A U.S. NAVY SHOCK TRIAL

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ABSTRACT

One of four shock tests of U.S.S. *Kauffman* was observed from on board. Whereas British tests use small charges close to the hull, U.S. practice is to use much larger charges further away, resulting in an almost plane shock wave. The U.S. Navy uses higher shock factors for testing than the Royal Navy.

Introduction

A visit was arranged in 1987 to observe and experience the U.S. Navy's methods of ship shock testing, to aid decision-making in the NATO Frigate Replacement (NFR 90) project.

The visit arose from an invitation from the U.S.A.'s NFR 90 shock committee member to all member nations. This was prompted by the need to arrive at NFR 90 first of class shock trial specifications, in view of the different approaches adopted by the various nations. The trial was carried out on U.S.S. *Kauffman* (FFG 59), a new frigate and the last of the OLIVER HAZARD PERRY (FFG 7) Class. The third of a series of four shots was witnessed from on board.

The trial is particularly relevant to the NFR 90 because of the similarity in size and roles of the FFG 7 Class and the proposed NFR 90 design.

The objectives of the test were to:

(*a*) assess shock hardening modifications made as a result of the FFG 7 first of class trial in 1978;

(*b*) identify new shock hardening initiatives which should be applied to other ships in the class;

(*c*) demonstrate the capability to fight the ship in the shock environment.

Differences between U.K. and U.S. Methods

There are two main differences between U.K. and U.S. ship shock trials, the first being the charge geometrics and the second the 'fight ship' concept.

U.K. policy has been to use small charges placed relatively close to the hull to generate the required shock factors, while the U.S. use much larger charges placed further away. This results in the ship being hit with a sensibly plane shock wave as opposed to a spherical wave front produced by U.K. methods. The main effect of a plane wave front is that the ship experiences greater whole bodily displacement as opposed to more localized displacements experienced from U.K. testing. Higher shock factors are used in the U.S. which result in a more severe test and hence a greater confidence that the ship has been subjected to a meaningful test. One practical disadvantage of the U.S. method from U.K.'s viewpoint is the need for a deep water test area. The *Kauffman* trial, for example, was conducted 65 miles off the coast of eastern Florida in water approximately 2000 feet deep (imperial units are used throughout in this article, as it is reporting a U.S. trial).

The fighting ship concept is embodied during shock testing by conducting tracking and weapon engage exercises prior to and immediately post shock. Also, for a period of 30 minutes after the shock, the crew 'fight the ship', the main aim being to maintain full combat readiness without external assistance; this applies to weapon, hull and mechanical systems. During the trial *all* systems are functioning and the propeller shaft is turning with CPP set for zero thrust.

Test Configuration and Levels

Due to the deep water and running ship requirements the test is conducted in open ocean about 65 miles off shore. Three support ships were employed, together with fixed and rotary wing air units for attack simulation and photography and fish spotting (environmentalists have a strong lobby in the U.S.). A series of four tests are conducted, each at increasing Shock Factor (SF). Tests are specified in terms of 'Imperial Keel SF' (KSF), the severity being higher than that for U.K. first of class trials.

For all tests the charge used is 10 000 lb of HBX 1 explosive suspended 200 feet below the surface from a large float. KSF is varied by adjusting the horizontal distance from the charge to ship, which is set by physical restraint but checked by optical and laser range finding from targets on the float. The charge is assumed to hang vertically below the float. FIG. 1 shows how the charge was positioned for shot 3. The ship is stationary in the water and the float is located by ship's ropes let out to pre-determined lengths. Tension in the ropes is maintained by the support ship after the charge has been attached to the float and armed. The support ship is sufficiently far from the charge to be safe and maintains ahead revs. The whole system is then drifting free while final preparations for firing are made. During this period the ship is subject to mock air attack to test her combat systems.

The ship is fully fuelled and carries representative dummy weapon stores, some of which are instrumented during the test. However the missile launcher was unloaded and no helicopter embarked when the shot was fired.

Trial Instrumentation

During the test approximately 100 ship riders were aboard, most of them concerned with the trial instrumentation. As well as the U.S. Department of Defence (DOD) instrumentation, several equipment suppliers sent teams to instrument their specific equipment independent of the DOD effort. However, all instrumentation was approved by DTRC/UERD and co-ordinated into a central trigger system.

The main instrumentation effort comprised 48 piezo resistive accelerometers, 4 velocity meters, 4 strain gauges and 5 high-speed cameras. The non-video data, totalling 56 channels, was recorded on eight 7 channel tape recorders without prefiltering, the bandwidth of the recording machine being 4kHZ. The recorders have auto-calibration at 20 and 10 seconds before the shot. All instrumentation and cameras are activated by a central signal which also controls detonation countdown, thus ensuring that all data-capture equipment is on line at the correct time. Tapes run for 3 seconds, which is adequate to capture the effect of bubble pulse on the vessel.

Instrumenting a ship is a huge task requiring dedicated deck and bulkhead penetration and miles of cable. Interestingly, compensation cables were not used for the various gauges but cables were earthed at their point of deck penetration. Clay cones were also used to measure maximum deflection under machinery seatings; this is a simple and cheap method of gathering shipwide data on machinery excursions under shock loading.

During the trial the electricity power supply was monitored. This helps in trouble-shooting post shock; e.g. if an equipment trips out the cause may be power supply interruption or equipment breaker failure. Power supply monitoring resolves this.

It was stressed that long-term forward planning must be thorough to ensure smooth running of a trial. In this case planning started two years before the test series.

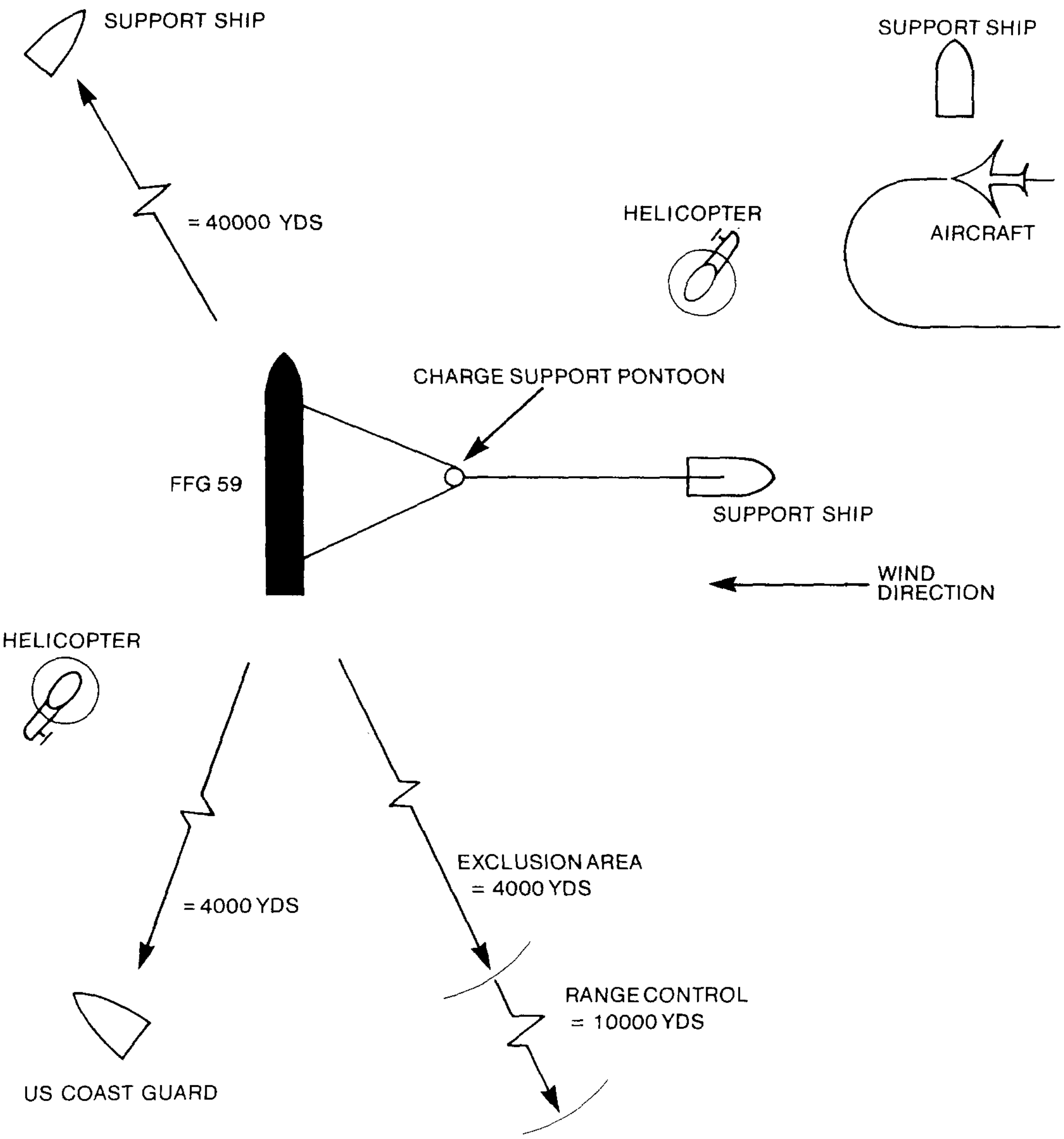

FIG. 1—SHOCK TEST OF FFG 59: DISPOSITION OF SUPPORT UNITS

Data Processing

The tape cartridges are first processed to give an unfiltered time-compensated analogue signal. This is fed into an A-D converter via a 4 kHz anti-aliasing filter. Note that the sampling rate is 20 kHz, i.e. 5 × the filtered bandwidth to ensure no loss of data. Digital data is then put onto disc in 7ch multiplexed form. The data can then be processed by any method required without loss of the recorded raw data. The usual outputs are plots of raw data, filtered data at 250 Hz and Maximax shock spectra with zero damping (sampled at 1 Hz spacing from 0 to 250 Hz). Fast Fourier transforms could also be produced but are not routinely done. Accelerometer results are integrated to give velocity and displacement plots. All graphs are plotted on linear/linear scales.

The level of automation in the data processing is such that a full set of graphs for each of the 56 channels can be produced in high quality print within two hours of receiving the tapes. Thus the trials team can begin preliminary analysis of results within three hours of the ship coming alongside. This is useful to check that the shot has fired correctly and to highlight areas of interest for following shots.

The video tapes are ready for viewing shortly after berthing, enabling a slow motion visual comparison of induced motions with those from previous shots. These films are impressive in that they highlight the distortion and motion of masts, gun barrels, magazines and machinery which cannot be seen in real time due to the short time scales and the startling effect of the shock on the observer.

FIG. 2—THE PLUME FROM THE 10 000 LB EXPLOSION

The Big Bang

Preparations for the firing made, the various NFR 90 representatives dispersed through the vessel kitted out with lifejackets, helmets, goggles and ear plugs. I was allocated to the towed array area situated above the tiller flat at the extreme stern of the vessel. With knees bent and a firm grip on some overhead structure, the blue touch paper was lit (FIG. 2). The jolt felt as the shock wave hit was surprisingly strong and there followed a period of pronounced whipping for several seconds. Veterans of the first two shots of the trial agreed that shot 3 felt significantly more severe than shots 1 and 2.

Test Assessment

At the end of the 30 minute 'fight ship' period each department submitted damage reports to enable the ship to signal an initial status report. On shot 3 the main items of damage were:

(*a*) TACTAS (towed array) blew a transformer putting the winch out of action.

(*b*) RAST (helo retrieval system) out of action.

(*c*) Otto Melara 75mm gun dislodged a shell in the loading belt—simply fixed.

An inspection of the hull showed some dishing of plates, up to half an inch in some cases. This was expected by the trials teams, and dishing of one inch was predicted for the fourth shot (fired against the other side of the hull).

After the initial assessment of the third shot damage reports it was found that less equipment had failed throughout the ship on the third shot than the second. This is anomalous because of the increased severity of this shot. The explanation appears to be that the first two shots acted as a shakedown for the ship as a system, exposing most of the accidental shock weaknesses which are inevitable in a structure the size of a warship. Once these had been fixed between the shots, subsequent failures were 'genuine' shock deficiencies in design. This evidence supports the view held by U.S. shock experts that as well as first of class shock trials, every ship of a class should be exposed to low severity shocks to 'iron out the bugs', e.g. levels equivalent to shot 2 of this trial. A simple one-shot test would suffice. Obviously cost would be a factor. However, it would not be necessary to provide detailed instrumentation, only sufficient to ensure the shot had fired correctly, so cost could be minimal. It might even be possible to test two ships with the same charge.

Post-Test Actions

Damage is repaired after each shot and before the next test, though repair is not undertaken for Cat.B equipment, which is not designed against shock, if it is obvious that failure will result at the next test. At the end of the test series the ship will be docked as necessary for repairs/modifications arising from the trial. Hull dishing caused during shots 3 and 4 was repaired by welding brackets to the affected plates and pulling them back into position.

It is the responsibility of the shipbuilder to repair failures of equipments which were supposed to be designed to withstand levels of shock greater than those employed for the test programme.

Modifications resulting from lessons learned during the tests are to be introduced into the rest of the class as soon as resources allow.

Summing Up

Although a detailed comparison of the performance when subject to non-contact underwater explosion between FFG 7 and FFG 59 is not available, the feeling among those present was that the shock hardening measures introduced as a result of the first of class trial had significantly improved the class capability in this respect.

The lessons are loud and clear:

(*a*) That a first of class shock trial should be completed on the first of class as soon after she enters service as possible (i.e. immediately following ship acceptance) to highlight weak areas in the design.

(*b*) Although low shock levels expose many minor failures this does not necessarily mean that higher levels will cause a proportionate rise in the number of failures. The use of higher shock factors during testing must have real benefits towards ship survivability in action.

(*c*) The U.S. approach of simulated combat condition prior to and post shock is an excellent way of proving the ability of a ship to survive and fight alone in a shock environment.

(*d*) Single shot (large charge, plane wavefront) tests at a SF corresponding to shot 2 of these trials should be conducted against all new build vessels, preferably with the shipbuilder being responsible for repair of systems/equipments designed to withstand greater shock levels than those of the test.

Acknowledgements

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