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AN ANALYSIS OF THE HISTORICAL EFFECTIVENESS OF ANTI-SHIP CRUISE MISSILES IN LITTORAL WARFARE

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AN ANALYSIS OF THE HISTORICAL EFFECTIVENESS OF ANTI-SHIP CRUISE MISSILES IN LITTORAL WARFARE

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This thesis examines the historical effectiveness of anti-ship cruise missiles used in littoral warfare. Missile leakage rates, probability of hit on a given target, and small combatant staying power with respect to Exocet missile equivalents are derived from historical data. These parameters are extended to modern U. S. warships displacing 7,000 tons or less, which are expected to operate in littoral waters, to determine the number of missiles needed in a salvo to inflict a combat kill or sink the warship.

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EXECUTIVE SUMMARY

The modern ships of today's U. S. Navy are designed to be extremely effective in combating incoming enemy threats. The layered defense in depth concept provides a "steel curtain" of defenses, making it virtually impossible for any threat to penetrate into a combat alert battle group. But the shape of warfare is changing, allowing less space and less time for reaction to the enemy and its threats. The term "littoral warfare" has been used almost exclusively to describe the threats the Navy will encounter in the near future. The ability of the Navy to adapt to this new environment will determine how successful the Navy will be and what roles and missions it will play.

Naval battles have been fought only in the littoral arena since the first anti-ship cruise missile was fired in anger in 1967. Conflicts such as the Indo-Pakistan War of 1971, the Arab-Israeli War of 1973, the Iran-Iraq War of 1980-1987, the Falklands War of 1982, the Battle of Sidra in 1986, Operation Praying Mantis in 1988, and the Gulf War of 1991 all were littoral scenarios matching various formidable offensive capabilities of anti-ship weapons with the defenses of the naval vessel. Reduced battle space, reduced reaction time, land launched anti-ship weapons as well as air and ship launched anti-ship weapons, and the lack of layered defenses are the common denominator in all the above conflicts.

Raw data was collected on each of the ships and the missiles involved in the above conflicts. Probability of hit was computed for three different types of targets which anti-ship missiles were employed against. These targets consisted of defenseless, defendable, and defended targets. Additionally, ship full load displacement, total missile weight, warhead explosive content, and missile speed were gathered to develop a functional relationship between ship and missile characteristics for ships put out of action and ships sunk. This relationship was used to predict the number of missiles needed to put modern warships out of action and to sink them.

There are many lessons to be learned from the historical record of anti-ship missiles in combat. Historical missile hit probabilities are summarized in the following table.

	Total Probability of Hit	Post 1982 Probability of Hit
Defenseless Target	0.913	0.981
Defendable Target	0.684	0.630
Defended Target	0.264	0.450

Table 1. Probability of Hit by Category.

The trend in this data favors the anti-ship cruise missile, with a marked increase in the probability of hitting a defended target. Ship defensive firepower and staying power must increase proportionately if ships are to survive in combat situations of the future.

Softkill measures employed against anti-ship missiles were extremely successful, seducing or decoying every missile they were used against. In every engagement where a defender was alert and deployed softkill measures, every missile salvo was entirely defeated.

Hardkill measures were not as successful, with only one case confirmed. This is understandable since hardkill measures used to date have primarily consisted of manual firing systems. More data is needed to assess the combat capabilities of modern hardkill systems.

For the ships in the data set, an average of 1.2 hits put the ships out of action, while an average of 1.8 hits sank the ships. With these numbers, a leakage rate of 0.25 or higher would have a disastrous impact on the outcome of the conflict. It is emphasized that the ordnance quantity-full load displacement relationship is based wholly on a statistical correlation. It is hard to find a physical explanation for why combat kills would correlate best with missile kinetic energy, while sinkings correlate best with missile explosive content. It is also emphasized that because most anti-ship missile victims were small warships, this analysis is unreliable when extended to warship larger than 7,000 tons displacement. Accepting these cautions, the following figure is offered as the best possible functional relationship between the number of anti-ship missile hits (normalized to Exocet missile equivalents) and combat kills or sinkings as a function of warship size, based on 30 historical examples of warship damage.

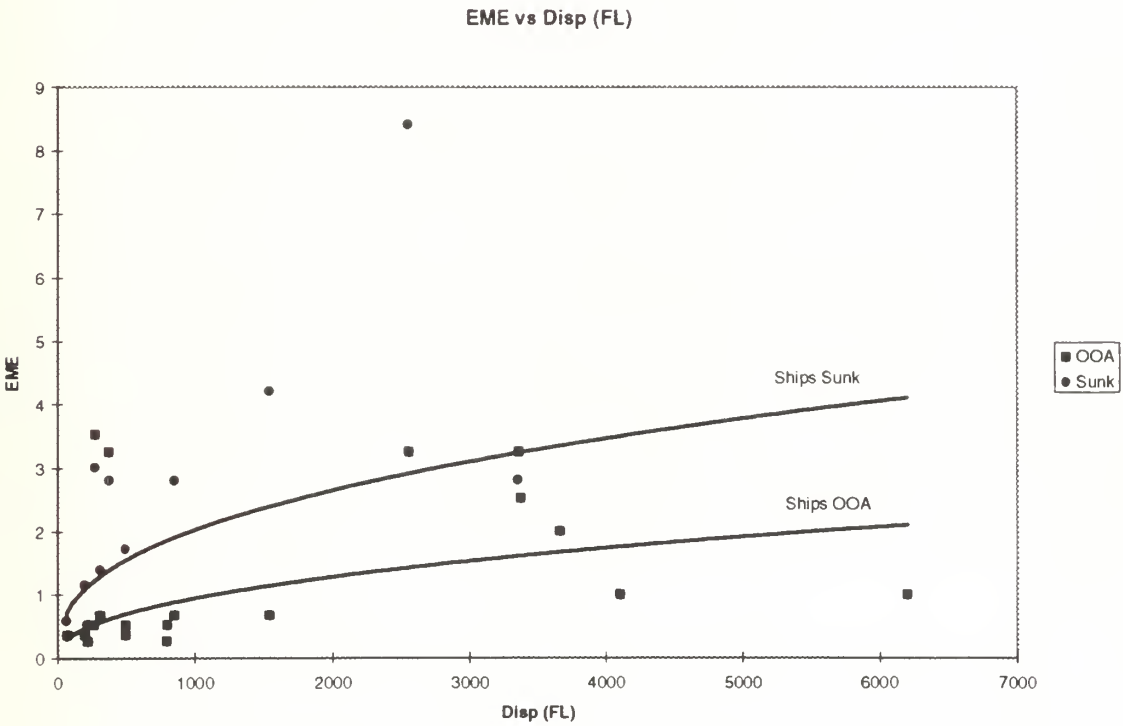

Figure 1. Best fit models for ships OOA and ships sunk.

I. INTRODUCTION

The modern ships of today's U. S. Navy are designed to be extremely effective in combating incoming enemy threats. The layered defense in depth concept provides a "steel curtain" of defenses, making it virtually impossible for any threat to penetrate into a combat alert battle group. But the shape of warfare is changing. Less space and less time for reaction are allowed for the enemy and its threats. The term "littoral warfare" has been used almost exclusively to describe the threats the Navy will encounter in the near future. The ability of the Navy to adapt to this new environment will determine how successful the Navy will be and what roles and missions it will play.

Naval battles have been fought only in the littoral arena since the first anti-ship cruise missile was fired in anger in 1967. Conflicts such as the Indo-Pakistan War of 1971, the Arab-Israeli War of 1973, the Iran-Iraq War of 1980-1987, the Falklands War of 1982, the Battle of Sidra in 1986, Operation Praying Mantis in 1988, and the Gulf War of 1991 all were littoral scenarios matching various formidable offensive capabilities of anti-ship weapons with the defenses of the naval vessel. Reduced battle space, reduced reaction time, land launched anti-ship weapons as well as air and ship launched anti-ship weapons, and the lack of layered defenses are the common denominator in all the above conflicts.

Of all the existing threats, the most formidable is the anti-ship cruise missile.

Today, 66 countries possess anti-ship cruise missiles, with 43 of these countries being Third World countries. Supersonic and/or sea skimming missiles launched from land, air, or sea would test the U. S. abilities to counter these threats, especially under adverse littoral conditions. [Ref. 1]

Previous conflicts mentioned above provide insight as to the methods of employment and time factors that play a significant role in the outcome of each attack.

These scenarios have three categories of targets for anti-ship cruise missiles. The first is the defenseless target, having no capabilities to engage or deceive an incoming missile. The second is the defendable target, which has the capability to engage or deceive an incoming missile but does not, due to surprise, inattentiveness, or equipment malfunction. The third is the defended target, which utilizes hard kill and/or soft kill defenses to defeat incoming missiles. Hard kill defenses refer to organic missiles or guns, or escort/battle group hard kill capabilities. Soft kill defenses refer to deception seduction, jamming, maneuver, or other tactics to defeat an incoming missile without destroying it.

The most valid evaluation of a weapon system's effectiveness comes from observing its performance in actual combat against an enemy. Experience thus gained is invaluable in developing and predicting the effectiveness of new systems. [Ref. 2]

The goal of this thesis is to provide a statistical analysis of the effectiveness of anti-ship missiles in previous littoral scenarios, in order to extrapolate possible implications for future littoral scenarios faced by the U. S. Navy. Analysis will be conducted on the historical probability of hit by a missile (susceptability) and warship damage when hit (vulnerability).

II. CHRONOLOGY OF EVENTS

A. DATA COLLECTION

The first step was an extensive search for references detailing all anti-ship cruise missiles fired in anger. Although complete information was not available for every missile launching, data was normally not difficult to find regarding total missiles launched, number of missiles assessed as hitting their targets, damage from the missile impact, number of missiles which missed their targets and type of missile used. Information on numbers of personnel casualties (killed or injured) was not always readily available however. Where casualty data was ascertained, it is documented, so that some inferences may be drawn. Sources for the information gathered in this chapter are listed in the bibliography.

1. Sinking of the Eilat (1967)

The first anti-ship cruise missile attack occurred in 1967, off the coast of Port Said in the Mediterranean Sea. While on her daily patrol of the Sinai coast, well within Egyptian territorial waters, the Israeli Destroyer Eilat was attacked with Soviet made Styx missiles that had been fired from Osa-class missile patrol boats. The ship was surprised by the attack, and took no measures to defeat the incoming missiles or engage the Egyptian missile boats involved in the attack. Four Styx missiles were fired at the Eilat. Three found their target. The fourth missile may have missed due to the lack of visible freeboard on the Eilat for the missile to acquire. Forty-seven sailors were killed and 91 sailors were wounded in a crew of 250. After the attack, it was revealed that Israeli intelligence knew of the missile threat present in Port Said, but failed to pass this information to the Captain of the Eilat. This incident is classified as a defendable target. The Eilat was equipped with 4.5 inch guns and 40mm guns, but did not use either because of surprise.

2. Sinking of the Orit (1970)

In 1970, the Egyptians sensed that war with the Israelis was a possibility. They also saw the Israeli Navy transformed into a surface fleet of smaller, more maneuverable patrol boats. Knowing the Styx missile was not designed to attack such small, maneuverable targets, the Egyptians attempted to assess their ability against the Israeli patrol boats. An Israeli fishing vessel, the Orit, wandered into Egyptian territorial waters. An attack was conducted on the Orit, using four Styx missiles. Although no missiles hit the vessel, a near miss was enough to sink the wooden vessel. The two men onboard the fishing vessel escaped unharmed. Since the Orit was roughly one-third the size of the Israeli patrol boats, this engagement showed limited capability for the Styx missile to attack a small target. This incident is classified as defenseless target for obvious reasons.

3. The Indo-Pakistan War (1971)

In 1971, war broke out between India and Pakistan. On the night of December 4, three Indian missile patrol boats, escorted by two Indian destroyers, bombarded the port of Karachi in a surprise attack. Seven Styx missiles were fired toward the harbor. Six found a target. Two Pakistani destroyers, the Khaibar and the Badr, were on patrol near the harbor. Each received a single missile hit. The Khaibar sunk, while the Badr was severely damaged. The missile impacted at the Badr's bridge, destroying all command and control capability. One additional naval vessel, the minesweeper Muhafiz, sank after a single Styx missile hit. Command and control capability was destroyed for the entire port of Karachi, causing shore batteries to fire on their own vessels repeatedly throughout the remainder of the conflict. A count of personnel casualties was not available to the author. Both the Khaibar and the Badr were equipped with 4.5 inch guns and 40mm guns. The guns were not used by either vessel due to surprise. This incident is classified as a defendable target.

4. Indo-Pakistan War: Merchant Vessel Attack (1971)

On the night of December 8, a single missile patrol boat was detached to attack shore targets in Karachi harbor. The missile boat launched two Styx missiles. One hit an oil storage tank. The other hit a British merchant ship and sank it. This incident is classified as a defenseless target.

In summary, the Indo-Pakistan War produced nine Styx missile launchings. Eight of these missiles hit both land and sea targets. In one night, the Indian Navy put 25% of the Pakistani Navy out of action and demonstrated that attacking the enemy effectively first is both possible and rooted in sound logic.

5. Arab-Israeli War: Battle of Latakia (1973)

In October 1973, the Arab-Israeli War broke out. This conflict produced the first missile boat on missile boat engagement in history. The Egyptians and the Syrians were armed with the Styx anti-ship cruise missile, with a range of about 25 nautical miles. The Israelis were armed with the Gabriel missile with a range of approximately 12 nautical miles. The first battle took place on October 6, 1973. The Israelis were actively patrolling the coastal area around Latakia with five Saar-class missile patrol boats. Only four of the Saars were missile equipped. The Israeli vessels were detected off shore by two Syrian picket ships - a torpedo boat and a minesweeper. The Syrian ships engaged the Israeli force with gunfire with little effect. Both the Syrian ships were sunk, one exclusively with gunfire, the other with three Gabriel missile hits. Syrian missile boats were alerted, however, and launched their Styx missiles against the Israeli force. Eight Styx missiles were launched and all were deceived by Avshalom (chaff) launches. The Israeli missile boats returned fire by launching five Gabriel missiles and scoring four hits. One Komar-class missile boat was sunk with a single missile hit. A second Komar-class missile boat was hit with one Gabriel missile and run aground. It was later destroyed by gunfire. Lastly, one Osa-class missile boat was sunk with two Gabriel missile hits. In summary, eleven Gabriel missiles were launched and six hit their target. Eight Styx missiles were launched by the Syrians with no combat kills. These were all engagements between defended targets.

6. Arab-Israeli War: The Battle of Baltim (1973)

The Battle of Baltim took place off the Egyptian coast on the night of October 8, 1973. A force of six Saar-class missile boats (five missile equipped) were engaged by four Osa-class missile boats. The Osa-class missile boats launched their Styx missiles first at the Israeli force at a range near 25 nautical miles and immediately fled towards the shore at high speed. The Israeli force evaded the Styx missiles, pursued, closed to within Gabriel launch range and launched twelve Gabriel missiles. Three Osa-class missile boats were sunk. Each received two missile hits. The fourth Osa-class missile boat escaped undamaged into the harbor. In summary, twelve Gabriel missiles were launched and six hit their target. Sixteen Styx missiles were launched with no successful hits. These engagements are categorized as defended targets.

7. Arab-Israeli War: Second Battle of Latakia (1973)

A second clash between Syrian and Israeli forces took place off the coast of Latakia on the night of October 10, 1973. Seven Saar-class missile boats were actively patrolling and bombarding the Syrian harbor. A Syrian force, consisting of one torpedo boat, one conventional patrol boat and three Osa-class missile boats, challenged the Israeli force. A new and unique tactic was utilized by the Syrian force during this battle. Syrian missile boats maintained large merchant vessels between their missile boats and the Israeli force. They darted out from behind the merchant vessels only to launch their missiles. The merchant vessels served as missile decoys, which provided the Syrian missile boats with additional defensive capability. A volley of missiles ensued. Eight Gabriel missiles were launched at the Syrian force and twelve Styx missiles were launched at the Israeli force. Five of eight Gabriel missiles hit targets, but two of the targets were merchant vessels. Two Osa-class missile boats were sunk. One was hit with two Gabriel missiles and one was hit with a single Gabriel missile. All twelve Styx missiles were deceived with chaff launches, active jamming, and high speed tactical maneuvering. The missile boat on missile boat engagements are categorized as defended targets; however, the merchant vessels hit are categorized as defenseless targets.

8. Arab-Israeli War: Battle of Tartus (1973)

A final force on force battle took place off the coast of Tartus on October 11, 1973, just before midnight. Five Saar-class missile boats were shelling Syrian oil storage tanks and shore counter-fire batteries when they were challenged by two Osa-class missile boats. As in the previous battle, the Syrians used merchant vessels for protection. In the ensuing exchange, eight Gabriel missiles were launched at the Syrians and three Styx missiles were launched at the Israelis. Both Osa-class missile boats were sunk. They took two Gabriel missile hits each. Two Gabriel missiles hit a Russian merchant ship, and it sank. All three Styx missiles missed their target due to chaff launches and active jamming equipment. The missile boat on missile boat engagements are categorized as defended targets. The merchant vessel hit is categorized as a defenseless target.

9. Arab-Israeli War: Additional Incidents (1973)

Additional clashes occurred during the war, in which only one side launched its missiles against the enemy forces and no missiles hit their targets. On October 6, an Israeli force of two Saar-class missile boats attacked an Egyptian force consisting of five Osa-class missile boats. Eleven Gabriel missiles were launched, but none hit their target. The Egyptian force fled to the safety of Alexandria Harbor. On October 7, after the successful Israeli engagement of the Syrian force, two Komar-class Syrian missile boats challenged the Israeli force of five Saar-class missile boats. The Syrian missile boats launched four Styx missiles from the mouth of Latakia harbor and ducked back inside. No Styx found their targets. On October 12, two Egyptian Komar-class missile boats fired four Styx missiles at three Israeli tank landing ships (LSTs). All four missiles missed and exploded inland. All incidents are classified as defended targets.

In summary, 19 of 50 Gabriel missiles hit their targets (discounting the merchant vessels hit), while zero of 47 Styx missiles hit their targets. Some reports claim as many as 55 Styx missiles were fired. In the war there were three instances where incoming missiles were downed by small arms or machine gun fire. Many of the officers involved believed the missiles had been or would have been diverted from the ships by the electronic warfare measures employed. Therefore, a firm assessment of hardkill effectiveness cannot be made. All missile boat on missile boat engagements of the Arab-Israeli War are classified as defended targets utilizing missiles, decoys and jammers for defensive capability. The three cases involving merchant vessels are classified as defenseless targets.

10. Iran-Iraq War (1980-1987)

In September of 1980, the Iran-Iraq War began. The major naval involvement was the so called Tanker War. It was conducted by both Iran and Iraq. The Tanker War was designed to stop the export of oil through the Arabian Gulf. Attacks concentrated on transiting unprotected oil tankers and freighters. Although there are no exact numbers of missiles fired and hits, reports through 1984 show 52 of 53 Exocet anti-ship missiles hit their targets, and 50 of the 52 hits detonated properly [Ref. 12]. No new tactics were developed until the reflagging effort of the United States. The Exocet missile remained unchanged throughout the duration of the war; therefore, it is assumed that the performance of the missile continued as it did up through 1984. Results of missile hits differ with the size of the vessel hit. Among smaller freighters/tankers of 13,000 to 30,000 tons displacement, a split of 20% sinking, 60% major damage, and 20% minor damage was produced. Of large tankers 70,000 to 300,000 tons displacement, 60% of the ships were heavily damaged, and 40% saw minor damage. All incidents here are classified as defenseless targets, since the only defense these tankers had against ASCM attacks was size. In 1987, when the reflagging effort began and tankers were escorted by naval vessels, missile attacks on tankers ceased.

11. Falklands War: Attacks on Argentine Patrol Boats (1982)

The initial use of anti-ship missiles of the Falklands War occurred on May 3, 1982, when two British Lynx helicopters attacked two Argentine patrol boats with Sea Skua missiles which had been hastily fitted on Lynx helicopters. Each helicopter fired two missiles and achieved four hits. The Alferez Sobral (A-9) took two missile hits and sustained severe damage, but it was later repaired. The Somellera (A-10) took two missile hits and sank. Both patrol boats attempted to engage the incoming missiles with 20mm and 40mm rounds, but they failed to score any hits. This incident is categorized as a defended target.

12. Falklands War: Attack on HMS Sheffield (1982)

The best known incident of the Falklands War is the sinking of HMS Sheffield. On May 4, 1982, HMS Sheffield was assigned a radar picket station along the Argentine coast. An Argentine Super Etendard attack aircraft fired two AM-39 Exocet air to surface missiles indiscriminately at the British force. One missile did not acquire a target. The other missile hit HMS Sheffield. Although the missile warhead did not detonate, rocket fuel ignited and caused extensive fires to burn out of control. The ship was eventually scuttled. Due to limited battle space and lack of forewarning, HMS Sheffield did not take any actions to counter the incoming Exocet missile. This incident falls under the category of a defendable target.

13. Falklands War: Firing at HMS Ambuscade (1982)

On May 25, the Argentines launched a major air attack on the British force. Skyhawks (A-4s) and Super Etendard aircraft attacked the British ships guarding the entrance to Falkland Sound. The A-4s attacked the picket ships, while the Super Etendards punched through and attacked the main British fleet which was patrolling farther to the east. The Super Etendards attacked the first major ship to appear on their radar. Two Super Etendards fired one Exocet missile each. Their target, the HMS Ambuscade, detected the missile launches and launched chaff to decoy the missiles. The chaff was successful in seducing the missiles away from the HMS Ambuscade. This incident is classified as a defended target, which was successfully defended.

14. Falklands War: Sinking of the Atlantic Conveyor (1982)

Once through the chaff cloud, the Exocet missiles that had been fired at the HMS Ambuscade looked for another target. The target they acquired was the converted VTOL/helicopter carrier SS Atlantic Conveyor. Both missiles locked on this target, and both missiles hit and detonated despite the use of small arms and machine guns to fire at the missiles. Twelve sailors were killed, and the Atlantic Conveyor sank six days later due to uncontrollable fires. Both the escort ships and the Atlantic Conveyor took measures to counter the incoming missile, but to no avail. This incident is classified as a defended target.

15. Falklands War: Attack on HMS Avenger (1982)

Although the Argentines did not have the shore launched version of the Exocet missile, they managed to produce a trailer-mounted MM-38 Exocet missile. On May 27, this missile was launched at the HMS Avenger. The HMS Avenger neither took evasive action nor tried to engage, but the Exocet did not hit its target. Although the missile did not hit, this incident is classified as a defendable target because the HMS Avenger took no measures to engage the incoming missile.

16. Falklands War: Attempted Attack on HMS Invincible (1982)

Argentine Skyhawks and Super Etendards attacked the British task force on May 30. Their aim was to sink or damage HMS Invincible, the British carrier. One Exocet missile was launched from a Super Etendard, but it did not hit its target. This incident is classified as a defended target, although it is not known what defense was actually taken.

Some reports claim the Exocets were engaged by guns, but other reports claim the missiles were seduced away by chaff.

17. Falklands War: Attack on HMS Glamorgan (1982)

On June 11, a shore based Exocet missile was fired at HMS Glamorgan as it bombarded Port Stanley at night. HMS Glamorgan attempted to shoot down the incoming missile with a Sea Cat missile, but it failed. The Exocet detonated near the helicopter hangar, killing 13 sailors and injuring 17 sailors. HMS Glamorgan suffered slight damage and was out of action for 36 hours. This incident is classified as a defended target.

18. Falklands War: Attack on HMS Penelope (1982)

Also on June 11, while in company with HMS Glamorgan, HMS Penelope was attacked by an anti-ship missile. It is unclear exactly what kind of missile was used in this attack, but one strong possibility is the Israeli Gabriel anti-ship cruise missile. It was suspected after the war that the Israelis may have sold Gabriel missiles to the Argentines. This missile did not hit its target and exploded harmlessly in the water. This incident is classified as a defendable target. Although the missile did not hit its target, no measures were taken to engage the missile.

19. Battle of Sidra (1986)

The United States attacked Libya on March 24, 1986. Libya's claims of territorial waters and the "line of death" provoked the United States into action. On the first day of this minor conflict, a Libyan Combattante II G missile equipped patrol boat was sunk with one Harpoon anti-ship missile that was launched from an A-6E Intruder. Later the same night, a Nanuchka II patrol boat was sunk by two Harpoon missiles. In all, six Harpoon missiles were fired at various targets, resulting in the three hits mentioned above. The reason for the Harpoon misses is believed to result from firing at "phantom targets" which the Libyans used to trick the United States into firing unnecessary missiles. It is unknown whether the successful Harpoon missiles were engaged by the patrol boats, but, due to the political climate of the time, it is assumed that Libya was aware of possible United States aggression and engaged the incoming missiles. These incidents are classified as defended targets.

20. USS Stark Incident (1987)

The USS Stark (FFG-31) was attacked while on patrol in the Persian Gulf by an Iraqi F-1 Mirage aircraft. The pilot had mistakenly identified the USS Stark as an Iranian warship. The pilot fired two Exocet anti-ship missiles approximately 30 seconds apart. Both missiles hit the USS Stark, but only one warhead detonated. Rocket fuel from both missiles kept the fire burning uncontrollably for many hours. The fires were eventually extinguished and the ship brought into port. Heroic efforts of the crew saved the USS Stark from sinking, but it was out of action for nearly one and a half years. Thirty-seven sailors died in the attack. This incident is classified as a defendable target. The USS Stark had the necessary equipment to engage the incoming missile, but, due to inattentiveness and complacency, the missiles were not countered.

21. Operation Praying Mantis (1988)

Operation Praying Mantis was conducted by the United States against Iranian targets in retaliation for Iran mining the Persian Gulf. The first engagement force consisted of three U. S. warships: USS Wainwright (CG-28), USS Bagley (FF-1069) and USS Simpson (FFG-56). They challenged an Iranian patrol boat, the Joshan. The Joshan was warned that it was going to be attacked and elected to counter with the launch of a Harpoon missile. All three U. S. warships and a U. S. helicopter detected the launch and immediately deployed chaff. The missile passed down the starboard side of the USS Wainwright, deceived by the chaff. The U. S. reply on the Joshan consisted of five Standard missiles launched in the surface-to-surface mode, all five hitting the target, which caused the Joshan to sink. A final Harpoon was launched against the Joshan, but missed due to the lack of freeboard present for the Harpoon missile guidance radar to acquire. This incident is classified as a defended target for both the U. S. forces and the Iranian patrol boat.

22. Operation Praying Mantis: Second Incident (1988)

The second incident of this conflict involved three U. S. warships: USS Joseph Strauss (DDG-16), USS O'Brien (DD-975) and USS Jack Williams (FFG-24) and an Iranian Saam-class frigate, the Sahand. The Sahand was first hit by an air launched Harpoon from an A-6E aircraft. Two more Harpoons were fired at the Sahand, one air launched and one surface launched. They achieved a near simultaneous time of impact. The three Harpoon hits caused the Sahand to sink. This incident is classified as a defendable target, because the Sahand made no observable attempt to engage the incoming missiles.

23. Persian Gulf War (1990-1991)

The Persian Gulf War produced a limited number of missile engagements, because most of the attacks conducted on naval targets were done by A-6Es with precision guidance weapons and naval assets were used for tactical missile launches, picket duties and the amphibious force escort. This war did provide a first. It occurred when HMS Gloucester, using its Sea Dart system, shot down a Silkworm missile launched at the USS Missouri on February 25, 1991. A second Silkworm was also fired at the USS Missouri, but it did not hit its target. This is the first confirmed successful use of surface-to-air missiles against an incoming missile attack in fifty years of anti-ship cruise missile production and use. This incident is classified as a defendable target, which was defended successfully.

24. Persian Gulf War: The Battle of Bubyian Island (1991)

The Battle of Bubyian Island on January 29-30, 1991, produced incidents matching the helicopter launched anti-ship missile, the Sea Skua, against various smaller combatants. Fourteen Sea Skuas were launched and eight missiles hit their targets which caused heavy damage to four small combatants. This battle is classified as defendable targets, because no opposition was met by the Coalition helicopters.

25. USS Saratoga Incident (1992)

On October 1, 1992, the USS Saratoga, while taking part in a NATO exercise, inadvertantly launched two Nato Sea Sparrow missiles at a Turkish destroyer, Mauvenet. One missile hit the destroyer's bridge. It killed five sailors including the Commanding Officer. The other missile did not hit a target. This incident is classified as a defendable target, but could just as easily be regarded as a defenseless target. Fratricide complicates this analysis, but since capabilities do exist to counter such a friendly "threat", these incidents will fall into the defendable target category.

III. MISSILE PERFORMANCE ANALYSIS

A. OVERVIEW

Warships are designed to counter incoming missile threats with a variety of countermeasures. Battle group escorts, aircraft coverage, extended range sensors and organic systems all contribute to protect warships against missile attacks. However, the littoral setting degrades the above defenses. Not all missiles fired at warships in the past have been engaged, and not all missiles engaged have been shot down or evaded. The ability of a warship to recognize a threat and quickly engage or relay the information to a warship that can engage will be the determining factor in warship survival.

A leaker is defined as a missile fired at a warship that pierces the defenses of the warship or its escorts due to either superior performance by the missile or ineffective performance by the warship or its escorts. The following is a historical look at how well warship defenses have performed.

B. PROBABILITY OF MISSILE HIT

1. Defenseless Targets

The incidents catalogued in the previous chapter are broken into three categories. The first category is defenseless targets. These targets are primarily merchant vessels transiting a war zone. This category is valuable in the analysis because it demonstrated that anti-ship missiles fired up to the present have been very accurate weapons, absent any countermeasures taken to defeat them. Table 1 summarizes the data regarding defenseless targets.

A probability of hit on defenseless targets is calculated as 57.5 hits divided by 63 total firings, or a probability of hit equal to 0.913. Historical data supports high reliability and accuracy of the anti-ship cruise missile.

Incident Number	Missile Type	Number of Missile Hits	Number of Ships OOA	Number of Ships Sunk	Total Missiles
2	Styx	0.5[1]	1	1	4
4	Styx	1	1	1	2
7	Gabriel	2	2	2	2
8	Gabriel	2	1	1	2
10[2]	Exocet	52	37	7	53
Totals		57.5	42	12	63

Table 1. Defenseless Targets.

2. Defendable Targets

The next category is the defendable target. The performance of anti-ship missiles is degraded in this category, which intuitively makes sense. The ability of an attacked warship to retaliate on the delivery platform should impact the accuracy of the missile shot. An anti-ship missile launch platform may travel unimpeded to a defenseless target and fire at ideal range to ensure a hit. An attack on a warship that could defend itself, if alerted, would not allow for an attack at ideal range. This feature yields a larger probability of missile failure or missile aiming error. In addition, warships involved in incidents to date have been smaller on the average than defenseless merchant ships in the previous category, which makes them more difficult to acquire. Table 2 summarizes the data regarding defendable targets.

A probability of hit from defendable targets is calculated as 26 hits divided by 38 total firings for a probability of hit equal to 0.684. Warships are harder to hit, whether they engage the incoming missile or not.

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[1] Near miss, enough to sink vessel.

[2] Numbers up through 1984 only.

Incident Number	Missile Type	Number of Missile Hits	Number of Ships OOA	Number of Ships Sunk	Total Missiles
1	Styx	3	1	1	4
3	Styx	6	3	2	7
12	Exocet	1	1	1	2
14[3]	Exocet	2	1	1	2
15	Exocet	0	0	0	1
18	Gabriel	0	0	0	1
20	Exocet	2	1	0	2
22	Harpoon	3	1	1	3
24	Sea Skua	8	4	0	14
25	Sea Sparrow	1	1	0	2
Totals		26	13	6	38

Table 2. Defendable Targets.

3. Defended Targets

The final category is the defended target. These targets are historically the most difficult targets to hit, which should not come as a surprise. A variety of tactics and weapons, primarily softkill, have been used to defeat missiles. It is interesting to note that only one case of confirmed hardkill exists. Softkill, maneuver, decoys and deception have been the primary means used against missiles to date. Table 3 summarizes data regarding defended targets.

A probability of hit from defended targets is calculated as 32 hits divided by 121 total firings for a probability of hit equal to 0.264. On the average, warship defenses have been able to shoot down or deceive 3 out of 4 missiles fired.

[3] Same missiles as incident 13.

Incident Number	Missile Type	Number of Missile Hits	Number of Ships OOA	Number of Ships Sunk	Total Missiles
5	Gabriel	6	3	3	11
5	Styx	0	0	0	8
6	Gabriel	6	3	3	12
6	Styx	0	0	0	16
7	Gabriel	3	2	2	8
7	Styx	0	0	0	12
8	Gabriel	4	2	2	8
8	Styx	0	0	0	3
9	Gabriel	0	0	0	11
9	Styx	0	0	0	8
11	Sea Skua	4	2	1	4
13[4]	Exocet	0	0	0	2
16	Exocet	0	0	0	1
17	Exocet	1	1	0	1
19	Harpoon	3	2	1	6
21	Harpoon (US)	0	0	0	2
21	Standard	5	1	1	5
21	Harpoon(Iran)	0	0	0	1
23	Silkworm	0	0	0	2
Totals		32	16	13	121

Table 3. Defended Targets.

C. LEAKER PROBABILITY

The historical parameters calculated above can be extended for use in the following formula:

[4] Same missiles as incident 14.

$$P_{AC} \times P_{L|AC} \times N_{LAUNCH} = N_{HIT} \quad (1)$$

where

P_{AC} = Probability a missile acquires a target

$P_{L|AC}$ = Probability a missile is a leaker given it acquires the target

N_{LAUNCH} = Number of missiles launched

N_{HIT} = Expected number of missile hits

Rearranging the formula, the probability of a leaker can be solved for explicitly:

$$P_{L|AC} = (N_{HIT} \div N_{LAUNCH}) \times (1 \div P_{AC}) \quad (2)$$

The term $(N_{HIT} \div N_{LAUNCH})$ or probability of missile hit, was determined above for each category of target. The term P_{AC} is best estimated from the defenseless and defendable categories, where no countermeasures were taken to defeat the missile. P_{AC} is calculaled by taking the total number of missile hits from the defenseless and defendable targets and dividing that number by the total number of missiles from those two categories. This calculation yields a P_{AC} equal to 83.5/101 or 0.827. For a warship in a littoral setting that is surprised by an attack, the probability a missile hits a ship, given that it acquires the ship as a target, is calculated as:

$$P_{L|AC} = (N_{HIT} \div N_{LAUNCH}) \times (1 \div P_{AC})$$

$$= (26 \div 38) \times (1 \div 0.827)$$

$$= 0.827$$

A similar calculation done for defended warships yields the following probability of missile leakers:

$$P_{L|AC} = (N_{HIT} \div N_{LAUNCH}) \times (1 \div P_{AC})$$

$$= (32 \div 121) \times (1 \div 0.827)$$

$$= 0.320$$

A second set of calculations was done for incidents involving modern warships with modern anti-air warfare defenses. From the discussion in the previous chapter, data was collected from incident 12 (sinking of the Sheffield in 1982) to the present. Using the same value for P_{AC} as calculated above, for a surprised ship in a littoral setting, the probability a missile hits, given that it acquires the ship as a target, is calculated as:

$$P_{LIAC} = (N_{HIT} \div N_{LAUNCH}) \times (1 \div P_{AC})$$

$$= (17 \div 27) \times (1 \div 0.827)$$

$$= 0.761$$

A similar calculation done for defended warships yields the following probability of missile leakers:

$$P_{LIAC} = (N_{HIT} \div N_{LAUNCH}) \times (1 \div P_{AC})$$

$$= (9 \div 20) \times (1 \div 0.827)$$

$$= 0.544$$

While these numbers would not be expected to apply to the most modern U. S. warships, such as the Ticonderoga class cruisers or the Arleigh Burke destroyers, they may apply to such ships as the Perry class frigate (FFG-7), an Avenger class mine countermeasures ship (MCM-1), or a new construction coastal patrol ship (PC-1) that do not have the capability to engage a large number of missiles simultaneously.

IV. VULNERABILITY ANALYSIS

A. INTRODUCTION

Staying power is defined as the capacity of a warship to take hits and continue fighting, measured in the number of hits by a standard or notional weapon. A methodology used by T. Beall [Ref. 3] estimated the staying power of warships after hits by bombs, shells, and torpedoes from World War II data. His method is extended here to predict the number of missiles needed to achieve a combat kill and to sink a warship.

B. DATA COLLECTION

The following quantitative data was collected on all warships damaged or sunk in the conflicts documented previously for analysis:

- Ship full load displacement
- Missile total weight (lbs)
- Missile warhead weight (lbs high explosive or HE)
- Missile speed (Mach)
- Number of missiles used to put ship OOA
- Number of missiles used to sink ship

Appendix A summarizes the raw data collected for this analysis.

C. MODEL STRUCTURE FOR COMBAT KILLS

The goal of this analysis was to model the relationship between the number of standard missile equivalents necessary to put a ship out of action and ship full load displacement.. Two equation forms were tested as possible candidates:

$$S_i = \beta_0 + \beta_1 \times f(d_i) \qquad (3)$$

or

$$S_i = \beta_0 \times (f(d_i)^{\beta_1}) \qquad (4)$$

where

S_i = number of standard missile hits needed to put platform i out of action.

$f(d_i)$ = function of the full load displacement of platform i, d_i.

β_0, β_1 = constant coefficients.

The use of full load displacement as an explanatory variable is intuitively appealing. It is the independent variable used by both T. Beall and R. Humphrey [Ref. 4]. Full load displacement is also backed by data on tanker casualties in the Iran-Iraq War, where the only defense a merchant ship had was its size. Tankers displacing between 13,000 and 30,000 tons were heavily damaged 80% of the time by single Exocet missile hits, while tankers displacing 70,000 tons and greater were heavily damaged 60% of the time.

D. DATA ANALYSIS FOR COMBAT KILLS

The functional relationship between the independent variable $f(d_i)$ and the dependent variable S_i was calculated from the raw data contained in Appendix A, which contains all attack incidents against warships.

1. Independent Variable

Various functional forms of the full load displacement were examined to assess which would provide the best fit curve. These functions included:

$$f(d_i) = d_i \qquad (5)$$

$$f(d_i) = (d_i)^{1/2} \qquad (6)$$

$$f(d_i) = (d_i)^{1/3} \qquad (7)$$

$$f(d_i) = \ln (d_i) \qquad (8)$$

2. Dependent Variable

The total number of Exocet missile equivalents needed to put a ship out of action was used as the dependent variable. The Exocet missile was chosen since its use and effectiveness was widely known because of the Falklands War, the Tanker War, and the attack on USS Stark. Each missile was normalized with respect to the Exocet missile according to warhead explosive content (250 lbs high explosive), total missile weight (1439 lbs), and total missile kinetic energy content. This value was calculated by applying the equation describing kinetic energy:

$$KE = \frac{1}{2} \times Mass \times (Velocity)^2 \qquad (9)$$

Because Exocet missile equivalents is in the form of a ratio, constants were disregarded in the calculation of the standard value and other missile kinetic energy content. The standard value was calculated by multiplying the total missile weight (1439 lbs) by the missile velocity squared, or $(0.93\ \text{Mach})^2$. These combinations produced 12 scatter plots of dependent variable versus independent variable.

3. Analysis Procedure

Scatter plots were constructed, matching the different functional forms of full load displacement against the three Exocet missile equivalent categories. Figure 1 is a scatter plot of Exocet missile equivalents with respect to warhead weight versus full load displacement for ships put out of action. It is apparent from this plot that a transformation such as a natural logarithm or a cube root is needed to glean a relationship between the independent and dependent variables. The line shown on the graph is an example of a power function which is a best fit curve to the untransformed independent variable. Square data points represent superimposed data.

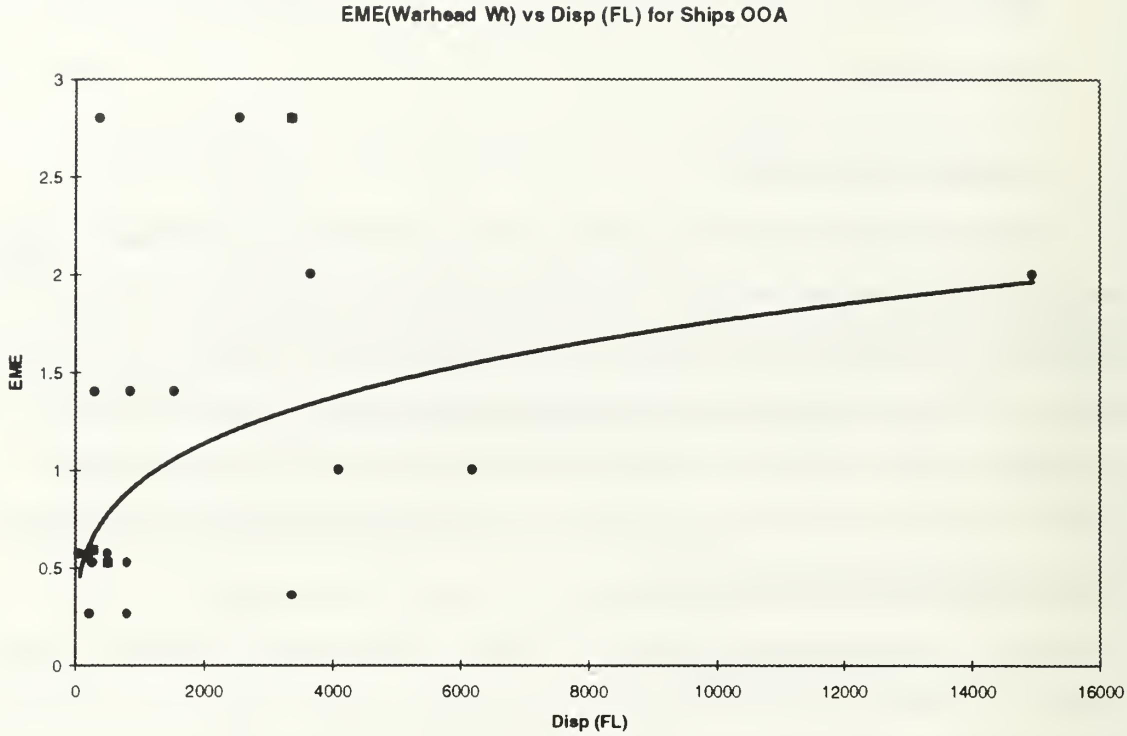

Figure 1. Exocet missile equivalents with respect to warhead weight versus full load displacement with fitted line (OOA).

Linear regression was conducted to determine the least squares best fit line and the R-squared value for each plot. (Equation (4) was transformed by taking the natural logarithm of both sides of the equation, then linear regression was conducted on the transformed model). The calculated linear and non-linear functions were then superimposed over the scatter plots. Scatter plots for which the data appeared distributed most evenly about the fitted line were further analyzed by conducting a Chi-square goodness of fit test on the residuals to test that the errors in the linear regression model are indeed mean zero normal random variables. For models still in contention, the one with the highest R-squared value was selected as the appropriate model.

4. Results

The model that best fit the above criteria is as follows:

$$\hat{S}_i = 0.0057 \times (f(d_i))^{2.6572} \tag{10}$$

where

$\hat{S}_i$ = fitted number of Exocet missile equivalents with respect to missile kinetic energy.

$f(d_i)$ = $\ln(d_i)$

A Chi-Square goodness of fit test produced a test statistic of 36.24 for which the null hypothesis is rejected for any reasonable α. However, looking at the numbers which generated the test statistic, two data points contributed to the majority of the magnitude, the Muhafiz and the Joshan. Both of these incidents represent gross overkill situations for which much smaller missiles would have accomplished the task. Subtracting out the contribution of these two incidents, the test statistic value is 9.83. The null hypothesis is not rejected at an $\alpha = 0.05$. An R-squared value of 0.4414 was calculated for this model; however, there were a number of attributes of the scenarios which were difficult to quantitatively analyze. The damage control capability and training of the crews, impact point of the missile, extent of compartmentation aboard the warship, and type of ship all impacted the number of hits each ship was capable of taking. The ability to quantify each of these categories would have been beneficial, but the data available would not support such an effort.

The following figure displays the data plotted against the fitted line for ships put out of action. Square data points represent superimposed data.

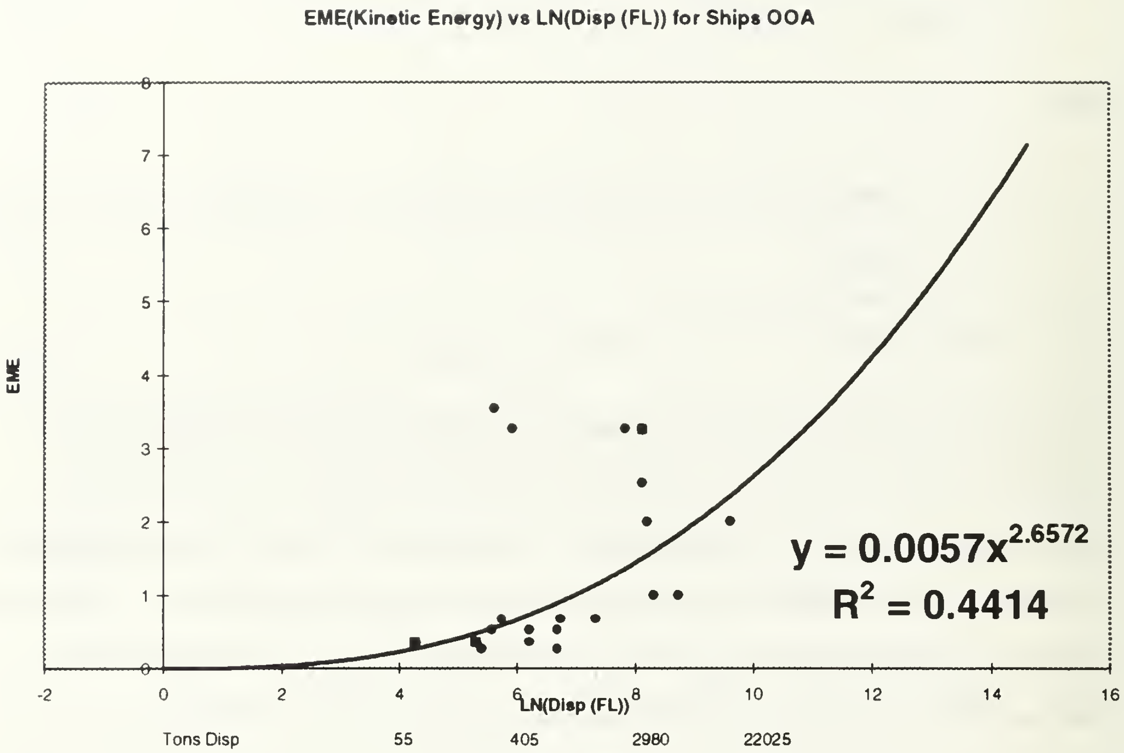

Figure 2. Exocet missile equivalents with respect to kinetic energy versus natural logarithm of full load displacement with fitted line (OOA).

A transformation such as a cube root or a natural logarithm of the Exocet missile equivalents would have reduced the variation in the dependent variable; however, no physical correlation could be easily recognized between a functional form of the dependent variable and a real world phenomenon.

> In contrast, curve-fitting methods work backward from the values they purport to predict, arriving at coefficients (and, in some cases, even a whole model) justified solely on the grounds of a good fit. [Ref. 5]

Reality must be the foundation when considering models to choose from. This purely statistical analysis is explored in Appendix B.

E. DATA ANALSIS FOR SINKING

1. Analysis Procedure

The same procedure conducted for combat kills was done for ships that were sunk. The same independent variable, dependent variable, and model structure were used as above. This analysis proved more difficult for a number of reasons:

- There is less data, since more vessels were put out of action by missiles than were sunk.
- It is much easier for attackers to concentrate fire on a wounded ship. They are less likely to return fire, which essentially makes them defenseless targets. As seen in the previous chapter, defenseless targets are hit with great accuracy. Salvo warfare allows for multiple weapons to hit a target in a short time interval, which makes analysis difficult on the minimum number of weapons needed to sink a warship.
- The data was biased towards smaller vessels, since most sinkings occurred on ships displacing 1000 tons or less.

For consistency, the same independent variable used for combat kills was used in this model, the natural logarithm of full load displacement. The model used here went through the same analysis steps as above. Figure 3 is a scatter plot of Exocet missile equivalents with respect to warhead high explosive content versus full load displacement for warships that sank. The line shown is an example of a power function which is a best fit curve to the untransformed independent variable. Square data points represent superimposed data.

2. Results

The final form of the equation for ships sinking is as follows:

$$\hat{S}_i = 0.038 \times (f(d_i))^{2.0256} \tag{11}$$

where

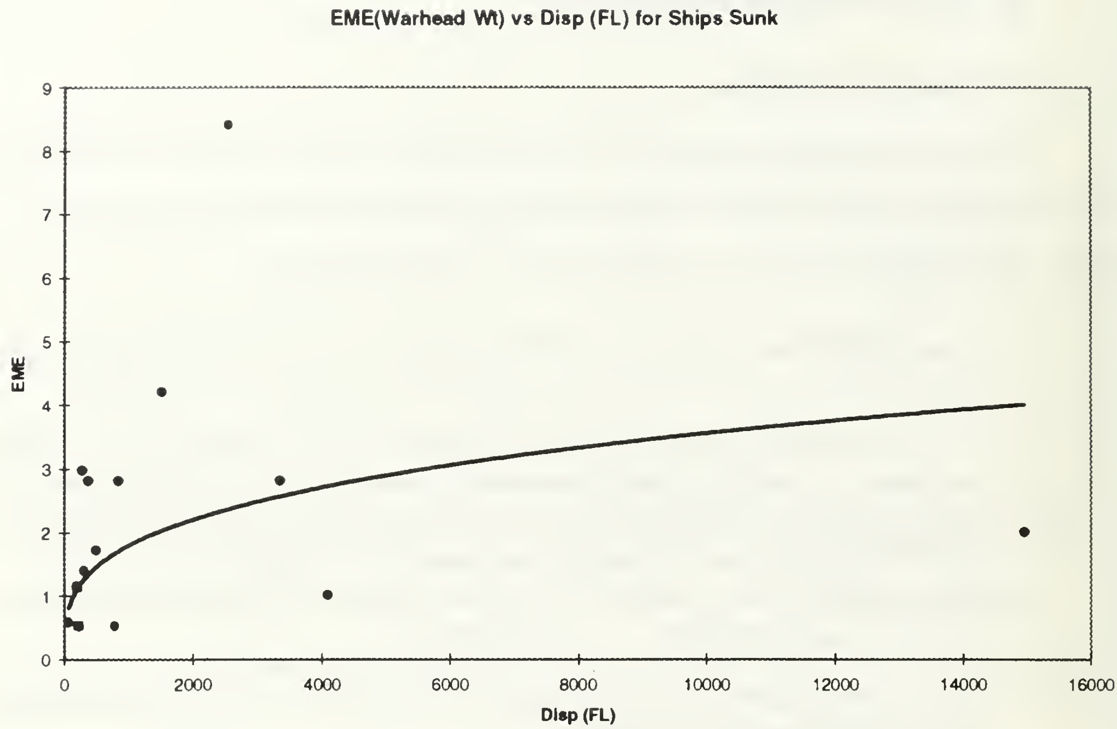

Figure 3. Exocet missile equivalents with respect to warhead weight versus full load displacement with fitted line (sinking).

$\hat{S}_i$ = fitted total number of Exocet missile equivalents expressed in terms of total warhead weight.

$f(d_i)$ = $\ln(d_i)$

A Chi-Square goodness of fit test produced a test statistic of 23.78, for which the null hypothesis is rejected for any reasonable α. However, looking at the numbers which generated the test statistic, one data point contributed the majority of magnitude of the test statistic. The sinking of the Eilat contributed 14.28 to the calculated test statistic. This scenario represented gross overkill, with multiple missiles hitting the target in near simultaneous fashion. The Styx missile was designed by the Russians to be used against U. S. carriers displacing 60,000 tons or greater. Its use against the Eilat displacing 2,555 tons was obvious overkill. Subtracting out the contribution of this data point to the test statistic yields a statistic of 9.50, for which the null hypothesis is not rejected at $\alpha = 0.05$. An R-squared value of 0.3751 was calculated for this model. The following figure displays the data plotted against the fitted line.

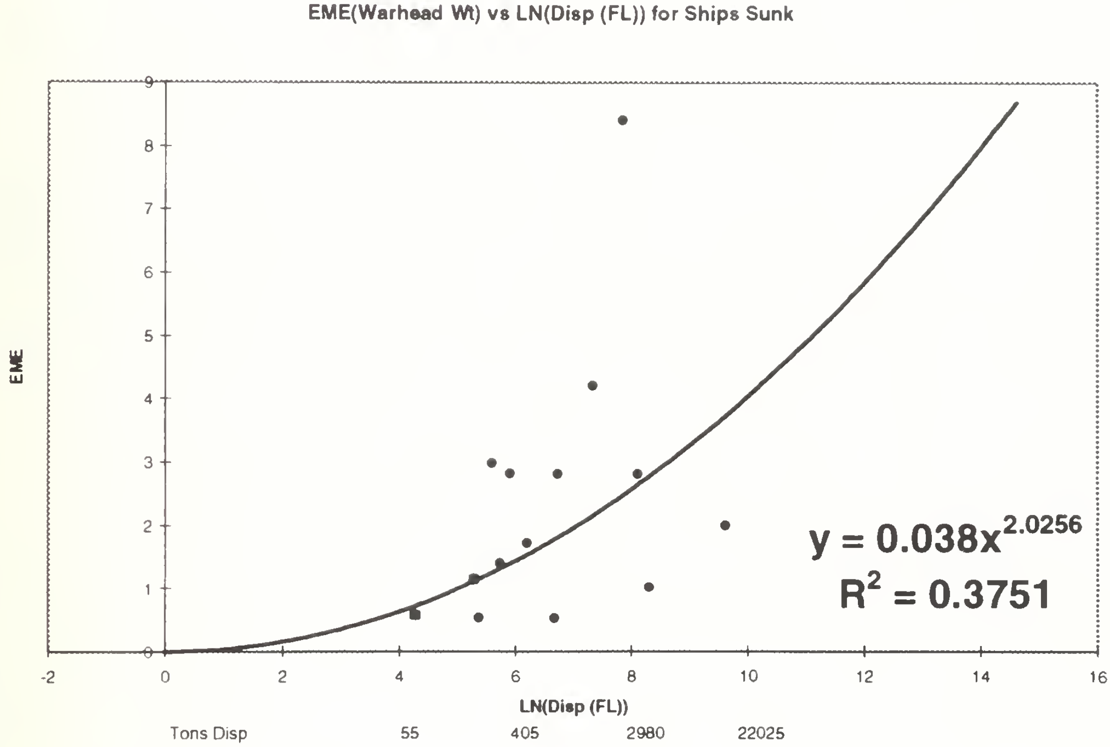

Figure 4. Exocet missile equivalents with respect to warhead weight versus natural logarithm of full load displacement with fitted line (sinking).

F. MODEL WEAKNESSES

There are some weaknesses to both models. Since data was not abundant, and only a few conflicts generated the data analyzed, there was not a great spread in the full load displacement of the ships hit with missiles, nor was there a great spread in the types and sizes of weapons used. R-squared values for both models were not particularly high, but there is some explanation for this. The missiles involved varied in points of impact on the ships, type of warhead fuzing, and missile technology. The ships involved varied in types of warships, damage control capabilities of the crews of the ships, countries involved, and ages of the warships hit, all of which were not addressed in the model.

G. CONCLUSION

The above analysis demonstrates that the two models produce credible measures of: (1) small warship staying power against modern anti-ship cruise missiles, and (2) number of anti-ship cruise missiles needed to produce a combat kill or sink a ship. Problems which exist are the small data set and small ship sizes, so the "best" model must await further data. Although there exists some unexplained variability in the models, the fitted curves fit the existing data reasonably well, and can be used for further analysis.

V. APPLICATION OF MODEL

The model developed above does not apply to all warships in littoral warfare, such as the Arleigh Burke with its incredible defensive capability, but it can apply to at least three types of U. S. warships, such as the Oliver Hazard Perry frigate (FFG-7 class), a mine countermeasures ship (MCM-1 class), or a new coastal patrol ship (PC-1 class).

A raid is defined as an attack on a platform with multiple missiles arriving in a compact time interval which does not allow the platform to recover from previous damage, or counter an incoming threat due to saturation of defenses. The scenarios that follow will all consist of a small, compact Exocet missile raid, since the analysis above was based on Exocet missile equivalents.

A. FFG SCENARIO

It is evident from historical records that the FFG-7 class ship is vulnerable to missile attacks. Most ships of this class have the ability to engage only one target at a time due to fire control channel constraints. Therefore, it is conceivable that the FFG-7 class ship in littoral waters could suffer the leaker rates determined in Chapter 3. Using the leaker rate for a ship surprised, a value of 0.761, and the staying power of an FFG calculated from the model, the expected number of missiles needed in a raid to put an FFG out of action was calculated from equation (1). Under surprise conditions, a raid of size 3 would put the FFG out of action. To sink the FFG, under the same conditions, a raid of size 5 would sink the warship. Under alerted conditions, similar calculations were computed with the leaker probability equal to 0.544. To put an FFG out of action under these conditions, a raid of size 4 would put the ship out of action, while a raid of size 7 would sink the ship.

B. MCM SCENARIO

Avenger class mine countermeasure ships are particularly susceptable to missile attack, since the primary area of operation is close to the shore. These ships have little defensive capability and must be escorted. Depending on the capability of the escort, it is conceivable that the MCM-1 class ship in littoral waters could follow the leaker rates determined above. Using the leaker rate for a ship surprised, a value of 0.761, and the staying power of an MCM calculated from the model, the expected number of missiles needed in a raid to put an MCM out of action was calculated from equation (1). Under surprise conditions, a raid of size 2 would put the MCM out of action. To sink the MCM, under the same conditions, a raid of size 4 would sink the warship. Under alerted conditions, similar calculations were computed with the leaker probability equal to 0.544. To put an MCM out of action under these conditions, a raid of size 3 would put the ship out of action, while a raid of size 5 would sink the ship.

C. PC SCENARIO

New construction coastal patrol ships were built to operate near the shore delivering special forces personnel. With only Stinger missiles and guns for hardkill defensive fire power and its small size and maneuverability as softkill features, it is conceivable that the PC class ship in littoral waters could follow the leaker rates determined above. Using the leaker rate for a ship surprised, a value of 0.761, and the staying power of a PC calculated from the model, the expected number of missiles needed in a raid to put a PC out of action was calculated from equation (1). Under surprise conditions, one Exocet missile would put the PC out of action. To sink the PC, under the same conditions, a raid of three Exocet missiles would sink the warship. Under alerted conditions, similar calculations were computed with the leaker probability equal to 0.544. To put a PC out of action under these conditions, a raid of two Exocet missiles would put the ship out of action, while a raid of three Exocets would sink the ship. Due to its small size and limited defensive capability, alerted or not to an incoming missile makes little difference in the outcome with a raid of more than one missile.

Although little data is available on casualties in anti-ship missile incidents, what is available provides some insight into the lethality of the missiles against personnel. The warships hit suffered up to 25% of the crew killed, and up to 35% injured. On the average, approximately 10% of the crews were killed in anti-ship missile incidents. This figure equates to 21 deaths aboard a FFG-7, 8 deaths aboard a MCM-1, and 3 deaths aboard a PC-1.

VI. CONCLUSIONS

There are many lessons to be learned from the historical record of anti-ship missiles in combat. Historical missile hit probabilities are summarized in Table 4.

	Total Probability of Hit	Post 1982 Probability of Hit
Defenseless Target	0.913	0.981
Defendable Target	0.684	0.630
Defended Target	0.264	0.450

Table 4. Probability of hit by category.

The trend in this data favors the anti-ship cruise missile, with a marked increase in the probability of hitting a defended target. Ship defensive firepower and staying power must increase proportionately if ships are to survive in combat situations of the future.

Softkill measures employed against anti-ship missiles were extremely successful, seducing or decoying every missile it was used against. In every engagement where a defender was alerted and deployed softkill measures, every missile salvo was entirely defeated.[5]

Hardkill measures were not as successful, with only one case confirmed. This is understandable since hardkill measures used to date have primarily consisted of manual firing systems. More data is needed to assess the combat capabilities of modern hardkill systems.

For the ships in the data set, an average of 1.2 hits put the ships out of action, while an average of 1.8 hits sank the ships. With these numbers, a leakage rate of 0.25 or higher would have a disastrous impact on the outcome of the conflict. It is emphasized

[5] Incidents 5, 7, 8, 13, 16, 21.

that the ordnance quantity-full load displacement relationship is based wholly on a statistical correlation. It is hard to find a physical explanation for why combat kills would correlate best with missile kinetic energy, while sinkings correlate best with missile explosive content. It is also emphasized that because most anti-ship missile victims were small warships, this analysis is unreliable when extended to warship larger than 7,000 tons displacement. Accepting these cautions, Figure 5 is offered as the best possible functional relationship between the number of anti-ship missile hits (normalized to Exocet missile equivalents) and combat kills or sinkings as a function of warship size, based on 30 historical examples of warship damage.

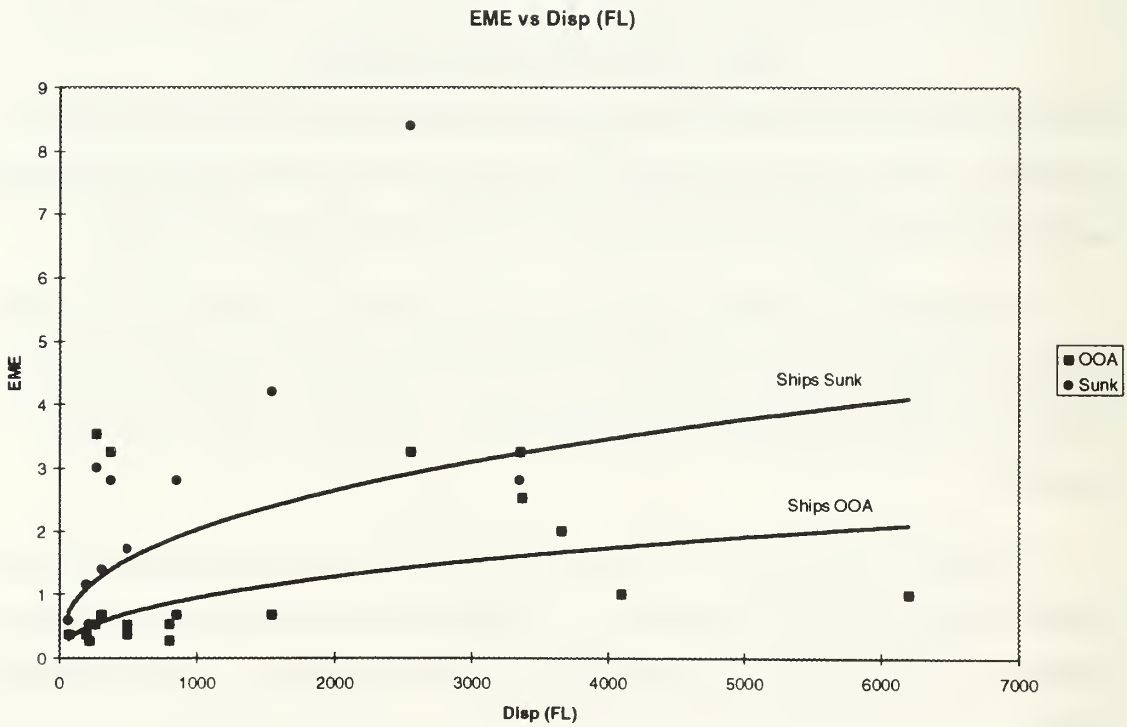

Figure 5. Exocet missile equivalents versus full load displacement for ships OOA and ships sunk.

For ships displacing between 150 and 7000 tons, it takes two to three times the number of missiles to sink a warship as it does to put it out of action.

This analysis reached other interesting conclusions:

- The staying power of small combatants against anti-ship missiles varies with the natural logarithm of the full load displacement. This differs from previous studies done for bomb, shell, and torpedo damage which concluded that staying power is proportional to the square or cube root of full load displacement. The natural logarithm transformation produces a flatter curve than the other transformations.
- The best statistical correlation for putting small warships out of action related the natural logarithm of the full load displacement and kinetic energy content of the missile. This relationship has not been examined in any previous study.
- The best statistical correlation for sinking a small warship occurred between the natural logarithm of the full load displacement and the explosive content of the warhead.

If the saying "history repeats itself" comes true, the U. S. could learn from the past that little effort is needed to make a big impact when using anti-ship missiles. Although the HMS Gloucester shot down a Silkworm fired at the USS Missouri, a study of the event shows that the results might easily have been a hit. [Ref. 6] The problems of weapon systems cutout zones, failures to detect an incoming missile for a variety of reasons, limited maneuvering room due to proximate minefields and inability to solve the Identification Friend or Foe (IFF) problem made engagement of the Silkworm very problematic. This study shows that little coordination is needed on the part of an enemy to put out of action or sink a frigate or smaller sized combatant. The U. S. must invest in the ability of a warship to detect and defeat incoming missiles, or increase the staying power of ships that are intended to sail in the littoral waters of an enemy.

As a side note, staying power is doubly important because it aids against secondary threats as well as anti-ship missiles. Torpedo attacks can produce disastrous outcomes, as seen by the Indian warship Khukri and the Argentine warship General Belgrano. The Khukri was hit by three torpedoes and sunk within three minutes, killing 191 personnel, while the Belgrano was hit by two torpedoes and sunk within one hour, killing 368 personnel. World War II also demonstrated the power of the torpedo, which was responsible for putting 19 U. S. cruisers out of action and sinking eleven. Mines can also be formidable weapons, with the USS Samuel B. Roberts, the USS Tripoli, and the USS Princeton the most recent examples of this. Research done at the Naval Surface Warfare Center, Carderock Division, produced a ship design which would increase the ships staying power by a factor of 5, while only increasing the price by 25%. [Ref. 7]. This increase in staying power would also increase the ships ability to withstand torpedo attacks and mine attacks but to a lesser degree. Advances in staying power would not only benefit the ship to counter anti-ship missiles, but would help to counter all threats.

VII. RECOMMENDATIONS

One obvious recommendation should be taken from this thesis:

- The use of softkill measures to defeat incoming missiles was effective in combat.

All warships which are intended for littoral warfare scenarios should be equipped with chaff, decoys and other softkill measures. These defensive weapons are proven in combat. While hardkill should also be employed, its effectiveness has yet to be proven in a wartime situation.

Recommendations for follow on work include:

- Adding more variables to the damage/sinking model to see if variability of data can be more fully explained.
- Relating the missile firepower to bomb firepower and torpedo firepower, and comparing the models developed here, with T. Beall and R. Humphrey models.

Emphasis on ship self-defense and threat detection must continue to be the highest priority, expecially U. S. Navy warships intended for littoral warfare.

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APPENDIX A. DATA COLLECTION

The following table represents the raw data collected for analysis conducted in this thesis.

Ship Name	Ship Type	Full Load Disp (Tons)	Missile Type	Warhead Weight (lbs HE)	Missile Weight (lbs)	Missile Speed (Mach)	Hits OOA	Hits Sunk
Eilat	DD	2,555	Styx	700	5,000	0.90	1	3
Khaibar	DD	3,360	Styx	700	5,000	0.90	1	1
Badr	DD	3,360	Styx	700	5,000	0.90	1	Not Sunk
Muhafiz	MSC	375	Styx	700	5,000	0.90	1	1
T-43	MSO	500	Gabriel	143	920	0.70	1	3
Osa	PBM	200	Gabriel	143	920	0.70	1	2
Komar	PBM	71	Gabriel	143	920	0.70	1	1
Komar	PBM	71	Gabriel	143	920	0.70	1	1
Osa	PBM	200	Gabriel	143	920	0.70	1	2
Osa	PBM	200	Gabriel	143	920	0.70	1	2
Osa	PBM	200	Gabriel	143	920	0.70	1	2
Osa	PBM	200	Gabriel	143	920	0.70	1	2
Komar	PBM	71	Gabriel	143	920	0.70	1	1
Osa	PBM	200	Gabriel	143	920	0.70	1	2
Osa	PBM	200	Gabriel	143	920	0.70	1	2
Somellera	PB	800	Sea Skua	66	450	0.85	1	2
A. Sobral	PB	800	Sea Skua	66	450	0.85	2	Not Sunk
Sheffield	DD	4,100	Exocet	250	1,439	0.93	1	1
Conveyor	VTOL	14,946	Exocet	250	1,439	0.93	2	2
Glamorgan	DD	6,200	Exocet	250	1,439	0.93	1	Not Sunk
Waheed	PBM	311	Harpoon	350	1,168	0.85	1	1
Ean Zaquit	PBM	850	Harpoon	350	1,168	0.85	1	2
Stark	FFG	3,660	Exocet	250	1,439	0.93	2	Not Sunk
Joshan	PBM	275	Standard	150	1,100	2.0	1	5
Sahand	FF	1,540	Harpoon	350	1,168	0.85	1	3
Patrol Boat	FPB	220	Sea Skua	66	450	0.85	1	2
T-43	MSO	500	Sea Skua	66	450	0.85	2	Not Sunk

TNC-45	PB	265	Sea Skua	66	450	0.85	2	Not Sunk
TNC-45	PB	265	Sea Skua	66	450	0.85	2	Not Sunk
Mauvenet	DD	3.375	Sparrow	90	503	2.5	1	Not Sunk

Table A-1. Raw Data

APPENDIX B. ALTERNATE STATISTICAL ANALYSIS

This appendix explores an alternate method of data analysis. This method shows no partiality towards reality, and only seeks to fit a line to the data. Analysis conducted in this thesis previously sought to relate full load displacement of warships with Exocet missile equivalents. These quantities are easily related to physical phenomenon. Scatter, however, is quite prominent in the data set. In order to reduce some of the variation in the dependent variable, transformations, such as cube roots and natural logarithm were taken of the dependent variable. The same models as above were fitted to the data. The drawback to this type of analysis is the final model lacks a solid connection to physical realities for which it was designed to explain. Figure B-1 represents the "best fit" model, with the highest R-squared value and the lowest Chi-square goodness of fit test value for ships put out of action. Although the R-squared value remains unchanged, the calculated Chi-square test statistic reduced to 1.79, for which the null hypothesis is not rejected at any reasonable α. In doing this transformation, the statistician is satisfied, but the model hides the obvious overkill scenarios which were present.

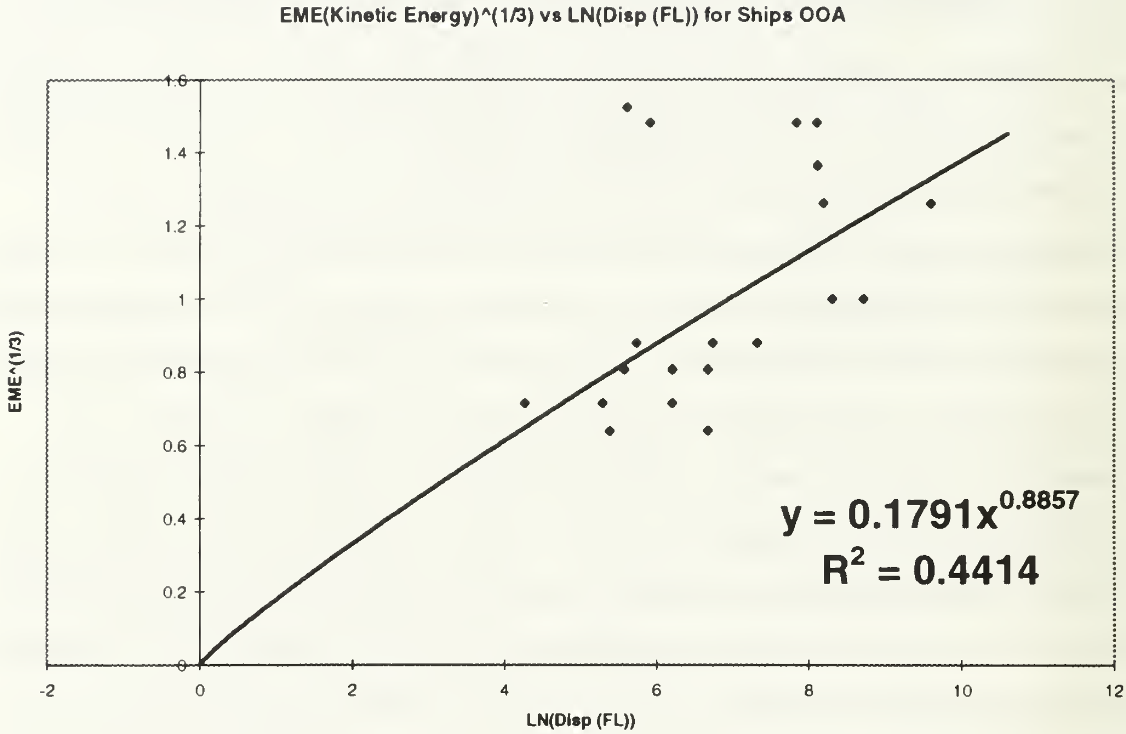

Figure B-1. Exocet missile equivalent versus natural logarithm of full load displacement with power function best fit line.

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