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This paper will assess the undersea balance between the U.S. and China by comparing their relative abilities to accomplish their respective undersea warfare objectives. I will assess both the current balance, and how it might evolve in the future. In the latter case, I will focus on opportunities each side will have to adopt competitive strategies, or strategies designed to exploit its unique strengths or its opponent's weaknesses in ways that create favorable asymmetries in the resources that must be committed to accomplish particular missions.

Defining the Undersea Balance

Naval warfare is at bottom a contest over who will be able to use the seas, how, where, and when. Traditionally, it boiled down to the fate of surface ships carrying civilian or military cargo between ports, or sea lines of communication (SLOCs). One was either trying to assure SLOCs, deny them to one's opponent(s), or both. And for stretches of time and in certain areas the balance could be such that SLOCs were denied to both parties to the conflict. Thus naval operations occurred in only two dimensions and tended to unfold in almost complete operational and tactical isolation from events ashore and vice versa.[1] The twentieth century saw submarines, aircraft, and earth orbiting satellites add a vertical dimension to naval warfare, and it also saw the obliteration of the coastline principle. In addition to revolutionizing naval warfare, the introduction of the vertical dimension has also wreaked havoc with analytical efforts such as this one that would seek to break apart naval warfare into discrete, self-contained mission areas or mediums of operation. Basically, surface, undersea, air, and space-based platforms have a role to play in almost all naval missions, and each operating medium has elements of all naval missions unfolding within it.[2]

For example, undersea warfare can be characterized both as what submarines do in naval missions like mine warfare, antisubmarine warfare, antisurface warfare, and conventional land attack, and what ships, submarines, aircraft, and/or satellites do to counter opposing submarines. In addition, different countries will use submarines differently, and they will also perform antisubmarine warfare differently. These variations are in turn a product of a myriad of structural factors concerning foreign and economic policy, technological skill, financial resources, and geography. Thus, states vary in the degree to which they see threats to their land borders and they embrace or are dependent on foreign trade. They also vary in their access to advanced technology, their ability to mobilize financial resources, and their maritime geography.

Today, China plans on using its diesel attack submarines (SS) for coastal defense, offensive mine warfare against potential regional adversaries, and likely as a local source of communication, electronic, and perhaps acoustic intelligence. China has a small nuclear attack submarine (SSN) and missile submarine (SSBN) force and may seek to

[1] The late Vince Davis referred to this isolation as "the coastline principle."

[2] Nuclear deterrence using ballistic missile submarines is perhaps the main exception to this rule.

increase both the size and capability of both forces in the near future. China also appears to be preparing to use its attack submarines to deny or limit the access of western navies to the larger sea space between what they call the first and second island chains, or roughly speaking the Philippine Sea.

At the same time, China has very limited ASW capabilities and appears not to be making major investments to improve them. The ASW capabilities it does have appear focused on coastal defense, and on the threat posed by the diesel submarines of potential regional adversaries as opposed to American SSNs.

The U.S. Navy plans on using its SSNs for forward intelligence collection and ASW. SSNs and a force of four converted SSBNs equipped with cruise missiles (SSGN) would also be used for land attack against fixed targets and in support of special operations to the extent they are needed. The U.S. also has and will maintain a robust force of SSBNs for nuclear deterrence. U.S. SSNs also inherently possess arguably the most potent anti-surface capabilities of any naval platform, but historically this has not been their primary mission, because it could be performed adequately by other elements of the U.S. Navy while the above missions could not.

In setting up an assessment of these opposing undersea objectives and capabilities it is possible to make some summary judgments at the outset. First, there is little reason to discuss U.S. SSBNs because there is no reason to assume that China will ever be able to develop a strategic ASW capability against them. Second, for reasons that will be discussed more below, current Chinese abilities to deny access to U.S. SSNs and SSGNs are very limited and U.S. submarines can currently operate freely in Chinese coastal waters. Third, current Chinese diesel submarines rarely deploy outside the first island chain and essentially never deploy beyond the second, nor would these submarines be well-suited for extended deployments into the Pacific or Indian Oceans because of range and crew habitability constraints. Fourth, current American ASW capabilities are substantially less in Chinese coastal waters than elsewhere for two relatively intractable reasons: the Chinese can deny or greatly limit the access of opposing surface and air ASW platforms near its coast; and very shallow water greatly limits acoustic propagation and therefore detection ranges for both active and passive sonars, the primary ASW sensors. Fifth, if for no other reason than that neither side will have a robust ASW capability in Chinese coastal waters, those waters will constitute a zone of "contested command" in which neither side can assure its use of the sea surface for either commercial or military purposes.[3]

Beyond these judgments, there is much uncertainty about the undersea balance. In the near term, there are two major questions concerning Chinese undersea warfare capabilities. First, could they use their attack submarines to attack Taiwanese shipping and/or mine the approaches to Taiwanese ports on a scale sufficient to support a successful coercion campaign? Second, could Chinese submarines deploy eastward

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[3] On contested command, see Bernard Brodie, *A Layman's Guide to Naval Strategy* (Princeton University Press, Princeton, N.J.: 1942) pg. 75.

through the barrier represented by the first island chain and successfully find and attack U.S. Carrier Battle Groups (CVBGs) operating in the Philippine Sea?

In the longer term, assuming further modernization of the Chinese submarine force, there appear two important questions regarding Chinese undersea warfare objectives and capabilities. First, might they choose to develop a larger SSBN force, and if so, how will they seek to ensure its survivability? Second, might they choose to develop a more global submarine operating posture, presumably using larger, more capable diesel submarines, or more ambitiously, nuclear submarines? Two specific objectives might be associated with more advanced submarines: the desire to break a distant blockade of Chinese shipping by U.S surface combatants operating in the Indian Ocean and the desire to acquire a precision land attack capability using guided missile submarines with conventional cruise or ballistic missiles.

There is also uncertainty regarding U.S. undersea warfare objectives and capabilities. Though there is little doubt that the U.S. will retain its ability to use submarines as intelligence collectors and precision land attack platforms essentially anywhere it chooses, and against opposing naval surface combatants if necessary, the submarine's current role as an ASW platform is more uncertain. In the more distant term, there is also the question of additional missions for U.S. submarines, to include land attack against mobile targets and missile defense. At the same time, there are questions about current U.S. ASW capabilities outside the submarine force, and how those capabilities might evolve in the future.

Enduring Factors Which Influence the Undersea Balance

Before addressing these particular questions, it is necessary at this point to at least outline the general technical, operational, geographic, and even tactical factors that determine ASW capabilities and the ability of submarines to counter them. Briefly, the important issues are active and passive acoustic sensor performance, submarine noise levels, water depth, chokepoints, and speed.

Active and passive acoustics remain the primary ASW sensors and will likely remain so because they generally provide the longest detection ranges and the most persistence. Communications intelligence (COMINT) has played a major ASW role in the past and likely will in the future, but it requires a cooperative adversary and can be quickly compromised. Radar also plays an important role in ASW, particularly against diesel submarines that must snorkel in order to cover long distances and/or generate a burst of maximum speed, but it is most useful when used on patrol aircraft, which can obviously be denied access to many littoral areas.

Active sonars are akin to radars in that they generate a powerful broadband signal and listen for a return off the target. Passive sonars are more akin to SIGINT sensors in that they listen for target-generated noise. Active sonar performance depends significantly on the power of the sonar transmitter, whereas passive sonar is more dependent on the strength and nature of the target's acoustic signature, and the sophistication of the signal processing used to extract that signature from the background noise. Ironically, the detection ranges of more than a thousand miles can result from the passive reception of relatively weak signals, whereas extremely powerful active sonars have difficulty achieving detection ranges of more than 30 miles.

The key to this seeming paradox is the typical sound spectrum of a submarine and the magic of narrow band signal processing. Like radio and radar, sound occurs on a spectrum of frequencies[4]. High frequency, short wavelength signals attenuate more quickly but can be detected with good angular resolution by small antennas, while low frequency, long wavelength signals propagate further but require antennas with much larger apertures in order to achieve directional reception. To detect a signal, it must be distinguishable from any background noise, whether in the propagation medium, i.e. the ocean, or in the receiver itself. The basic variable that determines whether detection occurs is the signal-to-noise ratio. There are two basic approaches to maximizing the signal-to-noise ratios achieved by a sonar, antenna gain and processing gain.

Because the optimum diameter or aperture of an antenna varies directly with wavelength, very low frequency sound reception is maximized by antennas with very wide apertures, which means that sonars designed to detect low frequency sound must be large. High gain antennas increase the signal-to-noise ratio by nulling out reception of noise from all directions except that of the main beam of the antenna, but noise within the main beam remains. Thus, even when the main beam of such an array is pointing directly at a submarine, there is noise that competes with the submarine's acoustic signature, and at long ranges this noise can still mask the submarine signal and prevent detection. Further filtering of this noise depends on signal processing within the sonar itself.

This processing usually exploits the fact that a submarine's signature contains both a continuous, broadband spectrum of sound, as well as discrete, narrowband tonals at specific frequencies along that spectrum that rise above it[5]. These tonals are caused by specific pieces of rotating machinery within the submarine, such as pumps, generators, and gears, whereas the continuous broadband spectrum is caused primarily by flow noise over the hull surface or by propeller cavitation. A submarine's broadband signature resembles background noise in that it contains a continuous spectrum of frequencies within which sound source levels at particular frequencies rise and fall in random fashion around a mean over time. By contrast, the narrowband component of a submarine's signature generates sound at several specific frequencies continuously. Thus, compared to the background noise generated at these specific frequencies, which will average out over time to x, the signal plus noise received at the tonal frequency will average out over time to x + y, with y being the source level of the signal. In order to listen for these specific tonals, a sonar is given a spectrum analyzer that passes an incoming broadband signal through a set of narrowband filters tuned to the frequencies of interest. Narrowband processing will detect signal y as long as it remains high enough to be reliably

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[4] A good textbook on the subject of the following discussion is Albert W. Cox, *Sonar and Underwater Sound* (Lexington, Mass.: Lexington Books, 1974).

[5] On tonals and other aspects of a submarine's acoustic signature, see William S. Burdic, *Underwater Acoustic System Analysis* (Englewood Cliffs, N.J.: Prentice Hall, 1991), pp. 339-45.

distinguished from the background noise x[6]. When first used in the early 1950s it was given the name LOFAR (LOw Frequency Analysis and Ranging).

Because machinery noise is low frequency, and because it is narrowband, signal processing can filter out most of the sound received by a passive sonar's antenna array, and focus only on those low frequency tonals in the target submarine's acoustic signature which propagate the furthest. In those narrow frequency bins, the submarine's signature is competing only with the background noise that exists at that very narrow frequency, rather than the entire broadband noise spectrum, and the sonar can therefore detect that narrow component of the submarine's overall sound spectrum at much greater ranges before noise drowns it out.

These detection ranges can be very long. The Sound Surveillance System (SOSUS) developed early in the Cold War could, and still can detect submarines with pronounced narrow band tonals across entire ocean basins. By contrast, very powerful broadband medium frequency sonars like today's SQS-53 struggle to achieve detection ranges of 30 miles. But this level of both active and passive sonar performance is dependent upon ocean depths sufficient for special propagation modes that minimize the interaction between acoustic pressure waves and the surface and the bottom.

The enemy of all sonar propagation, passive or active, is shallow water. And the enemy of passive, low frequency, narrowband signal processing are quieting techniques that insulate a submarine's rotating machinery from its hull, preventing the coupling of machinery vibrations to the hull and into the surrounding water, and thereby reducing the acoustic source level of the submarine's tonals below the background noise at those frequencies.

For the purposes of this discussion, shallow waters are the littoral seas like the northern part of the South China Sea and the East China Sea where the continental shelf extends outward from China's coast all the way to the First Island Chain, and where depths rarely exceed 100 fathoms (roughly 600 feet). Beyond the continental shelf, most ocean basins, including the Pacific, rapidly fall away to depths measured in tens of thousands of feet, which is the case both for the Philippine Sea and the southern part of the South China Sea.

In shallow water, all acoustic energy tends to reflect repeatedly off the bottom and the surface, whereas in deep water, acoustic energy can find its way into deep sound channels where it is refracted between warmer water near the surface and denser water near the bottom.[7] Reflected acoustic energy loses much more of its pressure than when it is

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[6] For a detailed, quantitative discussion of narrowband signal processing, see Tom Stefanick, *Strategic Antisubmarine Warfare and Naval Strategy* (Lexington, Mass.: Lexington Books, 1987), pp. 293-306.

[7] Refraction results from changes in the speed of sound in water that vary primarily with pressure and temperature. When the speed of sound is decreasing with depth, acoustic waves bend downward, and when it is increasing with depth, the waves bend upward. The speed of sound increases with both temperature and pressure, and when the two variables are working at cross purposes, i.e. the water temperature is dropping with depth and the pressure is increasing, temperature trumps pressure. A deep ocean basin usually has a surface layer of constant temperature and increasing pressure, a middle layer of decreasing

refracted. In the Cold War a Soviet submarine tonal that might propagate for many hundreds of miles in the Mid-Atlantic would propagate for only 10 miles in the Barents Sea. At the same time, powerful active sonars encounter a different problem in shallow water, which is that well before their signal attenuates into the background noise it experiences reverberation, or the generation of multiple echoes from the bottom and the surface which can not be distinguished from a target echo.

Quiet submarines without pronounced tonals cause problems for passive sonars regardless of water depth, because detection range can drop dramatically with small reductions in tonal strength if those reductions are sufficient to close of ideal deep water propagation paths. The U.S. experienced this problem toward the end of the Cold War, when Soviet SSNs without pronounced tonals were finally deployed. One solution developed by the U.S. in response, the Fixed Distributed System (FDS), demonstrates the key role that maritime chokepoints play in ASW, and the degree to which a chokepoint is determined by sensor performance.

The gaps between Greenland and Iceland, and between Iceland and the United Kingdom (i.e. the GIUK Gap), were considered chokepoints throughout most of the Cold War. Initially, this was because the propellers of Soviet diesel submarines passing through these gaps at speeds of over eight knots caused cavitation, the loudest of broadband signals, and American diesel submarines operating on battery and equipped with large passive bow arrays could detect these transiting submarines at ranges out to 30 miles. Thus, initial war plans called for deployments of a picket line of such subs deployed at roughly 60 mile intervals. Later, after the Cuban missile crisis demonstrated that picket lines were of no use if they weren't deployed, the decision was made to forward deploy SOSUS arrays of the type that had already been installed along both U.S. coasts. SOSUS arrays deployed off Iceland and the UK at the axis of the deep sound channel and connected to the shore by copper telephone cable could continuously monitor the entire GIUK gap by listening for the pronounced tonals that non-sound insulated diesel subs generate when they are snorkeling. First, second, and third generation Soviet SSNs (November, Victor I-II, Victor III) also produced pronounced, continuous tonals and SOSUS retained its capability to make the GIUK a chokepoint until the early 1980s, when the Akula class SSN was deployed by the Soviet Union.

Akula could not be reliably detected by SOSUS, and without SOSUS the GIUK threatened to become an avenue rather than a chokepoint, which is where FDS enters the story. FDS was an attempt to repair the barrier strategy by using 1000s of simple passive sensors in an upward looking array that did not rely on deep water propagation paths like the deep sound channel but instead used the reliable acoustic path (RAP), or the direct vertical path from the sensor on the ocean bottom to the surface. Each RAP sensor would cover a small cone of the ocean column, and fiber optic cable solved the heretofore impossible problem of providing the bandwidth needed to network this vast array of

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temperature and increasing pressure, and a bottom layer of constant temperature and increasing pressure. Thus, sound that gets into the middle layer can get trapped there and spread horizontally as its waves keep bending away from the surface and the bottom. This is what is known as the deep sound channel and its axis is where SOSUS arrays are deployed.

sensors and bring their output ashore for processing. FDS sensors could be used to listen to narrowband or broadband signals and were effective even against very quiet targets because RAP detection ranges can be very short, i.e. small multiples of the depth of the water column in which it is deployed. Even the quietest submarines can be detected if the range is short enough.

Finally, submarine speed is also an important variable in the ASW equation, particularly for diesel submarines. First, the quietest submarine, nuclear or diesel, will cavitate above a certain speed at shallow depths. One consequence is that diesel subs making long snorkeling transits in deep water expose themselves to long range detection, but if they slow down they significantly cut into the patrol time available when they reach their operating area before they must return to base. Nuclear submarines do not face this constraint because they can conduct high speed transits at much greater depth.

Second, the power required to propel submarines (and ships) grows exponentially with speed, so even the best diesel subs with the most advanced air independent propulsion (AIP) plants can not exceed 20 knots while on battery, and can only sustain speeds of 10-15 knots or more, as opposed to very slow patrol speeds, for short periods of time before they will have to snorkel. This complicates their ability both to maneuver into attack position, and to survive any post-attack ASW prosecution, when they are engaged in anti-surface operations against naval formations traveling at 25-30 knots with powerful ASW escorts.

Such targets can be detected at up to a 100 miles by a submarine, but in order for the submarine to close within torpedo range, it must essentially get in front of the target or targets before they pass by, which at best will usually require a sustained high speed run. Wake homing torpedoes don’t appreciably change the requirement for maneuvering within the limiting lines of approach, but they do reduce the need for periscope deployments in order to achieve a torpedo fire control solution. And of course, even when a diesel submarine is able to maneuver into position and attack, if the target has ASW escorts the submarine faces the prospect of persistent prosecution by active sonars with a depleted battery capacity and a significant speed disadvantage.

Submarine-launched, antiship cruise missiles reduce the need for maneuvering to get within weapon range and introduce a degree of standoff from ASW escorts, but they also introduce the need for offboard surveillance and targeting assets. Offboard cueing makes the diesel submarine’s life much easier but in turn can create a raft of additional vulnerabilities when the source or sources of cueing are themselves vulnerable to physical and/or electronic attack, as they almost always are. For all these reasons, diesel submarines operating against first class navies generally are most effective when their mission allows them to stay relatively near home, when their targets must come to them rather than the opposite, and when their targets do not have ASW escorts.

Assessing the Undersea Balance

China’s submarines face two distinguishable operating environments given what we can assume to be its two main undersea warfare objectives. The first operating environment is the shallow water littoral along its coast, comprising the Yellow, East China, and northern South China Seas. This operating environment is characterized by bad acoustic conditions and its air space would be contested if not controlled by China during a conflict. The second operating environment can be defined as the deep water of the Philippine Sea between the first and second island chains and in the southern part of the South China Sea. This operating environment is characterized by excellent acoustic conditions and mostly lies beyond Chinese abilities to contest air space.[8] Taiwan pulls the first island chain in closer to China, making the Taiwan Straits the narrowest portion of China's shallow water littoral seas, and giving China the ability to contest Taiwanese air space. The three main exits from the first to the second operating environment lie through the Ryukyus northeast of Taiwan, through the Luzon strait southeast of Taiwan, and southward into the deep South China Sea basin between Vietnam and the Phillippines.

China's first undersea warfare objective would be to defend its coastline from opposing naval combatants and, if necessary, interdict the commercial shipping of an opponent. In the latter case, analysts have focused specifically on a coercive, submarine-based, mine warfare campaign against Taiwan. Most if not all of such a campaign could unfold within the first operating environment.

The second undersea warfare objective would be to deter or prevent U.S. naval intervention in any conflict between China and one of its immediate neighbors, Taiwan again being the most likely contingency. In operational terms, this would in principal have both an ASW and an anti-surface component. The ASW component would occur in the first operating environment where the opponent would be American SSNs and SSGNs. The anti-surface component would occur in the second operating environment and the primary opponent would be American carrier battle groups.

The First Undersea Warfare Objective

As discussed above, China has very limited ASW capabilities and U.S. submarines are the most difficult ASW target in the world. Thus, China would have difficulty preventing U.S. submarines from operating in its shallow coastal waters. At the same time, those waters also significantly reduce the ASW capabilities of U.S. submarines, the only U.S. ASW asset that could safely operate in them under many circumstances. In such cases, the approaches to Chinese submarine bases and to Taiwanese ports would become the focal points where American submarines would maximize their detection opportunities against Chinese submarines, should they be assigned that task.

Most likely, American submarines would be deployed to the approaches to Chinese submarine bases for two reasons. First, if any warning of a conflict was available, they could be pre-deployed with an eye both toward warning of initial Chinese submarine

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[8] In using the terms first and second operating environments I am intentionally avoiding the more common usage of "inside the first island chain" and "between the first and second island chains" because I believe the latter usage fails to capture the variance in operating conditions in the South China Sea. Most of the South China Sea is deep water and outside the range at which Chinese fighters can be cued by airborne warning and control (AWAC) aircraft to perform intercepts, and therefore more akin to the operating conditions in the Philippine Sea.

deployments, and once conflict started, interdicting exiting submarines as well as those returning from initial missions. This is a better operating environment for American submarines than the approaches to Taiwanese ports, where Taiwanese and possibly American surface and air ASW and/or anti-mine operations would present significant potential for fratricide.

At the same time, American SSNs would face the danger of counter-detection by the best Chinese diesel submarines if they use traditional approach and attack tactics that use organic sensors and torpedoes. This is already driving the American submarine force to some combination of deployable, autonomous, distributed, sensor (DADS) arrays using both acoustic and non-acoustic detection methods for initial detection, and unmanned underwater vehicles (UUVs) for trailing and perhaps attacking very quiet diesels once they are located. In addition, smart mines deployed near opposing bases may play a larger role than in the past. These efforts are a sign that the American submarine force is acting to maintain its traditional tactical dominance over opposing submarines in submarine versus submarine ASW operations. If successful, the exchange rate in such operations will favor the U.S.

The possible purpose and course of a coercive mine warfare campaign by China against Taiwan has been much studied and debated.[9] The undersea balance would obviously play a role in its outcome, but in many cases political factors would actually be the decisive variables. The ideal scenario from a Chinese perspective is one in which a modest amount of pain is sufficient to cause a domestic political collapse in Taiwan, which presumably would lead to a relatively quick negotiated solution to whatever Taiwanese "provocation" or "threat to the status quo" caused the conflict in the first place. One might call this the "weak Taiwan" scenario in which Taiwanese domestic political conflicts over its relations with China are severe enough that it would lack the cohesion and political will to stand up to even a modest amount of punishment. In the weak Taiwan scenario it becomes difficult to imagine an undersea balance between China and the U.S. that would allow the latter to prevent successful coercion of Taiwan by the former.

In a "strong Taiwan" scenario, one in which Taiwan proved as resistant to coercion as most states historically have, a larger, more protracted coercion campaign would be required because China would need to do severe economic damage to Taiwan. If the U.S. came to Taiwan's assistance, American SSNs could cause significant attrition as Chinese submarines exited and returned to port. Even if initial Chinese submarine deployments occurred before a conflict started, and even assuming that direct attacks against Chinese submarines in port were avoided, submarines returning to port from mining or anti-shipping missions would be vulnerable to attack by U.S. submarines, submarine-launched UUVs, and/or submarine-deployed mines. Given very limited Chinese ASW capabilities,

[9] See Tomas J. Christensen, "Posing Problems without Catching Up: China's Rise and Challenges for U.S. Security Policy," *International Security*, Vol. 25, No. 4 (Spring 2001); Michael Glosny, "Strangulation from the Sea," *International Security*, Vol. 28, No. 4 (Spring 2004); and Andrew S. Erickson, Lyle J. Goldstein, and William S. Murray, *Chinese Mine Warfare: A PLA Navy 'Assassin's Mace' Capability*, U.S. Naval War College, China Maritime Studies, Number 3, June 2009.

American SSNs would likely suffer significantly less attrition than Chinese submarines in such operations. Given a projected force of about 60 non-ballistic missile submarines, and given other important roles these submarines play in Chinese naval strategy, it is entirely possible that over the course of a several month conflict, Taiwan's resistance to economic pain would be greater than China's willingness to lose submarines.

The pain China could cause Taiwan would of course be greatly increased were it to use its now formidable force of ballistic missiles and fighters to directly attack economic and military targets in Taiwan. But attacks launched from the Chinese mainland would also invite retaliatory attacks against the Chinese mainland. And in the event that the U.S. had become involved, attacks launched from the mainland against U.S. forces in the region, whether at sea or on local bases ashore, would invite U.S. retaliation against the source of those attacks.

The Second Undersea Warfare Objective

This leads to the second main Chinese undersea warfare objective, which is to prevent the successful operation of U.S. carrier battle groups in the second operating environment. Chinese capabilities in this mission area will primarily depend on whether or not their submarines can exit the first operating area covertly, and whether or not their ocean surveillance systems can provide accurate cues to the location of American battle groups in the second operating area. To further complicate matters, the answers to these questions will vary depending on which Chinese submarines are being discussed, how long the conflict lasts, the degree to which direct attacks from and against the Chinese mainland occur, and American willingness to incur losses of major combatants.

The following assessment will focus on a "reasonable" worst case scenario. Out of a total fleet of 60 non-ballistic missile submarines, the Chinese will have 50 SS/SSGs and 10 SSNs equal in capability to the best of each type in the current force; the conflict will last several months, as in the strong Taiwan scenario; attacks launched directly from and against the Chinese homeland will occur; and American stakes in the conflict will be such that they will be willing to incur the loss of major combatants as long as they retain the initiative as to the rate of such losses.

The assumption that the Chinese will have 10 SSNs equivalent to today's Shang class, of which there are two today, is conservative because the Shangs have not been deployed at the rate that was earlier expected. At the same time, I make a specific assumption about what the common description attributed to ONI about the Shang's capabilities means, i.e. that they are similar to or equivalent to the Soviet Victor III. Though a great improvement on their predecessors, the Victor IIIs were still vulnerable to long range, passive acoustic detection, both by ocean surveillance systems like SOSUS, SURTASS, and FDS, and by ships and submarines equipped with advanced towed arrays.[10] Therefore, I assume that

[10] From the second batch, or "Flight II," of Victor IIIs produced, all but the lowest frequency tonals had been eliminated, and the broadband signature was much reduced. The former mean't that only towed array-equipped platforms could prosecute IUSS contacts against Victor IIIs, and the latter mean't that American submarines had trouble "going from narrowband to broadband," i.e. converting an initial detection into the approach and attack maneuvers needed to achieve Mark 48 fire control solutions. Neither of these

descriptions of the Shang as being equal to the Victor III are a reflection of the fact that they are not equal to the Akula, the Soviet submarine that did finally eliminate the stable, continuous tonals that enabled long range, passive acoustics. In this case, Shangs could not pass into the second operating area undetected, they could be tracked at long range by modern passive acoustic surveillance systems, and they would be at a tactical disadvantage with ASW prosecution platforms like the Virginia SSN and the P-8 patrol aircraft.

Given this assumption, the worst case for American ASW efforts in the second operating area is actually a force of Kilos or Yuans that have transited from the first to the second operating area without detection, and which have available to them an enduring and secure source of broad area cueing against American battle groups operating in the second area. I find more reasonable a case where the U.S. can assure a fleeting detection of Chinese SS/SSGs leaving the first operating area, but cannot track them once in the open ocean of the second; and where it can only deny them cueing against its battle groups if it is allowed to physically or electronically attack the sources of such cueing, whether they be OTH-B radars today, or MTI radar satellites in the future.

American Acoustic Barriers. Geography and technology will favor U.S. efforts to form effective acoustic sensor barriers through which Chinese SS/SSGs must pass in transiting from the first to the second operating environment. The maritime geography in question is at least as favorable as that which the U.S. successfully exploited during the Cold War. The widest exit from China's shallow, inner seas, between Vietnam and the Philippines, is little or no wider than the Iceland-UK gap. The next largest exit, the Luzon strait, is half that size, and all the other exits are significantly narrower. In all cases, the land adjoining these exits is in friendly hands and could be used as the shore terminus for cable-based undersea surveillance arrays. In all cases, the waters in question are far enough from the Chinese mainland that maritime patrol aircraft deploying more temporary, buoy-based arrays could also operate safely.[11] And in all cases but the Vietnam-Philippines gap, redundant deep and shallow water arrays can be deployed because the exits from the inner seas all require passage from very shallow continental shelves directly into deep ocean basins.

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constraints need exist today because efforts begun during the Cold War to remedy them were successful. Towed arrays became ubiquitous, a return to explosive echo ranging (EER) greatly improved air ASW in deep water, and the development and deployment of hull-mounted, mid-frequency, flank arrays first on Seawolf and now on Virginia has eased the narrowband to broadband problem. On the Flight II Victor IIIs, see testimony by then CNO Admiral James D. Watkins in U.S. Senate Armed Services Committee, *Hearings on the FY1985 Defense Budget, Part 8*, pg. 3889. For a general discussion of Cold War ASW, and particularly the importance of barriers, see Owen R. Cote Jr., *The Third Battle: Innovation in the U.S. Navy's Silent Cold War Struggle with Soviet Submarines*, Newport Paper 16, Naval War College Press, 2003.

[11] The Luzon strait is 240 miles from China at its closest point and the southern tip of the Ryukyus is only a little closer. This is well beyond line-of-sight for Chinese AWACs operating in their own air space, and it is also too far for the establishment of standing patrols of Chinese fighters without extensive air-refuelling, which China currently lacks and shows no signs of seeking. In short, maritime patrol aircraft patrolling the Ryukyus from Japan and the Luzon strait from the Philippines would be safe from attack.

Details about the performance of current U.S. research and development into passive and active acoustic barriers are classified, but the nature of several such systems is known and deductions regarding their potential performance can be made. As discussed above, the worst case is a diesel boat without any stable low frequency tonals and a reduced broadband signature, under tactical and operational circumstances where it need not exceed patrol or transit speeds of 5-10 knots. It is possible that existing FDS/ADS, deep water, RAP arrays could still be effective against such a target, as FDS apparently was against Akula, but this would require shore stations in countries like Vietnam and the Philippines. Negotiating such access is certainly possible, and could also likely be kept covert if necessary. On the other hand, this would require advance knowledge of desired acoustic barrier locations, which might not be a problem, and would also be vulnerable to cable cutting, which is more of a problem.

Thus, the U.S. Navy has sought to replicate the performance of FDS/ADS without dependence on either seabed cables or shore processing stations, using aircraft or ships to deploy more temporary sensor arrays in a crisis. The reliable acoustic path vertical line array (RAP VLA) program, now in development, aims to create such an array. A key performance metric for RAP VLA is that its nodes provide detection of quiet targets at ranges 3 to 7 times water depth. This can result in coverage areas of 200-300 square miles per sensor measured at the surface, allowing sensor nodes to be spaced at 20-25 mile intervals. Buoys using a combination of acoustic and radio-frequency (RF) communications are also being developed to uplink RAP VLA data to distant shore processing stations.

Another temporary, rapid deployable, deep water array development program is the Deep Water Active Detection System (DWADS). DWADS uses both active and passive floating buoys to make convergence zone (30 miles) detections against quiet submarines. Such an active system would trade the endurance and covertness of a passive system for better localization and less dependence on acoustic conditions.[12]

Programs like RAP VLA and DWADS are showing great promise as a means of assuring a fleeting detection of quiet Chinese submarines as they exit the first operating environment. But a fleeting detection opportunity is not an ocean wide surveillance capability like SOSUS provided during the Cold War. With SOSUS, the U.S. had a persistent means of maintaining tracks on Soviet submarines. If and when it wanted to

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[12] On RAP/VLA and DWADS, and the progress made with both programs in just one year, see Briefing by Mr. Joe Johnson, PEO IWS 5A, Advanced Development for Underseas Systems Office, "Reliable Acoustic Path Vertical Line Array (RAP/VLA)," 08 October 2008, accessed at http://www.ceros.org/documents/briefings/JOHNSON%20RAPVLA%20SUBPAC.pdf on 18 November 2010; and Briefing by CDR Alan Boyd, PEO IWS 5ADEP, Advanced Development for Undersea Systems Office, 2009 National Defense Center of Excellence for Research in Ocean Sciences Industry Day, 14 September 2009, accessed at http://www.ceros.org/documents/FY09%20Industry%20Day%20Briefings/Boyd%20IWS5A%20FY10.pdf on 18 November 2010. On the key performance parameters for RAP/VLA and DWADS, the range of institutions involved in their development, and current and projected funding levels, see the RDT&E Project Justification for Project 3197 *Undersea Superiority* in the Navy's Proposed Fy 2011 Budget, February 2010, pps. 33-35, accessed at http://www.dtic.mil/descriptivesum/Y2011/Navy/0603561N_PB_2011.pdf on 18 November 2010.

prosecute or hold at continuous risk those contacts it could commit scarce tactical assets such as P-3s and SSNs, but it did not need to commit those assets to maintain the basic track.[13]

Simply establishing an acoustic trip wire around the first operating environment will not recreate this scenario. Chinese submarines that cross the trip wire during peacetime or in a crisis will not be attacked, and once past the barrier, will blend back into the background noise of the vast western Pacific basin. This presents a choice to the U.S. Navy as to how it wants to prepare for a scenario in which Chinese SS/SSGs are already deployed outside of the first operating environment when a conflict begins.

One approach would be to accept that some number of Chinese submarines would initially deploy out into the Philippine Sea and be lost to any surveillance capability. This would mean that U.S. battle groups operating in that area would have to use speed, radar flooding, their ASW escorts, and a myriad of tactical deception techniques to deny targeting solutions to submarines whose positions were unknown. At its core, this situation is analogous to that which the British faced around the Falklands. The British never knew where the sole Argentine submarine they faced was located, so they constantly had to exercise essentially defensive measures which they hoped would be sufficient to frustrate the efforts of the opposing submarine to obtain a fire control solution. In the end, those measures appear to have been sufficient, but it is important to note that in this scenario the British had to be willing to enter an operational/tactical ASW environment in which the opponent had the initiative. On the other hand, the opponent in that case lacked a capability to cue its submarine's search for the high value British naval assets. I now turn to the question of whether and how the Chinese might seek to provide such cueing and how the U.S. might seek to deny it.

Chinese Ocean Surveillance. Submarines, and particularly diesel submarines, benefit greatly from cueing that allows them to get into position for attacks without extended high speed runs, and cueing also enables concentration, whereby several or more submarines are able to attack simultaneously. Cueing is even more advantageous, if not necessary, for submarines launching anti-ship cruise missiles (ASCMs). Such cues in turn are generated by surveillance systems, systems which stare at or repeatedly revisit an ocean area with sensors that are able to detect ships, identify them, and locate them with the precision and timeliness needed for them to be attacked. In many cases, different systems divide the labor of detection, identification, and/or location, in which case each may become a necessary but not sufficient source of effective cueing. And in many cases, some systems perform well in peacetime or in a crisis, but become terminally vulnerable once a conflict has begun.

Taking the second point first, powerful airborne radars deployed on long endurance maritime patrol aircraft are excellent stand alone anti-ship surveillance systems, but they are not effective in contested air space and require bases. Thus, an obvious step might be

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[13] To be clear, I am looking at the worst case here. Many submarines in the current Chinese fleet exhibit pronounced tonals in their acoustic signature. Furthermore, more advanced submarines that begin life without tonals can acquire them if they are not maintained to the exacting standards required.

to put such radars on satellites. But satellites are very power-limited and it is very difficult to build "real aperture" radar satellites whose ground coverage is wide enough to assure overlapping coverage from orbit to orbit.[14] Low earth orbit (LEO) satellites also lack persistence, which means that large constellations are needed to assure regular coverage of any particular ocean area. And finally, satellites themselves, and particularly those in LEO, are vulnerable themselves, as has been so dramatically demonstrated recently by both the Chinese and the U.S.

Different sensors also display different strengths and weaknesses. As noted above, some sensors are excellent at providing an initial detection and track but ineffective at identification and/or location. For example, radars are excellent at detecting moving targets but can only provide crude images of them if at all. Optical sensors can image moving targets as well as fixed targets, but require a cue to do so because of their relatively narrow field of view. Some sensors operate day or night and/or in all weather, whereas others may be limited by cloud cover. Some sensors assume a cooperative adversary, such as a signals intelligence (SIGINT) system which can only function if the target uses radars and/or radios. And finally, different sensors have different vulnerabilities to passive and active counter-measures.

Broadly speaking, radar and SIGINT have been the primary ocean surveillance sensors. SIGINT, to include COMINT (communications) and, later, ELINT (radars), played a huge role in both World Wars and the Cold War. But SIGINT is difficult to assess in a forward looking view because it always requires a cooperative adversary. For example, code breaking has often resulted in stunning COMINT successes, but it is impossible to project that such successes will always be repeated in the future. Likewise, radars and radios obviously play a central role in naval warfare, but it is definitely possible to greatly reduce if not eliminate one's exposure to opposing SIGINT by taking extensive emission control (EMCON) measures.[15]

If we focus on radar for the time being, the choice is between ground-based over-the-horizon/backscatter (OTH/B) radars, airborne radars, and satellite radars. We know that China is experimenting with OTH/B, that it has not heretofore made major investments in either long range maritime patrol aircraft like the American P-3 (or modern, long range

[14] I mean here real aperture as opposed to synthetic aperture radar (SAR). SAR radars require much less power than real aperture radars because they compensate with a much wider, virtual antenna. This is why SAR satellites have been in space for years. A SAR satellite is essentially an all weather imaging satellite and is not useful for surveillance because like all imaging satellites it needs a cue to focus. The Soviet Radar Ocean Reconnaissance Satellite (RORSAT) system was a real aperture radar powered by a nuclear reactor. The U.S. has tried and failed twice to develop solar-powered, real aperture, or in the more common parlance, moving target indicator (MTI) radars. On the U.S. history, see Dwayne Day, "Radar Love: the tortured history of American space radar programs," The Space Review, January 22 2007, accessed at www.thespacereview.com on 16 November 2010; and Jeffrey Richelson, "Ups and Downs of Space Radars," Air Force Magazine, January 2009, pp. 67-70. Current solar array technology may be sufficient to address this problem, but battery power, weight, and life will remain challenges for solar-powered radar satellites. See U.S. Congressional Budget Office, Alternatives for Military Space Radar, January 2007, pp. 14-15.

[15] For a brief discussion of U.S. EMCON procedures during the late Cold War, see Norman Friedman, *Seapower And Space* (U.S. Naval Institute Press, Annapolis, MD: 2000) pp. 193-198.

ASCM aircraft like the Soviet Backfire), and that we can expect the already robust Chinese effort in space to include attempts at radar satellite development in the future. If we also assume for the time being that the U.S. will re-focus on EMCON procedures, updated appropriately with modern technology where the opportunities exist, than we can frame the discussion of Chinese ocean surveillance as primarily OTH/B in the near term, and perhaps satellite radar in the mid to longer term.

OTH radars are not a new technology. They use the same skywave propagation phenomenon that High Frequency (HF) radios use to achieve very long range, and were first developed early in the Cold War, initially as a ballistic missile warning system. Modern OTH radars include the Relocatable OTH Radars (ROTHRs) developed by the U.S. during the late Cold War, and used now in the drug war, as well as the Australian Jindalee system. OTH radars use Doppler to distinguish ships and aircraft from background clutter and their coverage consists of an annular ring that starts some 1000 miles from the transmitter and extends out to 1500 miles. Coverage will vary over the course of 24 hours because the electron densities and heights of various ionospheric layers are affected by both weather and solar activity.

Under normal circumstances, OTH radars have little or no capability to distinguish one aircraft or ship from another, and would therefore require another sensor for classification. Chinese experiments with OTH radars first gained serious attention in the U.S. when Australian researchers associated with Jindalee demonstrated how OTH radars could be used to identify aircraft carriers by noting the constant appearance and disappearance of multiple aircraft tracks around one vessel. More recently, the focus on Chinese OTH radars has increased significantly because it is viewed as the major source of targeting information for the DF-21 anti-ship ballistic missile (ASBM) that is also under development.

Little is known about actual Chinese progress with OTH/B. As in many other areas, assumptions must be made based on western practice. Formidable signal processing techniques need to be developed simply for an OTH/B radar to function at all, never mind to have it function against a complicated target set in the presence of active jamming. For the purposes of this discussion I will assume that Chinese OTH/B radar is or soon will be as effective as its western counterparts; that such radars are vulnerable to a variety of jamming techniques, but that those techniques can in turn be countered with even more sophisticated electronic counter counter-measures (ECCM), and that to assume successful jamming would therefore be to assume a cooperative adversary; and that as large, soft, fixed targets which must be deployed within 1500 miles of the ocean spaces to be surveilled, such radars are inherently vulnerable to conventional precision attack by cruise missiles. Thus, Chinese OTH radars will be assumed effective unless they are physically attacked.[16]

[16] These are heroically conservative assumptions. My intent is not to argue that they are realistic, but to show below that even with these assumptions it is possible to come up with means of denying the Chinese submarines success in their second undersea warfare objective.

This would provide an excellent anti-carrier cueing capability to Chinese submarines in the second operating area, and would put great stress on American decision-makers contemplating the deployment of carriers into the Philippine Sea or the southern South China Sea in a crisis. This is not because the U.S. would lack options for dealing even with effectively-cued Chinese submarines. In fact, potential near term U.S. capabilities in this regard are normally grossly underestimated. The problem was alluded to above in the context of the British experience in the Falklands – the U.S. would not be in full control of its exposure to Chinese submarines in any scenario where the latter had the initiative to take the first shot or shots, and where terminal defenses carry the main burden of protection against those initial salvoes. This is not an operational/tactical situation that any element of the U.S. military chooses if it can be avoided. It becomes particularly difficult in the relatively unique case of a conflict where the U.S. finds itself drawn into a conflict between China and one of its neighbors, presumably over issues that are vital to the local actors but significantly less so for the U.S.

There are several ways to argue that I am exaggerating U.S. vulnerabilities. U.S. ASW escorts are formidable enough in deep water such that Chinese submarines might not be able to get into attack position undetected, and would also be unlikely to survive their exposure if they were able to conduct an attack. Also, a conflict would not simply end after even a successful attack against a single or even several U.S. battle groups, and of course the barriers through which Chinese submarines have to pass to and from the second operating area in a more protracted conflict would become much less congenial once that conflict had started. Nevertheless, if the U.S. decided to send carrier battle groups into the second operating area under these circumstances, there would be tremendous pressure on American political leaders to strike Chinese OTH radars so as to deny cueing to Chinese submarines.

Certainly, the U.S. has the capability to strike these radars effectively with submarine-launched cruise missiles. And certainly the U.S. would be justified in attacking those radars if China had begun using land-based ASBMs to attack U.S. carrier battle groups. The difficulty would arise in a crisis or in a conflict that had remained limited to the sea, such as the canonical mine warfare coercion campaign against Taiwan described above. In order to dampen the danger of escalation that would exist in any conflict between nuclear-armed powers, the U.S. would like to avoid being the first to launch strikes ashore, but it would also face a situation not unlike that which the U.S. Sixth Fleet faced in the Mediterranean during the Yom Kippur War in which it would have great difficulty managing its exposure to the opponent's initial salvo.[17]

Conclusions Regarding the Near Term Balance

Assumptions regarding political will end up dominating an assessment of the near term undersea balance. Specifically, if China seeks to use submarines to coerce one of its neighbors and deter U.S. intervention on behalf of that neighbor, it will be the balance of wills in both cases that will most determine the outcome. If the target of Chinese coercion is divided politically over its relationship with China, then a fairly rapid, successful

[17] On this case, see the chapter on the '73 war in Joseph F. Bouchard, *Command in Crisis: Four Case Studies* (Columbia University Press, New York: 1991).

coercion campaign becomes more plausible, and there is very little that the U.S. could do to counter such a short campaign even if it was completely undeterred by Chinese submarines and other sea denial measures. That is because the U.S. can do little to stop an initial sortie by a large portion of the Chinese submarine fleet.

If the target of Chinese coercion is more robust politically, then it is more likely that a coercion campaign would induce a nationalist response and the ensuing conflict would become more protracted. All aspects of the undersea balance improve from a U.S. perspective in that case. Chinese submarines would have to run several times in each direction through SSN barriers near their home bases, and through the barriers established at the exits from the first operating area, where they would be prosecuted by patrol aircraft and surface combatants. The exchange ratios in both types of barrier would likely favor the U.S., perhaps significantly.

Yet, as in the case where the coercee is politically weak, if U.S. stakes in the conflict are low and its aversion to risk high, U.S. decision makers might still be deterred from initially committing carrier battle groups to the second operating area. Reasonable people will disagree over the consequences of such an outcome, or the perception in the region in advance of a conflict that such an outcome was likely. Importantly, and unlike the case where the coercee is politically weak, there are steps the U.S. could take that would make successful deterrence of even a weakly committed U.S. unlikely. There are also steps the U.S. could take that would leverage areas of enduring advantage to increase the threat that U.S. submarines pose to mobile, anti-access targets in China, and decrease the threat that a future Chinese ocean surveillance radar satellite system would pose to American naval forces.

Today's Balance, Competitive Strategy, and the Future Undersea Balance

The main step that the U.S. could take to further reduce or even eliminate the threat posed by quiet Chinese diesel submarines in the second operating area is to maintain persistent, overt, active trails of them once they have passed through the barriers separating the two operating areas. Such a step would not necessarily be an example of a competitive strategy, because it would be relatively asset-intensive, but it would greatly increase the odds that the U.S. Navy would prevail in the "battle of the first salvo" that would likely begin a conflict with China.

The U.S. also has at least two means of generating additional areas of military competition with China that would be relevant to the undersea balance where the imbalance in resources expended by both sides would favor the U.S. The first new area of competition would be between U.S. submarines and Chinese mobile anti-access systems such as modern surface-to-air missile (SAM) batteries. The second would be a competition to see which party could become least militarily dependent on satellites in general, and particularly those in low earth orbit.

On the other side of the balance, the Chinese could decide to give their submarine fleet additional missions, and attempt to reduce its vulnerability to existing and planned U.S. ASW capabilities. In the former case, China might expand its commitment to ballistic and cruise missile submarines, for nuclear deterrence, conventional land attack, and/or anti-ship operations. In the latter case, China might seek to develop further its nuclear submarine technology with the aim of achieving a truly quiet boat.

Improving Today's Balance

Holding Chinese submarines at risk once they enter the second operating area would have obvious benefits. The U.S. would either know where the submarines are at all times, or know where to concentrate ASW assets to search for and reacquire those submarines that somehow escaped an active trail. The assets engaged in active trailing would be very close to a fire control solution on their targets and could therefore prevent them from approaching and attacking American battle groups, or in cases where they were allowed to get close, launching more than one weapon. Most importantly, the political threshold for attacking submarines trying to get into firing position against U.S. battle groups would be much lower than for attacking the land-based radars used to cue those attacks. With such a capability, the U.S. could effectively manage its exposure to risk if it deployed carrier battle groups into the second operating area in a crisis or early in a conflict with much less concern about escalation.

The U.S. already has ASW assets that could perform this mission. The problem is either that those assets are scarce, multi-mission platforms that are the sole means of performing other important missions; or that they are dependent on the use of expendable sensors which could be exhausted in a protracted crisis or conflict.

For example, a DDG-51 with the latest version of the SQQ-89 ASW combat system can combine its powerful mid-frequency bow sonar, multifunction towed array, and two SH-60Rs with active dipping sonars in bi or multistatic modes. This creates an ability to maintain an active trail of even the most modern diesel submarines at standoff ranges of at least 30 miles and, if necessary, maintain a continuous or near continuous fire control solution with its helicopters. The problem is that DDG-51s are also primary fleet air and missile defense assets, as well as cruise missile shooters, and they can only be in one place at a time.

Likewise, P-3s and, soon, P-8s equipped with advanced, active, multistatic acoustic systems have regained the effectiveness in deep water operations that they lost when their mostly passive systems were first faced with truly quiet diesels such as the 636 Kilo. The problem is that these systems also arguably provide the most effective shallow water ASW search capability in the U.S. inventory. Additionally, all fixed wing air ASW assets are dependent on expendable sonobuoys for the acoustic side of their mission. Advanced multistatic systems use sophisticated buoys like the AN/SSQ-125 and the AN/SSQ-101 which may be difficult to procure in numbers sufficient to sustain continuous trails, as opposed to pouncing operations where contact on the target is maintained only as long as it takes to attack it, or for a more persistent surface ship to arrive and take over the trail.

For all these reasons, the U.S. should look carefully at both the numbers and, perhaps more important, the capabilities of the Littoral Combat Ship's (LCS) ASW module and the sea frame itself. Contrary to many expectations, American surface ships will not play much if any ASW role in the shallow waters of the first operating environment in a conflict with China, but the LCS's ASW suite is optimized for a shallow water environment. The sea frame lacks a mid-frequency sonar like the SQS-53 or 56 and it is not currently planned to deploy towed arrays. On the plus side, LCS will have a tremendous air operations capability and its often-maligned 50 knot top speed will, if combined with a torpedo warning system, reduce its vulnerability to wake homing torpedoes.

New, More Favorable Areas of Military Competition

Of the two proposed new areas of military competition, the submarine versus air defenses competition is directly relevant to the undersea balance as I have defined it, and I will spend the most time explaining this option. The proposed competition to reduce dependence on LEO satellites is of more general relevance and my discussion of that option will be shorter, but it will provide an opportunity to assess in a little more detail the Chinese ASBM threat and methods of countering it.

U.S. Submarines Versus Chinese Air Defenses. Most Chinese anti-access systems are land mobile. Mobile, precise land attack weapons can evade the U.S.'s crushing ability to destroy fixed targets while simultaneously holding at risk the U.S.'s ability to use land bases. And as discussed above, combined with an ocean surveillance system and a terminal guidance capability, land mobile missiles can also hold U.S. naval forces at risk.

The last 20 years of near constant combat operations have shown unequivocally that defeating mobile targets requires a persistent network of surveillance sensors and strike assets. Unlike traditional fixed targets that can be targeted well in advance of a conflict, mobile targets can normally only be found and targeted when they generate a specific signature associated with their mission. These signatures (and the sensors needed to exploit them) range from simple movement (moving target indicator {MTI} radar), operating internal combustion engines or high powered electrical equipment (long wave infrared {IR}), rocket or jet exhausts (medium wave IR), or radio and radar emissions (passive radio-frequency {RF}).

Persistence is the key concept. In the surveillance realm it means sensors or sensor networks that can approximate an unblinking, wide area stare, while in the weapons realm it means weapons that combine range, speed and basing mode in such a way that they are always available in timely fashion. Surveillance sensors need to be persistent because the mobile target signatures they exploit only occur intermittently, and the weapons need to be prompt because striking mobile targets is usually only possible when they are stationary. Thus, for example, if a targeting solution will only last for 20 minutes, the weapon to exploit it should not be more than 20 minutes away.

In the access-unconstrained environment that has characterized the war on terror this has led to an explosion of unmanned aerial system (UAS) use as a source of persistent surveillance. Air breathing surveillance platforms will likely remain the primary sensor platform for dealing with mobile targets.

The problem is that modern air defense systems will eliminate the sanctuary that airborne sensor platforms currently enjoy. To be specific, the increased missile range associated with modern “double digit” surface-to-air missile (SAM) systems will force airborne radar platforms like JSTARS, U-2, and Global Hawk to stand off beyond the range of their radars and will prevent airborne electronic intelligence (ELINT) platforms like RC-135, EP-3, and Global Hawk from geo-locating RF emissions with precision.[18]

Absent these persistent surveillance capabilities, it is impossible to deal with mobile targets, so dealing with double digit SAMs is a major anti-access challenge. The problem is that current approaches to destroying modern double digit SAMS all depend on land and sea-based tactical fighters whose access to the theater presumes a prior solution to the access denial challenge posed by mobile, precision land attack and anti-ship missiles. This in turn presumes persistent airborne surveillance, which in turn presumes a solution to the double digit SAM problem.

This vicious circle is one of the cores of the future access denial problem. Submarines have become uniquely capable of breaking this vicious circle because of the relatively recent development of time and frequency-difference-of-arrival (T/FDOA) ELINT signal processing techniques that can now be implemented using networks of even the smallest tactical UAS. Combined with a submarine’s traditional ability to provide a stealthy and persistent source of weapons in even the most access-constrained littoral environment, an organic UAS will provide submarines a fully organic capability to detect, identify, precisely locate, and quickly strike modern SAM engagement radars.

The unique benefit provided by T/FDOA is that it enables ELINT with sufficient precision to target modern strike weapons that use the global positioning system (GPS) for guidance. A single RF receiver, no matter its aperture, can never by itself produce a targeting solution for such weapons because it has no means of compensating for the inherent errors in angular resolution that characterize its bearing measurements when used to triangulate the location of an emitter.

True T/FDOA networks do not need to use bearing measurements to locate an emitter. Instead, two widely separated receivers are used to precisely measure and compare the time of arrival and frequency of the same signal pulse from an emitter. Roughly speaking, each set of measurements produces a hyperbolic line on the ground along which the emitter must lie and the two lines only intersect at one point.

T/FDOA is computationally intensive and legacy T/FDOA ELINT networks therefore still needed to use large aperture antennas and accurate bearing measurements to achieve a targeting solution in a dense signal environment and a tactically relevant timeframe. The Defense Advanced Research Projects Agency’s (DARPA) Advanced Tactical Targeting Technology (AT3) program successfully demonstrated T/FDOA signal

[18] The best unclassified source on double digit SAMs is *Jane’s Land-Based Air Defense, 2009-2010, 22nd Edition* (Jane’s Information Group, Alexandria, VA: 2009) pp. 214-215, which cites a range of over 200 miles. JSTARS’ MTI radar is cited as having a range “in excess of 124 miles” in “Air Force Almanac,” Air Force Magazine, Vol. 93, No. 5 (May 2010) p. 131.

processing that exploited the vast computational power now available in even the smallest package. AT3 enables the formation of a true T/FDOA ELINT network using very small omni-directional receivers deployable even on very small UAS.

This makes an enormous virtue out of what would have been a big vice for a submarine-deployed UAS. Smaller is better for the nodes in an AT3 network because AT3 accuracy, though always much better than traditional, single platform, angle-of-arrival techniques, still varies with the nodes' range from and their relative separation in azimuth to the emitter. Small size and slow speeds create stealth and allow small UAS to get close and maximize accuracy.

An added benefit of AT3 is that it works equally well against an emitter that only emits briefly and intermittently. This is important because modern SAM engagement radars are designed to operate in this way to eliminate their vulnerability to anti-radiation homing missiles such as the high speed anti-radiation missile (HARM) that depend on a continuous signal to destroy those radars.

A fast, coordinate seeking weapon is equally important for DEAD from under the sea. Once a modern SAM engagement radar has begun an intercept, it will have exposed itself and a clock starts ticking until the engagement is complete, the radar can break down, and relocate to another operating site. AT3 can quickly locate the radar as soon as it emits, but that will be of no use if a weapon only arrives after the radar has relocated. Air breathing weapons cannot provide such promptness from any kind of standoff distance but tactical ballistic missiles (TBMs) can.

Like AT3-equipped UAS, a GPS-guided TBM can be acquired off the shelf and deployed in existing submarine and surface combatant launchers for immediate experimentation and initial operational use in the war against terrorism. A TBM based on Standard Missile could provide a range of 300 miles and be traded one-for-one for Tomahawks, and a TBM based on the GPS-guided multiple launch rocket system (GMLRS) could provide a range of 50 miles and be traded several for one. Over the longer term, a new TBM could be developed that might build on the DARPA long range anti-ship missile (LRASM) program's investments in precision guidance in a GPS-denied environment.

Submarines equipped with organic, AT3-equipped UAS and TBMs may provide the only way to perform DEAD in an access-constrained environment. They constitute the only potential source of DEAD capability that is as persistent as the airborne surveillance platforms in need of continuous protection, they are the only platform assured access in even the most contested littoral environment, and they are the only platform whose DEAD capability would itself be immune to the air defenses it would be attacking.[19]

Of course, in addition to its direct benefits, a submarine-based DEAD capability would greatly expand the threat posed by U.S. submarines to China's overall military objectives

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[19] For a fuller discussion of submarine-based DEAD see, Owen R. Cote Jr., "Submarines in the Air Sea Battle (U)," Paper Presented to Submarine Technology Symposium 2010, Johns Hopkins University Applied Physics Laboratory, May 11 2010. <http://web.mit.edu/ssp/publications/conference.html>

in a conflict with the U.S. From a competitive strategies perspective, this would likely have one or both of two very positive effects for the U.S. First, it would greatly increase deterrence in that there is little in the near term the Chinese could do to counter such a capability. Second, should the Chinese decide in the longer term to try and counter this capability, it would force them into major investments in shallow water ASW against very quiet, fast, nuclear submarines. This is a mission area where the ratio between input and output is among the lowest, and even if the investments were made, success would not be guaranteed.

Which Side Can Become Least Dependent on LEO?

As discussed above, cueing is important for submarines seeking to engage fast surface targets in the open ocean, and denying such cueing is thereby an important ASW measure. Today, Chinese OTH radar provides the best near term source of such cueing against American carriers and other surface combatants in the second operating environment. But all OTH radars are inherently vulnerable to physical attack, and basic bi-static OTH radars like the current system in China are vulnerable to electronic attack and spoofing.[20] Thus, many analysts reasonably predict that China will seek to develop radar ocean surveillance satellites. I discussed above some of the technical issues associated with such a development. In this discussion, I will first show why the Chinese might be motivated to pursue development nevertheless, for reasons additional to the need for submarine cueing, and then discuss how the U.S. might respond.

In addition to the need for submarine cueing, the Chinese need to develop a means of targeting its ASBMs if and when the latter reach operational status. There has been much helpful discussion of this issue in the past year.[21] One issue that is rarely fully discussed regards the inherent target location error (TLE) associated with the various candidates identified as potential sources of Chinese ASBM targeting. Whatever TLE is it adds to the area of uncertainty already created by shooting a ballistic missile at a moving target and the inevitable delays caused by centralized command and control. In the case of both OTH radar and space-based SIGINT, the two candidates most often mentioned, TLE can be quite large.

For example, because an OTH radar operates at 3-30 mHz in the HF band it has inherently low resolution in both range and azimuth. Thus, an OTH radar's range resolution is never going to be less than 10 km, and even with a 1500 meter antenna diameter, its angular resolution will not be less than 1 degree, and a 1 degree error in azimuth against a target at 1500 miles is 40 km. This number can be reduced by deploying multiple, spatially separated OTH radars covering the same area, but it will remain at least as large as the error in range resolution.

[20] More complex multi-static OTH radars would be the next step in the ECM-ECCM contest. They would reduce the vulnerability to jamming and spoofing, but would remain physically vulnerable.

[21] See, for example, Andrew S. Erickson and David D. Yang, "Using the Land to Control the Sea: Chinese Analysts Consider the Antiship Ballistic Missile," and Eric Hagt and Matthew Durnin, "China's Antiship Ballistic Missile: Developments and Missing Links," *Naval War College Review*, Vol. 62, No. 4 (Autumn 2009; and Marshall Hoyler, "China's "Anti-Access" Ballistic Missiles and U.S. Active Defense," *Naval War College Review*, Vol. 63, No. 4 (Autumn 2010).

This is why the Chinese will likely develop a real aperture, MTI radar satellite constellation in LEO if they are serious about ASBMs. MTI radar satellites would provide much better geolocation capabilities than OTH radars, and unlike ELINT satellites, would not be vulnerable to EMCON measures. MTI satellites might still need some help with classification, but imaging satellites could do this once provided the all important initial cue by the MTI network.

Even assuming the technical solution of all the challenges described above, MTI satellites would still have some potential weaknesses. All radars are vulnerable to main lobe jamming when the jamming transmitter is more powerful than the radar transmitter, thus in any contest between a surface or ship-based jammer and a space based radar, the satellite will lose. But a jammer will only get access to a radar satellite's main lobe from a relatively limited area, making the jamming signal itself a powerful cue as to the target's location. This is why radar designers worry less about main lobe jamming than side lobe jamming, which exploits the fact that radar antennas do not perfectly focus the energy they transmit or their reception of incoming signals. Instead, some energy from the transmitter leaks out to the side of the main beam, and some energy can leak in from the side. If a satellite is vulnerable to side lobe jamming it becomes incapable of determining even the rough position of the jammer because it can not tell the difference between signals that come in through the main lobe versus the side lobes. Thus, western radar designers have developed very sophisticated techniques for "nulling" or blocking the side lobes of an antenna (and ELINT system designers are always trying to develop passive sensors that can detect side lobe as well as main lobe emissions). This remains an area of significant U.S. technical advantage.

One can imagine an ECM-ECCM race in this area as with OTH radar. If the Chinese can solve the side lobe nulling challenge, the U.S. could resort to main lobe jamming and force the Chinese to deploy additional assets in LEO that could locate the jamming signal and cue an optical imaging satellite that could determine the location of the carrier inside the area of denied reception. One might at great technical risk try to put all this capability on one type of satellite, i.e. an MTI radar, an ELINT capability that could roughly locate the jammer, and an electro-optic camera, or one could do as the Soviets did and provide these three functions using separate satellite constellations. Of course, the command and control of such a complicated constellation, including all of the uplinks, downlinks, and crosslinks required would also provide ample electronic warfare opportunities for a technically advanced opponent like the U.S.

Essentially all of these ocean surveillance, identification, location, and targeting functions can be done better from airborne platforms, assuming one has control over the relevant air space. Airborne radars can be given a much better power-aperture product than space-based radars, they are much less costly so that they can be deployed in much greater numbers, which more than compensates for the reduction in radar horizon involved. And of course, a reduction in radar horizon also translates into a reduction in the area from which a jammer can get line-of-sight to an airborne radar's or communication relay's side or main lobes. Indeed, this is the approach that the U.S. has largely taken, and it is incidentally the approach the Soviet Union came back to after the U.S. adopted strict

EMCON procedures for its carrier battle groups in the late 1970s and 1980s. High Altitude Long Endurance (HALE) UAVs that combine radar, SIGINT, and optics, like the Navy's Global Hawk-derived Broad Area Maritime Surveillance (BAMS) system, represent the future of this approach.

This combination of control of the air, assured in the end by carrier aviation, and distributed, persistent airborne surveillance by manned platforms like the P-3 and the P-8 and now unmanned platforms like BAMS, constitutes a huge asymmetry going forward between the U.S. and China. That is because in the end, the U.S. does not need access to LEO to control the seas that constitute the second operating area, while the Chinese will likely need access to LEO simply to contest control of those seas, never mind control them.

This directly raises the difficult question of LEO as a sanctuary in any conflict between China and the U.S., both of which have just recently demonstrated direct ascent anti-satellite (ASAT) capabilities. Few assumptions are more widely and firmly held than that which says the U.S. military is much more dependent on access to space than any of its potential adversaries, including China. This in turn leads to the belief that the U.S. would never be the first to use ASATs in a conflict because it would have much more to lose, much as people argued that it would be folly for the Royal Navy to introduce submarines at the turn of the 20th century when it had uncontested control of the sea surface.

Given the significance of this issue, it is worthwhile to unpack some assumptions about who uses space, what they use it for, and what part of space is used. The U.S. Intelligence community is the dominant user of space by far, and it is especially dominant in the use of LEO. It uses LEO primarily for imaging and ELINT in denied areas and deploys dozens of satellites for those purposes. These satellites are also now used extensively in support of the U.S. military, but in many cases because they are available, not because they provide unique capabilities. Also, a fairly large commercial space imaging industry has developed, using much cheaper EO and now SAR satellites with less resolution than the intelligence community demands, and DOD has become a big user of those services because their capabilities are sufficient and, because of classification issues, it is much easier to gain access to their products and distribute them widely. Space-based COMINT is done by the intelligence community from geosynchronous orbit (GEO), as is DOD's IR-based missile warning, and almost all satellite communications by any user. DOD GPS navigation satellites are in medium earth orbits (MEO). Finally, as noted above, DOD has tried twice and failed to jointly develop and deploy an MTI radar satellite constellation in LEO with the intelligence community.

Two things stand out from this outline. First, LEO is certainly used for military purposes but in most cases because the satellites in question are already there, not because they are the only source of IMINT and ELINT, both of which can be and are being done equally well with air breathing platforms in all but the most denied areas. Second, much, if not the majority, of both DOD's and the Intelligence Community's use of space occurs above LEO, in orbits that are immune to currently deployed direct ascent ASATs. These orbits are not immune from any conceivable ASAT attack, but the systems needed would be much more expensive, and would likely provide some considerable warning of their use.[22] And third, many of these uses of space are not a reflection of what is necessary, but of what was necessary. For example, DOD first got into the satellite communications (SATCOM) business in order to establish trunk lines to South Vietnam which lacked access to undersea cable telecommunications in 1965. Later, it got into UHF SATCOM so that Navy ships at sea could eliminate their dependence on HF radio. Today, commercial, trans-oceanic fiber-optic cables have become ubiquitous, and networks of HALE UAVs used as communication relays could solve the "last mile" problem from a fiber cable head end throughout much of the global littoral space.

From DOD's perspective, and more specifically from the U.S. Navy's perspective, it is worth asking whether the conventional wisdom about which side is more dependent on space, and on LEO in particular, is correct. More to the point, it is worth asking how much any current dependencies in this regard are inescapable under modern technological and operational conditions, or merely a legacy of the past, and in the case of the inescapable ones, how hard it would be to repair or replace them should they be lost.

This becomes a subject for another discussion but the consequences regarding a possible future Chinese MTI radar satellite constellation are obvious. Such a constellation will likely provide a necessary part of future Chinese efforts to contest control of the seas in the second operating area. This will require great investments and these investments, if they are made, will likely be based on the assumption that LEO is a sanctuary. If the U.S. is able to render that assumption obsolete after the system is developed it will likely have accomplished a major coup of competitive strategy.

New Missions For Chinese Submarines And/Or Better Submarines?

Just as I argue that the U.S. could seek new areas of military competition with China by giving its submarines new missions, the Chinese might seek to do the same. But the situation for the Chinese is different because they would not be building on a situation of current or inherent advantage like the U.S. would be. New, larger and longer range SSBs and SSGs would still be vulnerable to U.S. acoustic barriers and to overt, active trailing if they sought to exit the first operating area. Likewise, new SSBNs or SSGNs that were no more acoustically stealthy than the best current nuclear submarine, the Shang, would still be vulnerable to traditional, Cold War style, passive acoustic approaches to ASW, whether by American SSNs searching SSBN bastions, or by SOSUS-like systems tracking them in deep water.

Prior to a decision to seek new missions, or the ability to operate much further away from home, the Chinese would almost certainly need to ask the prior question of whether they could make their submarines less vulnerable to American ASW. I would argue that in acoustic terms, they have already reached the point of diminishing returns with regard to quieting their diesel submarines, so there is unlikely to be any way of eliminating the problems described above. So, it would appear that the crucial questions are whether the

[22] On this distinction, see Ashton B. Carter, "Satellites and Anti-Satellites: The Limits of the Possible," *International Security*, Vol. 10, No. 4 (Spring 1986) pp. 46-98.

Chinese could develop truly quiet nuclear submarines, how much such an investment would cost, and what the consequences would be if they were deployed.

Starting with the last question first, truly quiet nuclear submarines would still be vulnerable to detection while exiting and entering their bases, and while transiting between the first and second operating areas. The main difference would be that the U.S. would no longer be able to track them in deep water on an ocean basin-wide scale by systems like SOSUS, and they would be much less vulnerable to either covert, passive or overt, active trails. Once in range of a carrier battle group, the consequences would be less significant, because battle group ASW escorts have all already made the transition to bi or multi-static, active acoustics where the target's acoustic source levels are irrelevant. Thus, if quiet nuclear submarines were simply introduced into the current Chinese submarine mission set, replacing the fleet of Shangs on a one-for-one basis, the consequences would not be positive from a U.S. perspective, but they would not be revolutionary either because they would essentially return the U.S. to the position it currently occupies, in which the basic problem is risk management early in a conflict, not the ultimate outcome of a conflict.

But if one posits the addition of new missions and/or expanded deployment areas on top of the development of truly quiet nuclear submarines, then the consequences become more dramatic. Nuclear submarines that can neither be tracked from a distance nor trailed can go wherever they want at high transit speeds. The main remaining source of vulnerability is that they must expose themselves when they use their weapons. As noted above, this will remain a dangerous activity for even quiet nuclear submarines facing the ASW screen of a carrier battle group, but the capabilities of that screen are not replicable across wide areas. Thus, for example, a force of quiet Chinese SSGNs could deploy throughout the Pacific, holding high value, fixed military targets in Alaska, Hawaii, and west coast of CONUS at risk of precision attack. Those attacks will be risk free unless appropriate wide area, active ASW forces are deployed with sufficient density and breadth to protect the entire area. Quiet SSNs could obviously pose a similar threat to commercial shipping of all sorts. Alternately, a force of quiet SSNs could challenge a distant blockade of Chinese shipping by American surface ships operating on the Indian Ocean side of the approaches to the Malacca and Sunda Straits.[23] By comparison, quiet Chinese SSBNs would probably be the least of the U.S.'s concerns under the circumstances.

Looking at this scenario from a competitive strategies perspective, the Chinese would need to commit at the outset to what would be both an extremely expensive and still technologically uncertain program of nuclear submarine quieting, in return for the prospect of imposing the larger costs associated with wide area ASW against quiet targets when geography doesn't provide natural chokepoints or focal areas. As noted above, this is a different decision than the one faced by the U.S. Navy and its submarine force when they contemplate new submarine missions. The U.S. has already demonstrated, since the

[23] For an analysis of such a distant blockade, see Douglas Peifer, "Power Projection Versus Distant Blockade: China, the German Analogy, and the New AirSea Operational Concept," *International Security*, forthcoming.

introduction of the Thresher/Permits fifty years ago, the ability to establish and consistently maintain significant acoustic advantages for its nuclear submarines in a competition with a peer competitor, and as a result have already reached absolute levels of silencing such that their passage at close range can actually cause a dip in noise levels because background noise is being blocked by the submarine's hull.

The Chinese are still far from that position, but as in other areas, it would almost certainly be a mistake to assume that they won't eventually get there if they decide to try. There has never been a naval competition between great powers both wielding fleets of quiet nuclear submarines because the Cold War ended before the Soviets could fully participate in their half of the competition. On the other hand, should such a competition occur between the U.S. and China, it would also be the first competition between two submarine-equipped great powers both of whom were also dependent upon the sea. In the end, uncertainties abound as to how these competitions might play out, but perhaps the last word should be given to a submariner speaking just before the end of the Cold War:

"Eventually, U.S. and Soviet submarine capabilities will converge. Then we will have to think about different applications for submarines because ASW is only going to become a defensive business for submarines in my opinion. It will be blind man's bluff with other submarines…Many of the other roles for submarines will become more prominent as we go further into the future..."[24]

[24] The submariner was Admiral Kinnard McKee, the second Director of Naval Nuclear Propulsion, testifying about Seawolf. Subcommittee of the Committee on Appropriations, U.S. House of Representatives, *Department of Defense Appropriations for 1987*, Part 4, April 1986, pg. 456.