Aircraft Carrier-Surface Effect Ship

Donald P. Germeraad*
Lockheed Missiles and Space Company, Sunnyvale, California

The element of surprise is just as important today in Naval warfare as heretofore. The task force commander who has the high-speed capability of the surface effect ship, configured as an aircraft carrier under his command, has significantly increased operational flexibility. The projection of power over specific ocean areas at specific times and places can be accomplished expeditiously, thereby denying these to an adversary. This paper addresses major design features and operational characteristics of such a fighting ship.

Introduction

WITH the advent of the surface effect ship (SES) Bell Halter 110, being modified under Navy contract to a higher length to beam (L/B) ratio configuration,[1] there will now be a Navy sea-going test platform of significant size, i.e., length—160 ft, beam—39 ft. It will be used to evaluate performance, sea keeping, ride quality, and operational characteristics. Such a test craft will also provide invaluable design data for the next steps forward: First, a 1500-ton ocean-going test bed without a prescribed payload capable of evolving into a prototype ship. Various payloads representing appropriate Navy missions will be demonstrated later. Second, there is the inherent potential for prototyping an ASW escort, or an intratheater logistics ship for the rapid deployment force (RDF), or an amphibious support ship, and, escalating to SES aircraft carriers (SES-CV).

Basic SES Design Criteria

The surface effect ship was designed to solve a basic problem found in high-speed ships with displacement hulls. The latter encounter a wave-making drag phenomenon which increases roughly as the cube of the velocity. The SES concept alleviates this deficiency by riding on a cushion of air created by large vertical-axis fans which are contained between twin catamaran hulls and pliant seals fore and aft. These seals are essentially transparent to wave passage. Speeds on the order of 100 knots can thus be realized.

The SES advantages are immediately obvious:[4] 1) major speed increase over conventional ships; 2) high wind over the deck (WOD) for CTOL aircraft, eliminating the need for catapults and heavy duty arresting gear, Fig. 1; 3) excellent candidate for RDF as a fast logistics ship, an amphibious assault ship, or as an ASW escort ship; 4) less vulnerable to torpedo or missile attacks; and 5) excellent candidate for a light-weight nuclear propulsion (LWNP) installation vs gas turbine to provide unlimited range and speed options.

One of the major SES design parameters is the ship cushion L/B ratio. It is selected following careful consideration of the mission requirements stipulated by the customer; i.e., speed, range, payload, maneuvering, sea keeping, sea state, and ride characteristics.

As a cushion-borne SES accelerates from zero velocity, it encounters high hydrodynamic resistance initially, due primarily to forcing a wave front forward. As speed increases, this resistive wave front is overtaken, which immediately lowers the hydrodynamic drag appreciably. The speed at which this maximum drag occurs is called hump speed, derived from its characteristic shape on performance plots (speed vs drag). This is shown at roughly 40 knots for $L/B=2$ in Fig. 2.

Simply stated, as shown in Fig. 2, if high speed is required in the 80-100 knots range, then a low L/B provides lower drag. However, this configuration will suffer a higher drag penalty accelerating through hump speed, possibly requiring greater thrust. Fortunately, this is a transitory condition. An equivalent high L/B design, at the same pressure to length ratio (P/L), will produce greater drag at the higher speed range, but drag will be a significantly reduced transiting hump. It is important to note that as ship size is increased, hump speed also increases, which permits a high L/B, large ship design to cruise at a reasonable subhump speed.

A low L/B design has greater lateral stability because of the increased beam. This permits operating at a higher cushion height, providing the capability for maneuvering in higher sea states.

Definition and Feasibility Study of a Minimum Size SES-CV

Overview

Midway through World War II, the aircraft carrier had become firmly established as the mainstay of U.S. surface fleet attack capability. Events in the last 30 years have only served to reinforce aircraft carrier pre-eminence. Carriers played a vital role in the Korean conflict and during the war in southeast Asia. The versatility of the aircraft carrier concept has been proven conclusively since its inception. Not surprisingly, the carrier remains at the forefront of planning for meeting the Navy's high priority missions: 1) projection of forces; 2) sea control; 3) protection of sea lines of communication; and 4) crisis management.

The aircraft carrier has evolved into a highly effective and sophisticated mobile air base. Present ships require long construction time spans, enormous crew complements, and complex aircraft maintenance and servicing facilities. A CV/CVN (nuclear powered aircraft carrier) requires a formidable fleet of ships to escort it. Moreover, inflation and escalating operating costs have reached a point where aircraft carriers now represent a significant fraction of total Navy surface fleet resource expenditures and allocations. Future aircraft carrier force levels have been, in effect, predetermined by present and foreseeable economic constraints. On the basis of replacement and cost alone, the super carrier has become a high value target. Carrier aircraft have undergone a similar evolution, albeit with quantum jumps in combat capability. The number and type of first line carrier aircraft that can be procured is also subject to real and predictable budget contraints.

Currently, traditional U.S. Navy control of the seas is being seriously challenged. The threat posed to the U.S. surface

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*Manager, Ocean Systems Program Development. Associate Fellow AIAA.

fleet and to the accomplishment of its high priority missions is unquestionable. Obviously, this threat extends to the limited force of CV/CVNs which the Navy can deploy in this decade and the 1990s. The Navy has long recognized this situation and has been active in examining lower capability alternate solutions to the super carriers, including among others, the SES.

For the same price tag as an attack aircraft carrier, the fleet could have several SES aircraft carriers with three times the speed. These could be dispersed on key fronts for rapid "quick blow" engagements, then returned to the task force umbrella or a shore establishment for refurbishment before striking again at the task force commander's option. SES-CVs would complement, not replace, the task force CV/CVNs.

Study Objectives

The objectives of the SES-CV study were straightforward: to determine the feasibility of the SES-CV concept and to define the minimum size carriers with effective conventional takeoff and landing (CTOL) and vertical and short takeoff and landing (VSTOL) airwings.[2,3]

The study approach was to 1) analyze and formulate a matrix of representative missions and to validate them with recognized mission analysts; 2) to analyze and formulate current technology (CTOL) and advanced technology (VSTOL) airwings, including strike fighter and multimission configurations; and 3) to define the minimum size SES-CV for the candidate missions using CTOL and VSTOL airwings.

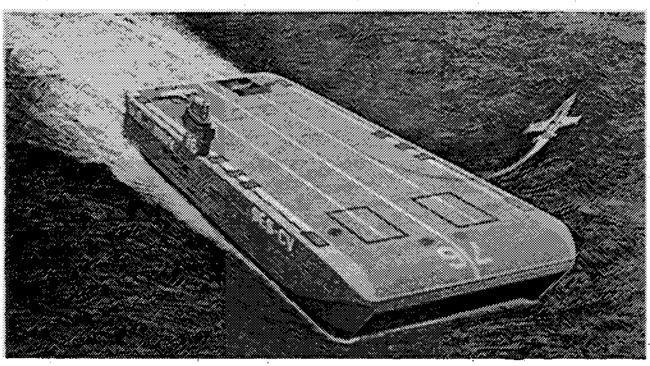

Fig. 1 SES-CV under way.

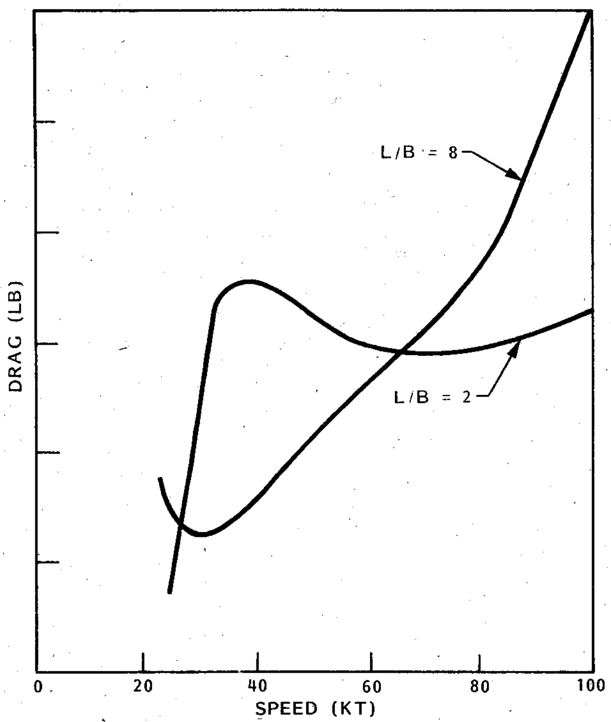

Fig. 2 SES L/B as a function of (D, V).

Study Support Areas

The mission analysis and formulation work was performed by A.D. Little under subcontract to Lockheed Missiles and Space Company (LMSC). The missions were validated by OSD, NAVSEA, CNA, WSEG, and NWC analysts. Matrices of mission-derived requirements for the SES-CV and its CTOL and VSTOL airwings were developed.

The aircraft analysis and concept formulation work was performed by the Lockheed California Company. NAVAIR provided inputs and reviewed aircraft physical characteristics and performance predictions. Matrices of current technology (CTOL) and advanced technology (VSTOL) aircraft for SES-CV deployment were developed.

SES-CV subsystem analyses and conceptual design were accomplished by LMSC. The analyses demonstrate that the subsystem technologies are either in hand or represent straightforward projections of current technology. Subsystem technology assessments included prime movers, power transmission, propulsors, lift fans, electric plant, combat systems, auxiliary systems, endseals, and aircraft handling provisions.

Several SES-CV design concepts were exercised. Major tradeoffs, including ship beam, ship length, number of decks, hangar deck area, crew accommodation area, machinery area, and aircraft handling, were examined.

Representative conceptual designs were developed and described. Speed and range vs sea state were optimized. Weight estimates were accomplished. The impact of wind over deck (WOD) and "runway" length on CTOL and VSTOL aircraft launch and retrieval were examined. Typical aircraft servicing, fueling, arming, launching, and recovery sequences were developed.

The costs associated with SES-CV development were estimated. The military worth of the SES-CV was examined. Development planning was accomplished, including preliminary design, detail design, subsystem development, long lead procurements, prototype construction, and test and evaluation elements.

In retrospect, the most critical, influential, and demanding guidelines are: exploit surprise tactics; deploy the SES-CV from a CV/CVN task force; emphasize strike carrier philosophy; design the SES-CV for notional strike fighter airwings; minimize the types of aircraft required; consider the LM5000 as the baseline GT, assuming a 60,000-hp output and using no more than six LM5000s; make compatible with existing facilities; consider SES-CV IOCs of the "1990 decade and beyond"; consider only two generic classes of aircraft—"fighter/attack" and "multi-mission"; consider only two generic airwing IOCs—"current technology" (1985-1990) and "advanced technology" (1990-2000).

Study Plan

The methodology involved in the conduct of this study is as shown in Fig. 3. Due to the necessity for brevity, only the CTOL/SES-CV will be discussed in detail.

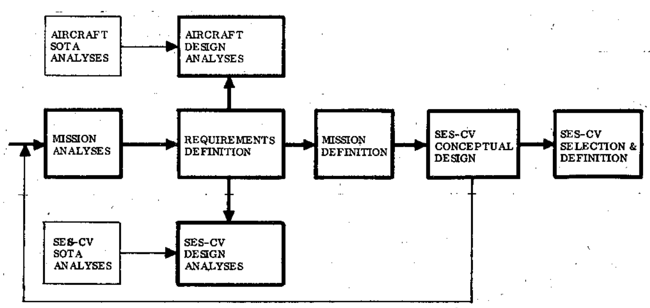

Fig. 3 SES-CV study methodology.

Final mission requirements: The final ship requirements developed as a result of mission analyses are in Table 1. These missions complement current battle group forces.

Selected CTOL/SES-CV: As the results of final mission and aircraft analysis were firmed, the results of generalized SES-CV design analyses were applied to the conceptual design of a CTOL/SES-CV for each mission. The outcome is shown in Table 2 (in the unboxed areas).

The selected ship was a result of the following conceptual design activities, considering dimensional tradeoffs, airwing provisions, and manning.

SES-CV Conceptual Design

Dimensional tradeoffs: Probably the most important design analyses in terms of contributing to the definition of minimum size SES-CVs involved dimensional tradeoffs— primarily length, beam, and height.

Length: In retrospect, minimum SES-CV length represents the most favorable compromise between aircraft takeoff run vs WOD, aircraft landing roll vs WOD, and aircraft stowage length requirements on the hangar deck.

Takeoff run vs WOD: One of the fundamental distinctions between the length of a minimum size CTOL/SES-CV and that of a CV/CVN is WOD (speed) regime. For the CV/CVN, the WOD potential is such that all aircraft must be catapulted—that is, the takeoff run required vs maximum WOD greatly exceeds the available deck length.

Landing roll vs WOD: For current CTOL carrier aircraft, the landing distance corresponding to CV/CVN WOD exceeds the available deck length. Thus arresting gear is required. For the CTOL/SES-CV, the WOD available greatly reduces landing distance. However, to minimize CTOL/SES-CV flight deck length, light-weight arresting gear is also required. Because of the higher WOD, runout distance is significantly reduced.

Aircraft stowage: For the CV/CVN, it is feasible to stow aircraft on the flight deck. A disadvantage of the high WOD associated with the SES-CV is that this approach is not feasible, or at least not desirable. An important distinction between the CV/CVN and SES-CV, then, is the deck area available for aircraft stowage—two decks on the CV/CVN and one on the SES-CV, plus the great difference in ship size.

In general, the tradeoffs demonstrated that takeoff deck length, landing deck length, and aircraft stowage length requirements were compatible for the CTOL/SES-CV.

Other considerations: The major length parameters have been summarized. However, other considerations must be recognized. These include bow seal design, sidehull design, elevator provisions, structural integrity, and sidehull drag.

Number of runways: The minimum beam SES-CV identified during the tradeoff phase was 125 ft. This dimension corresponds to a single "runway" served by fore and aft elevators. There are several limitations to an SES-CV with this beam which will be identified in later sections. In the context of this discussion, it was LMSC's judgment that a single runway was unacceptable for a carrier intended to be deployed into high threat areas. A single elevator casualty would disable all airwing operations. Based upon design tradeoffs, two parallel runways offer the desired redundancy and represent the best compromise with other beam dimension determinants, Fig. 4.

Aircraft stowage: As mentioned under the "length" discussion, aircraft cannot be stowed on the flight deck, making hangar deck stowage efficiency a primary consideration. A general conclusion of the design analyses was that hangar deck stowage became more efficient as the stowage geometry approached square (low L/B) ship dimensions. VSTOL aircraft tend to be smaller than equivalent CTOL aircraft, an asset in stowage.

Access aisle: Obviously, the beam dimensions could be reduced if no access aisle was provided on the hangar deck. However, this approach would limit the aircraft that could be launched to those "up" aircraft in the immediate vicinity of the launch (aft) elevators. For a ship where it is vital to minimize aircraft turnaround time and to stow "down" aircraft out of the primary traffic pattern, an aisle appears to be an absolute necessity. Fire is, of course, a major concern of an aircraft carrier. This concern is even more pronounced on a aluminum ship. A full length access aisle provides for extremely quick reaction to a fire anywhere on the hangar deck, particularly on a small ship.

Arresting gear: Lightweight arresting gear is a necessity to achieve the minimum length CTOL/SES/CV. On the basis of liaison with the Naval Aircraft Engineering Center (NAEC),

Table 1 Summary of CTOL/SES-CV mission requirements

Mission	Scenario events	SES-CV					CTOL	
		Flank, knots	Average, knots	Minimum, knots	Duration, h	Range, n.mi.	No.	Type
Strike warfare—Indian Ocean	Land strikes Antiship strikes Self-defense	80	72+	40	45	3200	13-14 0-4 2	SF AAWF AEW
Strike warfare—Mediterranean Sea	Crisis management Avoid pre-emptive strike Land strikes Antiship strikes AAW	80	64+	40	50	3200	13-14 0-4 2	SF AAWF AEW
Strike warfare—Norwegian Sea	Non-nuclear NATO war Surface combatants in transit	80	58+	40	35	3200	10-12 0-4 4	SF AAWF AEW
AAW defense of NATO resupply—Atlantic Ocean	Long-range AEW patrol Command launch intercept	80	45+	40	95	4240	0 10-12 4-5	SF AAWF AEW
Strike warfare—Atlantic Ocean	Search and destroy merchantmen	80	65+	40	55.2	3600	10-12 0 4-5	SF AAWF AEW
Crisis action—Pacific Ocean	Confrontation Evacuation	75	75+	6	50	3200	9-12 0 0 5-6	SF AAWF AEW HELOS

Table 2 Relative size of CTOL/SES-CVs

Mission	CTOL airwing No.	CTOL airwing Type	SES-CV length, ft: Airwing stowage	SES-CV length, ft: Arresting gear	SES-CV length, ft: Takeoff run	SES-CV beam, ft: Airwing stowage	SES-CV beam, ft: Arresting gear
Strike warfare—	14	SF		778 ft at 0 knots	1087 ft at 60 knots		
Indian Ocean	4	AAWF	600	713 ft at 20 knots	637 ft at 80 knots	184	196
	2	AEW		553 ft at 80 knots	297 ft at 100 knots		
Strike warfare—	14	SF		778 ft at 0 knots	1087 ft at 60 knots		
Mediterranean Sea	4	AAWF	600	713 ft at 20 knots	637 ft at 80 knots	184	196
	2	AEW		553 ft at 80 knots	297 ft at 100 knots		
Strike warfare—	12	SF		778 ft at 0 knots	1087 ft at 60 knots		
Norwegian Sea	4	AAWF	640	713 ft at 20 knots	637 ft at 80 knots	184	196
	4	AEW		553 ft at 80 knots	297 ft at 100 knots		
AAW defense of	0	SF		778 ft at 0 knots	1087 ft at 60 knots		
NATO resupply—	12	AAWF	610	713 ft at 20 knots	637 ft at 80 knots	184	196
Atlantic Ocean	4	AEW		553 ft at 80 knots	297 ft at 100 knots		
Strike warfare—	12	SF		654 ft at 0 knots	1167 ft at 60 knots		
Atlantic Ocean	0	AAWF	560	559 ft at 20 knots	627 ft at 80 knots	184	196
	5	AEW		539 ft at 80 knots	287 ft at 100 knots		
Crisis action—	12	SF		654 ft at 0 knots	587 ft at 60 knots		
Pacific Ocean	0	AAWF	545	559 ft at 20 knots	387 ft at 80 knots	184	196
	0	AEW		539 ft at 80 knots	227 ft at 100 knots		
	6	HELOS					

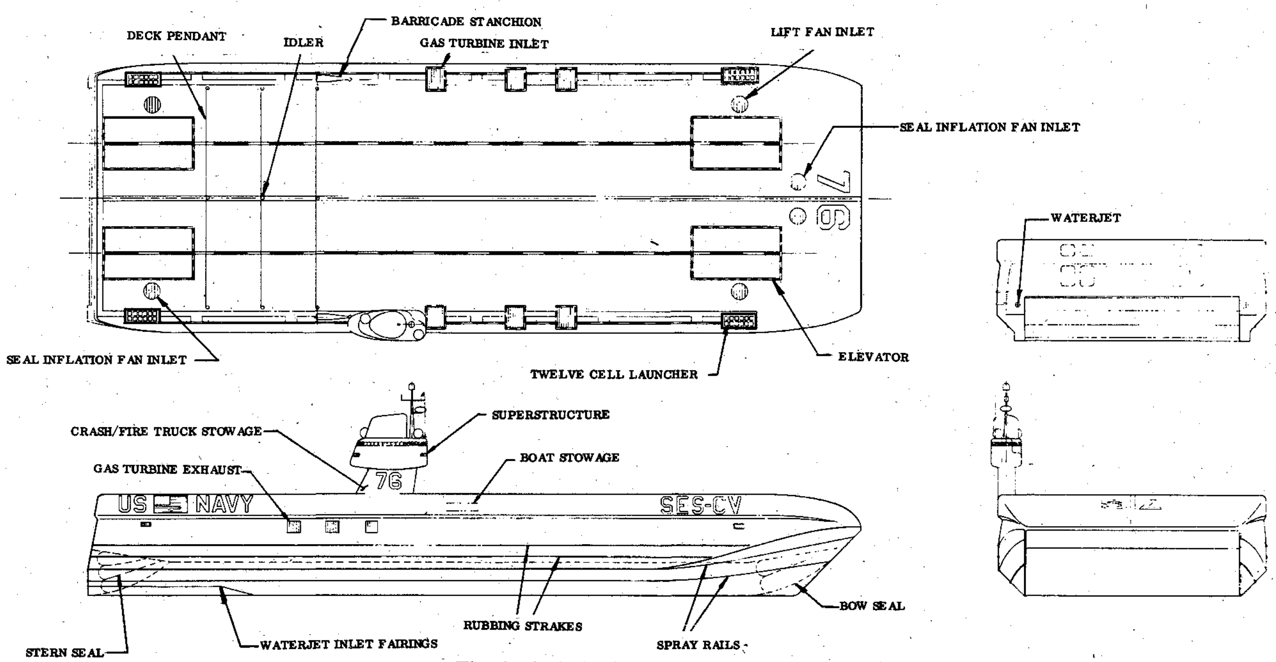

Fig. 4 SES-CV parallel runway layout.

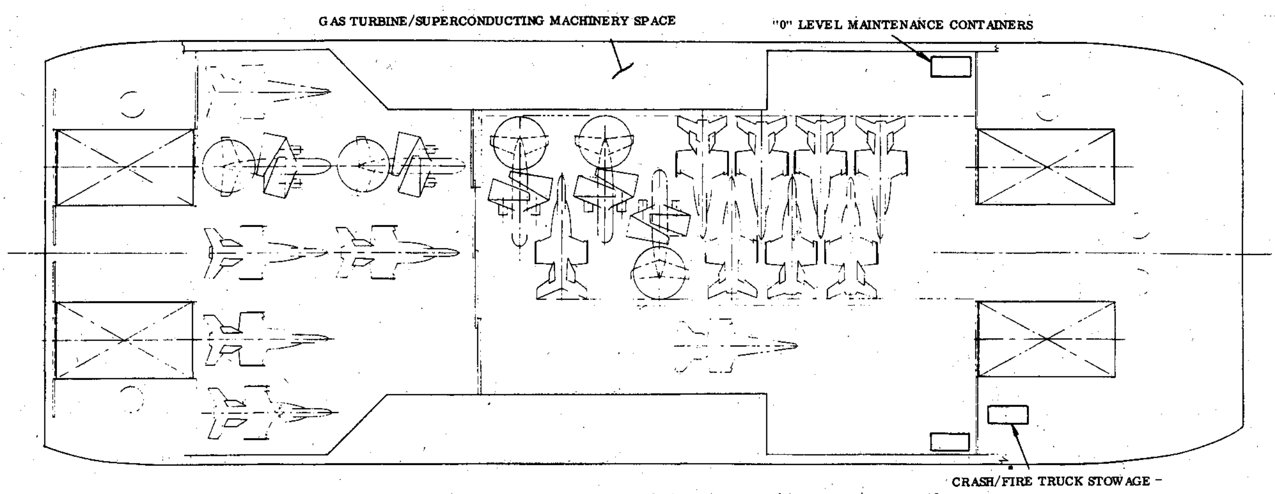

Fig. 5 Recommended airwing for "strike warfare—Atlantic Ocean" mission.

the current minimum deck pendant span is 120 ft. NAEC's staff predicts that pendant span could be reduced to a minimum of 80 ft. For a single arresting gear installation, the minimum CTOL/SES-CV beam would be 232 ft. Since the optimum beam dimensions tended toward the higher of these values, and two runways were favored, methods were sought to reduce the beam dimensions for a better compromise. Two approaches were found to be feasible: two Mk 14 installations staggered relative to one another, which reduced minimum beam to 196 ft; and an LMSC innovation—a single Mk 14 installation with a 160-ft pendant span with a large "idler" sheave dividing each 160-ft span into two 80-ft spans. This results in a beam of 196 ft. The staggered arrangement increases minimum ship length by the offset distance and requires two sets of arresting gear. The "idler" concept does not share these advantages, but may require more frequent deck pendant changes. The Mk 14 "idler" approach should be examined in more detail by NAEC.

Hull L/B considerations: These studies indicated that a low L/B was necessary to attain the 80-100 knots required speed. However, if the maximum design speed is reduced to the 50-60 knot range, a high L/B ship design will have better transport efficiency.

General arrangement: The general arrangement of the selected configuration is shown in Fig. 4. It reflects the results of the design analyses described earlier. The ship has four decks—flight, gallery, hangar, and machinery decks, respectively. Four elevators are utilized—the aft two for launching aircraft and the forward ones for retrieval. A modified three-wire Mk 14 arresting gear installation is used. Propulsion, lift, and seal inflation is by means of six LM5000 gas turbines mounted amid ships over each sidehull. Inlets are on the flight deck and exhausts over the side. Arresting gear and crew are housed on the gallery deck. All aircraft, as well as the main machinery, are stowed on the hangar deck.

Principal characteristics: These are summarized in Table 3.

Ship weight breakdown: Table 4 is a recap of the ship weight elements.

SES-CV State-of-the-Art Appraisal

The initial portion of LMSC's study effort was devoted to surveys and projections of SES-CV SOTA. These projections involved two categories of work—"large" SES SOTA surveys and projections and advanced aircraft carrier subsystem SOTA. As a result of this work, the following conclusions were reached:

1) The SES-CV hull structure represents a straightforward projection of current SOTA.

2) The SES-CV represents a more volume efficient hull as compared to a conventional monohull ship.

3) Of the prime movers surveyed, the aircraft derivative gas turbines, adapted to operate in a marine environment, represent the best near-term approach, while LWNP offers the optimum long-term approach.

4) An integrated (propulsion and lift) superconducting electric power transmission is favored over mechanical systems.

5) The endseals represent a significant scale-up from current SOTA.

6) Electric plant requirements can be met with current SOTA systems.

Table 3 Principal characteristics—Selected CTOL/SES-CV

Length (overall), ft	560
Length (cushion), ft	488
Beam (overall), ft	196
Beam (cushion), ft	156.8
L/B	3.11
Overall height, ft	153.5
Flight deck height, ft	73.5
Plenum height, ft	24
Crew	348
Ship	152
Airwing	196

Table 4 Weight estimate—selected CTOL/SES – TV

Group	Description	Weight
1	Hull structure	4212 LT
2	Propulsion, lift, seals	799
3	Electric Plant	253
4	Command and surveillance	25
5	Auxiliary system	1068
6	Outfit and furnishings	449
7	Armament	111
	Lightship condition	6917 LT
	Variable load	3503 LT
	Full load	10,420 LT

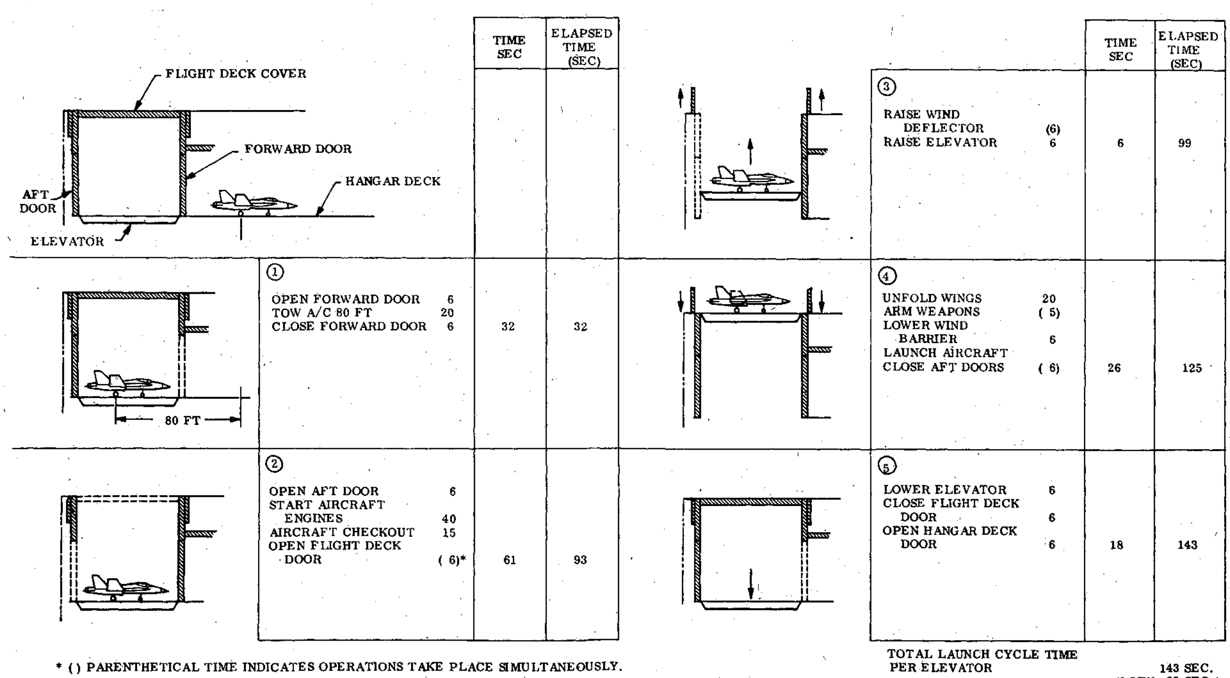

Fig. 6 Aircraft launch time sequence—CTOL.

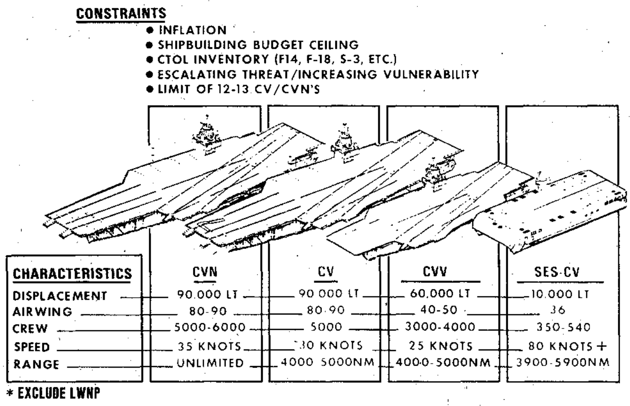

Fig. 7 CTOL aircraft carriers characteristics.

7) Command and surveillance systems needs can be met.

8) With the exception of the Mk 14 arresting gear and unique aircraft handling provisions, airwing auxiliary system requirements can be met.

SES-CV Conceptual Design

As the definition of SES-CV and airwing mission requirements evolved, the results of emerging aircraft and ship SOTA projections were utilized to initiate SES-CV design analyses. Several important conclusions were reached as a result of this phase of the study:

1) Minimum length is a compromise between flight deck aircraft takeoff run and landing roll and hangar deck aircraft stowage requirements.

2) Minimum CTOL/SES-CV deck length requires arresting gear.

3) An important length tradeoff is arresting gear runout vs WOD.

4) Minimum beam is a compromise between the number of flight deck runways, hangar deck machinery and aircraft stowage requirements, and aerodynamic and hydrodynamic considerations.

5) Minimum CTOL/SES-CV beam is affected by arresting gear requirements.

6) Minimum height is a compromise between the number of decks considered, roll stability, and aerodynamic drag.

7) A rectangular hull form represents the best structural and aerodynamic solution.

8) The minimum size ship has a moderate length/beam ratio.

9) Full-length sidehulls simplify hull structure and bowseal design.

10) Fore and aft elevators expedite aircraft handling.

11) Two runways expedite aircraft handling.

12) A designated hangar deck aisle expedites aircraft handling.

13) The best propulsion machinery location is amidships.

14) A designated aircraft service area expedites aircraft fueling and ordnance loading and reduces safety hazards.

15) LWNP contributes to a smaller SES-CV.

Operational Aspects

Again, due to the necessity for being brief, only aircraft handling aboard ship will be discussed here. See Fig. 5 for a typical hangar deck and aircraft arrangement for supporting strike warfare missions. An aircraft launch sequence is demonstrated in Fig. 6. Note that the total cycle time per aircraft is 2 min 23 s.

The flight deck wind deflectors would be designed for the largest aircraft to be handled aboard the SES-CV; however, the deflectors may be partially deployed for smaller aircraft. The deflectors must be compatible with the arrangement of the ship (i.e., compatible with the arresting gear wire installation, flush with the flight deck contour when retracted, and compatible with the design of the elevators and the ship structure). Wind tunnel modeling and full-scale tests are recommended, preferably utilizing real aircraft and flow visualization techniques.

For aircraft recovery, less than 2 min are required for each aircraft.

After landing, the aircraft are moved onto the elevators and the deflectors raised into position to deflect the air around the aircraft. Local wind speed around the aircraft is reduced to levels where existing wing fold mechanisms can function, the wings folded, and the aircraft brought down to the hangar deck. Deflectors can also reduce local wind speeds around the aircraft so that the canopy could be opened on deck in an emergency and the crew perform emergency functions such as disarming a malfunctioning weapon on the flight deck. The wind deflectors can be stowed vertically, between decks (on the gallery deck) and operate so that the aircraft can taxi across the retracted deflector.

Conclusions

Several important points were reached as a result of the study. It was determined that the SES-CV 1) is technically feasible; 2) represents a logical and acceptable extension of current SES technology; 3) is less vulnerable to the postulated threats; 4) has outstanding strike platform capabilities (Fig. 7); 5) is inherently a multiple-mission ship; 6) is highly cost-effective; 7) is a relatively low value target; and 8) implies new tactics to exploit its performance potential.

In closing, the SES-CV (preferably LWNP-powered) can perform herculean military effectiveness roles in accomplishing SED DEF's desires at much lower cost and manning levels per ship. In addition, it is recommended that the merits of an RPV minicarrier be addressed using the proposed 1500 LT SES as a test bed to validate its military worth.

Acknowledgments

This paper summarizes unclassified salient points resulting from two aircraft carrier SES design contracts accomplished by the Lockheed Missiles and Space Co., Ocean Systems organization for PMS-304 (Surface Effect Ships Project Office).[2,3] These contracts were under the direction of M.J. Stoiko, Chief of Advanced Design, PMS-304.

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