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Amphibious Assault Ship Hangar Bay Smoke Removal Tests Conducted Onboard the *U.S.S Saipan* (LHA-2) and *U.S.S. Peleliu* (LHA-5)

by
Terry S. Fay, Erin C. Mack, Arthur J. Parker and Robert L. Darwin
Hughes Associates, Inc.
Baltimore, Maryland

Howard L. Bowman, Glenn E. Risley, Ross Davidson, and Julie M. Wright
Naval Air Warfare Center Weapons Division
China Lake, California

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NAVAL AIR WARFARE CENTER WEAPONS DIVISION
China Lake, CA 93555-6100

FOREWORD

This report summarizes work performed onboard the U.S.S. *Saipan* (LHA-2) and the U.S.S. *Peleliu* (LHA-5) to review hangar bay smoke removal and ventilation tactics on board amphibious assault ships. The objective of this program was to describe scoping tests that were conducted for the purpose of providing guidance on changes to the ventilation procedures described in the NATOPS Firefighting Manual. The test results were used to provide recommendations for changes to the doctrine.

During these scoping tests, smoke generators were used to evaluate techniques for smoke removal from the hangar bay onboard the U.S.S. *Saipan* (LHA-2) and the U.S.S. *Peleliu* (LHA-5). Visibility within the hangar bay was used as the measure of performance, and the effects of door status and wind direction were evaluated during these tests. Doors that were used included the elevator doors, the door at the top of the flight deck, and a sponson opening to weather. The effects of crosswinds and headwinds were evaluated for the different door configurations.

Therese M. AtienzaMoore
Head, Energetics Research Division
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Terry S. Fay, Erin C. Mack, Arthur J. Parker, and Robert L. Darwin (Hughes Associates, Inc.) and Howard L. Bowman, Glenn E. Risley, Ross A. Davidson, and Julie M. Wright (NAWCWD China Lake)

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Report summarizes work performed onboard the U.S.S. *Saipan* (LHA-2) and the U.S.S. *Peleliu* (LHA-5) to review hangar bay smoke removal and ventilation tactics on board amphibious assault ships. The test results were used to provide recommendations for changes to the ventilation procedures for amphibious assault ships doctrine as described in the NATOPS Firefighting Manual.

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INTRODUCTION

Current U.S. Navy firefighting doctrine (Reference 1) requires that in the event of a fire in the hangar bay of an amphibious assault ship (LHD/LHA), all fire and elevator doors are immediately closed. This is intended to contain the fire, minimize the introduction of fresh air (which could increase the fire growth), and prevent further fire spread to unaffected areas of the ship. However, by closing the elevator doors, smoke and heat will accumulate within the hangar bay, severely reducing the visibility for firefighting personnel. Reduced visibility results in disorientation and deterioration of communications among the ship's crew in addition to reduced firefighting performance.

Ventilation guidance is provided in Reference 1, Section 8.7.6 of Chapter 8 (as a note) stating "Leave one elevator door open approximately 3 feet to facilitate venting of smoke. Request ship execute a turn in order to position the open door to leeward." The doctrine is interpreted to mean that the door should be open while firefighting operations are being performed (i.e., active desmoking).

The guidance provided in Section 7.7.7 of Reference 1 for aircraft carriers is not consistent with that in Section 8.7.6. Section 7.7.7 states that all fire and elevator doors should be closed immediately. As a note, it then says to "… Cross ventilate to facilitate venting of smoke. Utilize ship's direction to maximize ventilation efforts." Considering that the elevator doors are normally open to some degree in good weather, closing doors only to open them later is contradictory. The inconsistencies in the guidance provided in Chapters 7 and 8 resulted in the need for conducting testing to determine the appropriate door settings to maximize ventilation.

The effects of reduced visibility on firefighter performance have been observed in a number of manned tests conducted in small, below deck spaces onboard the Navy's full-scale Research, Development, Test & Evaluation (RDT&E) facility (ex-U.S.S. *Shadwell*, in Mobile, AL) (References 2, 3, 4, and 5) and during an actual fire involving hazardous materials onboard the U.S.S. *George Washington* (CVN-73) (Reference 6). Testing conducted onboard the *Shadwell* followed current doctrine where the mechanical ventilation system was secured upon report of the fire. In these tests, the Fleet participants were unable to perform firefighting operations (dressing out, advancing hose lines, extinguishing the fire, and maintaining boundaries) due to the intense heat and reduced visibility. During the aircraft carrier hangar bay fire, all doors were closed during firefighting operations (per doctrine), resulting in heavy smoke, heat accumulation and reduced visibility. The reduced visibility and excessive heat hampered firefighting efforts by preventing the fire teams from finding the hose lines, reaching the seat of the fire for an extended period of time, and extinguishing the fire (Reference 6).

Previous testing (References 2, 3, 4, and 5) has demonstrated the effectiveness of establishing ventilation pathways to remove heat and smoke from the fire space during firefighting operations using natural and mechanical ventilation. In a hangar bay, the opening of the doors may permit venting of the fire space, restoration of visibility, and lowering the heat threat within the hangar bay. In order to determine whether this should be a recommended practice, actual ventilation testing was conducted onboard the U.S.S. *Saipan* (LHA-2) and the U.S.S. *Peleliu* (LHA-5).

To identify the most effective smoke removal techniques and recommend more clear doctrine procedures, ventilation testing has been conducted onboard a Nimitz-class aircraft carrier, the U.S.S. *Eisenhower* (CVN-69) (Reference 7), a Wasp-class amphibious assault ship, the U.S.S. *Bonhomme Richard* (LHD-6) (Reference 8) and Tarawa-class amphibious assault ships U.S.S. *Saipan* (LHA-2) and U.S.S. *Peleliu* (LHA-5). These tests examined the effect of wind direction and door position (elevator, division, and sponson doors) on the smoke removal effectiveness for the specific hangar bay configurations. Evaluation of each hangar bay on the CVN was necessary because of the different door arrangements that opened to weather. The results showed that opening an elevator door 1 m (3 ft) had minimal effect on smoke removal from the hangar bay, regardless of the ambient wind conditions. Smoke removal was the most efficient when there were door openings on both the leeward and windward sides of the hangar bay. For situations where there were elevator doors on each side of the hangar bay, the results suggested that the most effective door configuration was to open the leeward door halfway and the windward door 1 m (3 ft) (assuming that the ship had turned to create a crosswind).

Since the doctrine is conflicting for aircraft carriers and amphibious assault ships, and the hangar bay configurations are different, it was necessary to conduct testing on the LHA amphibious assault ships.

OBJECTIVE

The objective of this test program was to conduct tests onboard the U.S.S. *Saipan* (LHA-2) and the U.S.S. *Peleliu* (LHA-5) for the purpose of providing guidance on changes to the ventilation procedures described in the current doctrine. The test results were used to recommend changes to the doctrine.

APPROACH

Smoke generators were used onboard the U.S.S. *Saipan* (LHA-2) and the U.S.S. *Peleliu* (LHA-5) to evaluate the smoke removal performance from the hangar bay with various door configurations. Visibility within the hangar bay was used as the measure of performance during these tests. The effect of door status and wind direction was evaluated. Doors that were used in this test series included the elevator doors and the flight deck ramp door. The side sponson rollup door was also used in the U.S.S. *Peleliu* (LHA-5) tests; however the tests involving this door were not completed due to technical problems. The effects of crosswinds and headwinds were evaluated for the different door configurations.

HANGAR BAY TEST SETUP

The test setup for all tests was comprised of smoke generators used to fill the hangar bay with smoke (i.e., cold smoke), visibility targets for observers to view, and the door configurations being evaluated. Fleet participants from the U.S.S. *Saipan* (LHA-2) and the U.S.S. *Peleliu* (LHA-5) assisted in the test setup, participation, and cleanup.

U.S.S. *Saipan* (LHA-2) and U.S.S. *Peleliu* (LHA-5) Hangar Bay

The Tarawa-class amphibious assault ship has one hangar bay located on the main deck, spanning from FR 83 to FR 121 and nearly the entire ship's width. Figure 1 provides a plan view of the hangar bay. The overhead height varied down the length of the hangar bay. In the aft 25 m (82 ft) the hangar bay, the overhead height was 9.1 m (30 ft). The volume in the aft portion of the hangar bay was, therefore, 5,400 m^3 (192,000 ft^3). The overhead height was 6.4 m (21 ft) in the forward 55 m (182 ft) of the hangar bay, resulting in a volume of 8,450 m^3 (298,000 ft^3). The hangar bay had two elevator doors as shown in Figure 1. One elevator door was centered in the port side hangar bay bulkhead. The other elevator door was centered in the aft hangar bay bulkhead. A roll-up door opening to weather was located in the forward portion of the hangar bay, on the starboard side, near the flight deck ramp.

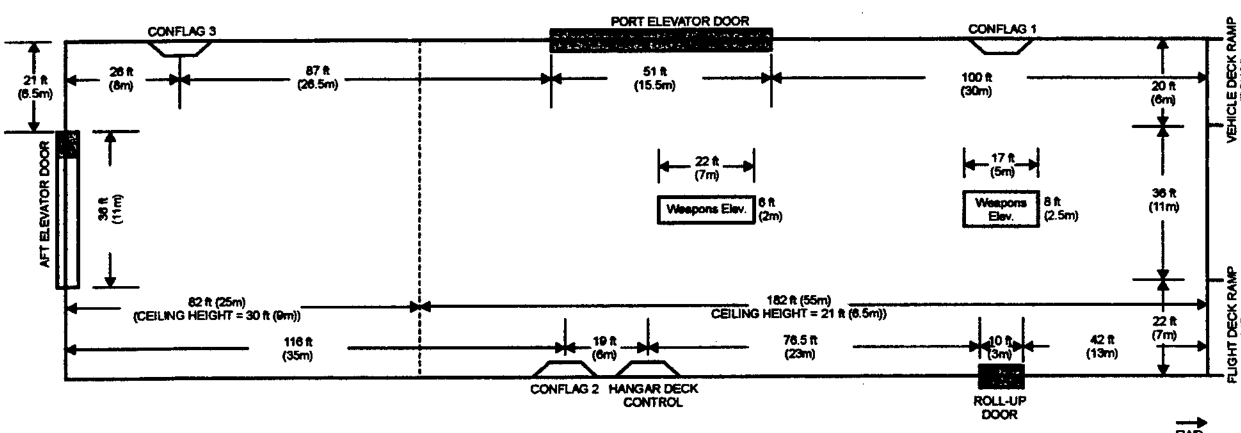

FIGURE 1. Plan View of Hangar Bay.

Direct access to the flight deck was provided by a ramp from the hangar bay deck (main deck) up to the flight deck (03 Level), located in the forward, starboard corner of the hangar bay. There were two doors to weather located at the top on the flight deck ramp and there was no door to weather at the base of the flight deck ramp. Figure 2 provides a plan view of the flight deck ramp. The flight deck ramp overhead was 4 decks high (approximately 14.5 m (48 ft) high) on the main deck and one deck high (approximately 3.7 (12 ft) high) at the flight deck level. This resulted in a flight deck ramp volume of approximately 3,150 m^3 (111,400 ft^3).

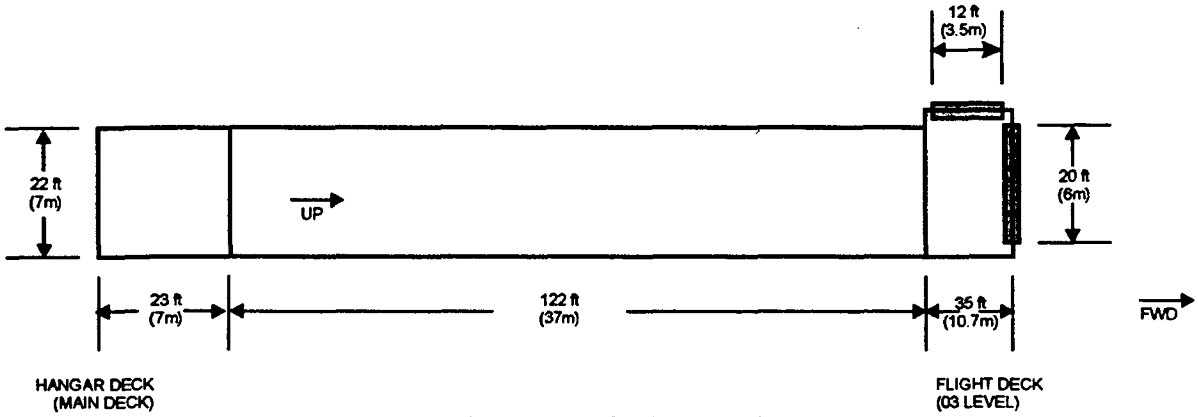

FIGURE 2. Plan View of Flight Deck Ramp.

Access to the vehicle deck (2nd deck) was provided by a ramp down from the forward, port corner of the hangar bay. There was no door at the top of the vehicle ramp in the hangar bay or at the bottom of the ramp on the vehicle deck. The well deck was located immediately aft of the base of the vehicle deck ramp, nearly the full ships width, and located directly under the hangar bay. Smoke accumulation and removal from the vehicle deck was not included as part of this test program. Provisions were included during the smoke testing to monitor smoke migration down onto the vehicle deck from the hangar bay and the effect the door configurations had on smoke movement within the ramp area. This was accomplished by the station located between the top of the vehicle ramp and the bottom of the flight deck ramp.

There is no provision for mechanical ventilation in the LHA hangar bay. To provide ventilation in the hangar bay, one or both of the hangar bay doors were typically one-half open, weather permitting. In the tests involving the U.S.S. *Saipan* (LHA-2), the hangar bay was relatively open (i.e. no parked aircraft), with only normal equipment and materials being stored. In the tests involving the U.S.S. *Peleliu* (LHA-5), the hangar bay was relatively full with parked aircraft in addition to the normal equipment and materials being stored. Figure 3 shows the general layout of the aircraft and equipment in the hangar bay during the smoke removal tests onboard the U.S.S. *Peleliu* (LHA-5). The shaded region on the lower left side of Figure 3 is where equipment was piled.

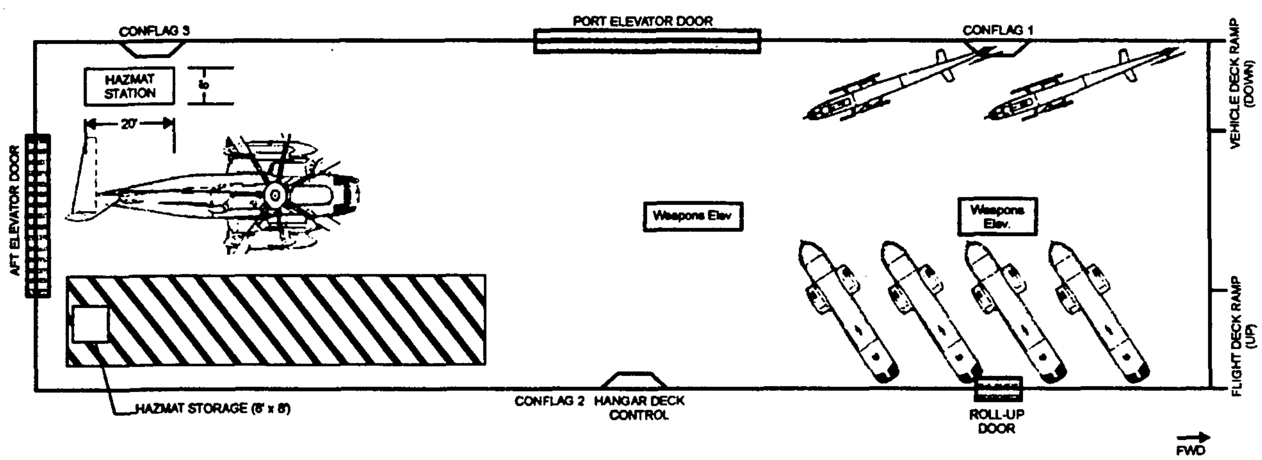

FIGURE 3. Layout of the Aircrafts and Equipment.

Table 1 provides the total volume for the test area, by space. The volume of the flight deck ramp was included since it was directly connected to the hangar bay. The volume of the vehicle deck was not included in the hangar bay volume calculation, as this was not considered part of the test space. This volume technique is similar to techniques used is previous tests. [8]. The column marked "Gross Volume" applies to the tests conducted on the U.S.S. *Saipan* (LHA-2), while the column marked "Net Volume" applies to the tests conducted onboard the U.S.S. *Peleliu* (LHA-5).

TABLE 1. Hangar Bay Volume.

Test area	Gross volume (empty bay) m^3 (ft^3)	Net volume (loaded bay) m^3 (ft^3)
Fwd Hangar Bay	8,450 (298,000)	7,450 (263,000)
Aft Hangar Bay	5,400 (192,000)	4,200 (150,000)
Flight Deck Ramp	3,150 (111,400)	3,150 (111,400)
Total	17,000 (601,400)	14,800 (522,000)

SMOKE GENERATORS

Smoke was introduced into the hangar bay using a combination of Symtron Systems Model SM-3K-B "suitcase" smoke generators and Rosco Model 1500 and Model 1600 "party" smoke generators. Onboard the U.S.S. *Saipan* (LHA-2), smoke was introduced using three Symtron Systems Model SM-3K-B "suitcase" smoke generators and one Rosco Model 1600 "party" smoke generator. The three Symtron smoke generators were owned and maintained by *Saipan* personnel. The Rosco smoke generator was borrowed from the U.S.S. *Ross* (DDG-71) by *Saipan* personnel for the series of tests. Onboard the U.S.S. *Peleliu* (LHA-5), smoke was introduced using one Symtron Systems Model SM-3K-B "suitcase" smoke generator owned and maintained by *Peleliu* personnel and six Rosco Model 1500 and Model 1600 "party" smoke generators supplied by members of the test team.

The smoke generators were dispersed throughout the hangar deck to provide equal filling. Figures 4 and 5 provide the approximate location of the smoke generators onboard the U.S.S. *Saipan* (LHA-2) and the U.S.S. *Peleliu* (LHA-5) respectively. All smoke generators were started at the beginning of each test. Smoke was continually produced throughout the test, simulating an ongoing fire event. The time from the start of the test to the time that all visibility observers lost sight of their targets, or that the test director determined that a sufficient quantity of smoke was present in the hangar bay, was defined as the filling time. In cases where visibility of one target was not lost because of its location, a decision was made by the test director to commence ventilation rather than delay the test. In these cases, the entire hangar bay was filled with a sufficient amount of smoke to allow for a meaningful assessment of the ventilation performance.

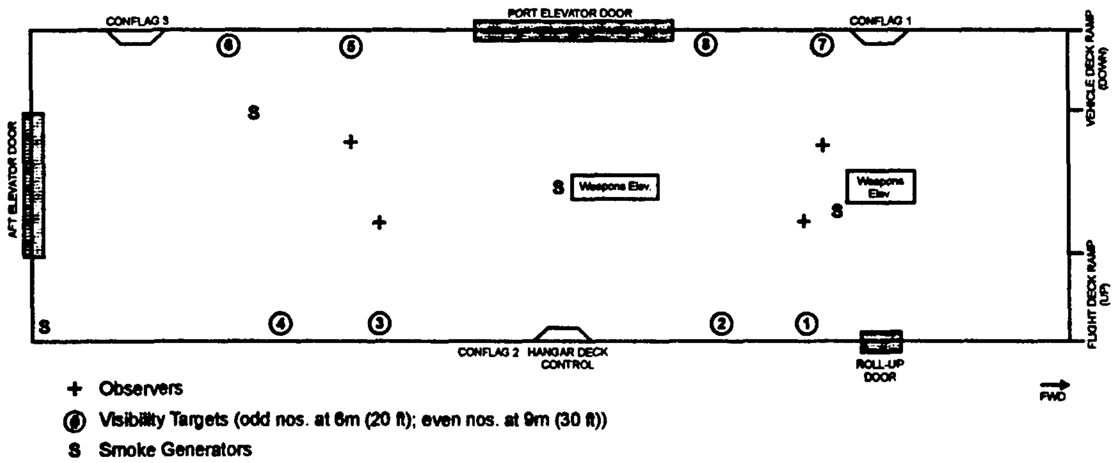

FIGURE 4. U.S.S. *Saipan* (LHA-2) Visibility Target Locations.

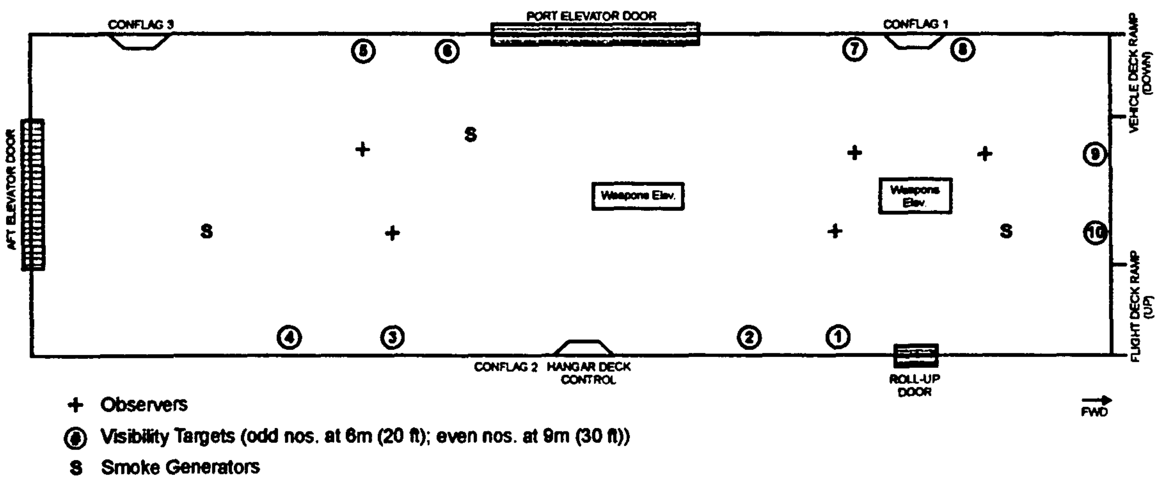

FIGURE 5. U.S.S. *Peleliu* (LHA-5) Visibility Target Locations.

VISIBILITY TARGETS

Eight visibility targets were used in the tests onboard the U.S.S. *Saipan* (LHA-2) and ten visibility targets were used in the tests onboard the U.S.S. *Peleliu* (LHA-5) to determine the effectiveness of each particular ventilation configuration. These targets consisted of white cardboard signs (22 by 28 cm (8.5 by 11 in.)) with a red cross painted on them (19 by 19 cm (7.5 by 7.5 in.)). The signs were hung approximately 1.5 m (5 ft) high on bulkheads. A single observer was used for two targets. One target was 6.1 m (20 ft) away and the other was 9.1 m (30 ft) from the observer. Targets were located on the bulkheads forward and aft of the port side elevator door, against the starboard bulkhead forward and aft of Hangar Deck Control and on the forward bulkhead between the flight deck ramp and the vehicle well ramp (for *Peleliu* only) (see Figures 4 and 5).

All of the observers were assigned a number for each of the two targets. The observers called out these numbers when visibility was lost and when visibility was recovered. One of these observers in each test was a crew member and the others were members of the test team. In tests onboard the U.S.S. *Saipan* (LHA-2), one test team member was stationed at the top of the vehicle deck ramp to monitor the amount of smoke that migrated down into the vehicle deck during the hangar bay filling time and the smoke movement resulting from the door sequencing. Particular attention was made to the smoke movement down into the vehicle deck are during the door sequencing because this movement would relate to the effect on well deck operations.

TEST PROCEDURES

Prior to each test, all of the elevator doors, flight deck ramp doors, and personnel doors around the perimeter of the hangar were closed. Safety monitors (Fleet personnel) were positioned at several of the personnel doors, to prevent non-test personnel from entering the space during a test. Fleet personnel were available to operate elevator doors, the port forward flight deck ramp door, and the starboard side roll-up door as requested by the test director.

A pre-brief was conducted prior to each test to detail the anticipated hangar bay conditions, to review the call-out procedure for visibility of the targets, and to explain the door configuration to be evaluated. Once all visibility targets, observers, and hangar bay doors were prepared, the test director announced the start of the test and power was turned on to the smoke generators. As the hangar bay filled with smoke, the observers were instructed to notify the test director after either target became obscured for more than approximately five seconds. When all targets were obscured, or the test director determined that the conditions were sufficient to start ventilating, Fleet personnel coordinated with the bridge to achieve the desired ambient wind conditions (i.e., crosswind or headwind) and ship speed. Upon achieving the desired outside wind conditions (or as close as possible), the particular door configuration was initiated to begin clearing smoke from the hangar bay. When the observers regained visibility of the targets, the test director was notified. If a period of five minutes passed and at least two targets were not visible, the door configuration was changed. In some cases, the door configuration was also changed to determine if further improvements in visibility could be made. The smoke generators continued to produce smoke as the doors were opened, simulating a fire that was still burning (i.e., active desmoking).

When a minimum of 7 targets in the U.S.S. *Saipan* (LHA-2) tests, or 75% of the targets in the U.S.S. *Peleliu* (LHA-5) tests, were visible, the test was terminated and the hangar bay was cleared of smoke. When running tests back to back, the test area was not fully cleared of smoke between tests to minimize the turn around time. Since the performance of each ventilation configuration was based on the initiation of the door configuration, residual smoke in the hangar bay had no effect on the test results.

VISIBILITY RECOVERY CALCULATION PROCEDURE

The measure of effectiveness was the time required for visibility to be recovered. Initiation of ventilation occurred at time 0:00. The effectiveness of the particular wind or ventilation condition was taken as the time (in minutes) to regain visibility of 75% of the targets (i.e., 6 of 8 or 8 out of 10 for *Saipan* or *Peleliu* respectively). This procedure normalized the varying visibility recovery times for each target and each position to permit comparison of all results. For example, if ventilation was initiated 30 minutes after the smoke generators were turned on, and target visibility was restored at 38 minutes, then the ventilation effectiveness was 8 minutes for that particular target location.

TEST CONDITIONS

During the U.S.S. *Peleliu* (LHA-5) tests, at certain headings and ship speed, a steady flow of air up the ramp, from the well deck existed. The source of this air could not be isolated, as it appeared to be coming from only a few vents on the well deck. All assurance were made that the ventilation system was secured thus it is assumed that this air was from natural ventilation. The up-flow of air tended to keep the top of the well deck ramp free of smoke as well as to gently push the smoke towards the aft elevator door.

There was also an issue with personnel entering and exiting the hangar bay at various times during the tests. Attempts were made to position fleet personnel at critical locations; however, there were not enough people to cover all the entryways into the hangar bay to restrict entry in to the test area. These disturbances had a small effect on Targets No. 9 and 10.

TEST RESULTS

A total of 6 tests were completed onboard the U.S.S. *Saipan* (LHA-2) during the period of 22 - 26 May 2002 and the U.S.S. *Peleliu* (LHA-5) during the period of 09–10 June 2003, with 3 tests occurring onboard each ship. The tests evaluated the effect of opening various doors (elevator and flight deck doors) under headwind and crosswind conditions. The U.S.S. *Saipan* (LHA-2) tests will be examined first, followed by the U.S.S. *Peleliu* (LHA-5) tests. Table 2 provides the test matrix for the tests conducted onboard the U.S.S. *Saipan* (LHA-2) with the general results of each test.

U.S.S. *SAIPAN* (LHA-2) TESTS

It should be noted that the wind speed/direction measurements are approximate. Generally, one set of measurements was provided by the bridge either at the start of the test or when ventilation began. The wind directions provided are with respect to the bow.

TABLE 2. U.S.S. *Saipan* Hangar Bay Ventilation Test Matrix and General Results.

Test no.	Test objective	Wind speed/direction*	General results
1	Shakedown test to determine if smoke generators could adequately fill hangar bay with smoke and identify closure status/leakage of hangar bay test area.	N/A	Test was terminated because of technical problems.
2	Evaluate effect of starboard beam crosswind	15 knots, starboard beam	Combination of crosswind, two elevator doors open, and roll-up door open resulted in quick removal of smoke. Larger ventilation opening was to leeward
3	Evaluate effect of headwind	18 knots, port to starboard beam	Sweep across the hangar bay resulted in quick removal of smoke. Tailwind was present instead of headwind; however, sweep was accomplished. Smoke was blown onto the flight deck, resulting in potentially undesirable conditions, should flight deck operations be conducted.

* Wind speed and ships speed as reported by the bridge

Test No. 1 Results (Shakedown/Smoke Filling Test)

For Test No. 1, the hangar bay accesses were secured and the smoke generators powered to start the test. After 60 minutes of smoke production, none of the observers lost visibility of their respective targets. In addition, during the test, a number of additional accesses were observed open, and ships personnel were observed traveling through the hangar bay despite the hangar bay being secured. Technical problems associated with the test caused the test to be terminated. The test procedure and location of the smoke generators were re-evaluated in order to maximize the smoke-production capabilities. Discussions with ships personnel indicated that acquiring additional smoke generators to conduct the testing was not feasible.

Test No. 2 Results (Starboard Beam Crosswind Test)

Test No. 2 was conducted to evaluate the effect of a starboard beam crosswind (15 knots at 45 degrees). Before starting Test No. 2, a thorough inspection of all accesses around the perimeter of the hangar bay was undertaken. Additional accesses were secured and miscellaneous mechanical ventilation sources (i.e. heaters, a temporary below deck ventilation duct, box fans) were secured. After 60 minutes of smoke production, only one of the eight observers had lost visibility of their target.

Based on the existing visibility conditions in the hangar bay, it was determined that visibility was not going to be substantially reduced with the existing number of smoke generators after continued smoke generation. The test team decided to visually evaluate the effect of door sequencing on the existing visibility conditions currently present at each target. Each observer was instructed to objectively judge the target visibility as the door sequencing progressed. The target visibility was quantified as:

1. "Obscured" when the target could not be seen
2. "Hazy" when the target could be observed; however, smoke was present between the target and the observer
3. "Clear" when the target was completely visible (i.e., no smoke)

Table 3 provides the observer visibility results from Test No. 2.

Table 4 summarizes the ventilation effectiveness for the door configurations tested. Initially, the two elevator doors were opened 3 ft, in accordance with the doctrine, as these were the leeward doors. No change in visibility was reported by the visibility observers. The opening of the starboard side roll-up door resulted in a sweep across the hangar bay, out of the two elevator doors. This resulted in 50% of the observers reporting clear visibility of their respective targets. When both elevator doors were opened halfway (and the roll-up door remained fully open), 88% of the targets were determined to be clear. The test was terminated at this point because more than 75% of the observers reported visible (i.e. clear) targets.

TABLE 3. Test No. 2 Observer Visibility Results.

Observer no.	Target no.	Test time, min.			
		Initial[a]	0[b]	5[c]	10[d]
1	1	Hazy	Hazy	Clear	Clear
1	2	Hazy	Hazy	Clear	Clear
2	3	Hazy	Hazy	Clear	Clear
2	4	Hazy	Obscured	Hazy	Clear
3	5	Hazy	Clear	Clear	Clear
3	6	Obscured	Clear	Clear	Clear
4	7	Hazy	Clear	Clear	Clear
4	8	Hazy	Clear	Clear	Clear

Door sequencing:

[a] Secured.

[b] Port elevator door open 1 m (3 ft); aft elevator door open 1 m (3 ft).

[c] Starboard roll-up door open.

[d] Port elevator door open halfway; aft elevator door open halfway

TABLE 4. Test No. 2 Ventilation Effectiveness Summary.

Time ventilation configuration established, min	Ventilation configuration	Cumulative target no.	Visibility recovery, %
0	Port elevator door open 1 m (3 ft) Aft elevator door open 1 m (3 ft)	N/A	0
5	Port elevator door open 1 m (3 ft) Aft elevator door open 1 m (3 ft) Starboard roll-up door fully open	5, 6, 7, 8	50
10	Port elevator door open halfway Aft elevator door open halfway Starboard roll-up door fully open	1, 2, 3, 5, 6, 7, 8	88

Test No. 3 Results (Headwind Test)

Test No. 3 was conducted to evaluate the smoke-removal effectiveness of a nominal headwind (18 knots, varying between 315 and 45 degrees), which was established before opening any doors. The door sequencing began at 37 minutes, after the hangar bay had filled with smoke (as much as possible). The observer visibility results for Test No. 3 are summarized in Table 5.

Table 6 provides the ventilation effectiveness for the door sequencing evaluated. Initially, the aft elevator door was opened 3 ft, in accordance with the doctrine, because this would be the leeward door in a true headwind. A strong tailwind was immediately observed which had the effect of pushing the smoke towards the forward part of the hangar bay. After 5 minutes, the flight deck ramp door (forward door only) was fully opened. This resulted in the majority of the smoke in the hangar bay being pushed up the flight deck ramp and out onto the flight deck, effectively clearing the hangar bay. This sweep across the hangar bay area started to clear the smoke, resulting in 38% of the targets becoming visible. When the aft elevator door was opened halfway, all observers reported clear visibility of their targets (100% visibility). Smoke was also observed moving down into the vehicle deck area when the aft elevator door was open 1 m (3 ft).

This test was intended to be a headwind test, whereby outside air would enter through the forward flight deck door, sweep across the hangar bay, and exit out the aft elevator door. For unknown reasons, the opposite wind conditions existed during the test. Based on the smoke-removal performance of this test, it was determined that if a true headwind condition was present, similar smoke-removal performance could be expected. The headwind would be expected to push the smoke out the aft elevator door and not onto the flight deck. This would prevent undesirable conditions on the flight deck from developing, especially if flight operations were being conducted.

TABLE 5. Test No. 3 Observer Visibility Results.

Observer no.	Target no.	Test time, min.			
		Initial[a]	0[b]	5[c]	10[d]
1	1	Hazy	Hazy	Clear	Clear
1	2	Hazy	Hazy	Clear	Clear
2	3	Hazy	Clear	Clear	Clear
2	4	Hazy	Hazy	Clear	Clear
3	5	Hazy	Hazy	Clear	Clear
3	6	Obscured	Hazy	Clear	Clear
4	7	Hazy	Clear	Clear	Clear
4	8	Hazy	Clear	Clear	Clear

Door sequencing:

[a] Secured.

[b] Aft elevator door open 1 m (3 ft).

[c] Flight deck ramp fully open

[d] Aft elevator door open halfway

TABLE 6. Test No. 3 Ventilation Effectiveness Summary.

Time ventilation configuration established, min	Ventilation configuration	Cumulative target no.	Visibility recovery, %
0	Aft elevator door open 1 m (3 ft)	N/A	0
5	Aft elevator door open 1 m (3 ft) Flight deck door fully open	3, 7, 8	38%
10	Aft elevator door open halfway Flight deck door fully open	1 to 8	100 %

U.S.S. *PELELIU* (LHA-5) TESTS

A total of 3 tests were completed onboard the U.S.S. *Peleliu* (LHA-5) during the period of 09–10 June 2003. The tests evaluated the effect of opening various doors (elevator and flight deck doors) under headwind and crosswind conditions. Table 7 provides the test matrix for the tests conducted with the general results of each test.

It should be noted that the wind speed/direction measurements are approximate. Generally, one set of measurements was provided by the bridge either at the start of the test or when ventilation began. The wind directions provided are with respect to the bow.

TABLE 7. Hangar Bay Ventilation Test Matrix and General Results.

Test no.	Test objective	Wind speed/direction*	General results
1	Evaluate effect of port headwind with port side flight deck ramp door	12-knot port headwind (345°)	Headwind and opening port side flight deck ramp door resulted in quick removal of smoke. Larger ventilation was leeward. Wind sweeping across bay was noticeable.
2	Evaluate effect of crosswind with port and aft elevator door	12-knot port to starboard crosswind (310°)	Combination of crosswind with two elevator doors open resulted in quick removal of smoke. Leeward and windward openings were approximately the same size. Strong wind entering from port side.
3	Evaluate effect of positive pressure from well deck fans w/aft el door	10-knot port to stbd crosswind (285°)	Well deck pressurization resulted in quick removal of smoke. Constant light breeze was effective in pushing the smoke out the aft El door. (Supply and exhaust fans were on until 8:00 minutes into test at which time the exhaust fans were secured.)

* Wind speed and ships speed as reported by the bridge

Test No. 1 Results (Port Headwind Test With Port Side Flight Deck Door)

Test No. 1 was conducted on 09 June 2003 to evaluate the effect of a port headwind (12 knots at 345 degrees). The hangar bay accesses were secured and the six Rosco and one Symtron smoke generators were powered up to start the test. After 90 minutes of smoke production, only eight of the ten targets lost visibility. Targets No. 1 and 5 were visible throughout the course of the test and were removed from all further calculations. The observer visibility results for Test No. 1 are summarized in Table 8, which consists of the time each target regained visibility and the door configuration at that time.

During a headwind condition, the aft elevator door would be the leeward door and the forward flight deck ramp door would be the windward door. However, mechanical issues with this door lead to the use of the port side flight deck ramp door in lieu of the forward ramp door.

TABLE 8. Test No. 1 Observer Visibility Results.

Target no.	Ventilation effectiveness, min	Ventilation configuration at visibility recovery
1	0	Hangar bay secured
2	10	Aft elevator door open 1 m (3 ft) Port flight deck door open fully
3	15	Aft elevator door open halfway Port flight deck door open fully
4	19	Aft elevator door open fully Port flight deck door open fully
5	0	Hangar bay secured
6	12	Aft elevator door open halfway Port flight deck door open fully
7	11	Aft elevator door open halfway Port flight deck door open fully
8	11	Aft elevator door open halfway Port flight deck door open fully
9	7	Aft elevator door open 1 m (3 ft) Port flight deck door open fully
10	12	Aft elevator door open halfway Port flight deck door open fully

Table 9 provides the ventilation effectiveness for the door sequencing evaluated. Initially, the aft elevator door was opened 3 ft, per the doctrine, as this was the leeward door. The visibility observers reported no change in visibility during the five minutes at this condition. The opening of the port side flight deck ramp door resulted in a crosswind sweeping across the entire hangar bay and out the aft El door. This resulted in 25% (2 of 8 targets) of the observers reporting clear visibility of their respective targets. When the aft elevator doors were opened halfway (and the port side flight deck ramp door remained fully open), 88% of the targets were determined to be clear. After the aft elevator doors were open fully, 100% of the targets were determined to be clear. The test was terminated at this point as all of the observers reported visible (i.e., clear) targets.

TABLE 9. Test No. 1 Ventilation Effectiveness Summary.

Time ventilation configuration established, min	Ventilation configuration	Cumulative target no.	Visibility recovery, %*
0	Aft elevator door open 1 m (3 ft)	N/A	0
5	Port flight deck door open	2,9	25
10	Aft elevator door open halfway	2,3,6,7,8,9,10	88
15	Aft elevator door open fully	2,3,4,6,7,8,9,10	100

*Targets No. 1 and 5 are excluded from this table, as they never lost visibility. The percentage is based on only 8 targets

Test No. 2 Results (Port Crosswind Test With Port and Aft Elevator doors)

Test No. 2 was conducted on 09 June 2003 to evaluate the effect of a port crosswind (12 knots at 310 degrees). After 40 minutes of smoke production from the six Rosco and one Symtron smoke generators, nine of the ten targets had lost visibility. Target No. 1 remained visible throughout the course of the test and is excluded from all future calculations. The observer visibility results for test No. 2 are summarized in Table 10.

Technical difficulties during this test delayed the opening of the elevator doors from five to eight minutes and limited the available time for this test. Instead of restarting the test (which would have required significant time for smoke re-filling), the test was revised to evaluate the opening of the doors halfway.

Table 11 summarizes the ventilation effectiveness for the door configurations tested. Initially, the aft elevator door was opened 3 ft, per the doctrine, as this was the leeward door. The visibility observers reported only one target (11%) becoming visible during the eight minutes at this condition. When the aft and port elevator doors were opened halfway, 100% of the targets were determined to be clear. The test was terminated at this point as all of the observers reported visible (i.e., clear) targets.

TABLE 10. Test No. 2 Observer Visibility Results.

Target no.	Ventilation effectiveness, min	Ventilation configuration at visibility recovery
1	0	Hangar bay secured
2	10	Aft El Door open halfway Port El Door open halfway
3	9	Aft El Door open halfway Port El Door open halfway
4	9	Aft El Door open halfway Port El Door open halfway
5	5	Aft El Door open 1 m (3 ft)
6	9	Aft El Door open halfway Port El Door open halfway
7	9	Aft El Door open halfway Port El Door open halfway
8	9	Aft El Door open halfway Port El Door open halfway
9	11	Aft El Door open halfway Port El Door open halfway
10	11	Aft El Door open halfway Port El Door open halfway

TABLE 11. Test No. 2 Ventilation Effectiveness Summary.

Time ventilation configuration established, min	Ventilation configuration	Cumulative target no.	Visibility recovery, %*
0	Aft El Door open 1 m (3 ft)	5	11 %
8	Aft El Door open halfway Port El Door open halfway	2,3,4,5,6,7,8,9,10	100 %

* Target No. 1 is excluded from this table, as it never lost visibility. The percentage is based on only 9 targets

Test No. 3 Results (Positive Pressure from Well Deck Test w/ Aft El door)

Test No. 3 was conducted on 09 June 2003 to evaluate the effect of positive pressure from the well deck. The test was started after all ten targets had lost visibility due to the smoke production from the six Rosco and one Symtron smoke generators. The observer visibility results for Test No. 3 are summarized in Table 12.

TABLE 12. Test No. 3 Observer Visibility Results.

Target no.	Ventilation effectiveness, min	Ventilation configuration at visibility recovery
1	10	Aft El Door open halfway Well Deck Supply Fans on High
2	11	Aft El Door open fully Well Deck Supply Fans on High
3	3	Aft El Door open 1 m (3 ft) Well Deck Supply Fans on High
4	11	Aft El Door open fully Well Deck Supply Fans on High
5	2	Aft El Door open 1 m (3 ft) Well Deck Supply Fans on High
6	9	Aft El Door open halfway Well Deck Supply Fans on High
7	9	Aft El Door open halfway Well Deck Supply Fans on High
8	9	Aft El Door open halfway Well Deck Supply Fans on High
9	N/A	Not included in results
10	N/A	Not included in results

Targets No. 9 and 10 were located between the flight deck ramp and the vehicle deck ramp. The close proximity to one of the smoke generators and the lack of strong wind in this test made these two targets cycle from clear to obscure throughout the test. These targets will not be included in further analysis.

Table 13 provides the ventilation effectiveness for the door sequencing evaluated. Initially, the well deck ventilation fans were turned to their 'high' setting and the aft elevator door was opened 3 ft. The visibility observers reported two targets (25%) becoming visible during the five minutes at this condition. After five minutes, the aft elevator door was opened halfway resulting in 6 targets (75%) being reported visible. After eight minutes, it was noticed that the exhaust fan were running as well as the supply fans, the exhaust fans were secured at this time and the supply fans were left running. After ten minutes, the aft elevator door was fully opened and resulted in all targets (100%) being visible during the four minutes at this condition. The test was terminated at this point as all of the observers reported visible (i.e., clear) targets.

TABLE 13. Test No. 3 Ventilation Effectiveness Summary.

Time ventilation configuration established, min	Ventilation configuration	Cumulative target no.	Visibility recovery, %*
0	Aft El Door open 1 m (3 ft) Well Deck Supply Fans on High	3,5	25 %
5	Aft El Door open halfway	1,3,5,6,7,8	75 %
10	Aft El Door open fully	1,2,3,4,5,6,7,8	100 %

*Targets No. 9 and 10 are excluded from this table. The percentage is based on eight targets.

COLD SMOKE LIMITATIONS

It should be noted that the tests conducted onboard the U.S.S. *Peleliu*, U.S.S. *Saipan*, the U.S.S. *Bonhomme Richard* (LHD-6) (Reference 8) and the U.S.S. Eisenhower (CVN-69) (Reference 7) used cold smoke rather than hot smoke which would be produced during an actual fire event. The use of cold smoke introduced some limitations to the tests since it lacked the buoyancy characteristics of real fire smoke. The density differences between hot and cold smoke are critical for evaluating smoke accumulation and movement within a fire space. During a fire event, ambient air is drawn into the fire compartment at the deck level, passes through the fire where it is heated, and then is "pumped" up into the overhead. As the smoke layer develops and descends, the hot smoke spills or vents out the top of the fire compartment and spreads to adjacent compartments or to the outside. In the presence of a vent opening, strong air currents will develop, naturally drawing fresh cool air into the fire down low and pumping the hot smoke into the overhead and out of the compartment. Heated air flowing through the fire creates the density differences required for the smoke to rise to the overhead and accumulate prior to venting out of the compartment. If no vents are present (i.e., all doors shut), the smoke layer will develop and descend down to the deck, reducing visibility to zero.

Because cold smoke lacks the buoyant forces present in a real fire, only air currents developed by natural or mechanical ventilation can remove it. Therefore, in the testing conducted onboard the U.S.S. *Peleliu* (as well as the U.S.S. *Saipan,* U.S.S. B*onhomme Richard (LHD-6)* and the U.S.S. *Eisenhower* (CVN-69) the cold smoke would have eventually settled in the hangar bay in the absence of ventilation. During an actual fire event, however, the buoyant forces generated by the fire are powerful enough to vent themselves, even under still air conditions. Applying this principle to the test results, the actual ventilation times developed during these tests may be reduced. In other words, hot smoke is more efficient in venting itself, especially when no mechanical ventilation is present as is the case in an amphibious assault ship or aircraft carrier hangar bay. This smoke venting and spread can also work against firefighting operations because the smoke will spread on its own, infiltrating unaffected spaces, degrading visibility, and leading to increased disorientation.

For many years, researchers have emphasized the importance of using hot buoyant smoke in smoke movement studies (References 9 through 19). In one study, the performance of a smoke control system located in the Washington Plaza Hotel was evaluated using hot smoke produced from controlled fire sources and cold smoke produced using smoke bombs (cold smoke). Using wood cribs with peak heat release rates ranging from 1.0 to 3.0 megawatts produced the hot smoke. The smoke bombs were not described, however, they generated large amounts of visible smoke at ambient temperatures for three minutes. It was observed that the smoke control system performed more efficiently with the smoke bombs than with the smoke produced by the wood crib fires. This difference was attributed to the smaller quantity of smoke generated by the smoke bombs, the short smoke generation time of the smoke bombs, and the lack of buoyancy in the smoke. The use of smoke bombs with greater smoke generation rates and longer burn times would minimize some of these differences. However, the driving force behind system performance remains the buoyancy of the smoke.

In Australia and New Zealand, all new buildings are required to demonstrate satisfactory performance of the installed smoke control systems when evaluated during a hot smoke test (Reference 9). To perform the hot smoke test, metal fire pans are filled with a predetermined amount of denatured Methylated Spirits to produce the desired fire size. Methylated Spirits are used in lieu of other flammable liquids because of its cost effectiveness, clean combustion byproducts, and low radiation output because there is no visible flame. The metal fire pans are placed within larger water filled metal pans. These water filled pans prevent heat transfer from the fire pans to the supporting structure. A smoke generator is positioned near the edge of the fire pans to inject smoke into the hot buoyant plume for dispersal throughout the building. This test arrangement allows for a safe, controlled, and clean method to evaluate the performance of an installed smoke control system under simulated fire conditions.

CONCLUSIONS

The NATOPS firefighting manual provides guidance for venting smoke generated during a fire event in a hangar bay of an amphibious assault ship (Reference 1, Chapter 8). The guidance, in the form of a note, allows for utilizing cross ventilation to facilitate smoke removal. The intent of this guidance is to reduce the heat and smoke threat to the firefighting personnel.

Testing was conducted onboard the U.S.S. *Saipan* (LHA-2) and the U.S.S. *Peleliu* (LHA-5) to evaluate the effectiveness of opening a hangar bay door approximately 1 m (3 ft) under both crosswind and headwind conditions. Results of the previous testing (References 7 and 8) indicated that irrespective of the ambient wind conditions (headwind or crosswind), opening the windward or leeward elevator door approximately 1 m (3 ft) had minimal effect on reducing the smoke level within the hangar bay. Based on these test results, further testing was conducted to determine the most effective door configuration for removing smoke from a hangar bay under various ambient wind conditions (crosswind and headwind).

On the U.S.S. *Saipan* (LHA-2), based on the test results, the introduction of clean air in through a relatively small windward side opening (flight deck or roll-up door), sweeping across the hangar bay, and exiting through the elevator door(s) halfway open resulted in recovery of visibility by the observers. For the headwind test (where a tailwind was actually evaluated), smoke within the hangar bay was forced up the flight deck ramp and out onto the flight deck. This resulted in complete recovery of conditions within the hangar bay; however, conditions on the flight deck were degraded. This would have created potentially hazardous conditions on the flight deck if flight operations were being conducted.

The results of the starboard beam crosswind test were similar to the results of testing onboard the U.S.S. *Eisenhower* (CVN-69) (Reference 7) in Hangar Bay 1 where the configurations were similar (albeit reversed). Entry of the fresh air through a relatively small windward opening and exiting through an elevator door halfway open resulted in more than 75% of the visibility target becoming observable.

The effect of a starboard beam wind was not evaluated. Based on the results of the headwind test, and testing conducted onboard the U.S.S. *Bonhomme Richard* (LHD-6) (Reference 8), it was surmised that opening the port side flight deck ramp door fully and opening the aft elevator door halfway would result in a sweep across the length of the hangar bay.

On the U.S.S. *Peleliu*, for the headwind test, air was entering through a relatively small windward side opening (flight deck ramp door) and exiting through the larger opening at the aft elevator door, which was halfway open. Clean air traveled down the flight deck ramp and pushed the smoke across the hangar bay and out the aft elevator door. Several helicopters were located in the path of the wind and created a large blockage at approximately the same height as the targets. This type of configuration within the hangar bay is a typical representation of actual deployed conditions and may have reduced the effectiveness of the wind clearing the smoke obscuring targets No. 3 and 4. These two targets were the last two to recover visibility and had a noticeable time gap from the rest of the targets. These targets were located near the aft elevator door and would be expected to be the last to recover visibility as all the smoke was being pushed in front of these targets before being pushed out the aft elevator door. The test resulted in 88% of the targets being visible with the aft elevator door open halfway.

The port crosswind test had fresh air entering through the port side elevator door (windward door) and exiting thought the aft elevator door (leeward door). Technical difficulties delayed the opening of the elevator doors by a couple of minutes. This test did not have the typical sequencing of doors but rather went from initial condition straight to optimal conditions. The effects of opening both elevator doors halfway at the same time resulted in strong winds sweeping across the aft section of the hangar bay. The strong wind immediately created a noticeable effect on the smoke and resulted in all the targets recovering visibility three minutes after opening both elevator doors halfway.

The use of the Well Deck fans to provide mechanical ventilation during a headwind condition was evaluated, however the first eight minutes of the test had both the supply and the exhaust fans running. After eight minutes into the test, the exhaust fans were secured. The air supply up from the Well Deck ramp, when the fans were set to their "high" setting, was not as strong of a breeze in comparison with the wind from the other tests. The area at the top of the Well Deck ramp was quickly cleared, however the remaining smoke was pushed a little slower in comparison to the other ventilation tests. This slower movement of the air along with the obstructions located throughout the hangar bay made it more difficult to clear targets No. 2 and 4 located on the starboard side bulkhead. The test resulted in 75% of the targets being visible with the aft elevator door open halfway.

From the test results, it was clear that all the scenarios work in actively clearing the cold smoke from the hangar bay. However, the best scenario would be use of the well deck supply fans in combination with opening the forward flight deck ramp door and the aft elevator door. This scenario would be expected to provide results better than either of the tests conducted by allowing air to sweep down both sides of the hangar bay and out the aft elevator door, clearing the smoke a little more effectively. If future testing on a Tarawa-class ship (LHA) is pursued, this option should be evaluated.

RECOMMENDED CHANGES TO NATOPS MANUAL (NAVAIR 80-R-14, CHAPTER 8)

Incorporating the test results and conclusion discussed above, recommended changes to Chapter 8 of the NATOPS firefighting manual have been developed. These changes are intended for both LHD and LHA class ships. In order to balance guidance without being overly restrictive to the personnel implementing the doctrine, it is recommended that NATOPS 80R-14, Section 8.7.6 read as follows:

8.7.6 **Hangar Deck.** The following additional procedures for aircraft fires on the hangar deck shall be followed:

1. Return all elevators to the flight deck level
2. Leave all hangar deck lights on
3. Close all weapons elevator doors and hatches
4. Close all doors and hatches from the hangar to the interior of the ship except as noted below

Note

Open elevator door closest to the fire halfway. Request the ship execute a turn in order to position this door to leeward.

Obtain a fresh air source upwind of the fire, to facilitate venting of smoke. An elevator door open 3 ft and/or other door(s) opening directly to weather fully will suffice. This may include the use of the flight deck ramp door(s).

Open the vehicle deck/well deck door fully (if applicable). Turn well deck ventilation fans onto low speed (i.e., supply) to pressurize the hangar bay and facilitate venting smoke. *This procedure should only be used in situations in which there is no threat of the fire spreading into the well deck, fuel flowing down the vehicle ramp, or ongoing well deck operations which may be effected by smoke and reduced visibility.*

Although there are some configuration differences between the hangar bays of the LHD and LHA amphibious assault type ships and an aircraft hangar, the test results and conclusions described herein are similar to previous test results. The proposed changes follow the same rationale recommended for the aircraft carriers in that a crosswind should be established and the largest door opening should be on the leeward side of the ship. (Reference 7) The one substantial advantage for the LHD and LHA amphibious assault type ships is the single hangar bay and the flight deck ramp door which can be used to create a sweep of the hangar deck when headwind conditions exist.

Recommendation for Additional Testing on LHA Ships

Technical issues resulted in only three tests being successfully completed onboard the *U.S.S. Peleliu* (LHA-5), and three tests onboard the U.S.S. *Saipan* (LHA-2). However, it is believed future cold smoke testing onboard a LHA would not produce any more meaningful results. Based on this, it is recommended that if future testing is sought onboard an LHA, hot smoke tests should be carried out similar to the type conducted for the commissioning of buildings in Australia.

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