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Developing a Family of Analytical Tools for Seabasing Analysis

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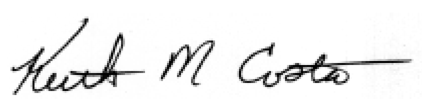

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Contents

Introduction and summary

The Family of Seabasing Analysis Tools is a CNA-initiated project started in April 2006. Our initial objective was to identify a consistent set of inputs for several existing analysis tools and to begin the process of refining and developing new tools that address a wide range of seabase functions. Our near-term goal is to adapt pre-seabase models to the new seabasing concept, and our long-term goals are to develop new tools where no existing model exists and then to build an integrated family of models that tie together the closure, arrival and assembly, employment, sustainment, and reconstitution of sea-based forces.

This paper describes our analysis of several, key seabasing areas and the modeling implications of that analysis for developing new seabasing analysis tools. We highlight several companion reports:

- CNA Research Memorandum D0016403.A2, A*nalysis of Amphibious Force Closure for Major Combat Operations*, Mar 2008
- CNA Research Memorandum D0016406.A3, *Historical Analysis of LCAC Well-Deck and Beach Times*, Mar 2008
- CNA Research Memorandum D0016387.A3, *Analysis of Aircraft Spotting Factors on L-Class Ships*, Apr 2008

We also discuss our analysis of amphibious shipping capacities and the development of several key seabasing analysis tools.

This paper is organized into two parts: The first discusses research focused on the identification and analysis of key inputs to various seabasing processes; the second addresses our efforts to build several, first-generation seabasing models. We conclude with a synopsis of key lessons learned and modeling challenges we face in developing an integrated set of seabasing models.

Identifying consistent set of modeling inputs

- *LCAC well-deck and beach times.* In 2002, NAVSEA released a publication that described notional well-deck times substantially higher than the ones CNA had used in the past for several amphibious models. Consequently, we examined historical well-deck times based on past CNA exercise data to better understand the loading/unloading/refueling of LCAC and to identify appropriate time-in-well and time-on-beach factors.

- *Aircraft spotting factors.* Our analysis focused on a recently promulgated NAVAIR "Gator" multiple spreadsheet tool that allows users to spot aircraft on the flight and hangar decks of big-deck amphibs. There remains, however, uncertainty about the appropriate deck multiple for individual L-class ships and the operational constraints of parking various aircraft mixes on board. Our analysis focused on the impact that key missions have on the number of aircraft and aviation logistics material that can fit on these ships.

- *Surge rates of amphibious ships.* Over the years, CNA has made different assumptions in various studies about how long it takes to deploy a certain sized force for major combat operations. How many ships can get underway and how fast these ships get underway is a critical determining factor in sea base arrival time lines, as well as the overall responsiveness of a given fleet force posture for a crisis. Our analysis focused on how quickly the Navy has surged ships in the past and what this suggests about the appropriate planning factors for a sea base closure tool.

- *Amphibious ship capacities.* Despite the sensitivity of analysis to assumptions about how many troops and how much equipment and cargo can fit on amphibious ships, there is no single, definitive source of information about amphibious ship capacities and, as a result, different studies have made vastly different assumptions about the amount of vehicles and cargo that amphibious ships can lift. This complicates analysis and leads to possibly erroneous conclusion about the overall amount of lift needed to meet Marine Air-Ground Task Force (MAGTF) requirements. As a result, we developed a set of gross ship lift capacities for a variety of ship classes, so that we could more easily apply broken stow, unit integrity, and pre-boating factors to amphibious ships and develop a common baseline for future modeling and ship capacity analysis.

Updating/refining/creating models for new seabasing process

In addition to re-examining several key planning factors associated with sea base modeling, we developed and refined several seabasing modeling tools:

- *A sea base-to-shore connector tool (SSCT)* that essentially updates the old amphibious analysis tool (AAT) that we developed for the DoN Lift 2+ Study for new seabasing concepts. The revised connector tool has additional ship entities and model logic that allows for skin-to-skin transfer of loads at sea. We have also incorporated improved process logic and updated planning factors based on our historical LCAC research.

- *An LCAC queuing tool* that we built to tell us the effect that well-deck time would have on LCAC surface assault time lines. Our historical analysis of LCAC ship-to-shore time lines has revealed a great deal of variance in how long it takes to load LCAC. A number of factors affect how long an LCAC takes to be loaded and refueled, such as the amount of equipment to be loaded, the amount of fuel that has to be received, the type of refueling/loading that occurs, what is going on with the ship at the time LCACs are loaded, etc. The purpose of this stochastic model is to complement the sea base-to-shore connector tool by providing an estimate of how much longer, on average, an assault might take given the degree of beach and well-deck variance we have historically observed.

- *A sea base force closure tool* that calculates the fleet's surge potential, using current ESG ship schedules, a variety of possible force structures, and historical scheduling parameters as key inputs. The model essentially determines the probability of closing a certain sized force in a given amount of time from a variety of potential starting points, thus allowing a more realistic assessment of the tradeoffs the Navy might make as it attempts to balance its amphibious fleet against some amount of pre-positioned platforms and material.

Future efforts /way ahead

Our analysis highlights the first-step challenges in constructing an integrated sea-based model. This includes the lack of operational data about key seabasing processes, uncertainty about how various seabasing areas impact each other, and a general lack of definition about how new seabasing concepts improve or change old amphibious assault concepts. What's more, there is uncertainty about the general integrated nature of all aspects of the close-assemble-employ-sustain-reconstitute phases of an amphibious assault needs to be worked out. In short, many unknowns have yet to be resolved before we can develop a truly integrated model.

Overall, the study has given us a better sense of the data inputs for key seabasing areas—well-deck operations, aircraft deck spotting, and surge amphibious operations. But we need to know more about how future MAGTFs will conduct arrival and assembly operations from the sea base, how operational missions impact amphibious ship load outs, the consumption rates of ground forces performing different types of missions, and the timing and support requirements of joint forces flowing through the sea base. As a result, we remain wedded in our models to traditional fingerprints of lift—troops, equipment, supplies, and aircraft and LCAC connectors—as our primary means to describe and analyze afloat MAGTF operations. At some future point, we need to incorporate new fingerprints that emphasize the sea base's capabilities to conduct throughput, maintenance, medical, C4I, and tactical resupply operations. Additional research is also needed to determine exactly how these "new" fingerprints complement older, capacity-based fingerprints, as well as the operational challenges of conducting joint force, sea-based maneuver and resupply. This essentially is the modeling challenge we face in our future efforts.

Modeling amphibious ship capacities

This section provides information about the shipping capacities of select amphibious, connector, and prepositioning ships. There is currently no single definitive source of information about amphibious ship capacities. As a result, different studies have made vastly different assumptions about the amount of vehicles and cargo that amphibious ships can lift, leading to possibly erroneous conclusions about the overall amount of lift needed to meet future Marine Air-Ground Task Force (MAGTF) lift requirements.

In this summary, we discuss our attempts to identify a definitive set of gross ship lift capacities for a variety of ship classes. An agreed-upon set of gross capacities would allow uniform broken stow, unit integrity, and pre-boating factors to be applied evenly across amphibious ship studies and lead to a general consistency of effort that has often been lacking.

In table 1, we highlight the gross ship capacities and various command and control (C2) and medical capabilities of select amphibious and prepositioning ships. We used several references to construct this table, which we denote using a color code. In table 2, we provide a key that allows readers to identify the source of a particular set of numbers/characteristics. Overall, the table provides the following information about a number of different ship classes:

- Crew and staff accommodations
- Gross troop, vehicle, and cargo capacities
- Landing craft and aircraft capacities
- Medical facilities
- Specialized storage and C2 functions
- Fuel capacities.

Table 1. Amphibious and prepositioned ship characteristics

Ship characteristics	LHA	LHA-6[a]	T-LHA(R)[b]	LHD	T-LHD[c]	LPD-4	LPD-17	LSD-36	LSD-41	LSD-49	MLP[d]	T-LMSR	T-AKE[e]	T-AK[f]	HSV	JHSV[g]
Crew/staff accommodations	1,043	1,100	189	1,266	206	552	493	426	413	413	60	83	129	28	43	41
Troop, vehicle, & cargo capacities																
Troop bunks	1,902	1,392	2,435	1,964	2,539	883	799	335	504	507	862	267	68	93	140	104
Vehicle (k sq ft)	26.8	29.9	29.9	25.4	20.9	15.5	25.0	19.0	19.0	22.4	50.0	275.0	0	151.8	22.7	22.0
Cargo (k cu ft)	167.9	130.0	130.0	149.5	110.0	52.2	35.6	2.7	6.7	75.9	0.0	81.5	632.0	837.2	0.0	0.0
Landing craft & aircraft capacities																
Aircraft parking spots (MH-60S equivs)	56	84	84	72	72	5	5	1	2	2	0	2	2	1	1	2
Aircraft parking spots (CH-46 equivs)	43	64	64	55	55	4	4	1	2	2	0	2	2	1	1	2
Typical # of a/c operating spots	9	9	9	9	9	2	4	1	1	1	0	2	2	1	1	1
LCAC (or LCAC equiv) spaces	1	3	0	3	3	1	2	3	4	2	6	0	0	0	0	0
JMAC spaces (131 ft length)	0	2	0	2	2	0	1	2	3	1	4	0	0	0	0	0
LCU spaces	4	2	0	2	2	1	1	3	3	1	4	0	0	0	0	0
LCM-8 spaces	4	6	0	6	0	4	4	6	10	4	0	0	0	0	0	0
Medical facilities																
Operating rooms	4	N/A	N/A	6	N/A	1	2	0	1	1	N/A	N/A	N/A	N/A	N/A	N/A
Post-operations/ Intensive care (bunks)	17	N/A	N/A	18	N/A	0	0	1	1	1	N/A	N/A	N/A	N/A	N/A	N/A
Isolation ward (bunks)	4	N/A	N/A	6	N/A	4	4	2	2	2	N/A	N/A	N/A	N/A	N/A	N/A
Primary care (bunks)	48	N/A	N/A	36	N/A	8	24	8	5	5	N/A	N/A	N/A	N/A	N/A	N/A
Special storage and command facilities																
L-FORM	Yes	N/A	N/A	Yes	N/A	Yes	Yes	No	No	Yes	N/A	N/A	N/A	N/A	N/A	N/A
Combat info center (CIC)	Yes	N/A	N/A	Yes		Yes	Yes	Yes	Yes	Yes	N/A	N/A	N/A	N/A	N/A	N/A
Flag plot	Yes	N/A	N/A	Yes		Yes	No	No	No	No	N/A	N/A	N/A	N/A	N/A	N/A

Table 1. Amphibious and prepositioned ship characteristics (continued)

Ship characteristics	LHA	LHA-6[a]	T-LHA(R)[b]	LHD	T-LHD[c]	LPD-4	LPD-17	LSD-36	LSD-41	LSD-49	MLP[d]	T-LMSR	T-AKE[e]	T-AK[f]	HSV	JHSV[g]
Landing Force Ops Center (LFOC)	No	N/A	N/A	No		No	No	No	No	No	N/A	N/A	N/A	N/A	N/A	N/A
Joint Intel Center (JIC)	Yes	N/A	N/A	Yes		Yes	Yes	No	No	No	N/A	N/A	N/A	N/A	N/A	N/A
Supply Arms Coordination Center (SACC)	Yes	N/A	N/A	Yes		Yes	Yes	No	No	No	N/A	N/A	N/A	N/A	N/A	N/A
Tactical Air Coordination Center (TACC)	Yes	N/A	N/A	Yes		No	No	No	No	No	N/A	N/A	N/A	N/A	N/A	N/A
Helo Detection Center (HDC)	Yes	N/A	N/A	Yes		No	No	No	No	No	N/A	N/A	N/A	N/A	N/A	N/A
Fuel transportation capacities																
JP-5 (k gal)	408	1,300	1,300	484	400	289	215	32	53	51	906	227	1,045	971	20	N/A
MOGAS (k gal)	0.5	0.2	0.2	0.5	0.2	21.9	10.0	0.0	0.8	0.0	0.6	16.0	0.0	8.0	0.1	N/A

a. The LHA-6, scheduled to be delivered to the Navy in 2013, will have enhanced aviation capabilities but no well-deck for landing craft.
b. This is a modified version of the LHA-6, which has been stripped of several key self-protection systems and has a smaller, civilian crew than its fleet amphib counterpart. T-LHA(R)s are part of the MPF(F) family of ships.
c. This is a modified version of the LHD, which has a civilianized crew and does not possess select self-protection systems.
d. The mobile landing platform (MLP) is a new ship design that will allow for the transfer of equipment and cargo at sea.
e. These ships will replace existing auxiliary replenishment (AFS) class ships and will lift ammo, spare parts, and provisions.
f. A number of T-AKs are assigned to the Maritime Pre-Positioning Squadrons (MPSRONs) as dense-pack ships carrying USMC equipment and supplies.
g. The joint high-speed vessel (JHSV) is a Navy-led acquisition program designed to build a fast-speed, ferry ship.

Table 2. Primary sources of shipping capacities and characteristics

Legend	Source
	MCRP 3-31B, Amphib Ships and Landing Craft, 29 Aug 2001 [4]
	DoN, Draft CDD for MPF(F) Squadron Family of Systems, Rev 1, 20 Jan 2006 [5]
	USMC Brief, HSV-2 Swift Capabilities Overview, Jan 2003 [6]
	USMC Info Paper from Blount Island Command, MPF Ship Characteristics, Oct 2005 [7]
	Naval Sea Systems Command Brief, Draft JHSV Performance Specifications, 13 Sep 2006 [8]
	CNA estimate based on multiple sources of information

Several planning factors must be applied to the gross shipping capacities found in table 1 to derive net shipping capacity. The net capacity is the area/volume of a ship that is actually available for the transportation of troops, cargo, and vehicles. Gross shipping capacity refers to the physical dimensions of a ship, while net capacity reflects space lost as a result of current Navy practices (i.e., ensuring unit integrity of troops, adequate fire lanes are maintained in storage areas, etc.).

A ship's net cargo and vehicle capacity can be calculated using a broken-stow factor. This factor is the percentage of the gross capacity that is actually used on board a ship. A ship's net troop accommodations can be calculated using a tactical unit integrity factor. This factor reflects the percentage of the gross troop bunk capacity that is actually used, as compared to filling ships to their maximum berthing capacity. In table 3, we highlight the standard planning factors typically applied to gross shipping capacity. These are the factors CNA has used in the past to calculate net shipping capacity and reflect standard assumptions that have been used by seminal lift studies [4, 9, 10].

Table 3. Standard planning factors applied to gross ship capacities

	Cargo	Vehicles	Unit integrity
Adjustment factor	.75	.70	.90

In addition to adjusting gross capacities for broken stow and unit integrity, we must also account for pre-boating vehicles in landing craft. This refers to lift adjustments made for each ship class based on the number of landing craft each ship carries and the number of vehicles that can be parked on each landing craft. When there are no landing craft in the well deck, this space can be used to store vehicles and/or cargo. In table 4, we list adjustment factors for preboating vehicles and cargo on board JMACs, LCACs, and LCUs, which reflect the application of a .7 broken stow factor.

Table 4. Adjustment factors for landing craft[a]

Landing craft	Footprint (sq ft)	Vehicle preboat (sq ft)	Adjusted preboat (sq ft)
JMAC	5,852	2,406	1,684
LCAC	4,400	1,809	1,266
LCU	3,982	1,850	1,295

a. The DL2 study assumed that the average square feet of vehicles preloaded for LCAC in the high-threat case would be 750 sq ft and 700 sq ft in the low-threat case. The study further assumed a reasonable average load of 720 sq ft (see [9], Annex J, 3-1).

The area of a ship's well deck and well-deck ramp can also be used to load vehicles and supplies. The well deck and ramp spaces for different ship classes are identified in table 5.

Table 5. Amphibious ship well deck and ramp areas

Ship class	Well deck (sq ft)	Ramp (sq ft)	Net well deck space (sq ft)[a]
LHA-6	n/a	n/a	n/a
T-LHA(R)	n/a	n/a	n/a
LHD	18,490	1,457	13,963
T-LHD	18,490	1,457	13,963
LPD-17	9,000	n/a	6,300
LSD-41	21,619	635	15,578
LSD-49	9,000	n/a	6,300
MLP	34,121	n/a	23,885

a. Adjusted for broken stow

When a well-deck spot is not filled by a landing craft, that space is available for the storage of equipment and supplies. To determine the net gain in space, this area must be added to available storage space and then adjusted for broken stow, as we have done in table 5. To determine the net gain from having one less LCAC available involves multiplying the LCAC footprint by a vehicle broken stow factor and subtracting the square footage gained by preboating the LCAC. This nets approximately 1,814 sqft (4,400 sq ft x .70–1,266 sq ft) for each LCAC spot that is used for vehicle storage.

Implications for modeling

The goal of this portion of our analysis has been to develop a consistent set of capacities for seabasing modeling. In attempting to develop these inputs, we have found that different sources [2, 4, 11, 12, 13, 14, 15] tend to report vastly different ship lift capacities. The differences in capacities across all major sources are rather large. For instance, one source lists troop bunks as being 17 percent higher than what another source says it is for the same ship class. Similarly, another source says that vehicle square footage is 34 percent higher for LPD-17s than what another source says it is, and the average percentage difference for the cargo cube capacity values of all L-class ships is nearly 45 percent. These differences can significantly impact the determination of how much total lift is actually needed and ultimately should be bought.

In this section, we have highlighted the gross ship capacities of select amphibious, connector, and prepositioning ships, and the standard adjustments that are typically made. However, every source document makes the same assumptions about how space on board amphibious and prepositioning ships will be used or even what planning factors are used to determine how much net capacity is available. The lack of a centralized repository of information about the shipping capacities of specific ships contributes to this problem, as does the constant changes that are made to new ship designs during the early years of a program.

We believe that a central repository of information containing updated shipping capacities of individual ships would lessen some of these problems. Current practice calls for each amphibious ship to maintain a ship loading characteristic pamphlet (SLCP). These reports should be made more widely available and could form the basis for future analytical modeling efforts if gross and net capacities are routinely archived and updated. We have begun to build such a library of SLCPs at CNA, but absent a fleet requirement to submit updates to us on a regular and wide-scale basis, the archive will likely be dated and probably incomplete.

Modeling aircraft spot factors on L-class ships

This section discusses analysis contained in [3], which highlights the relative fit of various aircraft mixes on amphibious ships. Our analysis focuses on how different amphibious mission profiles impact the number of aircraft spots on big-deck amphibs and the amount of usable aviation logistics space that is left over. Our analysis highlights the importance of adjusting parking spot factors for the operational mission and de-emphasizing the “technical” physical spotting of aircraft. A number of operational employment factors impact the total number of aircraft parking spots on big-deck amphibis. They include the size of the aviation logistics footprint for a given aircraft mix, the number and location of “locked” aircraft, the timing and intensity of flight deck launch and recovery operations, and the amount of hangar and flight deck space that can be devoted to aircraft parking. In this summary, we describe the traditional approach to aircraft spotting, the use of a NAVAIR Gator Multiple Tool to estimate acceptable numbers of aircraft that can fit on amphibious ships and a number of mission sets that impact the number of aircraft that can fit on big-deck amphibs in an attempt to determine an appropriate set of L-class ship spotting factors for seabasing modeling purposes.

Current aircraft spotting methods

The spot factor of an aircraft describes the size of an aircraft relative to a reference aircraft. The CH-46 has been the unitary aircraft used to compare spotting factors, but with the advent of the MV-22 spot factors are now calculated in MH-60S spots. In table 6, we list current spot factors in MH-60S equivalents. The table includes different spot factors for aircraft parked on the flight and hangar decks. For aircraft parked on the flight deck, the width of each aircraft is the most important constraint because aircraft are typically parked perpendicular to the ship’s center and, therefore are limited by how closely they can be placed next to one another. For aircraft parked in the hangar deck, the shape rather than the width of the aircraft tends to be the driving factor for spot size.

Table 6. Current spot factors in MH-60S equivalents

	MH-60S	CH-46	MV-22	CH-53	UH-1N	UH-1Y	AH-1W	AH-1Z	F-35B	MV-22 maint. position	F-35B Triplet
Flight deck	1.00	1.32	1.75	2.41	0.89	1.28	1.01	1.29	2.96	N/A	5.28
Hangar deck	1.00	1.30	2.92	3.50	1.17	1.46	1.13	1.59	2.69	5.00	N/A

NAVAIR recently developed a spotting utility tool that allows users to gain a preliminary sense of what will or won't fit on a big-deck ship without the use of a scaling model [16]. The spotting tool, referred to as the Gator Multiple Ranges Spreadsheet, uses the most recent flight-deck and hangar-deck spot factors to calculate the deck multiples for different aircraft mixes on the flight decks and hangar decks of three different ship classes.

NAVAIR's Gator Multiple Tool provides a technical assessment of the relative fit of various aircraft mixes on big-deck flight and hangar decks. The tool highlights a range of deck multiples that distinguish between situations where aircraft are either in a locked condition or not. (Locked spots refer to situations where aircraft double-park other aircraft, thus limiting the flexibility of the onboard aviation combat element (ACE) to maneuver from parking to operating spots). In table 7, we highlight the range of parking spots the gator multiple tool denotes as fitting on big-deck amphibs without locked spots, with at least one locked spot, and with multiple locked spots.

Table 7. NAVAIR deck-multiple ranges (in MH-60 equivalents)

	LHA-1	LHA-6	LHD
No locked spots	0-47.5	0-56	0-50
At least one locked spot	47.51-51.0	56.1-61.75	50.01-56.75
Multiple locked spots	>51.0	>61.75	>56.75

While NAVAIR's tool highlights a range of possibly acceptable deck multiples, it is difficult to determine at what point a given aircraft mix exceeds the physical limits of a particular space because there is no information provided about the number of locked spots and type of aircraft that are locked in place.

Factors impacting relative fit of aircraft on big-deck amphibs

We analyzed various factors impacting the relative fit of aircraft on big-deck amphibs. This includes the relative size of new airframes to old airframes. In table 8, we show the evolution of spot factors in MH-60 equivalents from the early 1980s to the present.

Table 8. Evolution of spot factors (in MH-60 equivalents)

Year	H-46	H-53	H-60	MV-22	AH-1	UH-1	JSF/AV8B
Current flight deck	1.32	2.41	1.00	1.75	1.29	1.28	2.96
Current hangar deck	1.30	3.50	1.00	2.92	1.59	1.46	2.69
2002	1.15	3.08	1.00	2.55	1.07	1.08	2.21
1989	1.19	2.24	1.00	1.73	1.00	0.98	2.29
1981	1.19	2.76	1.00	1.43	.92	0.94	2.29

The overall trend is mixed—as some spot factors have increased (e.g., the MV-22) others have decreased (e.g., H-53s), and some are about the same (e.g., AH-1s). There are also significant differences in how aircraft fit on flight and hangar decks, as the current numbers suggest.

In addition to the relative growth of aircraft over time, the amount of aviation logistics material (AVCAL) associated with a given mix of aircraft has also increased. The MV-22, for instance, is expected to have a substantially larger AVCAL footprint than the aircraft it is replacing (the CH-46), and its larger size will occupy much more parking space than the CH-46.

A number of mission factors will impact the relative fit of aircraft on big-deck ships as well. This includes the relative tightness of fit of aircraft on a big-deck ship closing the sea base, conducting intensive flight operations with a single type/model/series aircraft, and conducting a mix of MEU ACE missions. We examine each mission in detail and highlight the impact these operations have on the relative number of locked spots that can be tolerated. In figure 1, we summarize our mission analysis.

Figure 1. Mission analysis of deck multiples

Spot conditions	MEB surge "close" (a/c ferry mission)	Intensive flight ops of single type/model (sortie surge ex)	Typical MEU ACE employment (mix of missions + a/c)
No locked spots	May not matter	May not matter	Provides maximum mission flexibility, aircraft are quickly accessible, MEU a/c mix minimizes available log space
At least one locked spot	May not matter	May not matter	Critical consideration unless a/c mix is single type, unclear impact on available log space
Multiple locked spots	May not matter	Likely to matter only if it slows down repositioning of a/c between launch & recovery	Critical consideration unless a/c mix is not single type, unclear impact on available log space
Physically cannot fit	Critical, but unclear when ship spots-out	Critical, but unclear when ship spots-out	May not matter because aircraft will "lock-out" before they max out in terms of available space

"Tightly" parked ←→ "Loosely" parked

The figure highlights those situations in which locked spots may matter more than in other situations. NAVAIR's Gator Multiple Tool does not provide information about the number of locked spots in the flight and hangar decks, the type of aircraft that are locked in place, and the impact that a given aircraft mix in the hangar deck has on available space for aviation maintenance support. Without this information, it is unclear how many aircraft can actually fit on a big-deck ship and under what circumstances.

Implications for modeling

The goal of this analysis has been to determine how many aircraft can fit on big-deck amphibious ships. While we identified a number of factors that impact the relative fit of aircraft on amphibs, we have not yet determined exactly how many aircraft can indeed fit because we simply do not know under what conditions certain aircraft mixes will be acceptable and under which they will not.

The overall implications of this are rather profound: Using different spotting numbers for aircraft located on the flight and hangar decks adds a degree of sophistication to aircraft spotting, but it also creates a situation where deck multiples change as aircraft move to and from the hangar and flight decks. This makes it hard to know at what point more aircraft placed on a flight or hangar deck impede the overall mission or, alternatively, physically can no longer fit.

What needs to be built is a tool that allows users to identify how loosely or tightly aircraft can be parked and provides information about the number and type of locked spots that different aircraft mixes create and the location where the locked spots occur, as well as aviation logistics and ground equipment tradeoffs with the selected, onboard aircraft mix.

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Modeling landing craft operations

This section describes analysis contained in [2], which highlights the time air-cushioned landing craft (LCAC) spend in amphibious ship well-decks and on beaches during amphibious assaults. The analysis is derived from historical reconstruction of fleet exercises from 1987 to 2001 involving LCAC. The purpose of the analysis was to determine the specific time lines for how long it takes to load, unload, and refuel LCAC for amphibious ship-to-shore modeling purposes. In this summary, we discuss the average historical loading/unloading times for LCAC, different types of LCAC refueling operations, and the relevance of historical distributions vice averages for amphibious assault modeling purposes.

Historical loading/unloading times for LCAC

The average historical loading time for LCAC in a ship's well deck is approximately 33 minutes. The average goes up by about 30 minutes—to nearly 60 minutes—when LCAC are refueled, as well as being loaded. The average time to load an LCAC in the well deck of an LSD and LPD is much lower than the average time the LCAC spends in the well deck of an LHD and LHA class ship.

In table 9, we show the average time to load an LCAC with and without refueling for select ship classes.

Table 9. Average historical well-deck times by ship (CNA historical analysis)

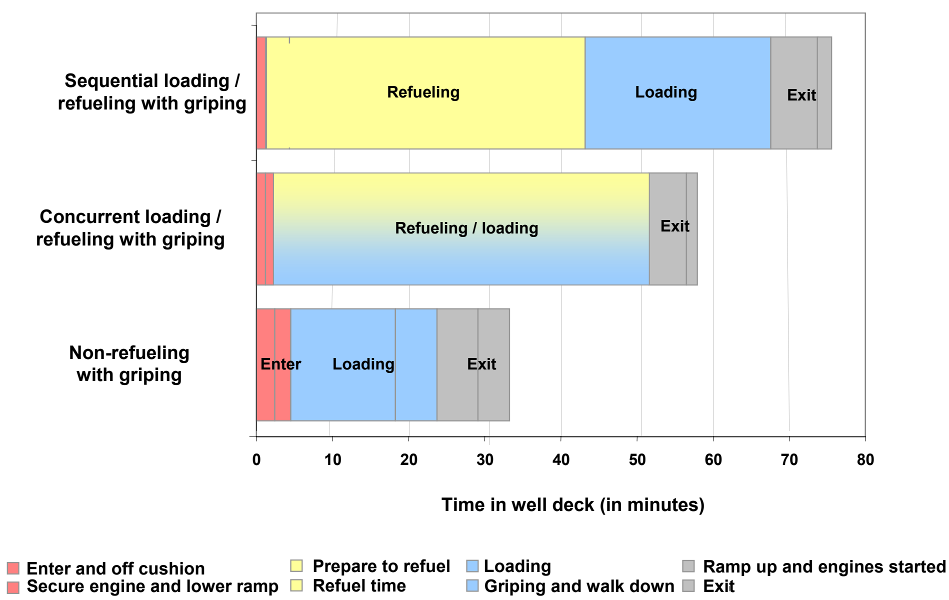
Ship type	Without refueling (min.)	With concurrent refueling (min.)	With sequential refueling (min.)
LSD	30.1	46.1	69.4
LPD	40.4	43.5[a]	113.0[a]
LHD	44.8	40.0[a]	68.0[a]
LHA	48.8	73.2	123.0[a]

a. Limited data availability.

Concurrent versus sequential refueling

We examined historical LCAC refueling operations and found that when LCAC refuel concurrently with the loading process, it takes less time in the well-deck than when they are loaded and refueled sequentially. Figure 2 shows the average time an LCAC spends conducting discrete events within a ship's well deck based on the type of refueling operation being performed. The figure distinguishes between the time it takes to load and refuel an LCAC sequentially, concurrently, and then loading without refueling. In addition to distinguishing between different types of LCAC well-deck operations, the figure also shows the average length of time to enter, refuel, load, and exit a ship's well deck, by type of operation.

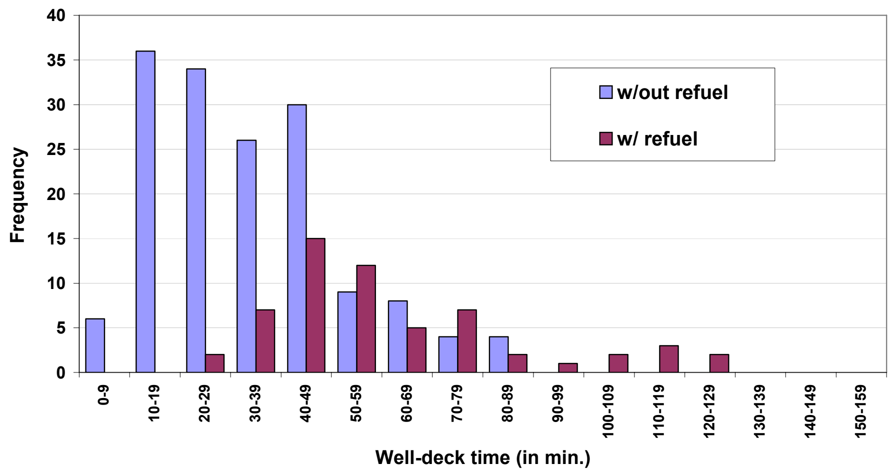
Figure 2. Comparison of time spent conducting discrete events in ship's well deck by different types of loading/refueling operations



Use of historical distributions versus averages

In addition to examining the average time to load/unload/refuel LCAC in a ship's well deck, we also examined the frequency of LCAC loading times. In figure 3, we show how much variance there is in how long LCACs spent in a well-deck during a number of fleet exercises throughout the 1987-2001 timeframe.

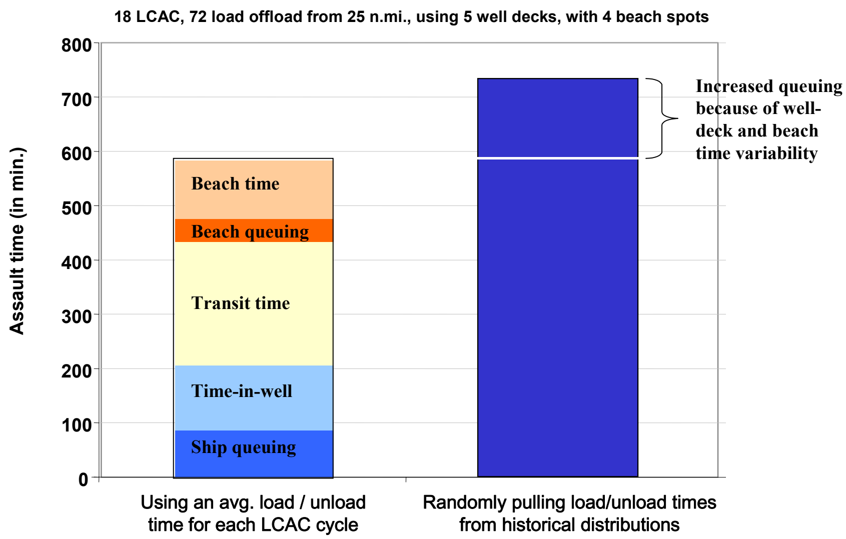
Figure 3. Frequency of well-deck times, 1987–2001



We used a chi-square test to determine the best model fit for LCAC time-in-the-well deck. Most of our data fell within two standard deviations of the mean, with our non-refueling data looking like what a normal, bell-shaped Gaussian curve is expected to look like. Our analysis suggests that log normal distributions fits LCAC well-deck times without refueling at the .96 confidence level and at the .74 confidence level with refueling, both of which were considerably better than how a Gaussian distribution fits the data.

In figure 4, we show how the above distributions impact the overall assault time line. Additional queuing arising from well-deck and beach time variability causes a net increase of nearly 2.5 hours in a 72-load, 25-n.mi. assault using five well decks and four beach spots.

Figure 4. Comparison of assault offload using historically-based average times versus randomly pulled historical loading/unloading times (90% confidence level estimate)



Implications for modeling

The goals of this analysis have involved developing a consistent set of inputs for the length of time LCAC spend in a ship's well deck. We believe the log-normal distribution closely approximates the amount of time LCAC spend in a well-deck and that randomly drawing observations from such a distribution pattern will provide more realistic assault times than simply using a planning average. This has significant implications for amphibious ship assault models, which mostly used straight averages that may grossly underestimate the time to complete an assault.

The results discussed above for time in the well-deck also apply to LCAC time spent on the beach. LCAC typically spend less time at the beach offloading equipment ashore than they spend on ship loading and refueling, but the same principles that apply to well-deck operations in terms of the importance of historical distributions would seem appropriate for modeling LCAC time at the beach as well.

Modeling force closure and surge operations

This section discusses analysis contained in [1], which examines several recent historical cases of amphibious surge operations. From these cases, we identify several key factors that impact the overall fleet's amphibious surge potential, including maintenance durations, non-deployed ship readiness levels, overall fleet deployment patterns, and major contingency operation (MCO) closure concepts. In this summary, we describe the impact that fleet size has on amphibious surge potential, drawing lessons from historical surge data; peacetime maintenance, training, and deployment schedules; and global force lay-downs. We then develop a sea base closure analysis tool based on this information, which helps us estimate the impact that force structure size has on force-closure capability.

Past historical surge operations

Large-scale amphibious forces have deployed for MCOs in only a few instances in the recent past. This involves the amphibious forces that deployed in support of Operation Desert Shield in 1990 and Operation Iraqi Freedom (OIF) in 2003.

In August 1990, there were 59 amphibs in the force structure, with 28 based along the east coast, 27 along the west coast, and 4 forward-based in Japan. This force was able to send 13 ships within 11 days of receiving a deployment order largely because at the time the deployment order was received 9 ships were then preparing for a large-scale exercise in Norway. A second task force was also requested several months later. This resulted in 13 ships surging to the MCO within 23 days of receiving word to deploy.

The OIF example is different in that there was much more warning time of a pending crisis and the force structure was smaller. This time, all available CONUS-based, non-deployed ships surged, except an amphibious ready group in maintenance and an ARG that had just returned from deployment. In total, seven ships from each coast surged within 24 days of receiving the formal deployment request and 12 days after beginning the loading process.

In table 10, we summarize our historical analysis. The table shows the overall size of the amphibious fleet, the total number of ships that deployed for each major contingency, and the length of time it took to surge these forces as measured from when a deployment order was received until the amphibious task force (ATF) sailed.

Table 10. Summary of historical surge examples

Examples	Total ship forces	Number of ships surged	Time to surge (in days)
Desert Shield			
Aug deployment	59	13	11
Nov deployment		13	23
Operation Iraqi Freedom (OIF)	37	14	24

The above examples highlight several critical factors impacting amphibious surge operations. First, warning time for different events can vary immensely. Second, the fraction of the fleet that deployed to these MCOs was much smaller than it may be in the future. Indeed, the closest case to surging from maintenance was the last west coast squadron in OIF, which cut short its usual training and may even have slightly cut short its maintenance.

Amphibious force closure planning factors

Closure of an amphibious task force (ATF) with an embarked MAGTF depends on several critical factors:

- Size and posture of the peacetime amphibious fleet
- Ship maintenance and training cycles the ships follow in peacetime

- Overall deployment pattern and closure concepts of the amphibious force.

Maintenance factors

We examined recent historical data as well as projected expeditionary strike group (ESG) schedules for the next few years to develop planning factors for maintenance duration, frequency of maintenance actions, and deployment frequency. We also collected information on the variation in ship maintenance schedules. We found that inter-maintenance periods have the least amount of variation (between 20 and 27 months) and last on average 24.5 months. We further found that the average duration for both dry-docked and no dry-docked big-deck amphibs were longer and more frequent than those outlined in the notional schedules described by the OPNAV Notice 4700 planning document [17].

In table 11, we highlight the nominal maintenance cycles outlined by the OPNAV 4700 Instruction.

Table 11. Nominal maintenance cycles from OPNAV Notice 4700

Ship class	PMA duration (in months)	Time between PMAs[a] (in months)	DPMA duration (in months)	Time between DPMAs (in months)
LHA-1	2	25	6	129
LHD-1	2	25	6	129
LPD-4	3	25	4	106
LPD-17	2	25	4	131
LSD-41/49	2	25	4	106

a. Refers to time between the end of one maintenance period and the next.

The OPNAV Instruction identifies two basic types of maintenance periods currently associated with CONUS-based amphibious ships:

- Planned maintenance availabilities (PMAs), which are short, labor intensive availabilities for ships in a planned maintenance program.

- Docking planned maintenance availabilities (DPMAs), which is an expanded PMA that includes maintenance and modernization actions requiring dry-docking the ship.

While the OPNAV Instruction provides guidelines for ship maintenance, actual ship schedules do not always conform to them. In table 12, we show a recent Fleet Forces Command Global Force Management (GFM) projection of ESG schedules from 2007 to 2014. The table includes data covering 7.5 calendar years and 69 ship years of data for CONUS-based ships.

Table 12. Global Force Management projection of future ESG schedule for FY2007 through FY2014 (Jan 2007 version)

Parameter	Obs.	Minimum (months)	Maximum (months)	Average (months)
PMA maintenance	21	2	8	2.7
DPMA maintenance	9	4	9	7.3
Time between maintenance	22	20	27	24.5

The table illustrates the variability in actual schedules, even in the absence of a disruptive major contingency. The time between maintenance seems to be the most stable metric of those listed, and it agrees surprisingly well with the OPNAV 4700 value of 25 months. Maintenance lengths, however, don't agree as well. In practice, they are significantly longer on average than the 2- and 6-month durations specified in the OPNAV notice.

Readiness factors

The readiness of an amphibious ship for surge to an MCO varies depending on where it is in its maintenance and training cycle when ordered to deploy. The historical MCO surge data indicate that ships early in their pre-deployment training schedules that are not immediately ready for surge can be made ready more quickly than they otherwise could in peacetime. Recent historical surge data do not, however, give any insights into how quickly a ship might exit maintenance in the event of an urgent deployment order. To estimate how long this might take, we examined the surge time for a ship already in its maintenance cycle. A general rule of thumb for carrier availability is that the maximum time needed to exit maintenance occurs one-third of the way into the planned maintenance period and is one-half of the planned time. We also consider the possibility that a ship in transit could fulfill some of its pre-deployment training en route to the objective rather than await departure while it completes its training syllabus.

Global posture and closure doctrine

The overall surge potential of a force depends on the interplay between the ship-specific variables listed above as well as the fleet's overall size, composition, and lay-down. Additionally, the fleet's deployment pattern, characterized by presence demands, independent ship deployments, operational tempo, and synchronization of schedules across fleets, are also key factors. Finally, force closure doctrine is an important indicator because it defines the metrics by which a fleet's surge potential can be measured (e.g., surge rules, warning time, and the number of ships needed). Overall, these factors constitute a set of general, global-level assumptions that must be considered when estimating a given fleet's overall surge potential.

Developing a force closure tool

We developed a sea base closure analysis tool to estimate the impact of force structure size on force-closure capability. The tool combines user-defined deployment and maintenance scheduling parameters with historically based expeditionary strike group (ESG) deployment schedules to estimate the surge potential of forces with different postures and sizes. The scheduling algorithm flexibly schedules ship deployment and maintenance periods to meet user-determined ESG deployment tempo and maintenance goals. The refined schedule is then used to calculate the closure rate for an amphibious force in various locations and starting points throughout its maintenance cycle. The result is a statistical picture of the fleet's potential to close to a major contingency from its peacetime posture.

We used the force closure tool to estimate how quickly different sized and postured force structures could close Marine expeditionary brigades to an MCO. Our analysis highlights the importance of keeping smaller force structures at higher average readiness levels, as they sometimes are capable of closing a force as quickly as larger force structures, but they are less frequently able to do so.

Implications for modeling

The MCO-response potential of an amphibious fleet depends not only on ship operational availability estimates but also on how precisely the ship is scheduled, how maintenance and readiness are managed, and on force structure and deployment patterns. Operational data can inform this type of analysis through the use of past and planned ship maintenance and deployment schedules. But there is not much operational data on how fast ships can accelerate their maintenance schedules. The best we may be able to do is capture the informed judgment of subject matter experts and use the limited data we have on hand to develop reasonable maintenance acceleration assumptions.

The bottom line of our analysis is that there are a set of broad assumptions that analysts must make when modeling amphibious surge potential. These include how ship schedules are phased across numbered fleets and the timing of a given crisis, neither of which can realistically be informed by past operational data. These assumptions can drive the final results and should be approached cautiously and with acknowledgment of past history.

Modeling ship-to-shore assaults

This section describes our efforts to update a ship-to-shore assault model to new seabasing concepts. Several years ago, we developed an amphibious assault analysis tool (AAAT) as part of the Integrated Amphibious Operations Update (DoN Lift 2+) Study [18, 19]. The tool was designed to examine the impact of changes in the way future amphibious assault operations might be conducted. The tool allowed users to easily modify the following:

- Assault element size and composition
- Distance the assault element traveled from ship to shore
- Dispersion of assault element among the ships of the amphibious task force (ATF)
- The number and dispersion of transport aircraft and landing craft (LCAC) across ships of the ATF.

The tool's output shows how changes to these attributes affect the delivery rates of combat power ashore.

Model updated

In this section, we describe modifications made to the AAAT model for new seabasing concepts. We undertook this effort because new seabasing concepts had changed the way the Navy and Marines intended to conduct assaults from the sea. The AAAT model was initially developed to estimate the time line for landing the assault element (AE) of an amphibious Marine expeditionary brigade (MEB). The SSCT model was intended to incorporate the at-sea transfer of loads from one ship to another as part of a sea-based assault. The new version, which we refer to as a seabase-to-shore connector tool (SSCT) is essentially an update of AAAT modified for new seabasing concepts. The revised connector tool has additional ship entities and model logic that allows for skin-to-skin transfer of loads at sea. We have also incorporated improved process logic, design, and functionality into the model. We characterize these changes as essentially complete but have not yet run the model through a full battery of sensitivity tests; hence the model should be thought of as a preliminary "beta" version.

Sea base-to-shore connector tool (SSCT)

We designed the SSCT to be flexible enough to handle a variety of inputs regarding the delivery of troops and equipment from ship to ship and to shore. The tool can accommodate a large variety of landing forces and landing plans, including sea bases of various size and scale. Users create and modify inputs in a Microsoft Excel spreadsheet file. They also import model results in an Excel spreadsheet file for manipulation and analysis.

As with the AAAT model, we used a commercially available software package, Promodel 2007, to track the movement of delivery craft from ship to ship and to shore. The model records the times at which landing and transport craft land loads ashore and/or begin movement from one ship to another prior to moving ashore. This allows us to track the length of time required to complete different portions of the landing from different starting positions.

We include instruction on how to manipulate the analysis tool in order to model actual amphibious assaults in the spreadsheets that the model uses as input files.

The remainder of this section summarizes key differences and modifications made to the original AAAT model.

Model design

The SSCT model is fundamentally the same model as the one built for the DoN Lift 2+ Study, but with several key alterations:

- Ship capacities have been updated—this impacts the amount of troops, vehicles, aircraft, and cargo that can be lifted by select ships.

- Maritime pre-positioning force (MPF) ships and joint high-speed vessels (JHSVs) have been added to ship lists—we used information contained in a draft set of capability development documents (CDDs) as the basis for these projections [20].
- Process logic has been added that models skin-to-skin transfer of troops and equipment from LMSRs or JHSVs to mobile landing platforms (MLPs) per current seabasing concepts.
- Input spreadsheets have been redesigned to allow for greater user selections and functionality.
- The inputs for how long key steps will take based on our analysis of LCAC time-in-the well deck have been updated.

The SSCT model has three primary components: an input spreadsheet file, an amphibious assault and seabasing simulation package, and output spreadsheet file.

Input spreadsheet file

This allows users to specify the size and composition of the assault force, the distribution of that force among the ships of the amphibious task force, and a landing plan. We have added a number of MPF(F) ships to the menu of available ships. As currently configured, the sea base itself can be as large as 33 ships. Older versions of the tool provided for only up to 18 ships as part of the ATF.

The new ships modeled include:

- One T-LHA
- One T-LHD
- Three T-AKEs
- Three MLPs
- Three JHSVs.

Amphibious assault and seabasing simulation

This is the ProModel simulation that governs how the transport aircraft, surface craft, and ship entities interact, as specified by the user-provided landing plan. The model itself consists of locations, entities, and processes. Locations include the ships, ship flight decks, and ship well decks. As noted above, there are 33 ship entities as part of the model. Each ship location is an aggregation of locations that represent the flight and well deck on each ship. Entities refer to the various delivery craft and loads they carry. We specify five basic entities in the SSCT model: MV-22 aircraft, CH-53 aircraft, air-cushioned landing craft (LCAC), expeditionary fighting vehicles (EFVs), and loads. Processes describe how aircraft, LCAC, EFV, and at-sea transfers occur within the model.

Table 13 highlights LCAC planning factor adjustments from the AAAT model.

Table 13. Updated factors used to model LCAC operations[a]

Factor	AAAT	SSCT
LCAC speed with load	43 kt	35 kt
LCAC speed when empty	43 kt	45 kt
Time to refuel LCAC	15 min	16 min
Loading time in well deck	35 min	30 min
Unloading time ashore	10 min	26 min

a. See [2] for details about LCAC well-deck and at-beach operations.

Table 14 highlights planning factors used for at-sea transfer of loads. Because no operational planning data are currently available on JHSV/LMSR/MLP ship-to-shore transfers, these are crude estimates based loosely on the latest MLP capability development document (CDD), which calls for the "marshalling, surface transfer, and staging of one-third of a battle land team (BLT) assault wave between an MLP and a LMSR within a 24-hour (objective) to 72-hour (threshold) period through sea state 3/4 conditions." In our model, we do not make adjustments for different weather conditions or other climate variables that might impact this process.

Table 14. Factors used to model at-sea transfer

Factor	Parameter
Ship to ship approach time	30 min
Per load transfer time	30 min
Ship to ship disengagement time	30 min
Additional time to load LCAC on board MLP	30 min

Output spreadsheet file

The output spreadsheet file summarizes the execution of the landing, allowing users to draw inferences about seabasing lift requirements. The output worksheet copies data from a worksheet that the simulation program creates. The worksheet provides information about the landing time of loads by type of aircraft (MV-22, CH-53) and type of lift (internal, external). The output sheet then automatically graphs the data into several charts for easy display.

For additional details about how this model works that are beyond the scope of this report, please refer to [19], which describe the original model in detail. We have included inside the front cover of this publication a reference disc with key reference material, including a copy of the updated ship-to-shore connector model.

Implications for modeling

The SSCT incorporates the at-sea transfer of troops, equipment, and material "loads," a process that could indefinitely sustain future sea-based operations. While the focus of the model is the ship-to-shore movement of a tailored assault force and the time lines needed to complete this maneuver, the model itself could easily be modified to calculate tactical resupply requirements for forces ashore, provided reasonable sustainment rates could be identified. The really unique modification from the earlier version is the model's transfer logic architecture, which incorporates the latest conceptual thinking about how the future sea base will operate. The model does have certain limitations (e.g., LCACs likely will not launch from MLPs at the same distance from shore that the at-sea transfer occurs, nor is it readily apparent how to change skin-to-skin transfer parameters within the model), but these are minor design flaws that future versions can easily resolve. The key point is that the new model should allow analysts to examine seabasing assault times in greater depth, with more realistic assumptions, and more rapidly than ever before.

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