kimball Operations Research approach. That is, "One must first see what is similar in operations…before it will be worthwhile seeing how they differ from each other. In order to make a start in so complex a subject, one must ruthlessly strip away details (which can be taken into account later), and arrive at a few broad, very approximate 'constants of the operation.' By studying the variations of these constants, one can then perhaps begin to see how to improve the operation…In our first study of any operation we are looking for these large factors of possible improvement. They can be discovered if the constants of the operation are given only to one significant figure…any greater accuracy simply adds unessential detail."[6] This approach should, if successful, show where the most benefit is to be gained from speed in a Littoral Combat Ship specifically and in littoral combat generally. Quantitative analysis will be limited to that useful at the tactical and operational levels of war (CSG/ESG/JTF Commander and below), as this is where the quantitative tools are most applicable and yield the most concrete insight. Quantitative methods form the core of our analysis. After presentation of quantitative results, however, we will also discuss more general issues that are not yet amenable to quantitative analysis, highlighting future directions for "speed analysis" that can have high impact on strategic investment decisions.

Definitions and Terms of Reference for Speed

Physical Speed

Precision in definition and terms is critical to clarity on this subject. Many concepts discuss speed, but only in general terms and frequently across warfighting domain boundaries. When discussing speed in warfighting domains other than the physical, issues regarding potential combat, operational advantage and even feasibility become very murky. For the purposes of this analysis we will consider two very broad classes of speed. The first, physical speed, is the rate at which platforms move through the battlespace and defined as distance, linear or angular, over time. Two other important quantities related to speed are velocity (speed with vector) and acceleration (rate of change of velocity). These terms are extremely important when discussing the value of speed in operational contexts. For example: speed is often cited as a valuable attribute for LCS-type ships because of its ability to enhance survivability in missile engagements. At first blush, this argument does not seem to carry much water because of the speed differential between and anti-ship cruise missile (mach) and the speed of the ship (~50 kt.). A simple look at limiting lines of approach (presented later in this paper) proves this point. However, further discussion with speed advocates reveals that it is maneuverability (turning rate) that they think has the ability to enhance survivability in a missile engagement, while classic AAW tactics tell us that it is chaff, decoys and separation in space from them that enhances survivability in a missile engagement—separation is enhanced by higher speed. With this as a context for thought, where should our analysis, aimed at understanding the operational utility of speed be focused? On detailed engineering and threat analysis? Or on more broad and general aspects of military competition in the context of speed? Our analysis will address attributes of speed that are above the level of detail requiring analysis of specific attributes of platform design and threat characteristics. As we noted earlier, the dynamic interplay between improved and faster decision making capability with physical speed is a crucial factor in gaining sustained competitive advantage in Information Age Warfare. This requirements demands analysis first of aggregate performance, specifically as speed relates to deployment, management, exploitation, refueling, repositioning replacing, recovery and redeployment (DMER5) of sensors and off-board vehicles. Following our quantitative analysis, we will highlight issues such as the arguments for and against speed in a qualitative sense (as in the evasions example) and make recommendations for areas where both further study and *experimentation* would be valuable.

In general, in our discussions, the technical difference between speed and velocity (directional component) will be immaterial. We are focusing on the “broad, approximate constants” of the problem and directional issues will generally be in the details of the abstractions.

Information and Cognitive Speed

The second class of speed, mutation and adaptation, is important to analyze if we are to gain an understanding of broader issues relating to multi-mission aspects of assured access and the LCS in the physical domain, such as modularity, mission profiles and Information and Cognitive Domain issues. We analogize these aspects of information and cognitive speed to scalar and vector speed in the physical aspects of operations. Mutation is analogous to distance: the ability to assemble capabilities in different ways or to alter the focus of operations. The countable number of differences in two capabilities or the countable number of different capabilities necessary for two operations is a measure of distance. Mutation capability is defined as the ability to swap either physical modules on individual platforms, individual platforms in a force package, crews or parts of crews on a platform or in a force package, teams or components on an operational commander’s staff or information and software components in the machinery of the force at large. We also consider the ability of personnel and teams to swap cognitive missions or functions (mine warfare to missile defense for example) as mutation. Mutation rate (speed) is the ability to mutate over time—how fast these swaps or conversions are conducted while still maintaining operational effectiveness. In summary, mutation rate is the time dimension of changing physical configurations of platforms and software programs as well as changes to the operational mission focus of individuals, crews, teams and staffs. It is a measurable quantity.

As an extension of the mutation and mutation rate concepts, we also view adaptation as mutation in the context of a problem or an adversary; it is the analog to the physical vector, velocity. This becomes a ‘sense and respond’ form of speed, widely applicable to all aspects of the force and to conceptions of its employment. Adaptation rate is the ability to adapt over time and is most effective when thinking about operational mission changes, strategic changes at higher levels of competition or other changes related to Information and Cognitive Domain issues.

Even more subtle sub-distinctions in the concepts of mutation and adaptation are variation and innovation. Variation is the rate at which existing capabilities are assembled in different ways. Innovation, in this context, is the rate at which new capabilities are developed and deployed. Both Variation and Innovation can occur at all levels of conflict and across all time scales of competition. These two concepts, as part of the concepts of mutation and adaptation for military forces and operations are rich and warrant more thoughtful exposition than this analysis calls for. We will only point out that variation requires investments in coordination, personalization or customization of information and workflow processes. This type of adaptation can tremendously enhance 'head-to-head' competitive advantage. Examples might include: instant messaging; self-service intelligence products, software 'bots' and operational force requirements integration with procurement systems. Adaptation can be measured by the number of different configurations of existing capabilities that can be assembled over time. Innovation requires a slightly different mindset, as it is defined as the rate at which new capabilities are developed and deployed. Generally, innovation requires investments in collaboration and knowledge management techniques and can result in economies of speed through adaptive innovation. Examples of the types of investments or activities in this form of adaptation might be: weapon expenditure pattern recognition, data mining and collaborative design of new TTPs. Innovation is measured by the number of completely new capabilities introduced (or capabilities made obsolete) over time.

Detailed discussion and assessment of these issues are beyond the scope of this analysis. However they are crucial next steps (or eventual steps) on the path toward full understanding of the dynamic interplay between improved decision making capability, faster decision making capability and faster physical capability.

Domains of Analysis with a Focus on Speed

Peace-Crisis-War

Speed is a characteristic that alters operational dynamics across the spectrum of conflict, from peace, through crisis response to the execution of war. The LCS and other Assured Access Forces must operate effectively across the spectrum of conflict. In peace, the ability to rapidly reconfigure and redeploy forces enhances operational efficiency. Speed can enable forces to interact with more coalition partners through bilateral and multilateral exercises as well as by conducting more port visits (and hence effecting more community interactions). This is a direct result of simply saving time over distance and of being able to arrive with a mission configuration suited to the coalition exercise or peacetime operation.

Speed in the transition from peace to crisis response provides operational commanders increased options in terms of time responsiveness. For example, increased transit speed and the attendant time responsiveness of an LCS can give a Combatant Commander or Operational Commander more time to remain engaged in one area before having to disengage to respond to a crisis, potentially enhancing aggregate engagement at the theater level, while giving diplomacy or other methods of response more time to work at the point of crisis. Roughly the same trades exist in the transition from crisis to war vis-à-vis speed. The ability to move forces quickly from one location to another allows for faster response as uncertain information conditions become more certain over time.

Strategic – Operational –Tactical

At the strategic level, speed is important because it is a fundamental driver for force posture and, derivatively, force structure. Decision time lines for crisis response are critically determined by the size of force that must be moved and how fast that force can move. Generally, lighter forces can move faster than heavier or more numerous forces. If technology can improve the movement of forces so that heavier forces can be moved faster as well as be delivered in a complete package then response timelines can be more flexible. Again, as with the peace to crisis transition, speed can provide national and theater leadership with valuable time to ensure all possible non-force options are given the opportunity to succeed. At the core, the strategic value of speed is at the heart of much transformation effort and debate, especially in the Army and Air Force.

At the operational level, speed provides the CSG/ESG/JTF Commander maneuver options and a more responsive force. For naval commanders, since the CSG/ESG is increasingly expected to operate and fight in the ocean littorals, operational speed provides an ability to match the complexity and scale of the force with the complexity and scale of the environment and operational problems likely to be encountered.[7] Sources of complexity and uncertainty in the littorals include shipping and air traffic lanes, highly variable atmospheric and oceanographic conditions, and more numerous enemy and neutral platforms. In the context of operational uncertainty and uncertain threat vectors, operational options and maneuver provided by both physical speed and adaptation speed increase chances for success. A greater variety of both types of speeds helps an Assured Access force cope with this complex littoral battlespace.

At the tactical level – the point of engagement with the enemy – speed generally confers great advantage in both offense and defense. Speed for maneuver can help ground forces position fires more rapidly or exploit the effects of fires before opportunity passes. In aviation, speed for evasion can enhance survivability in a missile engagement or air to air combat engagement. In submarine engagements, speed in combination with tactical positioning is the difference between life and death of the platform and crew. In surface combat, where missile engagements happen at mach speeds, information and cognitive speed are the breath of life. At the tactical level, the ability to get a weapon on an emergent target quickly can have operational or even strategic impact.

Physical-Information-Cognitive

Information Age Warfare is best understood by cognitively ‘chunking’ its fundamental aspects into the three domains that best capture the large scale differences caused by information dynamics in military operations: Physical Domain, Information Domain and Cognitive Domain.

Physical Domain

The Physical Domain represents the tangible physical world, the world of ships, submarines, missiles, aircraft, people, computers, satellites and the physical media they move in and that transmit information. In this domain, speed is important because of the rate of interaction of the physical entities with each other and with the Cognitive Domain (especially of the enemy). Physical Domain speed is also mostly relevant to the tactical and operational levels of war, though it can (and often does) have some impact at the strategic level.

Information Domain

Information is the formal method by which humans encode abstractions of the environment (Physical Domain) in order to collaborate effectively and to survive in the Physical Domain. Therefore the Information Domain intersects (and connects) the Physical and Cognitive Domains. The most relevant intersection in the context of warfare is in the information gathering, processing, storage and transport aspects of the Physical Domain. The Information Domain intersects with the Cognitive Domain, by the process of decoding information into meaningful chunks via abstraction, induction, deduction, abduction, pattern matching, etc., and placing information in context for cognitive processing and action. We note here that there are significant non-technological (but still scientific and technical) aspects to information. The most obvious of these technical aspects in a warfighting environment is face-to-face communication and interaction, which consists of large amounts of non-verbal information transfer. Many of these forms of communication are not yet well understood either in a quantitative manner or a commonly accepted qualitative manner. As a separate note, it is important to understand that the ability of technology to transcend the tyranny of face-to-face interactions is still very limited and ultimate limits are largely unknown, though there are some leading edge scientists and technology companies working very hard to enhance the sight, sound, smell and taste (non-verbal) aspects of communication over remote distances.

In a networked battle force relying on long distance information interactions to enhance combat power and operational effectiveness, the Information Domain becomes the critical domain of warfare. The Information Domain is where the connection between the mind (Cognitive Domain) of the commander and the minds (Cognitive Domain) of his tactical agents, the other warfighters and operators under command, is made. Therefore, the issue of speed in the Information Domain is really one of speed in the Cognitive Domain. Information travels at a fixed speed. Since all action in the world happens in the physical domain yet is driven by decisions made in the minds of humans, it is the ability of people to assimilate information for success in combat.

As a related issue to cognitive limitations on speed, the amount of information necessary to make a decision can be highly variable. Even though information moves very quickly, the volume of information necessary for making a decision coupled with certain limitations on information transfer through the environment can make the ‘apparent speed’ of information quite slow. These aspects of the Information Domain and speed have impacts across the spectrum of conflict and at all levels of competition.

Cognitive Domain

The Cognitive Domain, referenced above, is, more specifically, the domain of the human mind and brain. It represents the collective set of mental models, knowledge, experience and beliefs in an individual’s mind. It can also be represented in a collective sense, by the aggregation of a group’s behaviors, though this is an area of open research. Using our definitions of Physical and Information Domains, collective cognition is intimately tied to connections between individual minds that are made via the Information Domain and acted upon in the Physical Domain. A detailed discussion of this aspect, other than some general observations regarding relationships to speed in combat, is beyond the scope of this paper.

Connections and Dynamics across Domains

In the peace-crisis-war context of analysis, speed plays a factor in engagement and presence during peacetime operations. For a given level of forward presence, average transit speed determines aggregate force structure. In an operational sense, for forward deployed forces, speed is directly related to crisis response within and across theaters. Examples of this utility abound, specifically in the 1990s – aircraft carriers routinely shuttled between the Eastern Mediterranean and the Persian Gulf in response to crisis developments. The ability to conduct these operations at high speeds and without refueling proved of high utility to commanders both operationally and strategically. In the transition to war, again, speed is critical by providing options to the commander in the placement and maneuver of forces in order to shape the battle space.

In the strategic-operational-tactical context, raw physical speed is most useful at the tactical level of combat and operations. It provides wider area coverage per unit of force, opportunity for evasion (enhanced survival) and massing of forces (especially in an information rich, networked force, where mission orders, vice directive orders, can allow many forces to rapidly ‘connect’ to the enemy forces of interest as they become visible). Operationally, physical speed gives the commander the opportunity for multiple options by providing flexibility in time response that does not exist otherwise. A commander can keep forces committed to one part of the battle space longer before having to make recommit decisions, allowing better aggregate risk management than otherwise possible. If speed can provide the ability to conduct Assured Access operations faster, our ability to respond to emerging conditions as well as drive battlespace conditions (for example offensive operations can begin sooner), shortening the enemy’s window to adapt or prepare. At the strategic level, physical speed allows national authorities to reposition forces or delay commitment decisions, just as at the operational level. Cognitive speed or mission reconfiguration speed also provides the strategic commander more flexibility, as the chances that the forces on scene can respond effectively to unknown contingencies increases.

Across domains, there are clear implications for the impact of speed on strategic and operational decisions during peacetime operations as well as in times of crisis. As the threshold to war is crossed, the value of speed becomes critical across the levels of war. In a tactical sense, having the option for speed of maneuver confers advantages in terms of evasion, which enhances survivability of forces. In the operational sense, speed gives the Theater Commander a force that is more responsive to battlespace dynamics. Forces can be moved faster; more options for the employment and positioning of forces are opened as the force, individually and in aggregate, can move ‘faster’. At the strategic level, a faster force allows more options to national leadership. This discussion only focuses on the physical manifestation of speed, however. The value of exercising the option to use high speed forces is intimately connected to the context of the problem and its time evolution, especially the information and cognitive aspects of it, not only from the perspective of the enemy but also from multiple third parties that might be connected or have an interest.

Speed in a Distributed, Networked Force: Exploitation of Options and DMER5

Network/Networked Dynamics: Operational Implications of a Networked Force[8]

Beyond discrete, well-understood tactical engagement scenarios that do not require further analysis here, most of the advantages of speed (physical and adaptation speed) accrue to the operational level of war. There are, of course, tactical level issues that will be explored such as detection probabilities and sensor field maintenance requirements, but these will be analyzed at a level more appropriate to the operational commander than the tactical one. In the aggregate, the impacts of speed in naval combat are those of enabling other combat operations and options for commanders. The ability to complete access operations quickly enables power projection forces and ground forces to enter and engage the enemy without pause.

As discussed in Part 1, speed advantage manifests itself in two ways. The first, tactical advantage, is largely a result of physical speed, distance over time, which, for example, translates to faster transit, faster repositioning and improved self defense. The second, speed in reconfiguration and responsiveness of combat power to emerging actions of an adversary, is an advantage that accrues generally to the operational and strategic levels of war. Reconfiguration and responsiveness of combat power are enabled by three major attributes: physical speed (movement of forces: platforms, sensors, weapons), distribution and dispersion of combat power. *Distribution and dispersion of combat power, coupled with physical speed are, in turn, enabled by the ability to network the combat force.* Detailed analysis supporting this point will not be presented here, but is available in the compendium of work conducted by the CNO's Strategic Studies Group between 1997 and 1999, as well as by similar studies from the Naval Postgraduate School.[9]

The ability to network[10] the combat force enables force structure designers, engineers and programmers to build a force that can sever combat power from the physical confines of a ship or platform hull. The logical argument is: networking, coupled with computer processing power and information storage and transport capability enables unmanned vehicles to be deployed to the battlespace carrying sensors and weapons. These vehicles can be controlled either remotely or have autonomous control and can transmit their data to or have data transferred to them via the combat network. By disaggregating combat power from traditional manned platform configurations in this way, the enemy is presented with a force that is more numerous as well as more survivable and more maneuverable. These advantages accrue as a result of reconfigurability (adaptability) when presented with emergent problems or situations. The ability to reconfigure the force is an explicit and general property of networks and is the motivating force behind the drive toward network-centric concepts of operations and combat.[11]

As a simple thought experiment, assume that some percentage of sensors and weapons are moved to off-board vehicles and that each vehicle and every major manned platform can be connected to the off-board vehicles. The enemy, to gain requisite advantage, now has to find, fix, track, target and engage not only the large manned platforms, but also the unmanned, off board vehicles, each of which can be commanded by any one of the manned platforms. This multiplies the enemy's battle problem at one level by the number of sensor and weapon packages remoted from manned platforms. Viewed another way, the enemy's combat problem gets combinatorically harder as more and more combat power is disaggregated and then distributed and networked throughout the battlespace – the number of different combinations the enemy must account for is exponentially related to the number of entities in the network.[12] If the enemy chooses to target the manned platforms that either host or control the unmanned vehicles and is successful, the unmanned vehicles can simply be controlled and re-hosted to undamaged manned platforms. If the enemy chooses a non-lethal mode of attack (jamming communications networks) the force can simply operate more compactly (reducing distances between nodes) in order to mitigate the effects of the jamming. If the enemy chooses instead to target the individual nodes, it has a voluminous problem to tackle.

Offensively and at the operational level of command, a force of highly mobile units that is many places at once and that can host and exploit the information gathered from off-board vehicles is more responsive to crises than one with its combat power tied to hulls. A dispersed and networked force can also be engaged in peacetime many places at once. For example, with in-situ situational awareness in more places, the commander has more options regarding where to engage the larger, main, combat force on a day-to-day basis. If a crisis emerges at any location, off-board sensors or weapons can be dispatched to the location and either commanded remotely or operated autonomously and monitored remotely. A high-speed LCS platform can take command and host a force of off-board sensors much more responsively than the main combat force can move to the location. For example, an LCS that travels at 50 kt., a factor of 2.5 times the speed of the main body, can arrive 66 hours ahead of the main body in a 2000nm transit. An LCS close to the crisis location and the crisis only requires initial augment by sensor vehicles such as UAVs, which can travel up to 15 times faster than large platform surface ships or submarines.

Additionally, by building a force that can rely on smaller more dispersed units capable of higher speed operations and off board sensing capabilities, the operational reach, responsiveness and situational awareness of the total force is enhanced. With a more numerous force that is deployable, peacetime engagement operations can be conducted in more places and, augmented by unmanned vehicles, surveillance and reconnaissance operations can be conducted over a wider area than previously possible. In addition, a force that has a larger number of possible combinations of components for building combat mission packages both complicates the enemy's combat problem as well as increasing options and the likelihood of a favorable asymmetry for our forces. A chart depicting the general relationships among platform types, highlighting some of the critical parameters that give rise to asymmetries (as well as Information, as a type) is shown in Table 1.

	Air	**Surface**	**Submarine**	**Information**	**Space**	**Unmanned Vehicles**
Number of Targets	**10-100s**	**1s-10s**	**1s**	**1000s**	**1s**	**100s-1000s**
Speed	**100s**	**10s**	**10s**	**100000s**	**1000s**	**10s-100s**
Detection Mode	**EM/RF/EO**	**EM/RF/EO**	**Acoustic**	**Electronic**	**EM/RF/EO**	**Acoustic/EM/ EO/RF**
Decision Time	**Sec**	**Mins**	**Mins-Hours**	**Secs-Days**	**Hours-Days**	**Secs-Months**

Table 1

Generalized Scenario and Parameters for Analysis

The introduction discussed the many dimensions and levels of analysis where speed matters. Our main discussion and analysis, however, will be focused on the operational level (CSG/ESG Commander). Our parametric choices are driven exclusively by this commander's perceived needs.

Generally, the first order of business for the basis of decisions on a new platform design is performance at the tactical level of combat.[13] Our analysis will concentrate on broad tactical level issues that are tied to operational level advantage in combat and operations. This analysis does not include tactical engagement analysis, but instead looks at aspects of speed that relate to advantage for the operational commander:

- Crisis responsiveness (operational and strategic mobility)
- Advantage of speed for both CONUS and intra-theater surge operations of assured access forces
- Theater or area situational awareness

- ❑ Utility of off-board sensor fields in gaining and maintaining situational awareness

- ❑ DMER5 of off-board sensors and their relationship to speed and numbers

Geographically, our area of concern is a 400 nm x 400 nm area in the littoral. While this is much smaller than the area envisioned by some concepts (which can range up to 1240 nm x 1240 nm), it is commensurate with a CSG/ESG Commander's force size and consistent with the area used in other advanced concept generation, gaming and validation work.[14]

LCS-type Ships and Payloads

Current, open source discussion on attributes of LCS-type ships include transoceanic capability, sustained speeds of about 50 kt. and the capability to host off-board unmanned surface and undersea vehicles and manned and unmanned air vehicles in undetermined numbers.[15] For our analysis, we will consider a range of speeds from 3-10 times current sustained high speeds for surface ships. Specifically we will examine speeds as high as to 300kt.[16] While even the most advanced high speed shipping concepts only envision a 100kt. capability by 2010[17], the potential operational impact of 300kt. speed capability and the consideration of wing-in-ground technology must be considered. In addition, from an operational perspective, understanding when aircraft-like speeds become more valuable than ship-like speeds is important. For our purposes, the LCS will be considered to be capable of hosting (Deployment, Management, Exploitation, Refueling, Repositioning, Recovery, Replacement, Redeployment-DMER5) 30 total vehicles of various mixes by type of unmanned vehicle (surface, undersea, and air), a relatively small number of vehicles by the standards of most advanced operational concepts.[18] The LCS will have C2 capability to act as an operational information node in the larger combat and operational network.

DMER5 Context

Our basic scenario has two general parts. The first is a surge deployment either intra-theater (already forward deployed) or from CONUS to a crisis area. The second is an area sensor field deployment and maintenance phase (building total force situational awareness in pre-conflict operations). Our scenario will require the LCS to deploy and maintain a sensor field of either stationary sensors or sensors deployed on unmanned vehicles and then maintain the sensor field deploying additional, repositioning, replacing, refueling, recovering and/or redeploying existing sensors and unmanned vehicles.

Our geographic area for consideration in all cases is a 160,000 sq nm area in the littoral, notionally a square 400 nm on a side. This area was chosen because it is more challenging than a simple 100 x 100 nm box (10,000 sq. nm.) and much more manageable than the area used for analysis of the Navy Warfare Development Command (NWDC) Pervasive Expeditionary Sensor Grid, which is 1240 nm x 1240 nm (~1.5million sq nm). The larger area is not one that a force of LCS the size usually presented in concept documents will be able to manage credibly. 160,000 sq. nm. is also roughly the size used in past analysis for a wide variety of operational level of war scenarios, including those at the CNO's Strategic Studies Group (FORCEnet analysis in SSG XVII-XIX) and at NWDC (Capabilities of the Navy After Next analysis).

Our analysis of the second phase will start with a simple problem consisting of two basic tasks: (1) finding a single target of interest in this 400 nm x 400 nm area and (2) maintaining it free (or maintaining situational awareness of the target) for the duration of a 90-day contingency. The essential questions for the analysis are:

- Were LCS to sprint ahead of the main CSG/ESG force, how much speed advantage is necessary to prepare the littoral battlespace for assured access of the main force upon its arrival in the Area of Interest (AOI)?
- How long would it take a single platform to conduct these two tasks?
- How long would it take multiple platforms to conduct these two tasks?
- How sensitive are these times to platform speed?
- What numbers of platforms are required to conduct these two tasks to a specified degree of accuracy a P_{det} of 0.9 for various time constraints, but specifically the time constraint defined by CSG/ESG arrival?

Consequent questions from these initial ones might be[19]:

- In a notional 90-day campaign, what fraction of time might be spent in each speed range (slow speed loitering, high speed DMR5 operations, high speed combat operations and high speed deployment operations)?
- How dependent are the factors above on a specific mission profile? (and vice-versa)
- How sensitive are these times to detection ranges?

General Logical Flow of the Analysis

We will look at a 'baseline' case, grounded in current conceptions of how LCS-type ships will operate with CSG/ESG battle forces. We will look at LCS ships surging ahead of the CSG/ESG (Main Body) force with the objective of arriving ahead in enough time to establish a sensor field and prepare the operating area from an access standpoint. Based on current NAVSEA and NWDC concept and RFP briefings, this baseline case is 3 LCSs operating with a maximum speed of 50kt. and with 2-3 each unmanned air-, surface- and undersea- vehicles. Though technological advancement, experimentation, and wargaming may show these numbers to be low, the current concepts and experimentation efforts are within these boundaries. We will then conduct a sensitivity analysis for speed, numbers and mix of LCS and off-board vehicles. We will highlight some broad issues and tradeoffs that come through from this analysis--What (Where) is the point in the speed calculus that changes operational decisions and, hence, requirements and engineering decisions? For example: From a strategic perspective, where do LCS ships need to be forward deployed and where can they remain attached to the CSG/ESGs? What might be the tradeoff in numbers of LCS ships or in payload capacity of LCS ships in order to get the assured access mission accomplished in time for a surging Main Body arrival at the operation area? What if the size of the area or the endurance of the senor field changes? Can a 50kt. ship perform the task? Many people say that a 80-100 kt. capability is too expensive and not worth the added expense and technologigal difficulty when compared to a 50 kt. ship. Until the operational dynamics are explored these questions cannot be knowledgeably commented upon.

Our objective will be to show the dependence of performance of a relatively simple warfighting task on the parameters of speed and time. Thus, in our scenario LCS will surge forward from CONUS ahead of the Main Body, leaving port on the same day. The objective will be to clear a 400 x 400 NM box of a single threat platform (a surface swarm squadron and/or a diesel submarine and or a single mine field).

The general mission profile will be surge-transit-clear-maintain. Much of the DMER5 analysis will be related to the ‘clear-maintain’ (DMR5) portions of the timeline. Although it is recognized that a key reason fro DMER5 is, I n fact, the exploitation of data, and that the depth and breadth of exploitation will be a significant driver in the application of DMR5 tasks, exploitation is essentially an Information Domain and Cognitive Domain function. The analytical state of the art today places rigorous quantitative analysis beyond the scope of this study, so we will not address it except in a tangential and qualitative manner. We will also provide analysis of the relationship of speed to survivability from the perspective of evasion in the face of a threat.

There is a desire to understand better the ‘deployment-employment’ cycle for LCS as it relates to speed. *Our core analysis will show that, for the following assumptions:*

1. *50 kt. LCS;*
2. *3 ship squadrons operating attached to a CSG/ESG;*
3. *Surging ahead of the CSG/ESG to complete Assured Access operations prior to arrival of Power Projection forces;*

that

1. *LCsS must operate at maximum speed for the entire scenario (unless they carries at least double digit numbers of unmanned vehicles/sensors);*
2. *it requires warning time in almost all cases—implying that it must operate forward, independent of the CSG/ESG, even for intra-theater scenarios*.

[**or this wording]:**There is a desire to understand better the 'deployment-employment' cycle for LCS as it relates to speed. *Our core analysis will show that, for generally accepted/stated requirements for LCS, it:*

3. *must operate at maximum speed for the entire scenario;*
4. *requires warning time in almost all cases*

In other words, the Navy's current requirements are extremely stressing on the platform and crew. Alleviation of this stress will only be found in operational posture and employment policies and Assured Access area clearance limitations. If more operational slack (options) is (are) desired, then more ships, higher sprint speeds. For example, if we want the LCS to operate at slow speeds more often, then either more of them will be required, burst speed will have to be higher, more unmanned vehicles will have to be deployed, or unmanned vehicle/sensor endurance will have to be increased (or some combination thereof). *The trade-space for this analysis is highly complex and explicitly dependent on entering assumptions.* We have included charts based on the analysis space as Appendix A so that as questions arise, requirements evolve or different operational scenarios are defined, the impact on LCS design parameters can be assessed quickly.

Models

Analytical basis for quantitative results is based on *Search and Screening*, by B. O. Koopman, standard, simplified, queuing analysis as is found in *Operations Research: Applications and Algorithms*, by Wayne L. Winston and time-distance-speed arithmetic for forward deployment.

Koopman Search[20]

Since a significant part of DMER5 operations is search for threats, the majority of our analysis will be to highlight the trade-offs of various speed and payload options for this function. Our approach to search will be to characterize the perfect and random search problem in terms of speed (and by proxy, time) as the variable of interest. To illustrate the broad trade space choices, we will assume extreme best case and worst case for the simplest search problem, that of finding a single target:

- ❑ Our standard of detection will be 90% (with sensitivity analysis at 0.8, 0.95) for the non-‘perfect’ search
- ❑ Our problem will be to find only one target
- ❑ No preexisting knowledge of the target’s location
- ❑ Perfect detection probability out to specified detection range
- ❑ A random search and a ‘perfect’ search of the area.

The detailed proof of the search equations below can be found in as detailed in Chapter 3 of *Search and Screening*.[21]

The ‘perfect’ search follows a standard, regular coverage of the battlespace with no overlap and a detection range (in our case 5nm, exactly, for a surface target). Assume that detection range is ‘r’, which gives a sweep width along either side of the searcher track of W=2r. The searcher, traveling at velocity *v* sweeps out an area equal to

$$A_{sweep}=W^{*}vt$$

as it searches for the target. If the search is perfect, swept areas do not overlap, the target does not move significantly for the duration of the search and detection is assured if the swept area crosses over the target location. The search is completed when the total swept area equals the estimated threat area. These are extreme assumptions, but the ‘best’ one for our purposes of defining the ‘perfect’ search. Therefore, the ‘perfect’ search is completed when the swept area, A_{sweep}, equals the search area, A:

$$A= W^{*}vt$$

For multiple platforms searching the area:

$$A=nWvt$$

(where n = number of searchers)

We can use this formula to calculate the time necessary to conduct the perfect search of our 400x400 nm. area for various search speed and number of searcher combinations or, alternately the speed necessary to conduct a perfect search in a specified period of time. If $A_{sweep}/A<1.0$, the perfect sweep cannot cover the full area. If $A_{sweep}/A>1.0$, there are surplus search assets. Operationally, this equation tells us how fast our search must be to have an area cleared by a certain time – it tells us how far ahead of the Main Body an LCS or LCS squadron must be in order to have a ‘prepared’ battlespace upon arrival.

Equivalently, it also provides us the number of sensors or UVs required as payload for LCSs.

For the hardest (or most complex) search, we will use Koopman's random search formula

$$P_{det}=1-e^{-Wvt/A}$$

The derivation from *Search and Screening* is reproduced below:

Assumptions:

- ☐ The target's position uniformly distributed in A
- ☐ The observer's path is random in A in the sense that it can be thought of as having its different (not too near) portions placed independently of one another in A
- ☐ On any portion of the path that is small relative to the total length of path but decidedly larger than the range of possible detections, the observer always detects the target within the lateral range W/2 on either side of the path and never beyond.

To prove this, suppose that the observer's path L is divided into n equal portions of length L/n. If n is large enough that most of the pieces are randomly related to any particular one, the chance of failing to detect during the whole path L is the product of the chance that detection will fail during motion along each piece. If, further, L/n is such that most of the pieces of this length are practically straight and considerably longer than the range of detection, then…the chance of detection is the probability that the target will be in the area swept [as noted above] and this probability is WL/nA. Hence the chance that along all of L there will be no detection is $(1-WL/nA)^n$ and hence:

$$p=1-(1-WL/nA)^n$$

$$=1-e^{-WL/A} \text{ for large } n.\text{”}$$[22]

Figure 1 depicts this type of search:[23]

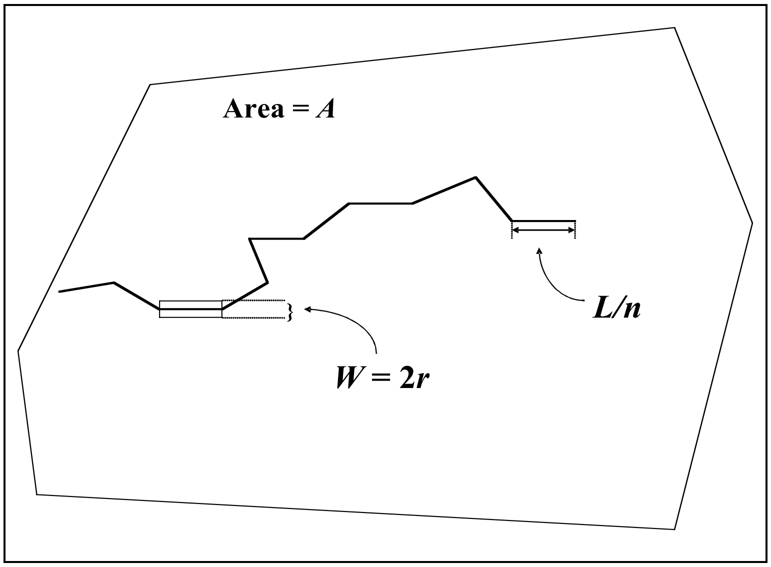


Figure 1.

As a final note, to contrast the perfect search with the random search, and to address potential questions regarding the simplicity of these two alternatives, a graphical depiction of these two searches is given in Figure 2 below. Many of our searches begin with cueing or other types of intelligence information that allow us to more efficiently utilize our search assets. However, no search can be more efficient than a perfect search and none can be more inefficient than the random search. Therefore, graphically, all other more sophisticated search methods must fall between the two extremes of Figure 2.

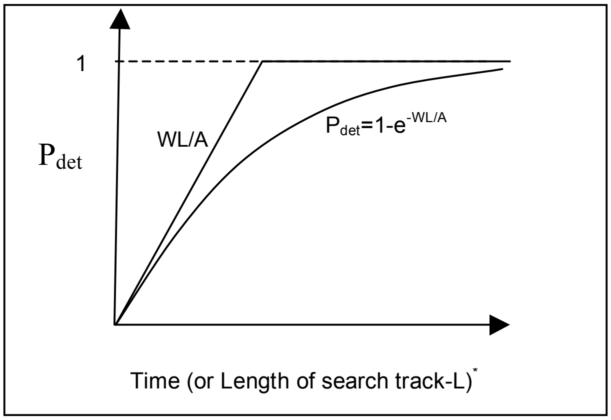


Figure 2

Queuing Analysis

For DMER5 (Deployment, Management, Exploitation, Refueling, Repositioning, Recovery, Replacement, Redeployment) operations of sensors and off board

(UV) systems, our operational goal will be to maintain a sensor or UV field with no gaps in coverage. This section of the analysis will use standard queuing theory at the boundary condition of no 'customers' waiting in queue. We will connect the search theory results with the queuing model for sustainment of sensor or UV 'fields', including the time for the field to be deployed. Our purpose here is two fold: first to keep the analysis independent of highly context dependent employment details for sensors and UVs. Factors such as sea state, sound propagation, white shipping, sensor capabilities, etc., are *not* factors in this analysis. We have chosen a very simple scenario that can easily be recalculated for different numbers and densities. Second, this method illustrates the most stressful case and how speed factors into operational requirements for LCS.

Our method:

The service rate (μ), the frequency at which the LCS will have to reposition to maintain the field, is simply the inverse of service time (t_s) plus transit time (t_t):

$$\mu = 1/(t_s+t_t)$$

The demand rate (λ), the rate at which nodes must be serviced is determined by the size of the field (N) and the endurance (t_e) of the nodes:

$$\lambda = N/t_e$$

The minimum number of LCS required to maintain the field without gaps in coverage (i.e., a sensor going dead or a UV remaining dead in the water) is therefore:

$$\#LCS = \lambda/\mu$$

For example, let's assume the following for a sensor/UV field of 400x400nm:

$t_e = 24$ hours
N = 80
$t_s = .5$ hr
Sensor spacing= 50nm
LCS transit speed= 50kt.
By time distance calculation:
$t_t = 1$hr
For each node, service time is:
$t_s + t_t = 1.5$hr, giving a service rate of:

μ=0.667 hour

In words, it takes an LCS one hour to transit from node to node and 0.5 hr to service the node before moving on to the next node. The field demands service 3.3 times per hour:

$\lambda = 80/24$
$= 3.33$

To perfectly match demand to service:

$LCS = \lambda/\mu$
$= 3.33/.667$
$= 4.99$ (or 5)[24]

So, five LCS platforms are required to maintain an immobile sensor field of 80 nodes in a 400x400 nm area, once it is in place

We will look at the number of LCS required for two basic conditions:

- ☐ to maintain a fixed number of senor or UV nodes in the area varying sensor/UV endurance
- ☐ to maintain a field of fixed sensor or UV density.

We will build this part of the analysis as a continuation of the surge ahead of CSG/ESG and deploy the sensors/UVs analysis. Since we are assuming a random search if the sensors are mobile, the servicing requirements for the mobile field are identical to the service requirements for a stationary sensor field.

Surge Deployment Analysis

For the NWDC Assured Access scenario, the operational concept envisions the LCS squadron surging ahead of the Main Body (CSG/ESG) in order to conduct operations that will ensure access to the area of interest upon arrival of the main body for the purposes of combat operations (power projection). To better understand the utility of LCS speed capabilities in this context, we will connect the search problem with the arrival of the LCS squadron in advance of the main body of the force. If the time required to search the battlespace equals the time it takes for the main body to arrive behind the LCS squadron, then the main body can commence offensive operations immediately upon arrival. If the search time is longer than the surge-ahead time, then the Main Body must assume a more defensive posture, limiting the amount of combat potential that can be applied to the enemy force. If search time is less than the surge-ahead time, then the Commander has operational flexibility in the employment and deployment of the LCS squadron. The value of interest in this analysis is when search and surge-ahead times are equal. For this we will calculate the LCS speed necessary to search the area and equate it with the LCS speed differential with the Main Body CSG/ESG.

First, how far ahead of the Main Body does a sprinting LCS arrive in a forward theater? Table 2 gives general geographic distances to Pacific, European and Persian Gulf theaters of operation. Also listed are two intra-theater distances, 1000 nm and 2000 nm so that we can generate information about forward deployed surge ahead operations.

Deployment Distances	NM
US East Coast to Med Sea	4300
US East Coast to PG	8400
US West Coast to Korea	5300
US West Coast to PG	11000
Hawaii to Korea	3200
Hawaii to PG	8900
Intra-theater A	1000
Intra-theater B	2000

Table 2[25]

The calculation of surge-ahead time is a very straightforward time-distance equation:

$$t_{surge}= D*(1/V_{CSG/ESG}-1/V_{LCS})$$

Surge ahead times are presented in Table 3 for LCS transit at 50 kt. and 100 kt., assuming a CSG/ESG surge speed of 20 kt.

LCS Days Ahead Arrival in Theater	50 kt.	100 kt.	Time delta (50 v. 100)
US East Coast to Med Sea	5.4	7.2	1.8
US East Coast to PG	10.5	14.0	3.5
US West Coast to Korea	6.6	8.8	2.2
US West Coast to PG	13.8	18.3	4.5
Hawaii to Korea	4.0	5.3	1.3
Hawaii to PG	11.1	14.8	3.7
Intratheater-1	1.3	1.7	0.4
Intratheater-2	2.5	3.3	0.8

Table 3

To equate surge time to search time, we must solve the Random Search Equation for time:

$$P_{det}=1-e^{-NWL/A}$$

Since length of search track, L, is simply:

$$L= v_{LCS}*t$$

Then,

$$P_{det}=1-e^{-NWvt/A}$$

Which, solving for time, results in the following relationship:

$$t_{search} = -(A/NWv_{LCS})*\ln(1-P_{det})$$

Equating t_{search} with t_{surge}:

$$-(A/NWv_{LCS})*\ln(1-P_{det})= D*(1/v_{CSG/ESG}-1/v_{LCS})$$

The LCS speed required to achieve sufficient lead time in order to search the Area of interest is:

$$v_{LCS}= v_{CSG}\ [1- (A*\ln(1- P_{det})/D*N*W)]$$

We call this value "Power Projection Lead Speed" (PPLS): the speed necessary for the LCS squadron to surge ahead of the Main Power Projection force so that it can complete access operations in time for the MPP force to commence operations upon arrival in the AOI.

Alternatively, expressed as time:

$$t_{PPLT}=[D*A*\ln(1- P_{det})/v_{csg-esg}]*(1/(N*W*D*v_{csg-esg}+A*\ln(1- P_{det}))$$

gives Power Projection Lead Time (PPLT)

Evasion Analysis

We address evasion only generally. Speed advantage in evasion is very complex, especially when dealing with high speed missiles (multi-mach). However, in general, for speeds commensurate with LCS speeds, and for problems of search, the area of uncertainty for an enemy following any interaction with an LCS or squadron of LCS is proportional to the square of the velocity. This is rather intuitive. If the enemy engages LCS and then loses contact through LCS evasion, the area the LCS could possibly be in is given by:

$$A=\pi*r^2$$

Since

$$R = (v_{LCS}*t_{evade})$$

$$A=\pi*(v_{LCS}*t_{evade})^2$$

Therefore, if speed doubles, the area of enemy uncertainty increases by a factor of 4. This analysis was one aspect of Navy's analysis in defense of Aircraft Carrier force structure during the 2001 Quadrennial Defense Review.[26]

In terms of evasion from weapons, traditional operational analysis uses the 'limiting lines of approach' (LLA) perspective presented in Koopman.[27] Without repeating the derivation here, we will present the equation for the angle that describes LLA and then a representative table showing the relationship between speed of LCS necessary to keep a searcher or weapon from closing to the ship:

$$\theta=\text{Arcsin}(v_{weapon} /v_{LCS})$$

A table of relationships is found in Table 4 for an assumed attacker at 20 kt. and at 70 kt. (swarming small boat attack). A more complete set of charts is provided in Appendix A.

v_{LCS}	$V_{attacker}$	θ	$V_{attacker}$	θ
20	20	90	70	n/a
50	20	23.5	70	n/a
80	20	14.5	70	61
110	20	10.4	70	39.5

Table 4

What is obvious from inspection is that current ships cannot evade small boat swarms using speed – there is no 'limiting line of approach'. If the tactical option of evasion through speed is to be retained, then the speed of the LCS must be commensurate with the speed of the threat, or else other options must be taken. This is a statement of the obvious, but can also become an avenue for discussing forms of tactical survival that have not received much attention. For example, the Navy currently focuses huge efforts on shooting down incoming missiles (AEGIS), with less emphasis (in decreasing order) on ECM, Close-in Weapons Systems and armor. Little discussion is had these days about advanced, lightweight, armor for enhancement of tactical survival and its operational level impacts and even less (and less rigorous) discussion is given to the tactical trades possible between speed and stealth, both of which are beyond the scope of this analysis.

Analytical Results

Our analytical results will start with the basic CSG/ESG-LCS relationship presented earlier. A squadron of 3 LCS will surge ahead of the main body and search a 400 nm x 400 nm AOI looking for a single surface target in order to achieve a probability of detection of 90%. We will look at whether a 50 kt. LCS will allow a search of the area in time for the main body to arrive, and then look at excursions in speed and in unmanned vehicles.

Baseline

Assuming the CSG/ESG surges from CONUS, can the LCS squadron arrive in theater in time? Table 3 provides the LCS advance arrival time. Using the equations presented in Part 4, we find that a squadron of 3 LCS, randomly searching a 160,000 nm. sq. area to a 90% probability of detection requires 10.4 days to complete the mission. If a perfect search is conducted, these three ships require 4.4 days to complete the task. This means that the only theater this type of operational scenario is effective is for a surge from CONUS to the Persian Gulf. In all other theaters the LCS squadron does not arrive in time for a random search to be completed. If our perfect search is possible, however, a surge from CONUS to any theater works (except for a surge from Hawaii to the Korean theater). Intra theater surges will not work—that is, surges from a forward deployed posture. In this case, the LCS squadron would probably need to be operated separately from the CSG/ESG so that it could be positioned close to potential crisis areas for quicker response. This also places a premium on continuously evaluated intelligence on potential crisis areas.

The results above tell us that, strategically, it will make sense to forward deploy LCS squadrons; that a surge from CONUS, in the context of a surge force posture, would not provide enough time for Assured Access Operations to be completed for the arrival of Power Projection Forces. Also note that we have only looked at the extremes of the simplest possible assured access scenario: a single surface threat. For a submerged threat, the search times will likely be much longer or will require many more sensors and off-board vehicles and the search much more problematic.

What if the LCS squadron could operate at 80 kt. vice the currently envisioned 50kt.? We find that the search time decreases by a factor of 0.62 to 6.5 days for random and to 2.8 days for the perfect search. This generates more flexibility in terms of the ‘tether’ for LCS operations in theaters with deployed CSG/ESGs as well as some strategic flexibility in the choice of forward deployment theaters.

Off-board Vehicles

As noted earlier, the current vision for LCS is for them to carry single digit numbers of off board vehicles and an undetermined number of off board sensors in a predetermined mix. Future concepts have LCS capable of carrying and maintaining more numerous off board vehicles. For our purposes we will assume that a single LCS can host a total of 10 off board vehicles and that they may be of any mixture. We will choose all unmanned surface vehicles. As before, our aim here is to look at the search of the AOI by these vehicles in the least demanding case (a single contact) to establish the boundaries of the problem.

When looking at the ability of off-board vehicles to search the area we will again reference the search equations in Part 3 and the charts in the Appendix which are derivative of them. We find that 30 unmanned surface vehicles, searching at 50kt. with a detection range of 5nm against a surface threat can complete the searches (random and perfect) in 24 hrs and 10.6 hrs, respectively. *This is a clear demonstration of the power of numbers to complete the assured access mission. The use of off-board vehicles can reduce the time required by a factor of 4-10.* It is also an indication that the numbers and mix of off-board vehicles for LCS should be robust (large).

Sensitivity analysis

What if the performance demands on LCS were relaxed? If the standard for clearance were only a P_{det} of 80%, the time for 3 LCS to search the AOI would drop to 7.3 days, a savings of about 72 hours, not enough to change the overall conclusions from the baseline. On the other side, increasing the P_{det} to 95%, increases 3 LCS search time by about 72 hours, effectively taking even the ‘surge to Persian Gulf’ option off the table.

Maintenance of Situational Awareness/Access

Once the AOI is cleared, we must continue the search to ensure our ability to track and if necessary prosecute new targets. How difficult is it to maintain 30 unmanned vehicles in continuous search? Referencing the queuing methodology from Part 3, we find that at 50kt. with a uniform distribution of 30 USVs in the AOI, 3 LCS can keep the USVs in service, if each requires service (R5) every 24 hours. If, however, the USVs require attention every 12 hours, 5 LCSs are necessary to maintain a ‘leak free’ search area. If we increase the endurance to 48 hours, only 1 LCS is required to maintain the USVs. This section of analysis tells us that an investment in USV endurance can buy flexibility in the employment of LCS platforms for other missions. For example, doubling USV endurance can free up 2 LCS platforms for operations other than USV maintenance.

Mission Profile

We have presented a limiting case in this analysis. The LCS, for purposes of the scenario presented here, has no mission profile, operating at 50kt. through the entire scenario. With the addition of 30 USVs for searching, although the search is completed in roughly 10-24 hrs, the limited endurance assumed for the USVs keeps the LCSs continuously at high speed to keep the USV field in operation. A more detailed analysis of LCS speed requirements for Assured Access mission performance could be conducted easily if a broader range of mission profiles requirements were developed. Alternatively, assuming certain speeds can produce a range of feasible mission profiles. The spreadsheets provided with this analysis can easily be manipulated to provide either of these answers.

For a postulated mission profile of xx% loiter speed, yy% transit speed, zz% spring speed, and a notional AA day operation, the operational dynamics are:…

Summary and Conclusions

Summary

Our analysis here has drawn on classic principles of operations research. We have shown that a strategic and operational level trade space exists for LCS. First, the addition of a moderate number of off-board vehicles can dramatically reduce the operational level of war speed requirement for LCS by a factor of over 6. Second, without off-board vehicles, LCS speeds in the 50-100 kt. range are a mandatory requirement if an area of interest is to be cleared in time for Power Projection forces to commence offensive operations upon arrival. Sensitivity analysis of this speed requirement to operational area was not conducted, but would be straightforward, once an area size of interest were identified.

We have also shown that not only is investment in off-board vehicles necessary to reduce the speed demand on LCS ships for surface search (ASUW), but also that the endurance of off-board vehicles has a dramatic impact on the number of LCS necessary to maintain uninterrupted situational awareness in the area of interest. Doubling the endurance of off-board vehicles that must be maintained by an LCS from 24 to 48 hours frees up two thirds of the LCS squadron for other missions.

Programmatic Implications

We can also conclude some very general things about force size and mix for an Assured Access force. We make the following assumptions:

- ☐ 50 kt. LCS will cost about $85M[28]
- ☐ Cost increases as the square of speed
- ☐ A USV costs one-tenth the cost of an LCS of comparable speed

Using these assumptions, we can use the information from the Power Projection Lead Speed (PPLS) equation to compute the number of USVs necessary for a 3 LCS squadron to support a search of our scenario area. Tables 5 and 6 show the costs of various force mixes for speeds of 50, 75 and 100 kt. One of the criitcla criteria here is that we assume/take the ‘worst case’ speed requirement in the calculation. For the PPLS, this equates to the shortest surge-transit distance of 1000 nm. intra-theater.

The basic process is to use the PPLS equation: $v_{LCS} = v_{CSG}$ [1- (A*ln(1-P_{det})/D*N*W)] to find the limiting speed (highest) for different LCS-USVs mixes.

For example: A force of only LCS platforms surging and searching at 100kt. against a 15kt. Main Body speed, a Pdet of 0.95, an area 400 x 400 nmj requires 8 platforms. Using our entering assumptions, each of these LCS costs 4 times as much as a 50kt LCS, leaving the force acquisition cost at $2.7B. For a force of 50kt. LCS, which requires 20 platforms, the cost is $1.7B. Table 5 summarizes these results.

	LCS	LCS	LCS
	100kt. cost ($M)	75kt. cost ($M)	50kt. cost ($M)
Unit Cost	260	146	85
Number LCS	8	12	20
Force Cost	2720	2295	1700

Table 5

For comparison, we can also calculate the total force cost if a mix of LCS and USVs are used for the search assuming, in addition, that the LCSs carry the USVs with them at sprint/transit speed. Recalling that the PPLS equation only tells us the total number of searchers necessary to clear the area before the Main Body arrives, we can 'mix and match' LCS-USV composition in a cost equation and compare various mixes for cost trade-offs. Table 6 shows that the costs from Table 5 can be lowered by almost an order of magnitude if an LCS squadron is mixed with unmanned vehicles for the search.

LCS/USV Force Mix		Cost ($M)
LCS	USV	
3 LCS, 100 kt	8 USV, 100 kt.	1292
3 LCS, 75 kt.	12 USV, 75 kt	765
3 LCS, 50 kt.	20 USV, 50 kt	425
3 LCS, 50 kt.	8 USV, 100 kt	527
3 LCS, 75 kt.	8 USV, 100 kt	846
3 LCS, 100 kt.	20 USV, 50 kt	1190
3 LCS, 50 kt	12 USV, 75 kt	485

Table 6

A cursory inspection of Table 6 reveals that the ‘value of speed’ can be explicitly quantified. For example, with 50 kt. LCSs $102M buys back the payload space of 4 USVs per LCS (12 total) as well as some operational slack: 3 LCS can adequately maintain a USV sensor field without having to operate at flank speed. Alternatively, $58M buys back payload space for 8 total USVs. In short, the dual drivers of surge and search conspire to suggest that higher search speeds by off board systems can reduce the requirement to invest in very high-speed hulls. This analysis, of course, was conducted with notional figures and assumed cost vs. speed curves. A more detailed cost analysis should be completed using the latest hull and off board vehicle cost estimates as they are produced from other emerging studies and design efforts.

One other conclusion that may be drawn from this analysis in the context of emerging design studies and operational concept generation for LCS. We assumed a *very small* ship. The NPS CROSSBOW and SEA LANCE studies as well as early *Streetfighter* concepts envisioned a small ship, less than 1000LT. Most of the current designs, as well as the implicit requirements articulated by NAVSEA[29] For LCS costs in the range of $200M, the ‘buy-back’ figures for USV roughly double (240M from 102M and 100M from 58M). Again, these are illustrative figures only. The importance here is the tool that allows quick exploration of the ‘trade space’ in the context of the operational problem of interest (Assured Access for Power Projection).

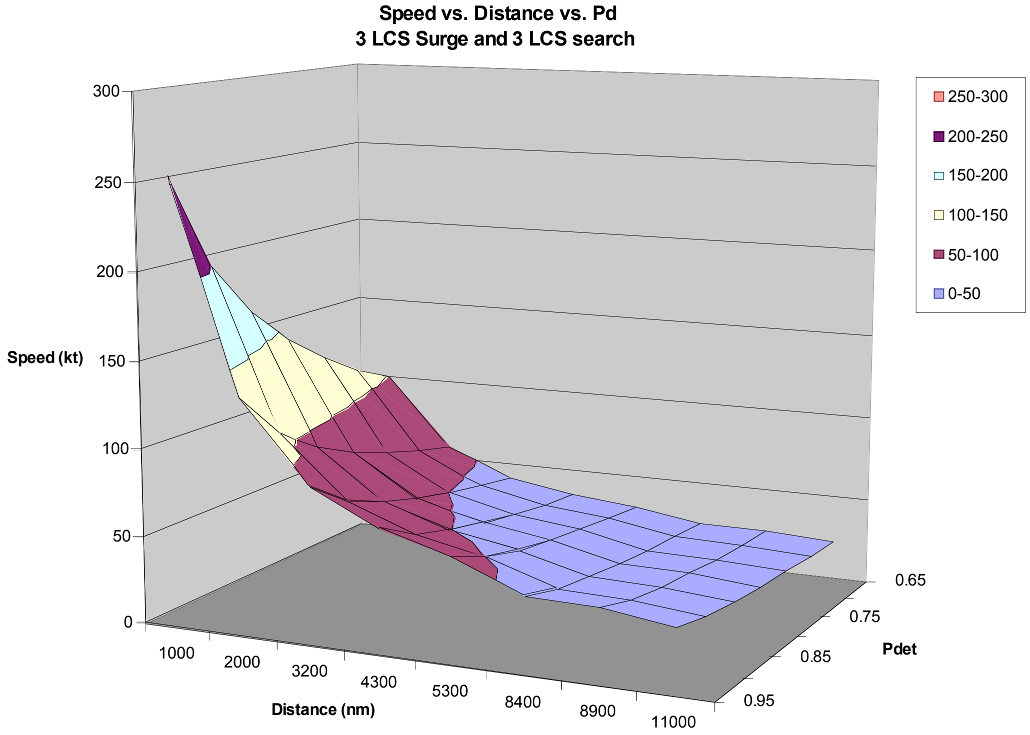
Conclusions

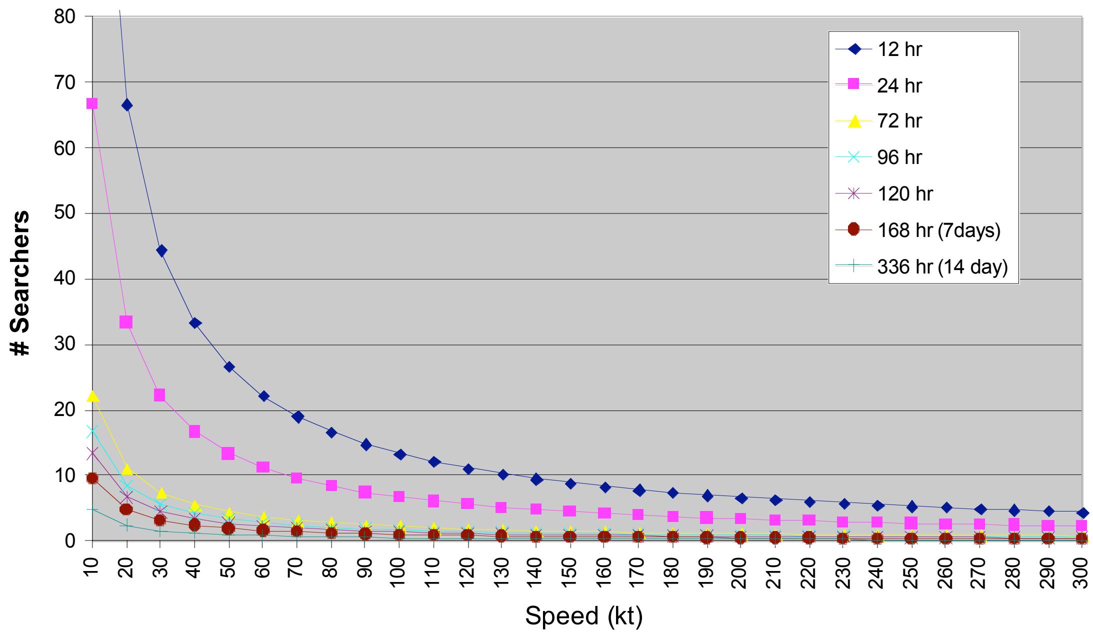
This analysis examined the impact of hull speed at the tactical, operational and strategic levels of warfare. Although the qualitative analysis in Part 1 offers some interesting perspectives on different types of speed, the quantitative operational level of warfare analysis has produced some useful, concrete results. In particular, the Power Projection Lead Speed/Power Projection Lead Time encapsulates the most important aspects of LCS development in a since measure of effectiveness. Not only does this measure allow comparison of different hull speeds, but it also describes regimes where even extraordinary speeds are insufficient. This last feature serves to describe the limits at which speed no longer becomes a universal good, but can become a commodity with decreasing returns to investment.

The appendix provides charts portraying the results of the analysis. These charts were produced with Excel™ spreadsheets, which are also provided in electronic format. Both the charts and spreadsheets are extremely useful in parametric analysis and should be routinely consulted as the LCS concept matures and new platform parameters are suggested.

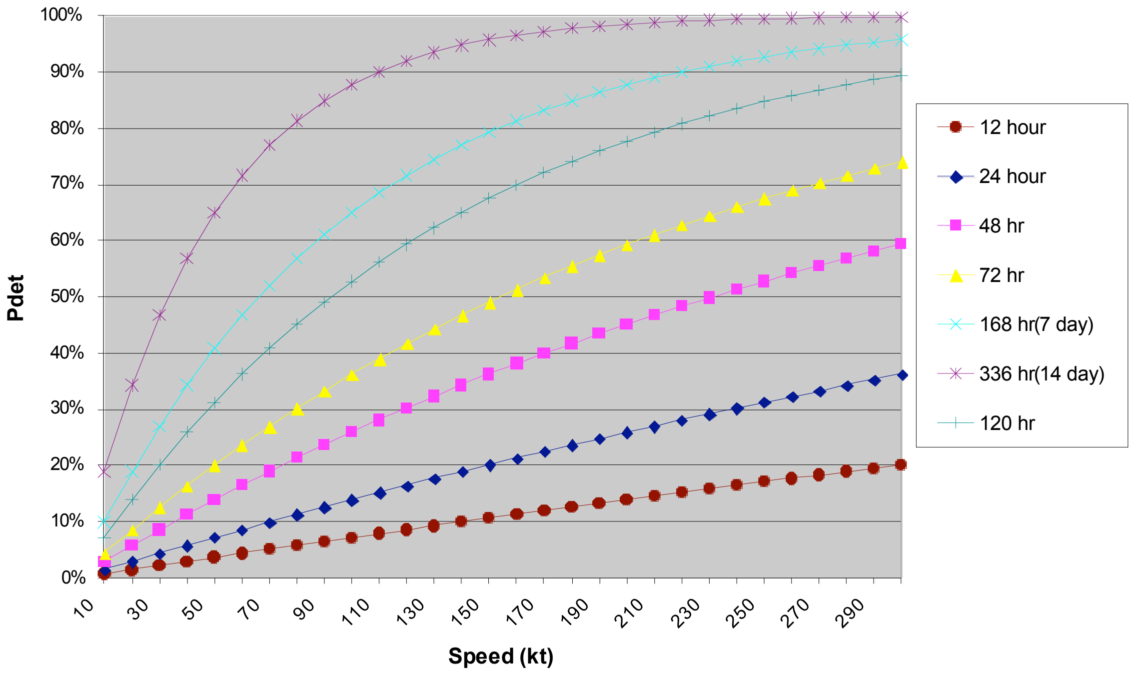
Appendix A: Charts Used for the Analysis

Spreadsheets used to generate the charts in this appendix are provided separately.

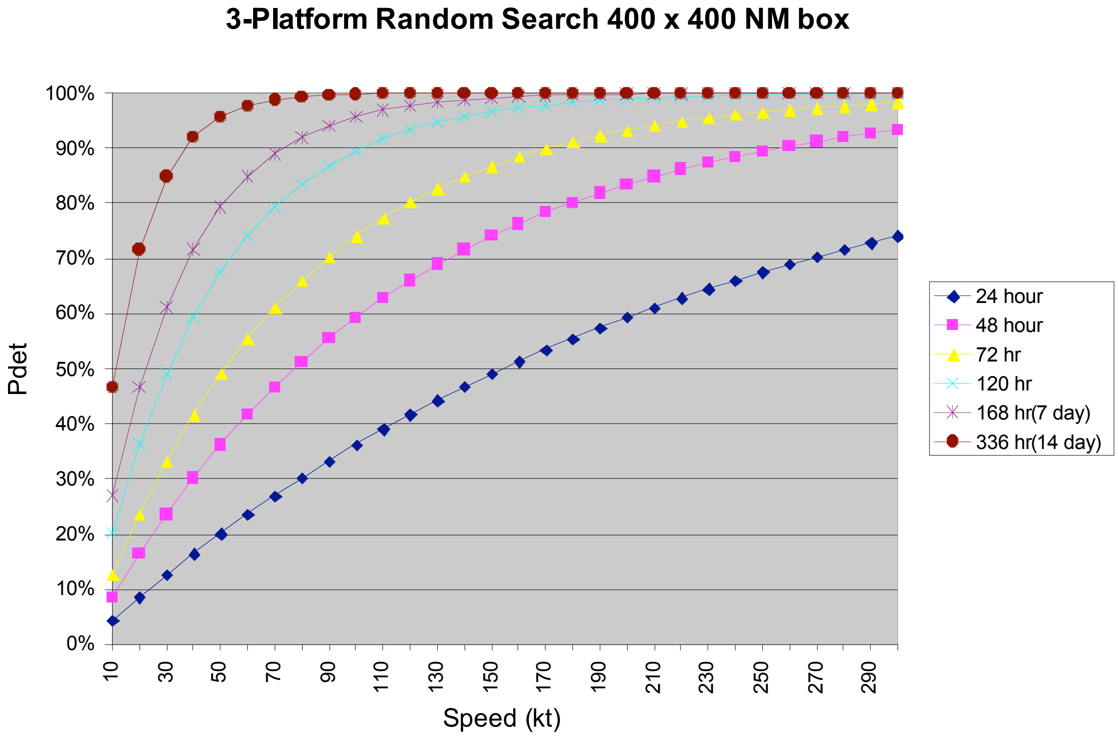


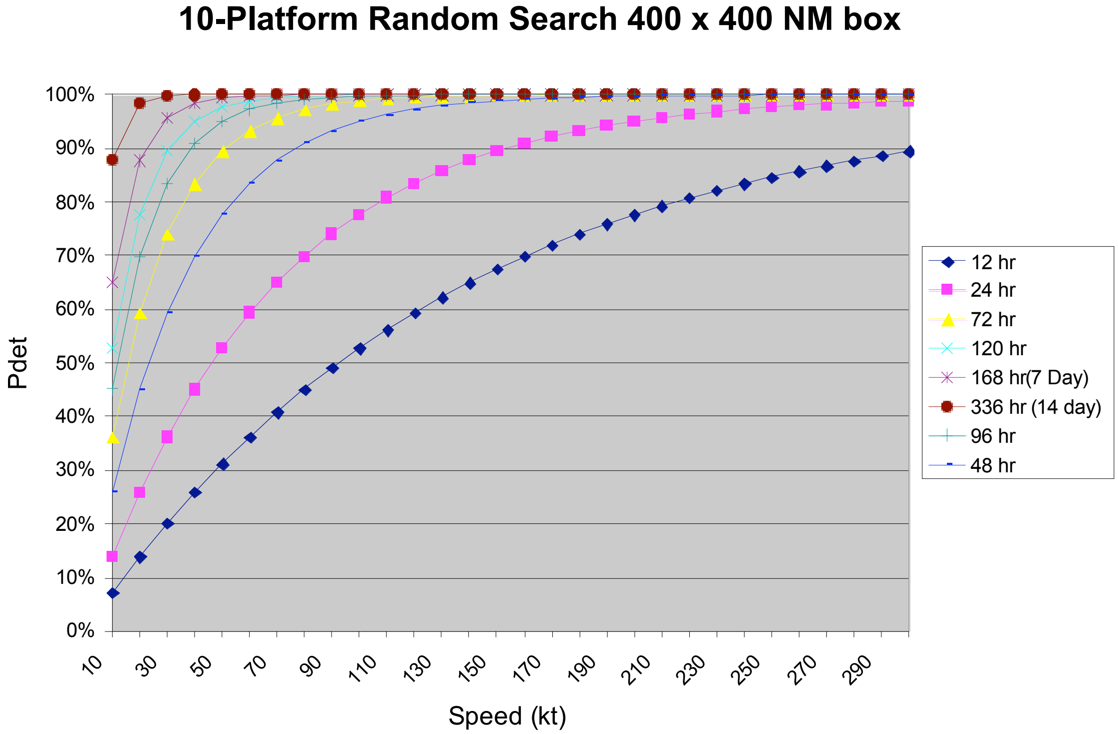


Platforms (LCS or UV) Required for Perfect Search
400x400 nm box

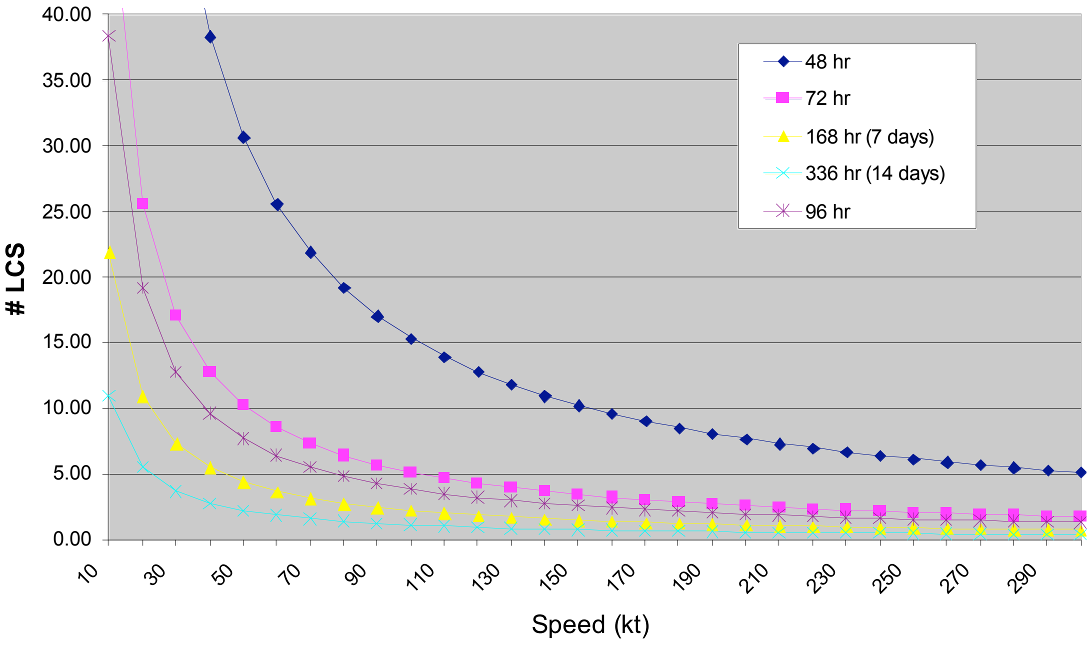


Single Platform Random Search 400x400NM

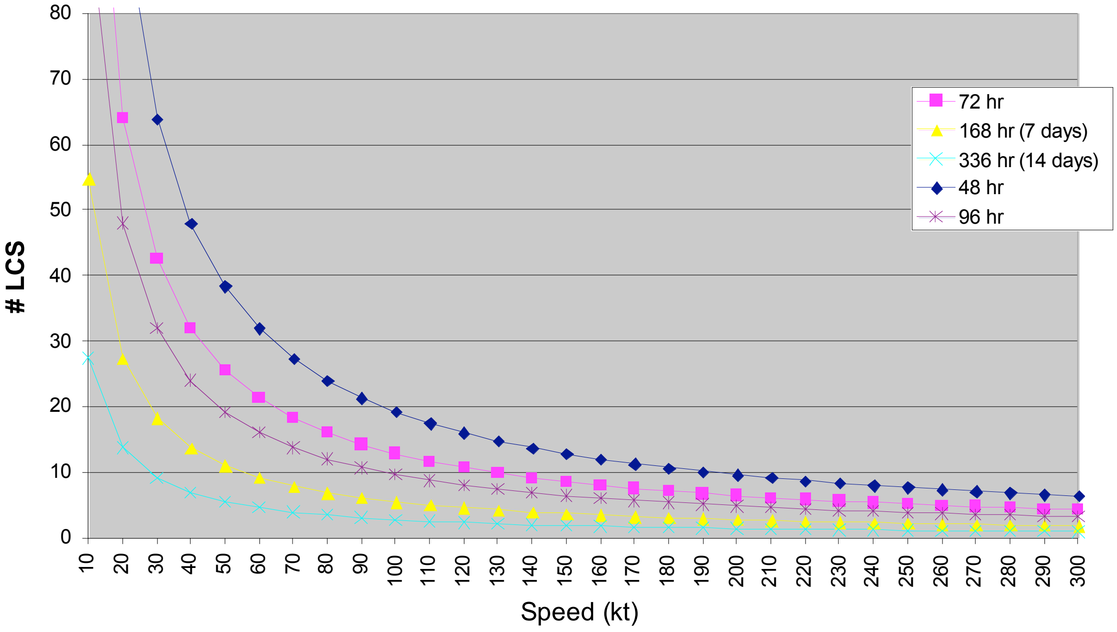

3-Platform Random Search 400 x 400 NM box


10-Platform Random Search 400 x 400 NM box

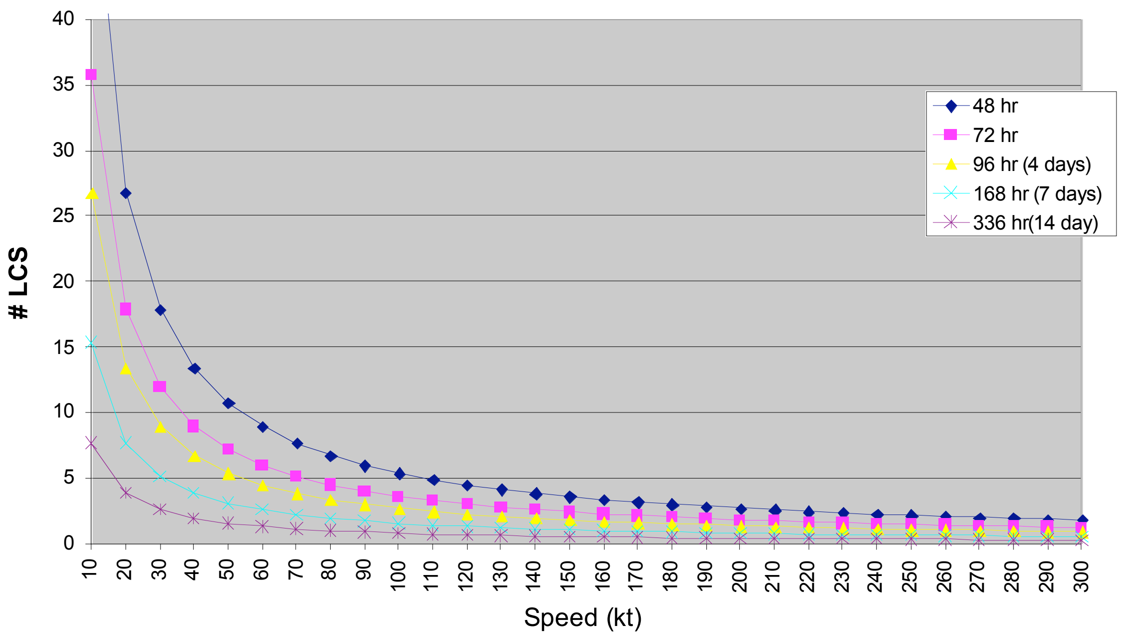
 # LCS Required for Pd=0.9 vs. Surface Ship(s)



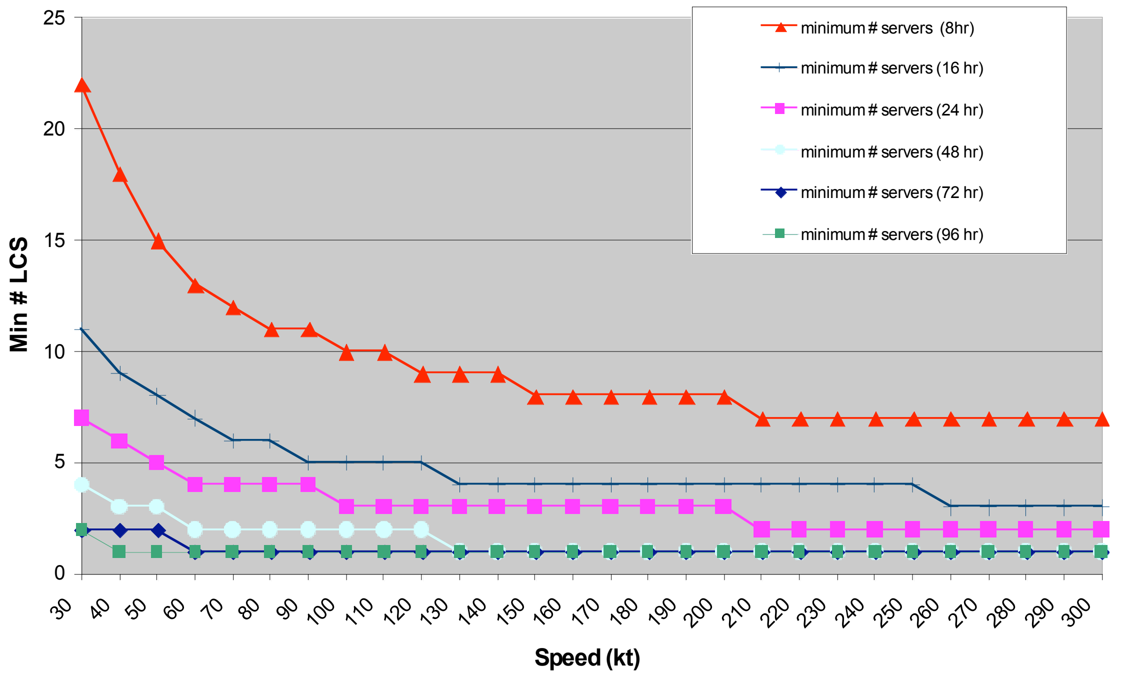
 # Platforms Required for Pd=0.9 vs. subsurface target

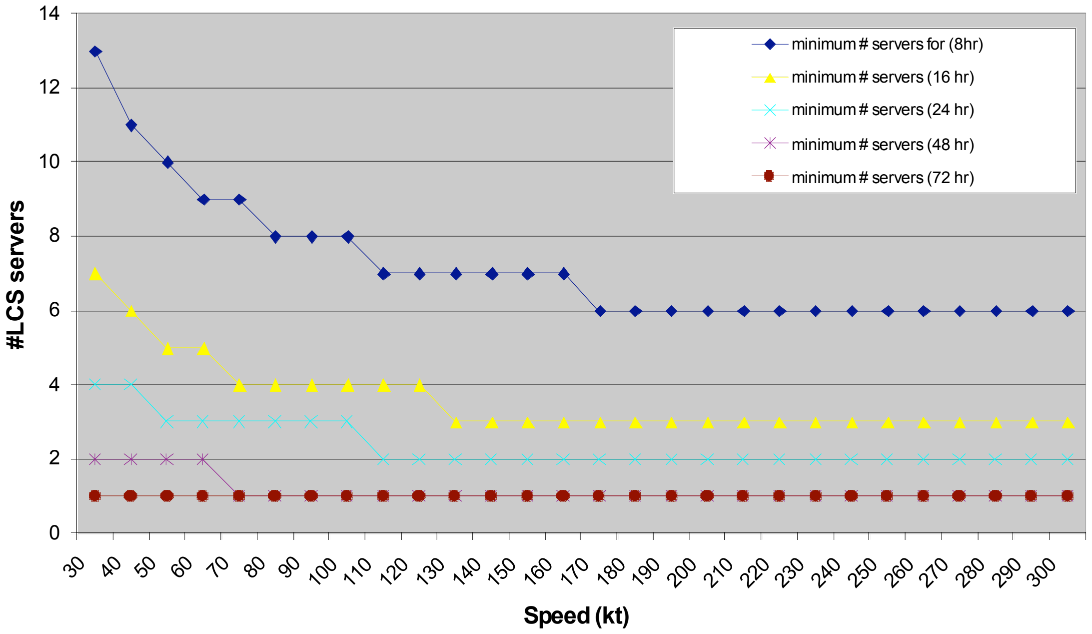


 # Platforms Required for Pd=0.8 vs. Surface Target

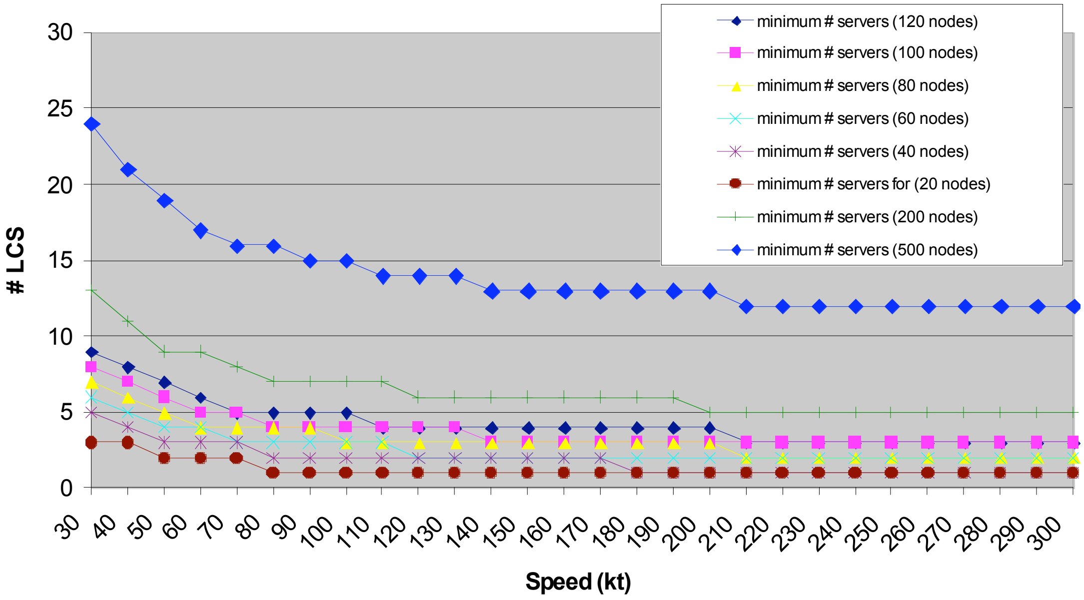


Min LCS (400x400nmarea) for 80 node grid variable endurance

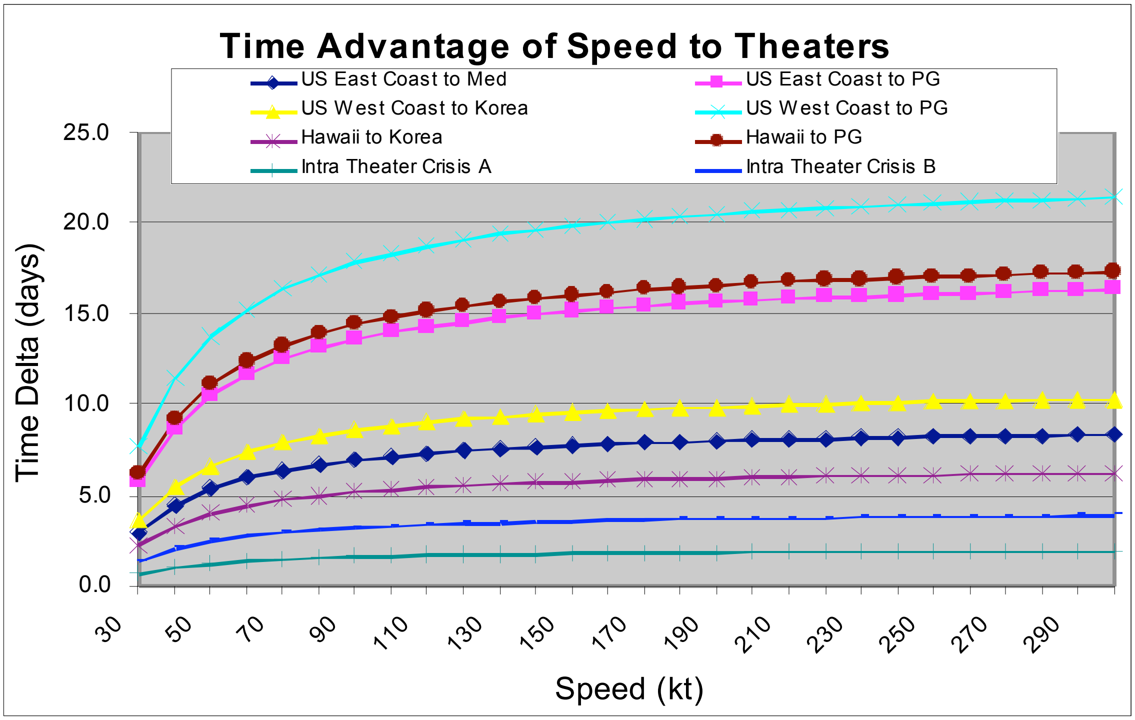


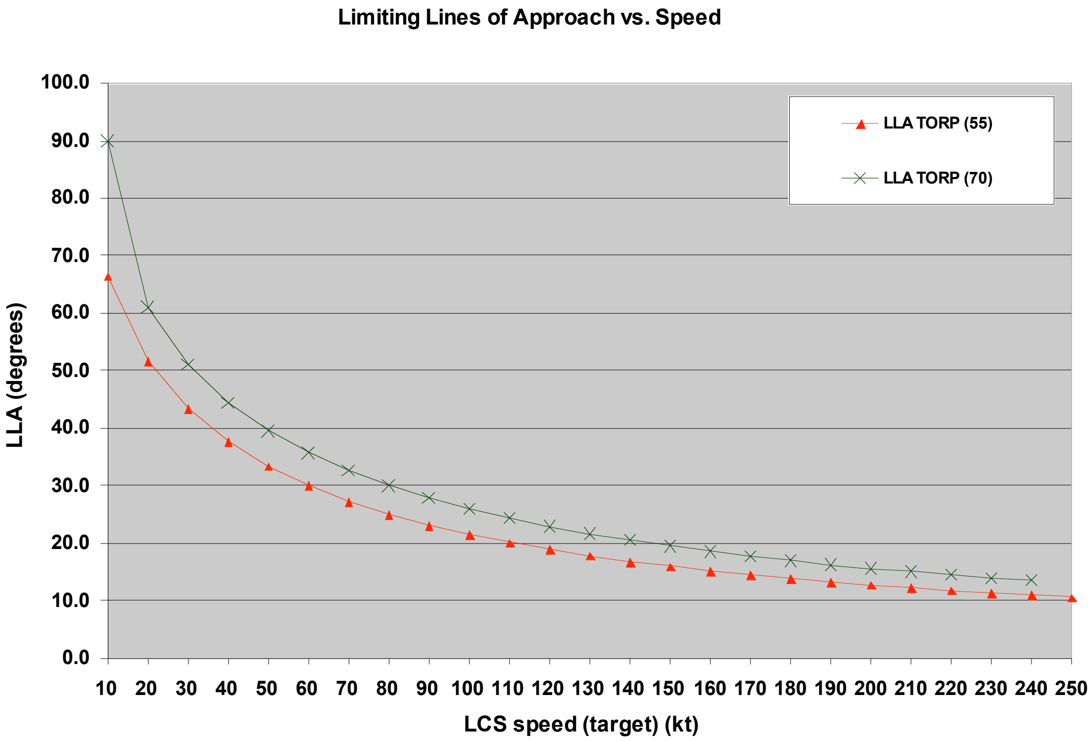


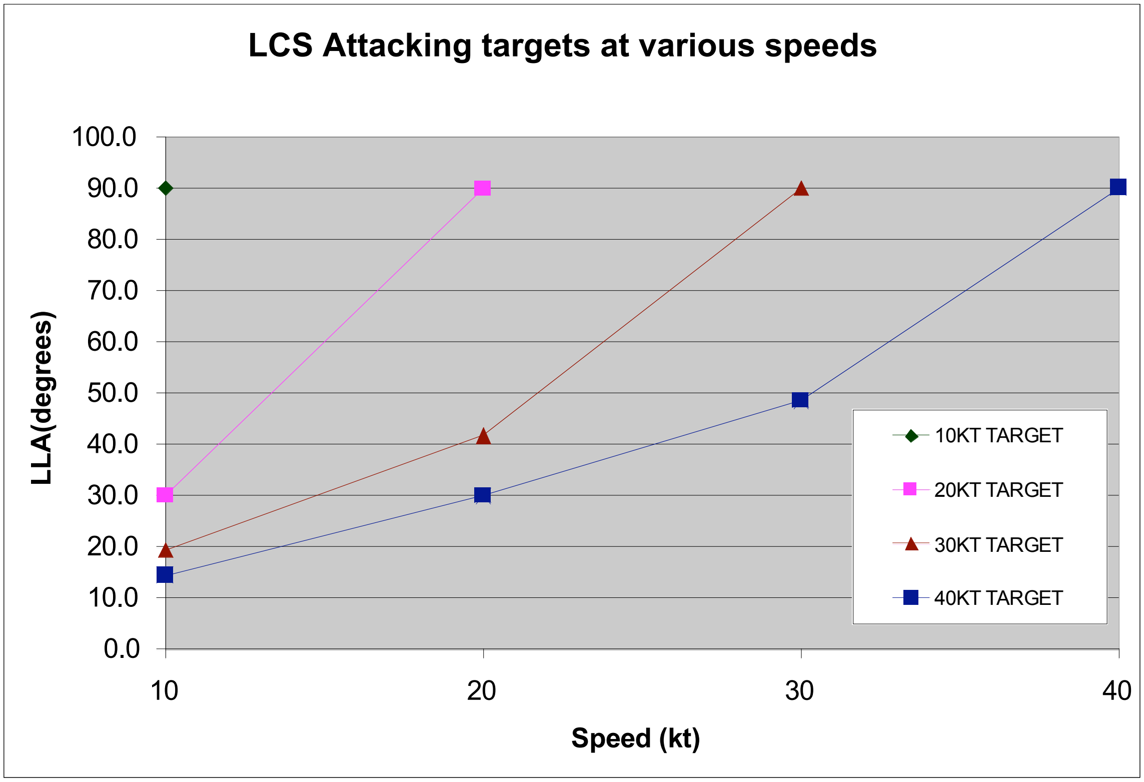
minimum # LCS to maintain 80 node grid (200x200nm), various node endurance



Minimum # LCS to maintain 24 hr grid of various sizes-400x400nm


Time Advantage of Speed to Theaters
US East Coast to Med
US East Coast to PG
US West Coast to Korea
US West Coast to PG
Hawaii to Korea
Hawaii to PG
Intra Theater Crisis A
Intra Theater Crisis B
Time Delta (days)
25.0
20.0
15.0
10.0
5.0
0.0
30
50
70
90
110
130
150
170
190
210
230
250
270
290
Speed (kt)


Limiting Lines of Approach vs. Speed
LLA TORP (55)
LLA TORP (70)
LLA (degrees)
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180 190 200 210 220 230 240 250
LCS speed (target) (kt)


LCS Attacking targets at various speeds
LLA(degrees)
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
10
20
30
40
Speed (kt)
10KT TARGET
20KT TARGET
30KT TARGET
40KT TARGET

Notes

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[1] Wayne P. Hughes, *Fleet Tactics and Coastal Combat*, p.40-44. This section of Chapter 1 argues for initiative in order to gain the square law effects of concentration of fire in naval combat.

[2] *Fleet Tactics*, p. 204-5. Hughes maintained this view as recently as October 2002 during discussions with the CNO Strategic Studies Group.

[3] No analytical paper discussing tactical instability exists. There are early unpublished briefing slides by LCDR Jeff Cares of the CNO's Strategic Studies Group. NWDC Assured Access Concept briefings and papers as well as briefings and writings by VADM Arthur K. Cebrowski while the President of the Naval War College and later as Director, Force Transformation, Office of the Secretary of Defense (for example: http://www.nwc.navy.mil/press/Review/2001/Summer/pf-su1.pdf) discuss the phenomenon in general. It is also addressed, tangentially but not directly, by the body of work from the Naval Postgraduate School's Operations Research Department on Salvo Combat.

[4] "The Imperative of Strategic Speed", PRTM's *Insight*, Summer/Fall 2001.

[5] For a thorough discussion of the dynamics of NASCAR racing, see "Social Science at 190 MPH on NASCAR's Biggest Superspeedways" by David Ronfeldt, available at http://www.firstmonday.dk/issues/issue5_2/ronfeldt/ index.html.

[6] *Methods of Operations Research*, Philip M. Morse and George E. Kimball, p. 38.

[7] For a thorough technical discussion of complexity and scale in littoral warfare, see Complexity of Military Conflict: Multiscale Complex Systems Analysis of Littoral Warfare, Yaneer Bar-Yam, New England Complex Systems Institute.

[8] This analysis is based on the compendium of analysis conducted at the CNO's Strategic Studies Group from 1997-1999 during SSGs XVII-XIX by Dr. Alan Krulisch and LCDR Jeff Cares.

[9] For example: Keith Jude Ho, An Analysis of Distributed Combat Systems, Masters Thesis, Naval Postgraduate School, Dec 2001.

[10] In this context, network means the technological ability to transfer information between entities in the combat force.

[11] For a specific articulation of the operational advantage of networking see "Sense and Respond Logistics: Turning Supply Chains into Demand Networks", Lewandowski and Cares, OSD-Office of Force Transformation, Dec 2001. A tutorial on network characteristics and fundamentals is included in the appendix.

[12] Depending on the specific characteristics and capabilities of the networked entities, this relationship could be factorial rather than exponential, creating problems many orders of magnitude more difficult.

[13] This assumption is increasingly open to debate, but that debate is not part of this analysis.

[14] For example, CNO-SSG concepts from SSG-XVII, XVIII and XIX areas for concept analysis range in size from 30 nm x 100 nm to 300 nm x 400 nm as do NWDC CNAN vignettes. The current NWDC Assured Access and Pervasive

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Expeditionary Sensor Grid work discusses a littoral battlespace that measures 2000x2000 km.

[15] LCS CONOPS briefings by PEO Surface Strike and OPNAV N76 indicate that the near term configuration, Flight 0, of LCS will have 1-2 manned helos, 3 Firescout UAVs, 2 USVs and one UUV. The CNO publicly called for a 50kt. vessel during his Sea Power 21 speech at Current Strategy Forum held at the Naval War College in May 2002.

[16] This speed range captures 'hemibel thinking': Unless the payoffs to an operational parameter or process change fall in the range of 3-10 times existing capabilities, the change is probably only marginal. The upper limit of 300kt. also has the benefit of encompassing speeds that include aviation technologies, specifically Wing-in-Ground vehicles.

[17] A presentation at the International Workboat Show and Conference held in November 1997, contained a briefing given by the National Center for Advanced marine Applications with the following vision: "In the year 2025, some envision that the vessels will be made of mostly composite and/or combination metals, have some form of dynamic lift capabilities, will carry 5,000 tons usable payload, traveling 8,700 miles without refueling, at speeds approaching 100 knots in most sea states, that can be loaded and off loaded in one (1) hour.", http://www.ccdott.org, accessed 20 March 2003.

[18] Note that the original FORCEnet concept envisioned the need for anywhere from 50-225 individual nodes of various types for an area access/area control-type mission for an area 25% the size of our area of interest.

[19] The analytic construct presented here will enable speedy detailed exploration of these questions when specific trade issues arise over the course of LCS requirements development.

[20] Bernard O. Koopman, *Search and Screening: General Principles with Historical Application*, Military Operations Research Society, 1999.

[21] *Search and Screening: General Principles with Historical Applications*, Bernard O. Koopman, Military Operations Research Society, 1999.

[22] Koopman, p. 70-74.

[23] LCDR Jeffrey R. Cares, USN, "On Dispersed Forces", CNO-SSG paper dated 15 April 1998.

[24] We round up to the next whole number of platforms, since we cannot deploy or operate fractions of ships and rounding down will not allow the maintenance of an uninterrupted sensor field.

[25] These distances are representative and may not be identical to official DoN distances used for policy and force structure analysis.

[26] "Carriers are Survivable", Navy QDR point paper, July 2001, states: "Targeting the carrier is much more difficult than finding its general operating area. The intelligence, surveillance and reconnaissance (ISR) challenge is complex and resource intensive: Carriers are mobile. Carriers conducting flight operations or transiting can move upwards of 30 knots. Consequently, this movement translates into a 700 square mile area of uncertainty every 30 minutes. Every 90 minutes, this area expands more than 6300 square miles. It takes a high level of

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technical and operational sophistication to maintain accurate, real-time surveillance over such a large area." It can be argued that LCS detectability is even harder due to the large size differential between carriers and LCS as well as the speed differential.

[27] Koopman, p. 33-36.

[28] This number is based on the NAVSEA approved model for acquisition cost as a function of displacement, Acquisition Cost = $1.8066 * Displacement^{0.585}$. Our assumption for LCS displacement is between 500 and 1000 LT. Details are contained in S. Brent Carroll, CROSSBOW COST ESTIMATION, Masters Thesis, Naval Postgraduate School, December 2001.

[29] The NAVSEA RFP for LCS allocates between $180M and $220M for the hull and core combat systems. Using the NAVSEA cost model in reverse, this implies that they expect the ship to come in between 2500LT and 3500LT. Interestingly, a research report from the MIT New Construction Naval Ships Design course for a Focused Mission High Speed Ship (FMHSS), arrived at a design of 3559 LT, with an estimated cost of $332.7M (the NAVSEA cost equation calculates $216M).