CTOL, STOAL, V/STOL: An Operational Comparison for Forward Deployed CVNs

W.P. Riviere Jr.* and N.P. Vignevic†
Naval Air Engineering Center, Lakehurst, New Jersey

A computerized model has been developed to aid in studies of mission system effectiveness for aircraft carrier operations with conventional takeoff and landing (CTOL), short takeoff arrested landing (STOAL), and vertical or short takeoff and landing (V/STOL) aircraft. The model systematically evaluates sensitivities to key input parameters associated with flight deck imposed limitations on aircraft movement, handling, and scheduling of major deck cycle operations. Sorties, time on station, and airwing requirements are predicted as a function of aircraft availability over a range of target and stationkeeping radii. Results are presented for the sea control and power projection missions which indicate significant operational advantages for V/STOL aircraft operating from large deck CVN class carriers or proposed smaller aircraft carriers.

Introduction

THE U.S. Navy is currently in debate over the type of air assets that would best suit its needs for future sea based aviation. Specifically, CTOL, STOAL, and V/STOL aircraft have been examined rather extensively through a number of recent Navy sponsored studies. These studies show that the effectiveness of the ship/air system is as important a consideration as the individual aircraft's capability. These studies were, however, restricted in their assessment of strike capability for future ship/air systems by an analysis based on a limited number of target and stationkeeping radii, and aircraft availability. In order to provide a broader based analysis accounting for different target radii, aircraft availability, and sensitivity to the various baseline assumptions, a mathematical model of the CVN power projection mission scenario was developed. This parametric method, with application to CTOL and V/STOL and a very limited number of sensitivity studies was documented in Ref. 1.

The information presented in this paper is an expanded treatise of the Ref. 1 material. The methodology has been refined and the application expanded to include STOAL operations, a sea control mission scenario, and a more comprehensive treatment of the sensitivities of system performance to changes in the various baseline operational constraints. In addition, an analysis of ship sizing requirements relative to the task role and specific levels of system performance is presented and provides an operational assessment of the large vs small carrier controversy.

Flight Deck Operations

Paramount to a discussion of the ship/air system performance results is a simple understanding of aircraft movement and flight deck scheduling constraints for each of the major deck operations. In the paragraphs that follow a brief explanation of operational mode for each generic type aircraft is presented. It should be noted that the CTOL mode is based on current fleet practice and has been optimized over a period of many years. STOAL and V/STOL operations are largely unknown in actual practice. The methods shown here are based on separate systems studies in which the flight deck functional layout and patterns of aircraft movement have been optimized to allow for maximum system performance.

Launch

Launch flow is similar for each type aircraft. In general they move from the after portions of the flight deck forward to the launching areas. The CTOL case, shown in Fig. 1, illustrates aircraft directed from the stern parking areas (shaded) to the waist catapults. The bow catapults are fed from the forward-starboard and amidship parking areas (shaded).

In the STOAL operation, shown in Fig. 2, aircraft are moved from the stern, port, starboard, and amidship parking areas (shaded) to two bow runways.

Launch flow for the V/STOL operation is exactly the same as that of STOAL, the only difference here being the layout of the flight deck. The angled portion of the STOAL flight deck is equipped with a series of sheaves and cross deck arresting cables (see Fig. 2). The V/STOL deck does not require this equipment.

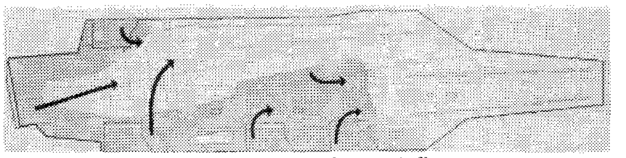

Fig. 1 CTOL aircraft launch flow.

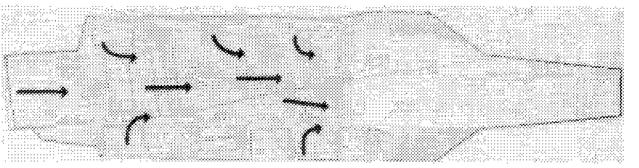

Fig. 2 STOAL aircraft launch flow.

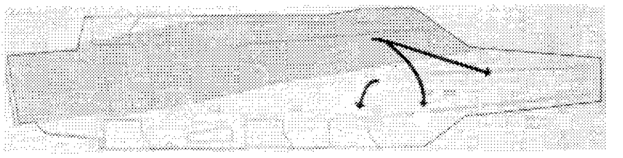

Fig. 3 CTOL/STOAL aircraft recovery flow.

Presented as Paper 81-1621 at the AIAA Aircraft Systems and Technology Conference, Dayton, Ohio, Aug. 11-13, 1981; submitted Sept. 17, 1982; revision received May 13, 1982. This paper is declared a work of the U.S. Government and therefore is in the public domain.
*Aerospace Engineer, Advanced Systems Office. Member AIAA.
†Aerospace Engineer, Advanced Systems Office.

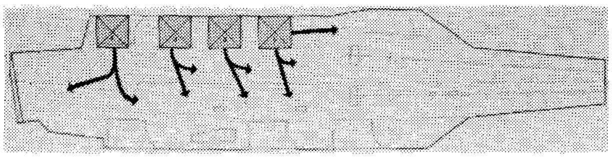

Fig. 4 V/STOL aircraft recovery/respot flow.

Recovery and Respot

Recovery and respot operations are precisely the same for CTOL and STOAL. For each aircraft type, a runway encompassing the entire angle deck portion of the flight deck must remain clear in order for aircraft to make conventional arrested landings (see shaded area of Fig. 3).

This area is required for a safe approach with sufficient ramp clearance, a touchdown area, a decelerating cable runout area, and, when recovery is complete, a turnout area. The aircraft then taxies forward to the bow and is parked. Later, when the total recovery has been completed, the aircraft must be respotted by towing them from the bow to their prelaunch positions or to an elevator to be lowered to the hangar. These prelaunch positions are those shown in the shaded parking areas of Figs. 1 and 2.

In the V/STOL case, shown in Fig. 4, the recovery and respot operations are simplified. Four vertical landing pads along the port side of the ship encompass only about one-quarter the area of the single long deck landing zone required for CTOL/STOAL. An aircraft is recovered on one of the pads and is taxied directly to its prelaunch spot and parked. Final positioning is accomplished with the aid of a tow tractor and crew.

Servicing

Following recovery, each aircraft requires several servicing functions prior to its next mission. Various checks are conducted, the aircraft is refueled and, if appropriate, rearmed. Servicing can start as soon as the aircraft lands and taxies to the bow (CTOL/STOAL) or directly to its prelaunch position (V/STOL).

Summary of Deck Operations

The CTOL/STOAL flight deck operation is programmed by the arrested landing requirement. Dependency on a long deck landing zone encompassing the entire angle deck portion of the flight deck requires that the major flight deck operations (launch, recovery, and respot) be conducted separately. The very large recovery zone imposes territory limitations which preclude simultaneous operations when maximizing system performance. Each operation uses the same portion(s) of the flight deck and hence the conduct of one fouls the deck for the other two. The unique capability of V/STOL permits vertical landings on relatively small landing pads removed from the launch area. V/STOL operations are therefore not territory-limited and hence can support simultaneous launch, recovery, and respot. The deck is never fouled for a particular operation.

Approach

Algorithms were developed and computerized to solve for aircraft movement, handling, and the scheduling of launch, recovery, respot, and servicing for CTOL, STOAL, and V/STOL aircraft.

Two combat mission scenarios were considered: 1) power projection in which the goal was to maximize the number of attack sorties during a 12-h operating period while maintaining adequate protection of the carrier through early warning, antiair, and antisub, and surface ship sea control sorties; and 2) sea control where the combat air patrol (CAP) time on station coverage is maximized during a 12-h operating period by utilizing all available fighter/attack aircraft in the CAP role while maintaining normal coverage in the remaining sea control functions.

Table 1 Deck cycle assumptions

	CTOL	STOAL	V/STOL
Launch rate, minutes per A/C	0.5	0.5	0.5
Recovery rate, minutes per A/C	1.0	1.0	0.5
Respot rate, minutes per A/C	10	10	4
Servicing rate, minutes per A/C	30	30	30
Number of weapons crews	12	12	12
Number of fueling crews	6	6	6
Number of tow crews	6	6	6

The generic aircraft were notional in design and assumed to have equal capability. That is, they cruise at the same speeds, carry the same payloads, and, in general, are capable of performing the same required missions. In doing this, it should be noted that the STOAL and V/STOL designs, in assuming the burden for acceleration in a short takeoff (STO) launch and deceleration for vertical landings (V/STOL only) are significantly larger in size than their CTOL counterpart. In this study, the V/STOL aircraft were assumed to be about 35% larger than CTOL and the STOAL aircraft 30% larger. Notional aircraft design study data found in Ref. 2 formed a basis for the aircraft size comparisons used here. STOAL pays for its larger size by being restricted to a smaller airwing. V/STOL embarks the same number of aircraft as CTOL, in spite of its larger size, because its ability to land vertically puts relatively little demand on flight deck real estate and, as a result, provides additional parking space not available to CTOL or STOAL. For this study, baseline conditions for the aircraft related parameters consisted of airwings of 100 aircraft for CTOL and V/STOL and 80 aircraft for STOAL, an availability of 60%, cruise velocity of $0.8M$, and fuel and reserves capable of 700 n.mi. station or target radii. All mission profiles included 2 min for takeoff and 5 min for landing in addition to the cruise out and back times. The attack mission profiles also included 2 min for formation and 5 min for combat.

Assumptions regarding the baseline rates and support crew requirements for the major deck cycle operations are based both on known historical data and the results of separate systems studies. These data are summarized in Table 1. It should be noted that the STOAL launch rate is a function of the takeoff run length. The data shown are based on a 400-ft run. Acceleration to flying speed with a full payload within 400 ft also drives the aircraft size. The airwing size noted previously reflects this capability. Smaller mission capable STOAL designs and hence larger airwings could be had by placing more of the burden for launch acceleration on the ship (i.e., longer takeoff runs). However, in so doing, the patterns of aircraft movement to the ready launch position become much less efficient and result in slower launch rates. It should also be noted that the servicing evolution is driven by the weapons loading requirement. The rate shown reflects this dependence.

Baseline ship size was a nominal 90,000 tons in the CVN 68 Nimitz class category.

The following four measures of effectiveness were used in the various parametric analyses presented herein:

1) Maximum sorties—The number of completed aircraft missions conducted within the designated 12-h operating period. The number is maximized within the constraints of the ship's flight operation's schedule.

2) CAP time on station (TOS)—Vigilant CAP aircraft time at a given station radius during the designated 12-h operating period.

3) Systems capability integral—An integration, from 0 to 700 n.mi., of maximum sorties-radius to target performance curves. This measure of system effectiveness provides a means whereby the combined effects of sorties and radius of action, again as limited by the constraints of the ship's flight operations schedule, may be evaluated.

4) Airwing size—The number of embarked aircraft on a specific size ship.

Results

The assumptions of the previous section were used in conjunction with the deck cycle model to generate baseline performance curves for two major naval scenarios: power projection and sea control using CTOL, STOAL, and V/STOL aircraft. In addition, studies of system sensitivity to variations in the baseline deck cycle and aircraft related input parameters and ship sizing trends were also conducted. Figures 5-17 and the explanations that follow detail these results.

Power Projection

In the power projection scenario the basic goal of the systems operation is to generate as many sorties as possible. Figure 5 illustrates this capability for each generic aircraft type's baseline airwing.

V/STOL is clearly superior to CTOL and STOAL in its maximum sortie output at any target radius. This performance benefit is the direct result of V/STOL's relative lack of deck constraints. STOAL, although limited by the same deck cycle inefficiencies as CTOL, does not match CTOL's capability because of its smaller airwing.

As the radius to target increases, the sortie potential for each system decreases. For CTOL/STOAL there are as many launch opportunities at extended range as there are at short range; however, the air assets on hand are not sufficient to fill the available launch slots. The V/STOL operation is also aircraft deficient at extended ranges and, in addition, loses launch opportunities with increasing radius to target.

Sea Control

The aim of the ship/air system in the sea control scenario is to provide the maximum aircraft time on station in the most efficient manner for the various defensive missions required by the task force. The CAP aircraft mission was chosen to illustrate each system's capability. CAP performance is given in Figs. 6 and 7. The trends presented are indicative of the overall sea control scenario.

The intent of each system shown in Fig. 8 was to man ten CAP stations for 12 consecutive hours with no gaps in station coverage (120 h total TOS). At short and medium range each system met this goal. Only at extended ranges do small differences in capability become apparent, with V/STOL providing the most and STOAL the least TOS.

Figure 7 shows the performance of each system while attempting to man 20 CAP stations (240 h total TOS). This additional burden has further taxed each system's aircraft assets causing all operations to fall short of the goal (240 h total TOS) at shorter radii. STOAL in particular is severely affected because of its small airwing and, even at very short radii, cannot man 20 stations for 12 h. Again, as in the ten CAP station case, V/STOL slightly out performs CTOL.

In general, maximizing TOS for sea control does not require maximizing sorties as in the power projection scenario. As a result, deck constraints, or the relative lack of them as with V/STOL, become less significant and, as a result the TOS performance curves for equal size airwings, whether they be V/STOL or CTOL/STOAL, tend to come together.

V/STOL does, however, attain operational advantages not apparent from the sea control performance curves of Figs. 6 and 7. An examination of the required airplans is necessary. Figures 8 and 9 present in order a typical V/STOL and then CTOL/STOAL sea control airplan. They are identically scaled for station radius and launch size and have been developed to provide the maximum CAP TOS in the most efficient manner. The key phrase here is "most efficient manner." In Fig. 8 it can be seen that when launch group 1's TOS is exhausted, launch group 2 has completed its cruise to station and relieves, with no overlap or gap in station coverage, the departing aircraft. Utilizing three launch groups, this airplan maintains continuous CAP coverage throughout the operating period. This airplan can only be accomplished with a V/STOL operation. CTOL/STOAL cannot work this airplan because of repeating foul deck situations. Reference to Fig. 8 shows that as launch group 1 is recovering and respotting, launch group 3 must takeoff. The arrested landing area and bow of the ship are in use and preclude launch operations. Thus, for the CTOL/STOAL operation, alterations to the airplan are necessary.

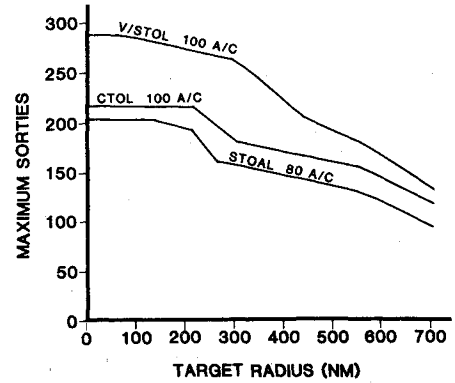

Fig. 5 Maximum sorties baseline airwing comparison, 60% A/C availability.

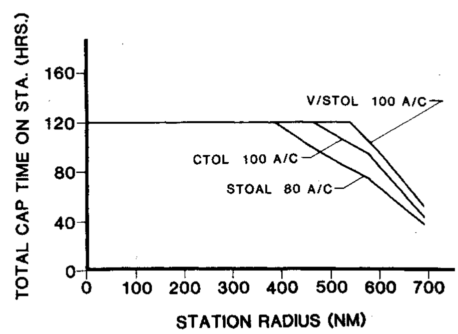

Fig. 6 Sea control mission comparison—10 CAP stations, 60% A/C availability.

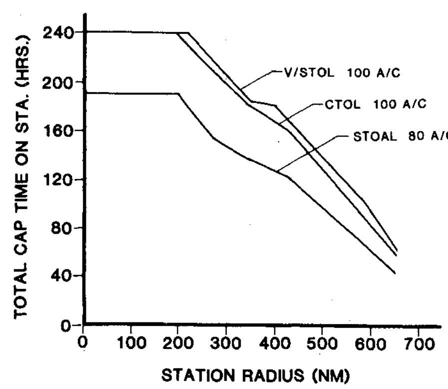

Fig. 7 Sea control mission comparison—20 CAP stations, 60% A/C availability.

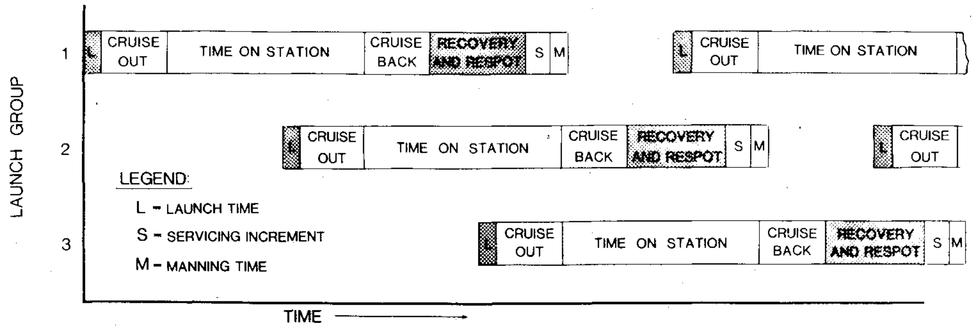

Fig. 8 Sea control airplan—V/STOL (unconstrained only).

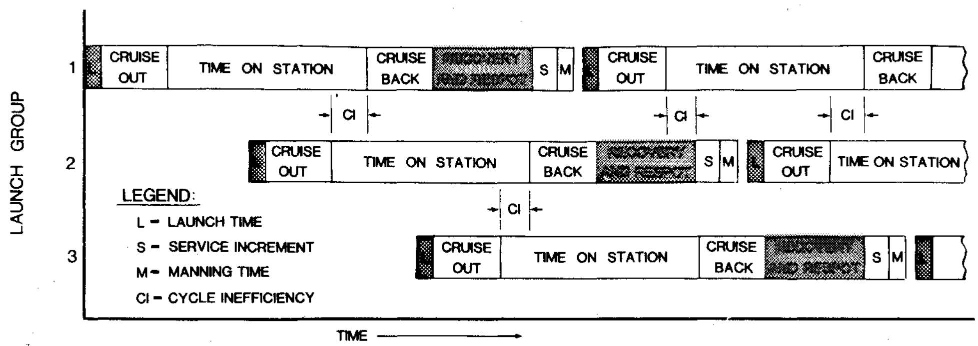

Fig. 9 Sea control airplan—CTOL/STOAL (constrained).

There are two practical solutions to this problem. The first would be to launch succeeding groups later and accept gaps in station coverage. The second solution, and the more desirable since it provides greater protection for the carrier, is to launch earlier and accept overlapping station coverage and additional sorties. This latter alternative is illustrated in Fig. 9. The launch interval was shortened such that each launch group following group 1 would arrive on station prior to when it was required. This cycle inefficiency, shown as CI on Fig. 9, results in the CTOL/STOAL operations making less effective use of each sortie and requiring more sorties than V/STOL to man all stations during the designated operating period.

Sensitivity Studies

The ship/air system performance represents a complex interaction of many diverse factors. These factors include both ship and air imposed constraints. In order to determine their individual effects, sensitivity studies were conducted for each factor. The sensitivities serve to establish the credibility of the baseline assumptions, provide indicators of the system potential, and, finally, show what factors are likely to provide the biggest payoff to the operators. The results of these studies are presented in the form of performance curves using the system capability integral as the dependent variable. The system capability integral was derived from sortie/distance data based on taxing the deck to its maximum capability for generating sorties. Two general notes are in order here. The first is that in all cases the independent variable was taken to extreme conditions, beyond what one might consider plausible or reasonable. The intent here was to explore the trend rather than the feasibility. The second note deals with the level of system performance. Even though the different operations (CTOL, STOAL, V/STOL) exhibit different sensitivities to changes in the baseline assumptions, V/STOL, because of its relative lack of deck constraints, always shows more performance than CTOL or STOAL, while CTOL always shows more performance than STOAL because of its larger airwing.

Aircraft Movement on Flight Deck

Aircraft movement on the flight deck is represented by the rate parameters of launch, recovery, and respot. The general curve shapes and sensitivity to variations in the baseline

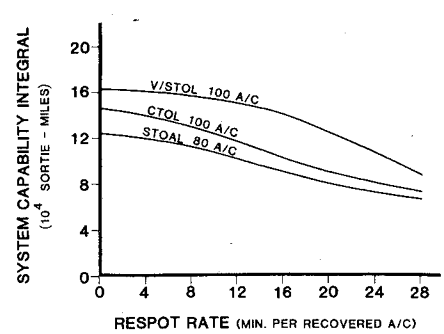

Fig. 10 System performance comparison: respot rate sensitivity, 60% A/C availability.

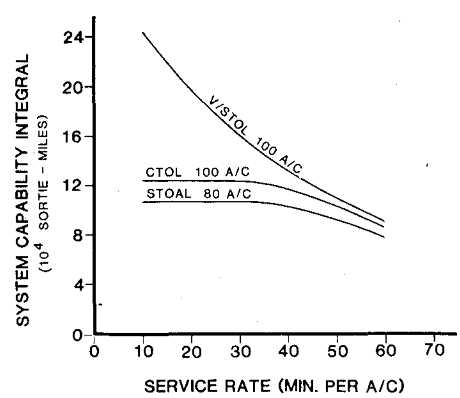

Fig. 11 System performance comparison: service rate sensitivity, 60% A/C availability.

values are similar for each parameter. Figure 10 illustrates these system trends using respot rate as the independent variable. The V/STOL system performance is shown to be relatively insensitive to changes in the respot rate. Improvements to the baseline 4 min per aircraft provide insignificant improvement to the system performance. Performance drops off noticeably only at rates considered well beyond the reasonable range. CTOL and STOAL are only slightly more responsive to changes in the respot rate,

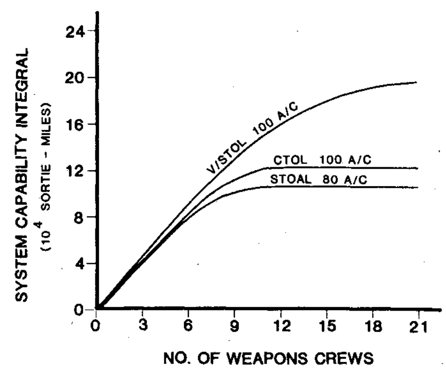

Fig. 12 System performance comparison: weapons crew sensitivity, 60% A/C availability.

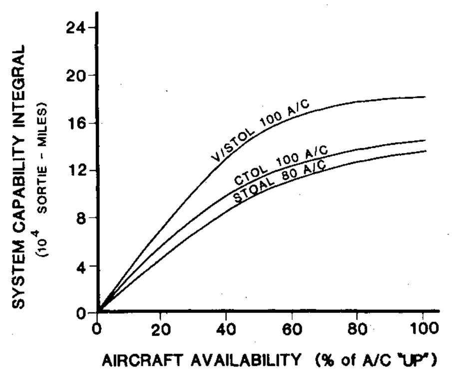

Fig. 14 System performance comparison: aircraft availability sensitivity.

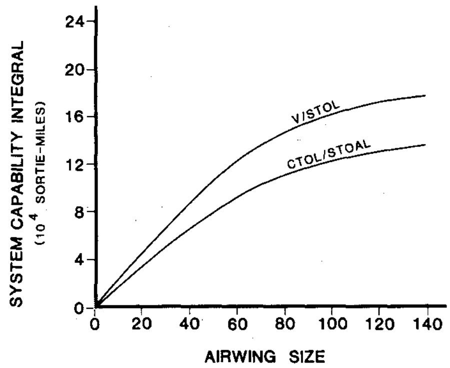

Fig. 13 System performance comparison: airwing size sensitivity, 60% A/C availability.

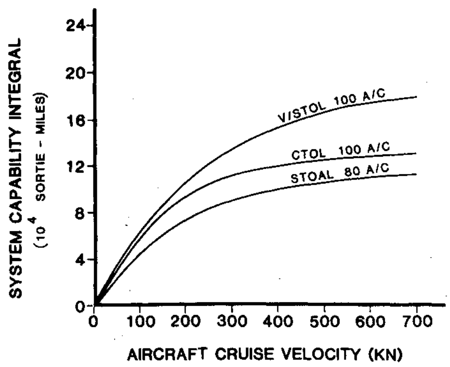

Fig. 15 System performance comparison: aircraft cruise velocity sensitivity, 60% A/C availability.

exhibiting shallow sloped near linear changes in performance at rates near the baseline.

Service Rate

The service rate, as shown in Fig. 11, has a great effect on the V/STOL system performance. It can be seen that improvements to the baseline 30-min rate provide, for the rates shown, an ever increasing gain in performance. A finite limit will be reached as the service rate approaches zero where the rates of launch, recovery, and respot will drive the cycle and cap the level of performance.

CTOL and STOAL, on the other hand, show no improvement in system performance with rates of servicing faster than the baseline 30 min per aircraft. At rates slower than the baseline condition, significant reductions in the system performance can be found.

The service rate is the primary driver of the V/STOL deck cycle and has a profound effect on the system performance. In the CTOL/STOAL operation it is of secondary importance since the cycle is already heavily constrained to the separation of launch, recovery, and respot. Only at the slower rates of servicing can the scheduling of servicing time become a driver of the deck cycle and negatively affect the system performance.

Weapons Crews

Figure 12 shows the system's sensitivity to changes in the number of weapons crews. Like the service rate, the number of weapons crews has a great effect on the V/STOL system performance. Additional weapons crews allow the launch size to be increased and thereby increase sorties and system performance. However, in so doing it also taxes the available air assets sooner. Hence the performance increases, but only at a continually decreasing rate and approaches a finite limit.

Increases to the number of CTOL/STOAL weapons crews, beyond the baseline condition, provide no further improvements in system performance. Launch, recovery, and respot constraints predominate here and prevent further gains in performance.

Airwing Size

Figure 13 shows the system's sensitivity to the number of aircraft in its airwing. As might be expected, as the number of aircraft in each system increases, the capability of that system also increases, but at an ever decreasing rate. Eventually a limit is reached, based on the constraints of each system's operation, where all opportunities to launch are filled and no further capability is available.

For the same airwing size V/STOL can always outperform CTOL and STOAL operations. Another way of interpreting this figure is that V/STOL can achieve the same level of capability with smaller airwings. For example, a CTOL or STOAL airwing of 100 aircraft has the same potential as a V/STOL airwing of 60 aircraft.

Aircraft Availability

Figure 14 shows the system's sensitivity to changes in aircraft availability. It can be seen here that, in general, each operation shows similar trends in system performance with variations around the baseline 60% availability and at any given availability the V/STOL operation outperforms CTOL or STOAL. It should also be noted that the larger V/STOL design is likely to exhibit a greater aircraft systems complexity and hence a lower availability than it's CTOL counterpart. However, as shown in Fig. 14, the V/STOL operation can tolerate a significantly lower availability and still perform at the same level as CTOL. V/STOL requires only about 38% availability to achieve the same level of system performance as the 60% available CTOL airwing.

Aircraft Speed

The final sensitivity examined is the systems' performance as a function of aircraft cruise velocity. Increasing cruise velocities bring a twofold benefit to each systems' operation. For the same mission time a faster aircraft can improve its radius to target, thus increasing its system capability integral by generating its sorties at a greater distance. Also at a given radius to target, a greater cruise velocity allows each aircraft to complete its mission sooner, thus improving its potential for generating sorties.

As Fig. 15 shows, the V/STOL system is better able to utilize the advantages that increased cruise velocity can bring to an operation. The CTOL and STOAL systems are restrained in their ability to utilize these same advantages, again owing to their more complex deck constraints, and beyond about 350 knots show very little improvement.

Another interpretation of this chart shows that a low speed V/STOL aircraft could achieve the same systems performance as a higher speed CTOL or STOAL. The important implication of this conclusion is that future V/STOL airwing compositions could consist of a higher percentage of lower cost, slow speed aircraft and still meet or exceed the performance of the future CTOL or STOAL systems.

Ship Sizing

The study results thus far have been based on operations from a large deck carrier of the CVN 68 Nimitz class. In recent years, the Navy has shown considerable interest in the development of smaller carriers that could offer the advantages of reduced cost, a wider dispersion of the available air assets, and the ability to scale down the ship size to better match lesser areas of conflict. In this section an analysis of ship sizing as related to various levels of system performance for both the sea control and power projection mission scenarios is presented.

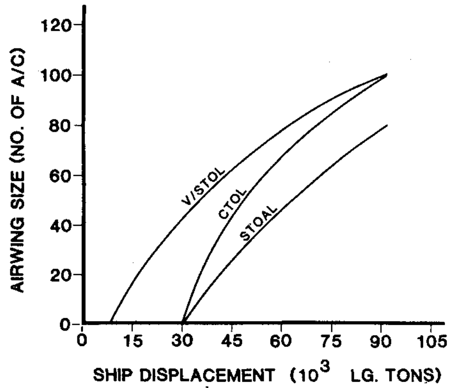

Fig. 16 Airwing comparison: airwing comparison, various size air capable ships.

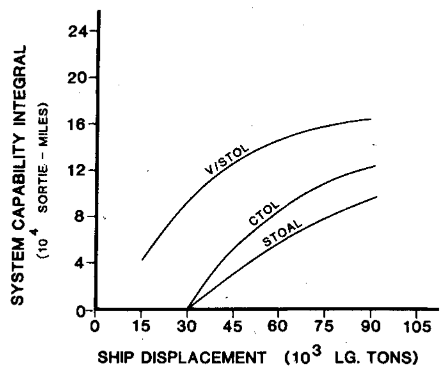

Fig. 17 System performance comparison: various size air capable ships, 60% A/C availability.

Sea Control

The large deck carrier results (Figs. 6 and 7) have shown that maximum performance in a defensive mission posture is primarily a function of aircraft numbers rather than the mode of operation. V/STOL, constrained to the same numbers of aircraft as CTOL on the large deck, provides about the same station coverage. However, if the ship size is reduced, the vertical landing capability of the V/STOL design offers an economy of scale not available to CTOL or STOAL. The driving factor in ship sizing, determined by the requirements for air operations, is the dimensions of the landing zone. For CTOL or STOAL, the landing zone needs to be on the order of 700 ft long and 100 ft wide. V/STOL operations require a square landing pad only slightly larger than the aircraft. Reductions in flight deck size, and hence ship size, must come from the parking areas in order to provide for the safe conduct of air operations. Downsizing the air platform for CTOL/STOAL operations results in a much larger percentage of its available flight deck parking real estate being lost than an equivalent reduction in ship size for V/STOL operations. The net result of these area tradeoffs is that CTOL/STOAL airwings are reduced in size faster than V/STOL airwings are with decreasing ship size. Figure 16 illustrates the relationship between airwing size and ship displacement for the CTOL, STOAL, and V/STOL operations. The curves were derived from data found in Ref. 2 and are based on notional design aircraft of equal mission capability. The V/STOL and STOAL designs have been appropriately penalized in size and weight, compared to the CTOL aircraft, to achieve the performance parity.

It can be seen here that as the ship size decreases, V/STOL's airwing advantage becomes more pronounced. For the same size ship V/STOL can embark more aircraft and therefore outperform both CTOL and STOAL in the sea control scenario. Many of the current Navy studies have centered on ships in the nominal 45,000-ton class. Using this size as a basis for comparison, V/STOL embarks 60 aircraft where CTOL and STOAL can only embark 45 and 25 aircraft, respectively.

Power Projection

Using the airwing data presented in Fig. 16, maximum system performance suitable to a power projection analysis is presented in Fig. 17.

Here for the 45,000-ton class ship the V/STOL design more than doubles the CTOL capability and quadruples that of STOAL. It can also be seen than V/STOL operations on a light carrier design of 45,000 tons can attain the same system performance as CTOL aircraft on today's large deck, 90,000-ton CVN class ship.

Concluding Remarks

Comparisons between CTOL, STOAL, and V/STOL have been made using a ship/air systems approach. Two important naval scenarios were analyzed: power projection and sea control. The system's sensitivity to changes in the number or efficiency of flight deck crews, ship installed or ground support equipment performance, or aircraft performance parameters were also evaluated. Finally, an analysis of the system performance, as related to ship sizing trends was presented. The basic conclusion that has been reached is that, for the operational measures of effectiveness used, V/STOL is superior to both CTOL and STOAL.

Operating from today's large deck carrier or from the smaller ships under consideration for the future, V/STOL shows clear and distinct advantages over both CTOL and STOAL in the power projection operation. Using the systems capability integral as the measure of performance, V/STOL performs 33% better than CTOL and 69% better than STOAL from the large deck carrier. When the ship size is decreased the V/STOL advantage becomes even greater.

In the sea control mission scenario, V/STOL shows only a small advantage over CTOL from the large deck ship. Performance here is primarily a function of how many aircraft are onboard rather than how they operate. STOAL, operating in the same manner as CTOL, but with less aircraft, shows a significant reduction in stationkeeping ability. Decreasing the ship size provides V/STOL with a major advantage. The economy of scale trend, characteristic of its vertical landing capability, results in larger airwings and therefore greater performance for V/STOL as compared to CTOL or STOAL.

The sensitivity analyses have shown that today's CTOL carrier airwings have reached a near optimum level of mission performance. Adding crews, improving their efficiency, or upgrading the capability of any of the aviation support equipment can provide only minimal gains in mission output. STOAL, constrained to the same type of operation, shows the same lack of potential for improvements to the system performance. An improvement is possible only if the CTOL/STOAL flight deck area could be increased to a point such that simultaneous launch, recovery, and respot operations could be conducted. Clearly, this is impractical. The V/STOL operation, on the other hand, permits substantial system performance gains without an increase in ship size. The addition of service crews for example, provides significant and easily attainable gains in system performance. A faster rate of aircraft servicing, as may be afforded by future advances in weapons and fuel systems support equipment technology, provides another, although not as easily attained, area for a considerable gain in system output.

The above conclusions are based on single parameter sensitivity analyses. These analyses demonstrate the limitations of CTOL/STOAL operations and indicate the improvements possible with V/STOL operations. Multiple parameter sensitivity analyses would verify that even further improvements in V/STOL operations are possible.

References

[1] Vignevic, N. and Riviere, W., "CTOL/VSTOL Comparison—A View from the Deck," AIAA Paper 80-1812, Aug. 1980.

[2] Chambers, C.E., Perkins, R.G., and Tyler, J.T., "An Assessment of Sea Based Air Master Study," AIAA Paper 80-1820, Aug. 1980.