A MARINE FORENSIC ANALYSIS of HMS *Hood* and DKM *Bismarck*

William Jurens (AM), William H. Garzke, Jr. (M), Robert O. Dulin, Jr. (V), John Roberts (V), and Richard Fiske (M)

ABSTRACT

The wrecks of the British battle cruiser HMS Hood *and German battleship* DKM Bismarck *were explored during July 2001. Bill Jurens, a member of Panel SD-7 was aboard the expedition ship and provided an analysis. This 2001 visit to* Bismarck *has clarified many details of damage and construction missed in the 1989 Ballard expedition. Comprehensive and systematic video coverage should eventually enable researchers to compile a complete survey of shell and torpedo damage to the exterior of the main hull and superstructure. A number of new items were discovered in the debris field including one additional main turret and almost the entire forward superstructure. A subsequent and related visit to the wreck of HMS* Hood *provided the first opportunity to investigate the damage caused by the explosion that tore this battle cruiser apart during her engagement with* Bismarck *on 24 May 1941. The wreck reveals the severity of that firestorm, and also exhibits significant implosion damage unlike that seen in the wrecks of* Bismarck, Titanic, Yorktown, *and* Derbyshire*. The unusual debris field of* Hood *also presents a number of interesting and mysterious characteristics that may eventually yield significant knowledge regarding the sequence of breakup as the ship approached the bottom. A concluding section provides an introduction to upcoming research, and some perspective regarding the state of marine forensics at the current time.*

INTRODUCTION

This paper presents the authors' findings on the design of these two famous warships, provides a brief description of how each met its fate, and presents preliminary analyses and descriptions of the condition of their wreckage and its distribution on the bottom of the sea. The paper also discusses proposed research into the effects of implosion and explosion on ship structures, the hydrodynamics of sinking, and the creation of debris fields. In addition, a discussion of "lessons learned" can be used to guide the work of future expeditions.

BRIEF HISTORY of HMS *HOOD* and DKM *BISMARCK*:

Design rationale and operational chronology – HMS *Hood*. In 1915, the Director of Naval Construction was asked to investigate the design of a new battleship based on the 24-knot *Queen Elizabeth* Class then just completing, incorporating the latest ideas in underwater protection and with a greatly reduced draft. Several designs were submitted along these lines, which were, in the end, rejected by the Commander-in-Chief of the Grand Fleet, who by then felt that design emphasis should be re-directed towards the production of vessels capable of engaging the 30-knot battle cruisers then believed to be building in Germany. Design effort thereafter focused on vessels with much higher speed and greatly decreased armor. Orders for three ships of the "Admiral" class were placed in April of 1916, with a fourth being added in July. This design, with an overall length of 262.1 meters, a beam of 31.7 meters and a full load displacement of approximately 36,300 long tons, formed the original basis for the design of *Hood*. The ships were to mount a main armament of eight 381 mm and sixteen 140mm guns. Speed was projected at 32 knots on 144,000 shaft horse power. The ships were designed around a relatively shallow draft of 7.77 meters at normal displacement, increasing to about 8.84 meters at full load. The original design was relatively lightly armored, with a 203 mm main side belt and mostly 25mm deck armor.

The Battle of Jutland, which took place on 31 May 1916, saw the destruction of three lightly-armored British battle cruisers due to magazine explosions under gunfire attack.[1] Inadequate armor was seen to be a major culprit in this unexpected and embarrassing disaster. Construction on *Hood*, which had just begun, was stopped, and the ship was subjected to a major redesign effort which increased the displacement some 4,900 long tons with a related increase in the draft from 8.84 m to 9.60 meters. The major component of that increase was the addition of 3,500 long tons of armor. The thickness of the main side belt armor was increased from 203mm to 305mm, and the armor was sloped 11.5 degrees, making it equivalent to about 350mm of vertical plate. Although the deck protection was also increased significantly, it still was distributed rather inefficiently (by World War II standards), and some doubts remained regarding its adequacy. Pressure from various sources to increase the thickness and distribution of armor was relentless.

In July 1918, when the ship's hull was nearly complete, firing trials with 381 mm bullets were carried out against a full-scale replica of the *Hood*'s armor system. As a result of these tests, some additional 76mm laminated deck protection was added around the magazines. In accordance with standard British practice of the time, the magazines were located above the shell rooms, an arrangement that was, incidentally, duplicated in *Bismarck*. Although the addition of even more armor would have been desirable, nothing more could be done – the ship, whose dimensions had not changed since the original design in 1915, had simply exhausted her displacement. She just couldn't take another ton…

Hood was launched in August of 1918. By the time she was commissioned in May 1920 she was not only the largest warship in the world – a record she held for all or most of her lifetime – but one of the most heavily protected ships in the Navy. Events had overtaken the three other ships in her class, which were all cancelled and scrapped on the ways in 1918. In 1927 the Director of Naval Construction proposed adding additional armor to her decks in order to further protect her from the threat of bombing attacks. However (and it must be remembered that ships, like men, tend to get heavier as they get older) *Hood* was then so near her displacement limits -- and so engaged in 'showing the flag' -- that the proposal was deferred, as it transpired, indefinitely. Some armor protection was provided to the above-water torpedo tubes during a 1929-1931 overhaul. *Hood*'s underwater torpedo tubes were removed in 1938, and her 140mm secondary armament was replaced with additional anti-aircraft installations in 1940. A major reconstruction was scheduled for 1942 during which her machinery would have been replaced, aircraft facilities added, and her deck armor protection augmented to match that provided to the *King George V* class battleships.

As completed, the ship carried two underwater and four above-water torpedo tubes. These were neither popular nor very useful, and the underwater tubes were removed just before the war.

Hood was the premier warship in the Royal Navy from her commissioning until her loss in May 1941. A number of changes were made to her before and during World War II, but none involved her armor protection. Most of these involved changes to armament, fire control gear, directors, ammunition arrangements, and the addition of radar. The ship, her draft relentlessly increased by weight additions during construction and afterward, remained notoriously "wet", even in moderate seas, throughout her career. She was the flagship of Force H and then the Battle Cruiser Squadron of the Home Fleet. She saw action against the French Fleet at Mers El Kebir and participated in the search for the German battle cruisers *Gneisenau* and *Scharnhorst* in the winter of 1941. General arrangement plans of *Hood* are given on Figures 1 and 2. Figure 3 gives a midship section.

Design rationale and operational chronology – *Bismarck*. *Bismarck* and her near-sister-ship *Tirpitz* were the first battleships delivered to the German Navy in over 25 years. An agreement reached in 1934 allowed the Germans to build to battleships with a standard displacement of 35,000 long tons; various "escalator" clauses had, with complete legality, increased this limit to 45,000 long tons by 1941. Conceptual development on a 35,000 long-ton vessel armed with a 305mm main battery commenced in 1932. This armament was considered inadequate and, in anticipation of future restraints being lifted, the Germans commenced development and testing of 380mm and 400mm guns in 1934. Detail design on what would eventually become the *Bismarck* class began in 1935. A requirement to pass through the Kiel Canal restricted the maximum draft to 11 m while docking and construction constraints limited the length and beam to 250 meters and 38 meters respectively. The Standard Displacement[2] was then estimated at approximately 43,900 long tons. The displacement was somewhat increased by the German Navy's reluctance to use triple or quadruple turrets for their main armament. Although some documents, including an official U.S. Navy study produced in 1942, suggest that *Bismarck* and *Tirpitz* were essentially derivatives of the *Baden*/*Bayern* design of World War I, other naval architects feel that the arrangements of their armor, armament, and propulsion plants were really quite different. Certainly the ships incorporated all of the latest technology.

Their true displacement, technically illegal at the time of design -- but not at the time of commissioning -- was kept a strict secret. "Battleship F" (*Bismarck*) was laid down on 1 July 1936. The ship was launched on 14 February 1939 and commissioned on 24 August 1940. She was not really war-ready until May 1941. General arrangement plans of *Bismarck* are shown on Figures 4 and 5. Figure 6 gives a midship section.

TECHNICAL CHARACTERISTICS of *HOOD* and *BISMARCK*

Tables 1 and 2 summarize the major characteristics of these two famous warships. Table 2 clearly shows that weight saved in *Bismarck*'s machinery installation was invested in supplemental armor.

Table 1
Principal Characteristics of DKM Bismarck and HMS Hood (1941)

	Bismarck	*Hood*
Standard Displacement	41,881 tonnes	42,311 tonnes
Full Load Displacement	49,406 tonnes	46,913 tonnes
Maximum Displacement	50,405 tonnes	49,136 tonnes
Waterline Length	241.55 meters	246.89 meters
Waterline Beam	36.00 meters	31.70 meters
Draft (design)	9.30 meters	8.84 meters
Armament	8 - 380mm in Twin Turrets 12 - 150mm in Twin Turrets 16 - 105mm in Twin Mounts 16 - 37mm Twin Machine Guns 12 - 20mm Single Machine Guns 4 Arado-196 Floatplanes	8 - 381mm in Twin Turrets 14 - 102mm in Twin Mounts 24 – 40mm pom-poms in Octuple Mounts 16 - 0.5" Machine Guns in Quad Mounts 5 "Unrotated Projectile" (i.e. rocket) Mounts 4 Torpedo Tubes
Shaft Horsepower	138,000 mhp	145,998 mhp
Speed	30.12 Knots	31.00 Knots[3]
Endurance	9,280 n.m. @ 16 Knots	7500 n.m. @ 14 Knots
Fuel	8,294 tonnes	4,064 tonnes
Protection	320mm – Main Side Belt 95mm – Deck (Magazines) 80mm – Deck (Machinery)	305mm – Main Side Belt 20-76mm– Deck
Complement	2100	1400

NARRATIVE of DENMARK STRAIT BATTLE AND LOSS of HMS *HOOD*

Bismarck, later joined by heavy cruiser *Prinz Eugen*, left Gotenhafen (now Gdynia, in Poland) on 19 May 1941 for a commerce-raiding mission against Allied merchant shipping in the North Atlantic. The Royal Navy soon became aware of this activity but lacked details regarding the exact routes the Germans were planning. British cruiser *Suffolk*, on patrol in the Denmark Strait between Greenland and Iceland, detected the German ships on 23 May. *Hood*, accompanied by battleship *Prince of Wales*, moved to intercept.

Table 2
Weight Breakdowns of DKM Bismarck and HMS Hood (1941)
(Figures in tons)
Adapted from figures in Roberts and Koop & Schmolke

Weight Group	*Hood*	%	*Bismarck*	%	*Hood/Bismarck*
Hull	15,636	34.0	12,700	27.1	1.26
Machinery	5,969	13.0	4,400	9.4	1.39
Armament	5,302	11.5	5,600	11.9	0.97
Armor	13,650	29.7	18,700	39.8	0.75
Equipment	913	2.0	900	1.9	1.04
Fuel	3,895	8.5	4,000	8.5	0.99
Reserve Feed Water	572	1.2	530	1.1	1.10
Aircraft	0	0.0	100	0.2	0.00
Total	45,937	100.0	46,930	100.0	1.00

The Germans detected the approach of *Hood* and *Prince of Wales* at 0515 on 24 May 1941. At 0535, *Hood* and *Prince of Wales* sighted the masts of the German ships. Both battle groups were proceeding at a speed of approximately 28 knots. The two British ships opened fire at a range of approximately 27,500 meters at 0553. *Hood* initially fired at *Prinz Eugen*, while *Prince of Wales* engaged *Bismarck*. We believe that *Hood* shifted fire to *Bismarck* shortly thereafter. The two German ships returned fire against *Hood*, which was then leading the British formation, at 0554. At approximately 0557 *Prinz Eugen* hit *Hood* with a 203mm shell that started a fire in some light steel ready service lockers on the shelter deck. This fire burned until the ship was lost. At 0557, at a range of about 16,650 meters an 800 kg 380mm armor-piercing projectile from *Bismarck* struck *Hood* slightly aft of amidships just as she was commencing a 20-degree turn to port. A spectacular explosion ensued, which tore the old battle cruiser apart. *Hood* sank within three minutes, leaving only three survivors in the water. The Germans immediately shifted fire to *Prince of Wales*, hit her seven times in quick succession, and forced her to retreat in heavily damaged condition.

Bismarck was also hit during the engagement. One 356mm projectile from *Prince of Wales* shell tore a one-meter diameter path through the bow, flooding two compartments and contaminating about 1,000 tonnes of fuel oil. Another shell from *Prince of Wales* fell short and hit *Bismarck* underwater in way of the forward boiler room on the port side flooding several wing tanks and an auxiliary machinery room. These hits caused a 9-degree list to port and 1-meter trim by the bow. A third hit was inconsequential.

After the battle, the Germans continued south into the Atlantic, with the British in hot, though cautious, pursuit. A general plan of the action is given in Figure 7.

NARRATIVE of SINKING of DKM *BISMARCK*

Later on 24 May, *Bismarck* was hit by a shallow-running aircraft torpedo that struck the 320 mm thick face-hardened side-armor belt amidships on the starboard side. This resulted in a slight displacement of the belt and failure of a welded seam in that belt. No significant flooding occurred in the area of this hit, although it did cause leakage through temporary patches installed in the port forward boiler room.

On 26 May, aircraft from the carrier *Ark Royal* hit *Bismarck* with three aerial torpedoes. These torpedoes, set for a depth of 10.4 meters, were equipped with contact fuzes and an explosive charge of 204 kg of TNT. One struck abreast of the after superstructure to starboard, one exploded in the same area to port, and a third hit further aft on the port side just aft of the 70mm armored bulkhead of the steering gear room. The first two hits were relatively harmless, causing some flooding in the wing tanks on the port side and slow flooding in the port engine room.

The torpedo hit aft, however, doomed the German battleship, since it jammed her rudders while *Bismarck* was executing a sharp port turn. According to the senior surviving officer, the rudder indicator locked at 12 degrees to port after the hit. As is typical when hits take place near the bow or stern, the ship experienced a rather severe transient whipping response that damaged equipment not designed to resist such forces. The most severe damage was to the stern overhang structure. Tears were opened in the side shell and bulkheads adjacent to the damaged area and the smoke-screen generating plant was completely destroyed. The propellers, also quite near the blast, were undamaged. Judicious use of these permitted the ship to maintain headway, but little else. Unable to steer, *Bismarck* could no longer avoid interception by her vastly superior fleet of pursuers.

Early on the morning of 27 May 1941, *Bismarck*, outgunned, damaged by torpedo and shell hits, unable to maneuver and manned by a somewhat demoralized crew who knew exactly what was in store for them, was engaged by British battleships *King George V* (10 - 356mm guns) and *Rodney* (9 - 406mm guns), and heavy cruisers, *Norfolk* and *Dorsetshire* (each with 8 - 203mm guns). In a bad-weather action that lasted from 0852 until 1031, the British ships fired 2,876 shells from 133mm to 406mm at *Bismarck*, scoring more than 400 hits. Twenty-three torpedoes were also launched at the unfortunate battleship as she pitched, yawed, and rolled violently in a Force 9 storm. The shell hits devastated the German ship, since most of the shellfire was from relatively close ranges, down to 3,000 meters. Unlike *Hood*, destroyed cleanly at a range of 16,000 meters, *Bismarck* suffered the proverbial “Death of a Thousand Cuts”.

Although *Bismarck*’s main and secondary armament was in essentially perfect condition at the beginning of the action, her gunfire control systems on were destroyed very early in the engagement and she scored no effective hits on her enemies. The next hour and a half saw the ship gradually battered into submission by a hail of incoming gunfire that killed hundreds of her crew. Short of fuel and unable to sink his giant target by gunfire alone, at 1022 Admiral Sir John Tovey ordered cruiser *Dorsetshire* to sink the *Bismarck* with torpedoes. *Dorsetshire* hit *Bismarck* with three 533 mm torpedoes, each armed with 340 kg of TNT and set to run at a depth of about 4.75 meters. Two of these torpedoes hit on the port side and one hit to starboard. As *Bismarck* was beginning to capsize slowly to port when this attack occurred, it appears that one of these torpedoes may have exploded against *Bismarck*’s port side superstructure at about 1031. (This was not a unique event; similar torpedo hits on the superstructure were received by USS *Oklahoma* as she capsized during the Pearl Harbor attack.)

Nine minutes later, at about 1040, the wrecked and flaming battleship capsized to port and sank stern first. There are anecdotal reports, including one from the senior surviving engineering officer, that the Germans assisted in the sinking of *Bismarck* by firing demolition charges in the engineering spaces shortly before she sank.[4] Although many hundreds of men successfully abandoned the sinking ship, as it turned out only 115 men were actually pulled from the water. A general plan of the action is given in Figure 8.

TECHNICAL EQUIPMENT USED IN THE SURVEY

Description of MV *Northern Horizon*

MV *Northern Horizon* was first built as a deep-sea freezer trawler, and later converted to a deep seismic survey ship and hydro-acoustic and ROV (Remote Operated Vehicle) survey ship. *Northern Horizon* is 74.88 meters in overall length, displaces approximately 2,028 long tons, and has accommodation for approximately 50 persons. The vessel is equipped with two 1,600 hp diesel engines yielding a top speed of 14 knots. In addition to the regular suite of navigational equipment appropriate to a vessel of this size, *Northern Horizon* is equipped with a DP (Dynamic Positioning) system and two athwart ship tunnel thrusters that enable it to establish (and -- in reasonable weather – maintain) its position to within less than ten meters in navigable waters virtually anywhere on the globe.

Description of *Magellan 725*

Note:
The authors regret that the original presentation of this paper contained an incorrect description of the Magellan vehicle. The following paragraphs have been modified to reflect corrected information.

The Magellan 725 is a dual-manipulator electro-hydraulic Remote Operated Vehicle capable of operating in depths to 8,000 meters. This capability, which far exceeds the requirements of most commercial applications, is relatively rare. The unit itself is 3.2 meters in length, 1.4 meters in width, and 2.4 meters in height with a weight in air of 2 tonnes. It is propelled by two axial, three vertical, and two lateral thrusters powered via a cable extending from the survey ship, meaning that (in the absence of breakdown) underwater endurance is essentially unlimited. The vehicle, which represents the state-of-the-art in unmanned submersible technology, has been used for a wide variety of deep-water intervention tasks including the 1998 exploration of the RMS *Titanic*, the recovery of *Liberty Bell 7*, and the unsuccessful search for USS *Indianapolis* (CA 35) in 1999.

The *Magellan 725* is controlled via a fiber-optic/electromechanical cable and is guided by pilots working from a portable operations-control van mounted on the deck of a support vessel. This fiber-optic multiplex system and sensor suite passes the video image and data from the ocean floor through an 11,000-meter fiber-optic umbilical to the control van. On this particular mission, the vehicle was equipped with a very high quality video camera for survey purposes, another video camera which was used primarily for navigation and self-inspection of the ROV, and a high-quality digital still camera, all of which were mounted on remotely-controlled pan/tilt heads. The ROV was also equipped with a very advanced lighting system that usually provided good quality video out to a range of at least 30 meters.

Guided by its sensors and controls, this ROV is maneuvered by a 25 horsepower electro-hydraulic power unit, which supplies the hydraulic fluid at 207 mPa to its seven thrusters and several five and seven-function manipulators, which can grasp and lift up to 90 kg. at a range of one-meter. The top underwater speed of the vehicle is in the vicinity of 1.5 to 2 knots in deep water.

The 9150 meter long umbilical cable, about 17mm in diameter, is stored on a take-up reel which feeds through a 907-kilogram line pull traction winch and through an overboard sheave. When ascending or descending, cable is typically paid-out at a rate of approximately 0.5 meters per second. In practice, the umbilical cable is usually led nearly straight down from the survey ship to a heavy "depressor" containing a transfer gear which is in turn attached to a relatively light "roving" tether about 100 meters long leading to the ROV itself. This "roving" cable is supported by floats that bring it to nearly neutral buoyancy. On this expedition the ROV was equipped with a 3-chip broadcast-quality camera that could deliver 850 lines of resolution and 1,200 watts of HMI lighting.

Designed for worldwide operations, the *Magellan 725* is air/sea/ground transportable in 20-foot ISO containers and easily mobilized onboard various ships of opportunity. The *Magellan 725* system comes with spare equipment, a workshop container, and in this case at least, a very skilled and dedicated crew.

Navigation and Recording Procedures

In practical terms, it can be of little use to be able to establish the position of the base vessel – in this case *Northern Horizon* – to within a few meters when the ROV itself, "dangling" as it were at the end of two or three thousand meters of cable subjected to unpredictable and often changing intermediate currents, can in fact be in quite a different, and often indeterminate, location.

The expedition did not deploy a transponder grid, which would have greatly assisted the ROV operators and researchers to reliably and repeatedly locate the ROV with respect to the wreckage below. Especially when primary exploration of a previously unknown site with few recognizable landmarks is the goal, establishing a transponder grid should always be considered.

In one notable incident, a minor "jump" in location of thirty-odd meters across the main hull of *Bismarck* (necessitated by the ROV temporarily reaching the end of its roving tether), required relocating the survey ship as well. This fairly routine repositioning, which required temporarily losing visual contact with the wreck, resulted in the total loss of the main hull for a period of three or four hours. This was unusual, but in many cases some frustration was experienced at being unable to return to a previously visited site because it simply could not be reliably relocated.

When the sensors on the ROV have relatively short range, as was particularly true on the *Bismarck* site due to the irregular bottom, exploring in the absence of a transponder net can be somewhat akin to mapping a department store by match light.

That being said, a case can be made that establishing and maintaining a transponder network on a relatively temporary site represents a considerable expenditure of both time and money which might be better spent on direct, though relatively unguided, observation. It can be a very tough judgment call. Our navigator did an outstanding job without one.

As it transpired, the survey ship was equipped only to handle PAL/SECAM formatted videotape. Although the PAL/SECAM system is well established in Europe, many potential interpreters and researchers are equipped only to handle the NTSC videotape system primarily employed in North America. As duplication of the master videotapes from one system to another is both cumbersome and expensive, many of these NTSC-equipped researchers remain, so far, effectively cut-off from effective access to the videotapes.

The expedition produced over four hundred hours of videotape in total, but much of this represents interviews with participants, in-transit images of mud flats obtained during relocations of the ROV, and general views which – while necessary to produce a high quality commercial production – are of relatively little value to engineers. Although a complete inventory remains to be complied, it is estimated that the expedition obtained approximately 80 hours of useful videotape of the *Hood* and *Bismarck* wreck sites, combined. This represents about 50% of the total time spent on the bottom.

Adherence to requests by several sponsoring and supporting groups has meant that the exact positions of the wreck sites of *Bismarck* and *Hood* have not been released. This is of little consequence to researchers, who – as they are almost always interested only in details of the wrecks themselves and perhaps the *relative* location of various artifacts on the bottom – need no absolute positions to complete their studies. Although much has been made of "secret" wreck site positions, in reality, the concept of a very precise wreck position per se is somewhat misleading, as the very nature of most wreck sites somewhat precludes precise and non-arbitrary definition. It's a bit like asking for the precise position of Montana. In practical terms, the location of both wreck sites would probably be easily recoverable by expeditions equipped with the necessary equipment to reach and explore a bottom at three or four thousand meters. Our expedition found *Bismarck* on the very first dive.

Expeditions to the *Bismarck* site are now becoming routine. It is unlikely that many more expeditions to the *Hood* site, in a much more remote location, and much less visually interesting, will be made.

Research Goals

Two individuals were specifically selected to accompany the television and survey teams in order to provide technical expertise and place expedition findings in an historical context. These were Dr. Eric Grove of the University of Hull, tasked with providing background on historical and to some extent tactical issues, and this author (Jurens), who represented both SNAME Panel SD-7 (Marine Forensics) and the technical journal Warship International published by the International Naval Research Organization (INRO). Jurens' major tasks were to ensure that good scientific and technical data was obtained, to analyze that data, to provide guidance to the television crews, and to support historical and tactical analysis. Prior to departure, he set his primary scientific and historical goals as follows:

a) To examine of the wrecks of both *Hood* and *Bismarck* in order to assess weapons effects and, if possible, develop methods to differentiate these effects from those caused by their descents to the bottom.
b) To examine the wrecks of both *Hood* and *Bismarck* to determine the source and magnitude of differences in deterioration occurring underwater.
c) To examine the debris fields formed by the wrecks in order to assist in the assessment and/or evaluation of debris fields formed by other wrecks.
d) To conduct small-scale experiments regarding the nature of pressure-induced implosions.

Of these four, only item d) remained unaccomplished.

NARRATIVE OF TRIP

Northern Horizon departed Cork, Ireland at midnight on 1 July 2001, arriving at the *Bismarck* site late on 3 July. A Force 6 gale and mechanical delays delayed the first dives somewhat, and the wreck of *Bismarck*'s main hull was not located until 6 July.

General Operations and Observations at the *Bismarck* Site

Narrative of dives: Three dives were made on *Bismarck* during July 2001. The first of these, which extended from 0048, 8 July through 1930, 8 July, came down right on the wreck site, but located only scattered debris. The second dive, which lasted from 1343, 9 July through 0206, 10 July located and allowed fairly detailed observations of the mainmast, one gun turret, and the forward superstructure. The third dive, from 0448, 11 July through 1206, 12 July, located and explored the main hull. Fortuitously, the ROV came upon the main hull of *Bismarck* exactly at the stern break. This enabled this area, along with the fatal torpedo damage to the rudder(s), to be examined in great – almost excruciating – detail. After commercial television commitments were satisfied and a plaque was laid to commemorate those lost, the expedition leader and the sponsor generously provided approximately six hours of dive time which could be specifically devoted to the completion of a complete and systematic survey of the entire main hull, including all vertical surfaces. It is anticipated that close examination of this videotape will result in the first complete survey of hits on the *Bismarck* wreck. Time did not permit investigation of a large nearby target, which was believed to represent the funnel.

The debris field of the *Bismarck* wreck is, in general, rather unremarkable. The forward command tower, the mainmast, and turret Caesar are located in relatively close proximity, which implies that they detached from the main hull at approximately the same time, presumably shortly after the ship capsized. The location of a second turret far south of the main hull, however, suggests that this arrangement may be simply fortuitous. The main hull of the ship created a considerable crater upon impact, thereafter sliding approximately 1,200 meters down a 14-degree slope to its final resting place. Unfortunately, damage to the shell plating done during this slide, much of which took place over a fairly rocky bottom covered in a few meters of soft mud, appears to have erased or at least obscured much of the hull damage done by British torpedoes. The site is bisected by an east-west telecommunications cable that at times is in actual contact with minor pieces of wreckage. This provided a convenient, and at times very welcome, point of reference for exploration.

The water at the wreck site proved to be remarkably clear, and – although there was one lighting failure – the resultant photography was excellent. Currents at the site are typically small, estimated at about a half-knot or less. Net sediment deposition in the sixty years since the sinking appears to be inconsequential, and is often absent entirely, amounting in most cases to a few millimeters of fine unconsolidated mud which was easily – in fact usually accidentally -- blown away by the propulsors on the ROV. The edges of the slide scar remain exceedingly sharp and fresh looking, as if they were, literally, made yesterday. Some evidence of previous visits by a MIR expedition team, which visited the site shortly before we arrived, was also seen on the bottom. A memorial plaque had been placed on the after weather deck of *Bismarck*, and several gouges, identified by our ROV operators as skid marks caused when the MIR exploratory submarines apparently bottomed from time to time, were also observed on the sea-bed. A memorial plaque was placed by this expedition as well.

The general condition of the *Bismarck* wreck is good. A substantial amount of paint adheres to various structures, although – as in the case of USS *Yorktown* – corrosion is heavy where fires have removed or damaged this protective coating. As fires were extensive, these corroded areas are extensive as well. The wreck is covered with large numbers of small circular or near-circular corrosion foci ranging from about 20mm to 250mm in diameter. In most cases it is difficult to tell whether these originate from age-related failures of the protective coating due to normal application variances or are due to localized damage due to the impact of shell fragments. "Rustsicle" formation is minimal. No significant pollution arising from fuel oil or any other contaminant was observed, and the marine ecosystem in the vicinity appeared entirely unaffected by the wreck. The main hull itself lies at a depth of approximately 4,700 meters.

A simplified plan of the debris field is given in Figure 9. A general plan of the main wreck itself is given in Figure 10.

Analysis of torpedo damage. *Bismarck* was hit by as many as nine torpedoes during her voyage. The most serious of these, at least from an operational viewpoint, struck on the port side of the ship at the aft end of the steering compartment. A quick analysis suggests that the torpedo detonated near the port rudder, about 1 or 2 meters aft of the aft armored bulkhead of the steering gear room. The port rudder is visible above the sediments, pushed forward somewhat and turned approximately 15 degrees. The rudder blade appears relatively undamaged, but the rudder shaft itself has distorted the hull at the entry point. Some of the damage to the rudder may have been caused by the slide along the bottom. The propellers are in excellent shape, with visible portions apparently unaffected by the torpedo explosion and the slide along the bottom.

There is a large hole in the portside superstructure in way of the amidships catapult. Although this hole is much smaller than that usually associated with a torpedo hit, there remains a good possibility that it was caused by one of the torpedoes launched by the cruiser *Dorsetshire* late in the action. If this torpedo, set for a depth of 4.9 meters happened to be running near the surface when it arrived, it is quite possible that it struck the superstructure of *Bismarck* as the ship capsized. Alternative possibilities remain to be fully investigated.

Sediments covered most of the areas where other torpedoes are reported to have hit. Damage to the shell caused by the 1,200-meter post-impact slide of the main hull appears to have erased, obscured, or otherwise modified much of the damage that may have been caused by additional torpedo hits from *Norfolk, Rodney* and *Ark Royal*. Although these torpedoes certainly damaged *Bismarck*, they did not play a major role in her sinking.

Analysis of stern break. The most remarkable feature on the *Bismarck* wreck is the area where the stern end separated from the ship. First observed in the 1989 expedition by Dr. Robert Ballard, there is a clean break in the steel and wooden planking, about 200 mm aft of the aft armored bulkhead. The 2001 Expedition approached within one meter of this hull failure, and examined the broken edge in detail. The break is remarkably straight and clean, and appears almost flame-cut in its precision. Preliminary analysis suggests that this failure probably took place along the heat-affected zone of a main erection weld. The torpedo hit in the stern probably started cracks in the welds in this area, which propagated due to unusual, heavy, and repetitive loads caused by the free motion of water in and out of the stern as *Bismarck* pitched and heaved in the heavy seas. Survivor testimony suggests that the stern was attached when the ship left the surface. It therefore appears probable that the stern detached as the ship sank through the water column, although it is also possible that the stern detached upon impact with the sea bed or during *Bismarck*'s subsequent slide along the bottom. The stern was not found in the debris field, which suggests that it lies in a relatively remote location, which in turn implies that the separation of the stern took place rather close to the surface. The after bulkhead at the break line is nearly complete, and previously published illustrations showing overhanging decks extending beyond the break line are incorrect.

Hit census and analysis/description of gunfire damage. *Bismarck* was heavily pounded before she sank. It is estimated that the ship absorbed some 300-400 hits during the 94-minute gunfire phase of the Battle of 27 May. These projectiles arrived from all virtually all points of the compass, many from very close range.

The entry and exit holes in the bow from the 24 May hit by *Prince of Wales*, of great interest to historians, could not be located. In most areas, the mud line around the *Bismarck* wreck is approximately at the load water line. It appears that the main hull slid more-or-less bow first after impact, in the process creating a substantial "bow wave" of mud that appears to have covered the area of interest. While *Bismarck*'s stem is almost buried, her stern is almost clear.

Considerable gunfire damage to the superstructure and some gunfire damage to the hull was visible above the mudline. Incoming projectiles appear to have damaged or carried away virtually every exposed piece of equipment above the weather decks including gun mounts, aircraft cranes, searchlights, masts, and rangefinders. (Some of these may have separated from the wreck after it capsized.) Relatively few major-caliber shell hits were observed in the side armor, although the 145mm thick upper belt was hit – though rarely penetrated – by large numbers of 152mm and 203mm projectiles, many of which produced a "splash" mark indicative of impact. Relatively few shells appear to have struck the 320mm thick main belt, and almost none of these penetrated. This belt was designed to be proof at all ranges to shells under 356mm caliber in any case. In most cases incoming trajectories were nearly horizontal, indicating that the range from firing ship to target was relatively short. The small number of hits on the waterline belt may be indicative of a gunnery concentration on the superstructure, or may stem from the inability of the British to actually get a clear shot at the main belt in the high seas in which the engagement took place. Rather than experiencing large numbers of aggravating "shorts" which would only ricochet wildly past the target and obscure the field of view with huge splashes, the British may have deliberately chosen to aim high. If so, this was unfortunate for *Bismarck*'s crew, who would have thus been subjected to very heavy concentrations of gunfire, which – because it would have arrived high in the ship – would not have hastened her sinking. More historical research may be able to clarify this issue.

One of the main rangefinders found on the bottom shows a rather spectacular large-caliber shell track, which passed transversly through the rangefinder near the back. This unusual track indicates that the rangefinder was perpendicular to the line of incoming fire when it was hit. This would suggest that the hit took place late in the action when it was no longer capable of being trained on potential targets, that the rangefinder was trained on one target while another firing ship was engaging from 90 degrees, or that the rangefinder was engaged in finding a cross-level when it was hit.

Damage to the 150mm gun houses surrounding the secondary armament is remarkable. Only a few of these were hit more than once, suggesting that each of these mounts was, in effect, surgically "neutralized" by a single hit, and was thereafter neglected. In some cases, escape hatches to these gun houses were open, indicating that at least some of the occupants had tried to escape. In others, the hatches remained closed, indicating that the men inside had been killed or disabled almost instantly. The positions of most gun houses and the general layout of major gunfire damage are clearly and quite accurately illustrated in several of Dr. Ballard's easily accessible books, papers, and articles. The expedition found that one secondary gun house was oriented differently from the Ballard illustrations. Anecdotal (and as yet unconfirmed) evidence indicates that this mount was not in fact properly imaged during the Ballard expedition, and that its orientation was therefore "made up" by subsequent illustrators.

There is evidence of two 356mm or 406mm hits on the exposed barbette of Turret Dora. Neither of these were complete penetrations. The forward conning tower, protected by 350mm plating, was hit by several heavy shells traveling nearly horizontally which, though they appear not to have fully penetrated, must have inflicted severe damage to the interior. There is also evidence of a large shell hit in the barbette of Turret Bruno. One main turret was found, inverted, with guns complete but buried in the mud, and with a large mass of superstructure plating wrapped around the faceplate. The "tail-hatch" was open, suggesting that at least some of the crew successfully escaped. The main turret found by Dr. Ballard in 1989 was not relocated.

Structural damage at break up/sinking. Bismarck apparently rotated approximately 135 degrees to port before her plunge to the bottom began. Her main battery turrets, and many other heavy rotating structures, were apparently held in place only by gravity, and therefore slid free of the hull as it inverted. The light plating wrapped around the faceplate of the turret located on this expedition suggests that it intercepted part of the superstructure during its descent.

The upper bridge tower separated from the main hull sometime during the trip to the bottom. This rather substantial piece of superstructure separated very cleanly from the main hull, with the approximately 15mm thick deck on which it sat remaining flat, clean, and marked only by some weld scars which preserved the plan of light interior partitions. The lack of significant structural through-connections at the break point – which was also noted at the stern break -- suggests that the detached area of the superstructure was probably installed as a sub-assembly.

The upper superstructure, found inverted on the bottom, had been heavily riddled with light and heavy gunfire, and showed very extensive fragment damage. The adjoining "bottom" of the superstructure also showed little distress or deformation along the attachment point. It appears to have simply broken at the welds. Light interior bulkheads in the superstructure were essentially still in place at the break point.

It must be remembered that welding was in its infancy when *Bismarck* was constructed. In that context, the failure of welds in the superstructure and stern most probably reflect inexperience rather than incompetence on the part of those who designed and built her.

As the main hull was almost completely filled with water before the descent to the seabed started, damage from implosion/explosion forces appears to have been minimal. No such damage is apparent on the visible portions of the hull.

No evidence to support (or refute) anecdotal reports regarding the employment of scuttling charges could be observed on the wreck. This is not surprising, as the relevant areas of shell plating are deeply buried in the mud, and, in any case, probably have been heavily damaged during the slide down the bottom.

Summary of new findings: The 2001 Expedition to *Bismarck* largely confirmed previous observations. The side armor of *Bismarck*, previously poorly imaged, showed few penetrations. The upper portion of the forward command tower was found, and the break between the superstructure and the remaining hull was found to be remarkably clean and undistorted. The torpedo damage to the rudder and the stern was imaged and inspected in detail for the first time.

General Operations and Observations and Observations at the *Hood* Site

Narrative of dives: *Northern Horizon* arrived at the *Hood* site on 17 July, and located the wreck at about 0330 19 July. Four dives were made on *Hood* between 20 and 25 July 2001. The first dive, which extended from 0811, 20 July through 0015, 21 July, located the inverted midsection of the hull and explored the debris field extending some 500 meters to the northwest. The second dive, from 0940 21 July through 11:25, 23 July, began at the main hull and proceeded northward about 850 meters, thereafter turning westward. This dive located the stern, the bow, one 381mm gun turret and a pair of propellers. The third dive, from 1440, 24 July through 0211, 25 July, located the conning tower about 1,400 meters northwest of the midship section and explored a number of other large pieces of debris. The forth and final dive located one additional gun turret, and returned once again to the bow section where a memorial plaque was laid by Mr. Ted Briggs, the last living survivor of H.M.S. *Hood*.

Debris field(s) The *Hood* wreck lies on a fairly flat bottom, at a depth of approximately 2,700 meters. The site is unusual in that it exhibits evidence of two clearly separate and substantial debris fields instead of one. The distribution of material in these debris fields, and to some degree even their extent, is difficult to analyze; it is often difficult for even skilled observers to separate the sonar echoes and images created by underwater geology from similar echoes caused by wreckage. In the absence of detailed examination, which remains to be done, it seems most plausible to assume that one of these debris fields may be associated with the explosion that tore the ship apart, while the other is related to the break in the hull forward, which was most probably caused by implosion. Initial investigation did not permit small items in the debris fields to be correlated with specific points of origin on the ship. The *Hood* debris fields, in an illustration adapted from Mearns and White, are shown in figure 11.

Description of midsection: The midsection of the ship, shown in figures 12 and 13, lies inverted on the bottom and extends from an implosion-induced separation just forward of "A" turret aft to the after bulkhead of the forward engine room at approximately frame 217. This inverted orientation is quite unusual, as the main hulls of most wrecks sunk in deep water – over 90% – end up bottoming right side up. This huge hull section, about 140 meters long, exhibits truly remarkable damage due to the forces of both implosion and explosion. As shown on figure 13, the implosion damage to this section is characterized by long parallel more-or-less continuous longitudinal trough-like depressions in the 25mm thick bottom plating. A number of relatively small irregular and/or ellipsoidal implosion failures are scattered about the bottom as well. Although it has not yet been possible to correlate these smaller failures with interior structure, the large longitudinal trenches can easily be correlated with normally void spaces in the ship's side protection system.

The shell plating covering these depressed longitudinal troughs exhibited remarkable ductility before failure. Some preliminary measurements of these depressions suggest that the elongation at failure was probably in the vicinity of 35-40 percent, suggesting that the steel was well into the plastic stage. Due to contractual agreements and respect for the site, it was not possible to recover steel for metallurgical and physical analyses, so the reduction of area associated with this quite remarkable stretching cannot be directly ascertained.

Clearly, there are no indications that excessively brittle steel in any way contributed to the loss of *Hood*, or that the design of the hull was in any way structurally deficient. In general, plate margins marking the edge of the after failure exhibit intact lines of intact rivet holes which suggest that when stressed to the limit the structure failed – as it should have – via shearing and "popping" of the fasteners rather than through tearing of the plate. Although occasional plate edges do exhibit the straight-line sharp edge pattern common to so-called "brittle" failures, in general these failures appear to reflect the presence of high strain rates rather than low ductility. This observation applies to the margins of the forward hull failure as well. The middle section of *Hood* is well-separated from the remainder of the wreckage, suggesting that it sank rather slowly, its inversion probably due to residual buoyancy remaining in double bottom voids which successively imploded as the main hull descended.

The upper decks in the forward area of the main hull are depressed some three or four meters, a situation which initially led Mr. Jurens to tentatively identify “A” turret barbette at the front of the break as the barbette of the forward “high” turret, “B”. This led to an associated misidentification of “B” turret as the forward surface of the conning tower. Subsequent location of the conning tower in another area of the debris field revealed that this initial assessment was in error. The bulkhead of the stern break is covered in cabling which apparently originated in the winch rooms that housed the cabling sheaves serving the hoists on the mainmast. A good deal of shell plating is missing from the starboard side aft. A very large number of so-called “crushing tubes” from the side protection system are widely scattered throughout the debris fields. Many of these were observed floating in the water shortly after the ship sank. They are indicative of extremely severe trauma to the main hull.

The breaks at the boundaries of the three main hull sections of HMS *Hood* were quite regular, essentially amounting to ragged transverse cuts through the structure, in each case bounded by a main bulkhead or barbette. The impact crater associated with the midship section is extremely large, with pronounced stellate boundaries.

Description of stern The stern section of *Hood* sits with the keel line perpendicular to the bottom, with the stern up and the forward bulkhead of the break, now horizontal, buried in the mud. It shows no significant signs of implosion damage. Large hatches in the weather deck have been either opened or blown away. A large “flap” of weather deck plating and planking almost the whole beam of the ship and about 15 meters long has been bent forward and upward at an angle of 90 degrees to the keel, placing its lower side flat on the bottom. This flap extends to the after margin of “Y” turrets’ barbette.

The inboard (after) propellers are intact in the mud, with their streamlined tail cones crushed by implosion pressures. The remains of the outer shafts and shaft struts were located elsewhere in the debris field. The rudder is clearly visible, canted approximately 30 degrees to port. This clears up a minor historical mystery by confirming that *Hood* had actually commenced her final turn when the fatal shell or shells arrived. There is no large impact crater associated with the stern.

Description of bow: The bow section, lying on its port side, terminates in a highly irregular failure slightly forward of “A” turret. Unlike the midship section, which characteristically exhibits trench like depressions and localized implosion punctures, the bow exhibits unperforated depressions and distortions on a much larger scale. Although no formal measurements have yet been made, the visual impression of these defects suggests that they are, in some cases, tens of meters in their greatest dimension, with central depressions perhaps one or two meters in depth. These distortions suggest that very large external forces were at work before the bow was fully and completely flooded. The structure forward, near the anchors, does not appear to exhibit the same degree of distortion observed in way of tankage further aft. This is probably due to the quick flooding of the chain lockers, which prevented subsequent implosion at that point. The lack of implosion-induced puncture failures appears to indicate that the framing system failed before the shell did. A web-like tangle of anchor chains extends for some distance around the bow. No associated anchors were located, although not all chains were followed to their terminus. There is no significant impact crater associated with the bow.

Description of other items: Hood’s forward superstructure and conning tower are located some distance away from the main debris field. As it has been as yet impossible to determine the exact point in the debris fields over where the ship actually exploded and sank, it is difficult to ascribe a cause to this substantial separation, except to note that it implies that the conning tower and associated superstructure separated from the main hull relatively early in the descent. The failure at the base of the 600-ton heavily armored conning tower, which lies inverted on the bottom, is remarkably clean, with light interior partitions right at the break point being almost entirely undistorted. As the main hull is inverted, the associated attachment point on the hull itself is buried in the mud and cannot be observed.

In addition to the material already described, the debris fields contain a number of rather irregularly shaped heavily traumatized bungalow-sized pieces of main hull that evidently represent the remains of main machinery and magazine spaces. One contained an entire turbine set. These mangled remains were passed over rather quickly, and a detailed analysis of the resulting videotapes remains to be done.

The after end of one torpedo was found. Although it appears most likely that this torpedo was bisected by implosion damage or simply represents the remains of a spare after body, the possibility remains that that the loss of the forward section was in fact due to the explosion of its warhead. Detailed imagery of this break was obtained which should enable ordnance experts to accurately evaluate this possibility in the future.

A good deal of wreckage, which can be associated with the after superstructure, including the mainmast and at least one 102mm anti-aircraft mount, was located and imaged. Corrosion damage on the wreck, while not substantial, made it impossible to establish flame propagation paths or to accurately discriminate plate failures and distortions caused by the blast itself from similar failures caused by structural breakup of the hull and superstructure as they sank.

The general condition of all the located wreckage of *Hood* was good, and many areas – particularly in the interior – show large areas of virtually undamaged paintwork. There is, of course, evidence of corrosion at work, but this expedition located few, if any rustsicles. The area where *Hood* sank has long been used as a fishing area, and it was expected that at least some of the wreck would be entangled in fishing nets which had been abandoned and/or lost near the surface. None were found.

Three of *Hood*'s four main gun turrets were located and examined by the survey team. "A" turret, less its gun house armor, remains in place inside "A" barbette, mashed into the mud at the front of the midsection. (This indicates that the turrets, like many of those in the U.S. Navy, were almost certainly vertically restrained, unlike those in the *Bismarck*.) It appears likely that that close investigation of the videotapes will reveal that "B" turret is in place in its barbette as well. Two additional turrets and at least one complete 381mm gun were found free in the debris field. Although a detailed analysis has not yet been made, these "free" turrets probably represent the two after units, "X" and "Y", which were certainly unseated during the explosion of the after magazines.

The debris fields are littered with hundreds of 102mm cartridge cases, the majority of which are oriented vertically, with the heavy closed end down. Although reliable reference works state that the ammunition for these guns was "fixed", i.e. that the projectile and cartridge case were stored and transported in pre-assembled form, none of these contained a projectile. Many were heavily deformed, and contained dents to the upper rim. Close examination of some of these cases failed to determine if there was propellant remaining inside. The expedition also located and imaged one of the ship's two main bells.

In general, the water surrounding the *Hood* wreck did not appear to be as clear as that surrounding the wreck of the *Bismarck*. The sea bottom around the wreck of the *Hood* is typically very soft, and quickly creates clouds of underwater "dust" at the slightest disturbance, including the reversal of currents. Currents at the Hood site are large – at times perhaps exceeding two knots – and remained quite unpredictable during the dive sequences. These current, apparently tidal in nature, sometimes made the ROV exceptionally hard to control and navigate, and at times precluded the investigation and re-examination of areas of considerable interest. No significant pollution arising from fuel oil or any other contaminant was observed. Effects on the marine biota in the vicinity appeared to be nil.

Analysis of the sinking. The Royal Navy conducted two inquiries after the loss of *Hood*. These reports, which will be more completely analyzed in subsequent papers, concluded that *Hood* was most probably lost due a magazine explosion caused by the detonation of a 380mm armor-piercing projectile from the *Bismarck* which penetrated her after magazines. Nothing was found at the wreck site that would suggest that this analysis was substantively in error.

Examination of the wreck site did, however, reveal additional information about the loss that could not have been known by the Board(s). These observations enable researchers to tentatively confirm some earlier suppositions, and rule out others.

It was, for the first time, possible to measure the precise extent of the damage caused by the initial explosion and break-up of *Hood*. As shown on figures 14, 15, and 16, the after explosion apparently involved the entire after magazine group, and completely destroyed an area approximately 85 meters long. In 1987, Jurens prepared a diagram illustrating the probable sequence of events during the explosion itself. This diagram, appended here as figure 17, retains its validity today. As might be expected, after the initial explosion, the engineering spaces must have flooded quite rapidly, causing the forward section of the ship to trim violently by the stern. Eventually, as *Hood*'s speed decreased and hydrodynamic effects supporting the forward section diminished, the rapidly flooding engineering spaces pulled the still dry bow to a nearly vertical attitude, "like the spire of a giant cathedral", one German observer noted. It appears from eyewitness reports that this rotation took place about an axis near the bridge, and that the ship initially assumed a near-vertical position with a waterline located in the immediate vicinity of "B" turret or perhaps slightly farther aft.

The area forward of "A" turret, though dry, was probably subjected to very considerable and unusual stresses as it was lifted bodily from the water during this transition. This forward section, which in the vertical position would have had relatively little water plane area, appears to have been rapidly pulled down by the by then more-or-less completely flooded stern. During this rapid descent, the hull, already subjected to considerable stress at the "hard point" just forward of "A" turret where the forward armor belt wrapped athwart ships, and perhaps heavily loaded from flooded chain lockers forward as well, apparently imploded at a point slightly forward of "A" turret. This implosion, which probably took place at a depth of about 30 meters, effectively destroyed the hull girder, permitting the now separated bow to proceed essentially independently to the bottom.

The authors regret that they cannot at this time support the supposition raised in recent media reports and television programs that the separation of the bow was due to a secondary explosion in the forward magazines. These conclusions, apparently based upon a very selective misreading of isolated eyewitness testimony and local observations of some outwardly-bent plating near the margin of the forward hull break, are believed to be erroneous. The forward magazine group, in fact, lies entirely aft of the point of separation. (Although drawings of the ship often locate a set of forward underwater torpedo rooms at the break point, these torpedo tubes and the associated warheads had been removed during modifications made in 1938. Although this modification was accompanied by increased internal subdivision which should have strengthened the hull in this area, there remains some possibility that structural discontinuities created during these modifications may have actually weakened some of the surrounding structure, exacerbating the high loads placed on this area during the vertical rotation.) Considering the extreme violence which must have accompanied the total separation of the bow, the local configuration of plate boundaries at the separation point -- which reflects the direction in which the plates *last* moved, and not necessarily the direction in which they *first* moved -- cannot be considered as highly indicative of an explosion-induced origin.[5]

The authors have not yet completed their studies surrounding the precise dynamics of the explosion that destroyed *Hood*. It does appear clear, however, that the explosion, which appears to have consumed no less that 120 tonnes of cordite, did contain elements of both deflagration – i.e. very rapid burning – and detonation. It is certain that detonations of gun type propellants, though relatively rare, have occurred in the past. Maximum pressures and pressure gradients inside the fireball remain to be calculated, although the observation of entire main turrets in the air would indicate that local internal pressures did, at least for a short time, considerably exceed the 4.2 kg/cm^2 (60 p.s.i.) that was probably required to lift one of *Hood*'s main turrets from its barbette against its holding clips.

The burning rate of gun propellant is exponentially related to the ambient pressure, and such propellants therefore require uninterrupted confinement, either mechanical or inertial, in order to continue to combust.

Combustion of burning propellants typically ceases almost instantaneously after pressure is released, i.e. after the propellant destroys or otherwise vents from its initial container. The absence of unburned or partially burnt propellant on the bottom, which has been found in the vicinity of other wrecks where magazines exploded, suggests – but by no means proves -- that the fatal burn was rather complete in nature, that is, that a substantial amount of the propellant had already been consumed before the explosion vented to the open atmosphere and "quenched". Some very recently received information seems to indicate that after a certain critical radius is reached, the boundary of the expanding fireball created in a propellant burn becomes unstable, thereafter creating tongues of flame which may follow capricious and somewhat unpredictable paths. Eye-witness evidence, not reproduced here, suggests that the explosion began at the most forward "star" shown on Figure 15 thereafter proceeding rapidly aft in "cigarette burn" fashion to "Y" magazine, shown by the aftermost star. Figure 17 illustrates the first portion of this sequence in slightly different form.

A detailed reconstruction of the action leading to the loss of the *Hood*, including a complete analysis of the probable path of the projectile, which led to her destruction, is now in progress, and should be completed by the end of this year. A reanalysis of armor penetration calculations first done in 1987 has so far found no evidence that would indicate that the previous computations were substantively in error. This analysis, and the geometry of the protection system as shown in figure 18, suggests that the fatal penetration occurred through the upper deck through the after engine room or slightly aft of the after engine room on the starboard side, in an area where a small section of 75mm laminated armor deck plating had been omitted in order to save weight. This is entirely in accordance with the findings of the original Admiralty Boards of Inquiry that investigated the loss in 1941.[6] It does not appear probable that the after above-water torpedo tubes were in any way involved in the loss.

Hood was a raised forecastle ship, like many present-day American destroyers and cruisers. This structural discontinuity may represent a source of weakness when such hull is damaged as occurred in the USS *Princeton* (CG 59) after a mine explosion in the 1991 Gulf War. Although there is no evidence to lead the authors to conclude that such a feature was in any way related to the loss of *Hood*, we believe that such a hull configuration should be avoided in favor a flush deck ship whenever possible.

NEW RESEARCH

It is evident that a great deal could be learned, and the interpretation of the wrecks of sunken ships greatly enhanced, by a greater appreciation of the dynamics of sinking. Although a good deal is often known about the ship on the surface and the (often dismembered) wreck on the seabed, relatively little is usually known regarding the dynamics of a ship's last voyage to the bottom. In that regard, the authors would be most grateful for any additional information readers may be able to supply regarding the sinking dynamics of full-sized ships. A preliminary survey suggests that model experiments, though not entirely useless in this regard, may be of relatively little benefit. It is hoped that some military research, thus far classified, may be located and released in support of this work.

The authors were very surprised to learn that there appear to be few or no items in the non-classified literature regarding the *creation* of debris fields. In the absence of systematic experiments to determine how the shape, size, and density of various items actually affects their distribution on the bottom, it is feared that many interpretations of debris fields, may, in fact, have more in common with the interpretation of tea leaves than with science or engineering. One of the authors is now in the process of organizing and sponsoring a set of experiments to systematically create debris fields in order to establish the magnitude -- and in some cases even the existence -- of coefficients and variables which would enable mathematical modeling and analysis to begin. This would, apparently for the first time, enable researchers to establish and apply equations to justify (and perhaps refute) their intuition. The authors are very early in this process – roughly at the proverbial stage of Galileo dropping cannon balls from the Tower of Pisa – but we are on our way.

The difficulties in interpreting the condition of wrecks on the bottom are very formidable indeed. Very often, particularly with older wrecks, forensic researchers have no "black boxes" to go by.

One need only to look at the (now relatively well-known) wreck site of *Titanic* to illustrate how confusing things can really be. Had there been no survivors to reveal the actual sequence of events which led to the loss, it is difficult to escape the conclusion that engineers arriving on the wreck site some sixty years later would not have ascribed the severed hull to some astonishing catastrophe in the engine rooms. Had a close examination of the wreckage suggested that the structural failure amidships was probably unrelated to an explosive event, researchers would have quite reasonably concluded that it most probably stemmed from simple structural inadequacy or poor workmanship.

Had anyone suggested that the ship did in fact hit an iceberg, this hypothesis would probably have been more or less immediately rejected by a close inspection of the bow – which remains essentially – almost eerily – intact. The relatively small pattern of punctures and tears caused by the iceberg, located in any case below the mud line, would probably have never been observed at all, and – if found – would have almost certainly been seen as a side effect of the main hull hitting the bottom. And the actual cause of the sinking, well hidden, might never have been discovered.

This does not mean that marine forensics represents a futile endeavor. But it does suggest that until considerably more expertise has been accumulated, the accurate interpretation of wrecks must be recognized as a very slippery and tricky process indeed. Experience counts. The members of Panel SD-7 continue to lead the way into this dark and often confusing engineering thicket, undeterred.

ACKNOWLEDGEMENT

The authors wish to thank Eur Ing David K. Brown RCNC for his assistance in the preparation of this paper. His insights into the mechanics of magazine explosions and his intimate knowledge of British warship design, both freely shared, proved to be invaluable.

REFERENCES

a) Mearns, David, and White, Rob: "Hood and Bismarck" Channel 4 Books, 2001, London. A very readable popular account of the entire *Hood/Bismarck* expedition, written by the expedition leader and a Channel 4 producer and journalist.

b) Roberts, John: *Anatomy of the Ship – The Battle Cruiser Hood*: 1982, 2001, Conway Maritime Press. Without doubt, THE reference source on the detailed construction of *Hood*. Many of Robert's other works deal, though more peripherally, with the design and construction of *Hood* as well. At least six copies of *Anatomy of the Ship – Hood* were taken on the expedition.

c) Koop, Gerhard, and Schmolke, Klaus-Peter: *Battleships of the Bismarck Class*: 1998 Greenhill Books, London. An excellent and easily accessible source, though not as comprehensive as Garzke & Dulin.

d) National Maritime Museum, Greenwich, England: Various original builders' plans of HMS *Hood*. The authors wish to thank Bob Todd and his staff for providing these.

e) German Military Archives: Various original builders' plans of DKM *Bismarck*.

f) Garzke, William H., Jr. and Dulin, Robert O., Jr.: "The *Bismarck*'s Final Battle", *Warship International* No. 2, 1994. A comprehensive description surrounding the last action of the *Bismarck*.

g) Jurens, William: "The Loss of HMS Hood – A Re-examination", *Warship International*, No. 2, 1987. A complete technical analysis of the loss of *Hood*. This paper is still available from the International Naval Research Organization, and has been reprinted at a number of sites on the Internet.

h) Garzke, William H., Jr., and Dulin, Robert O.: *Battleships – Axis and Neutral Battleships in World War II*. 1985, U.S. Naval Institute Press. The most reliable and comprehensive description and analysis of *Bismarck* available in English.

i) Preliminary Design Branch, Bureau of Ships, United States Navy: "Study of *Bismarck*", 1942. A Secret study of *Bismarck* based on captured official drawings.

j) Garzke, William, H, Jr.; Jurens, William; and Dulin, Robert O., Jr.," "*Bismarck* Encounter" – an unpublished book manuscript containing a detailed marine forensic, technical, and operational analysis of the *Bismarck* operation from both German and British viewpoints.

k) Brown, David K., The Explosion at Jutland and its Relevance to *Hood*. Unpublished manuscript scheduled for publication in *Warship International.*

---

[1] In a story perhaps too good to be true, a high-ranking British officer upon learning of the explosions is reported to have summed up the situation with the statement "Something seems to be wrong with our bloody ships today!"

[2] The so-called "Standard Displacement", artificially contrived to facilitate comparisons between ships and ensure compliance with inter-war treaty restrictions was officially defined as "…the ship, complete, fully manned, engined, and equipped ready for sea including all armament and ammunition, equipment, outfit, provisions and fresh water for crew, miscellaneous stores and implements of every description that are intended to be carried in war, but without fuel or reserve feed water on board."

[3] It is unlikely that *Hood*, due to be re-engined in only a few years, could have made this speed in 1941.

[4] This has led to a lingering debate as to who really sank the *Bismarck*. The condition of the wreck means that it is unlikely that the true situation will ever be known with certainty. The debate is moot in any case because by the time these charges are alleged to have been fired, Bismarck was already in a sinking , and probably irretrievable, condition.

[5] The authors have read the entire testimony of the witnesses called to the British boards of inquiry, and of a number of German eyewitnesses as well. Few of these suggest a forward explosion of any significance, and none can support an explosion of the forward magazines. One need only review the very extensive testimony revolving around an analysis of the plate margins in the hull of the old battleship *Maine*, sunk in Havana harbor in 1898, to see how easily an examination of localized plate failures can mislead even experienced observers.

[6] Mr. Nathan Okun was, so far as we know, the first to suggest and support the possibility of a penetration through the after engine room. Mr. John Roberts first mentioned the area of omitted plating to the other authors of this paper.