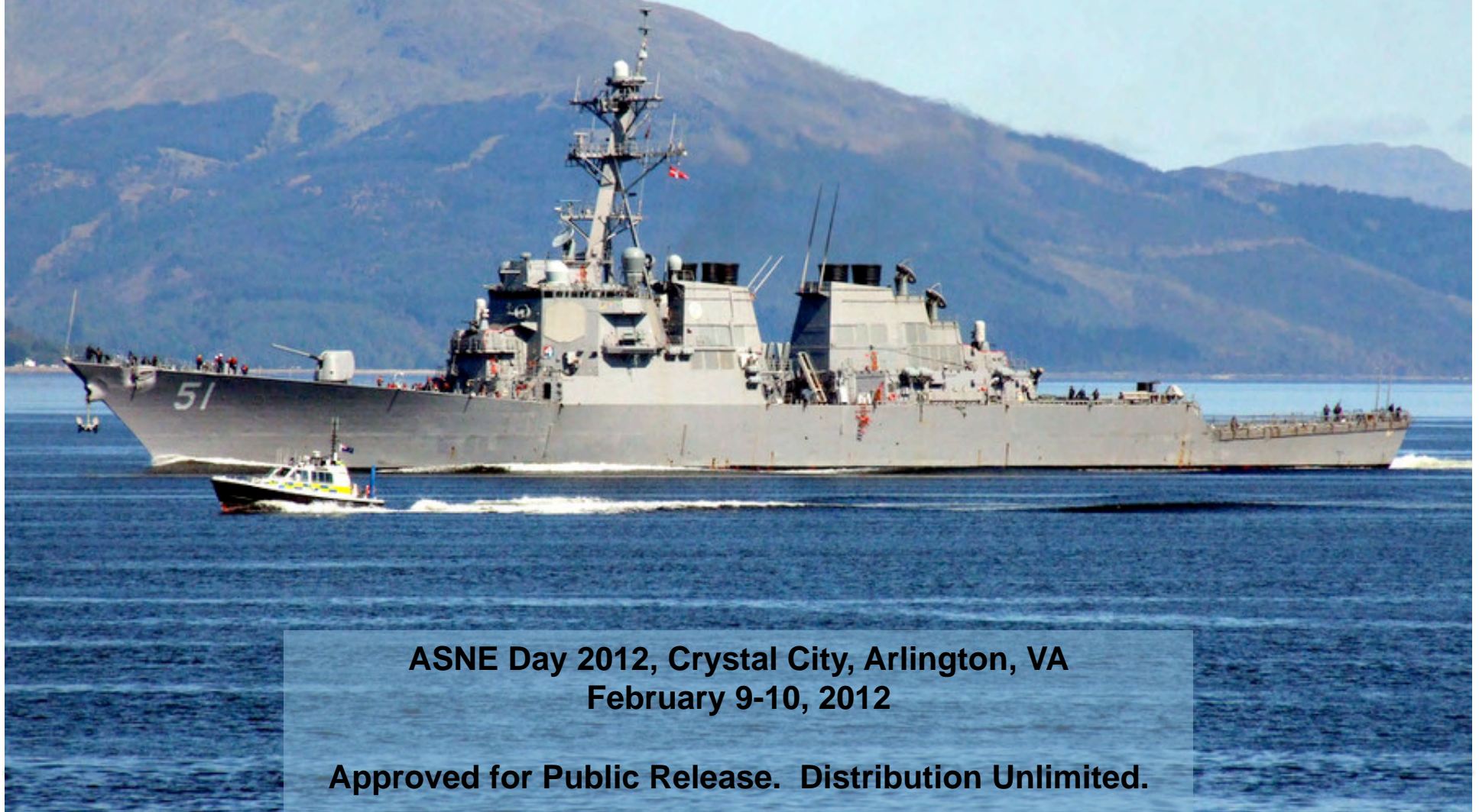


Hydrodynamic Energy Saving Enhancements for DDG 51 Class Ships

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Introduction

The ARLEIGH BURKE (DDG 51) Class destroyer represents the latest in a distinguished lineage of U.S. Navy combatants.

- The 62nd DDG 51 Class destroyer recently entered into service, and there are still many more to be built.

DDG 51 Flight I/II: (DDG 51-78), 28 ships active

DDG 79 Flight IIA: (DDG 79-112), 34 ships active

(DDG 113-122), 10 more ships scheduled

DDG 123 Flight III: extended plans (DDG 123-146), 24 additional ships

Current scheduled total number of DDG 51 Class destroyers is 72

- Good possibility for 96 destroyers!

Propulsion fuel efficiency and reduction of maintenance on the DDG 51 Class thus become fertile areas for cost savings.

A technology resulting in just a 1% propulsion fuel savings (564 bbls)

- Yields an annual fuel cost savings of nearly \$100K/ship (\$175/bbl)

Presentation Outline

Since the DDG 51 Class was introduced into the fleet, NSWCCD has unveiled numerous advances in ship technology and design.

Technologies to Reduce Fuel Consumption:

- 18 ft Diameter Propeller
- Contra-Rotation Propellers
- Retrofit Bow Bulb
- Stern End Bulb
- Accurate Pitch Measurement
- Updated Stern Flap
- Condition Based Hull and Propeller Cleaning

Technologies to Reduce Maintenance:

- Twisted Rudder
- Shaft Strut Alignment

Many of the designs are mature and several have been implemented; while others clearly require additional R&D.

Fuel Calculation / Savings

FY12 Navy Energy Usage Reporting System (NEURS) indicates the following for the DDG 51 Class, average annually, per ship:

- Total underway operational time: 3134 hrs/yr/ship
- Total underway fuel consumption: 76,269 bbls/yr/ship
- Total propulsion fuel consumption: 56,420 bbls/yr/ship

A technology resulting in a 1 percent propulsion fuel savings (564 bbls)

- Yields an annual fuel cost savings of nearly \$100K / ship
(standard fuel price of \$175/bbl established for FY12)

NAVSEA tabular method (2003) used for fuel consumption calculation:

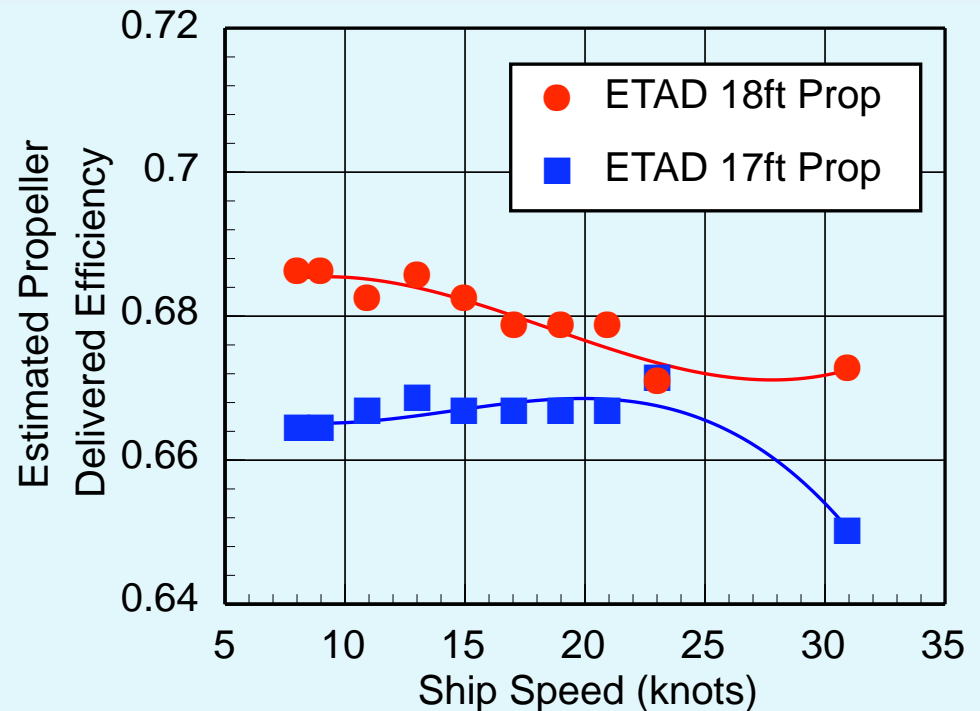
- Speed-Time Profile (STP) designates percent time-at-speed/yr
- Engine operating alignments and time profiles are defined;
Trail Shaft (1 engine); Split Plant (2 engines); Full Plant (4 engines)
- Propulsion engine fuel consumption rates, for each engine operating alignment, as measured during DDG 79 Trials

18ft Diameter Propeller

Increase propeller efficiency, Reduce fuel consumption

New 18 ft propeller design:

- More efficient than fleet 17 ft design at all speeds; estimated η_D increase in the range of 0 to 3.5 percent
- More efficient below 25 knots than the previous 18 ft design
- Employs all technology and advancements of the 17 ft New Blade Section Propeller



The increased propeller efficiency would result in an annual fuel reduction of 439 bbls/year/ship (0.8%), corresponding to a fuel cost savings of \$77K annually per ship

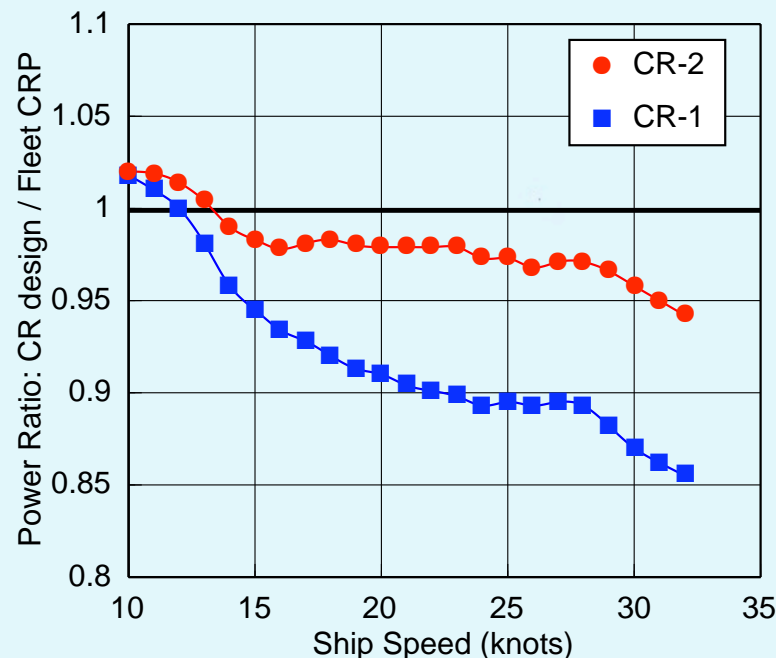
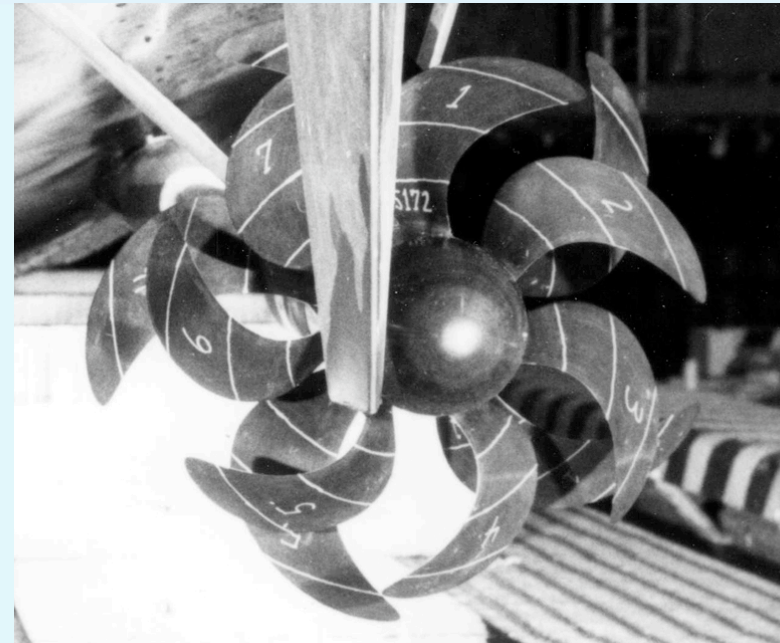
Contra-Rotation Propellers

Increase propeller efficiency, Reduce fuel consumption

CR-1 design (photo) was optimized for propulsive efficiency.

- Projected to reduce the annual fuel consumption by 1532 bbls/yr (2.7%); fuel cost savings of \$268K

CR-2 designed to minimize cavitation.



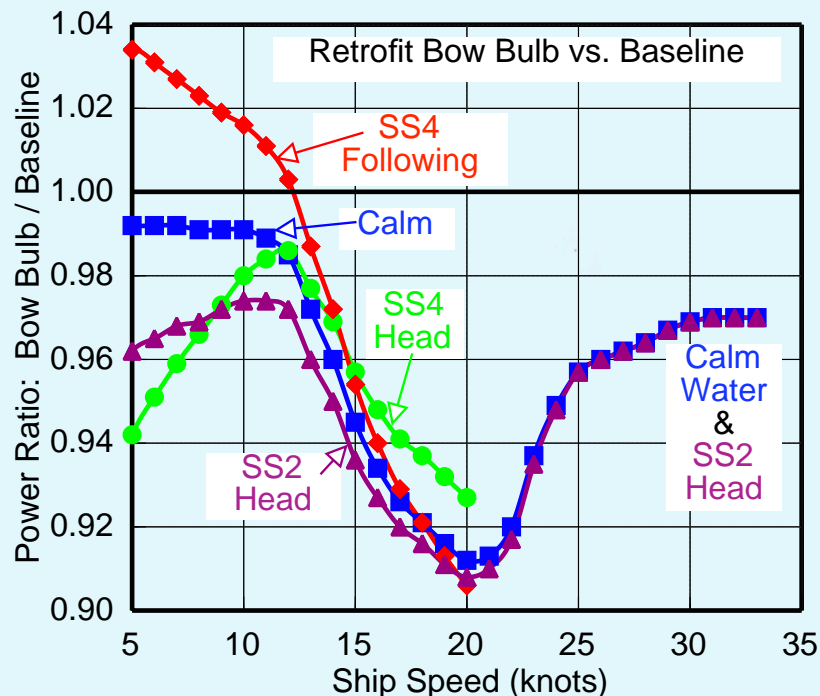
- Additional fuel savings is foreseen for CR design propellers through the tailoring of gear set ratios and designs and the matching of engine characteristics.

Retrofit Bow Bulb

Reduce fuel consumption

Small volume, near surface bow bulb integrated into a combatant bow that houses a sonar dome.

- Designed and optimized for both calm and rough water (SS2, SS4)



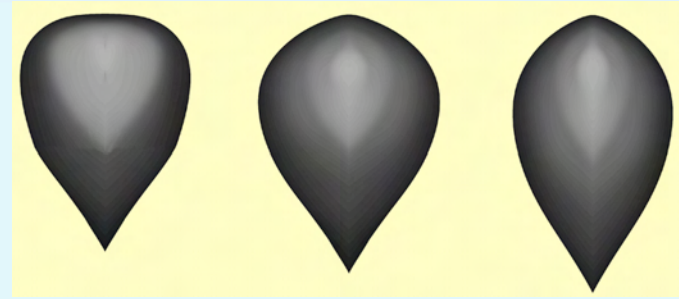
Propulsion fuel calculation accounted for annual sea state occurrences.

- Projected to reduce the annual fuel consumption by 1334 bbls/yr (2.4%); fuel cost savings of \$233K

Retrofit Bow Bulb

Reduce fuel consumption

- Cross-section shape optimized for rough water operations.
- Fillets developed at the upper and lower intersections with the bow stem
- CFD used to modify 'nose' shape and to predict pressure fields and streamlines over bulb and sonar dome.
- Seakeeping and slamming model tests were conducted
- Wave induced loads tests on the bulb were conducted
- Initial assessment made of bulb influence on hull girder vertical loads
- Dockside acoustic transfer function tests were made full-scale
- Initial acoustic design guidance was addressed
- Initial assessment made of bulb construction methods, materials, and mounting issues
- Anchor handling and mooring issues were assessed



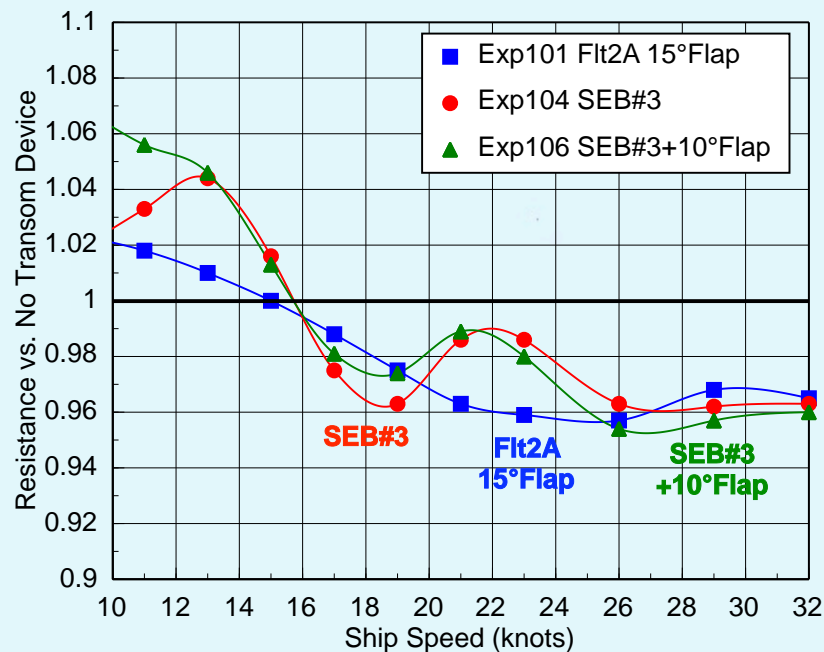
Previous major cost factor that caused the cancellation of the program, the relocation of the port side auxiliary anchor, is no longer applicable.

Stern End Bulb

Reduce fuel consumption

SEB continued design challenges:

- Overcome the performance of the existing stern flap
- Improve mid-speed performance
- Reduce low-speed penalty



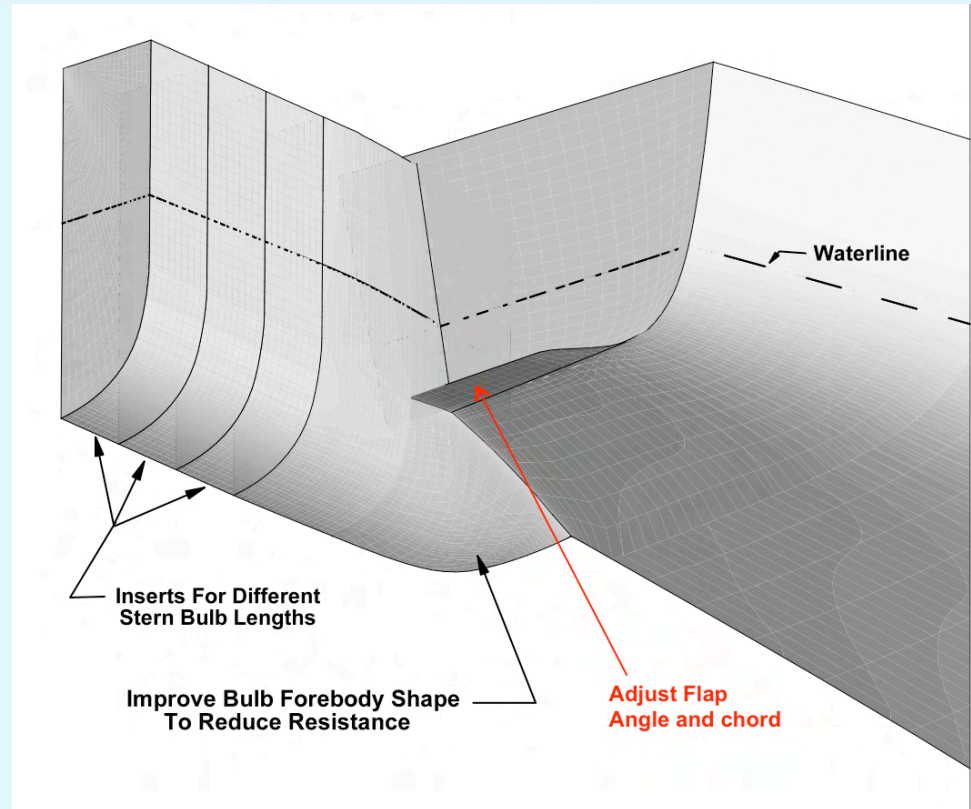
Promising results have indicated that a SEB could possibly reduce fuel consumption 1 to 2%; for a fuel cost savings of \$100-200K

Stern End Bulb

Reduce fuel consumption

CFD and model tests will be conducted to investigate the following SEB design changes:

- Modified afterbody shape to include a 'cut-off' transom stern design to avoid separation
- Variations in length and volume
- Modified forebody 'nose' shape for modified pressure drag and reduced resistance
- Variations in stern flap chord length, area, and angle.



Accurate Pitch Measurement

Reduce fuel consumption

The Program Control Module (PCM) fuel-efficient mode (FEM) utilizes propeller pitch schedules developed for minimizing fuel consumption.

- Offers fuel savings of about 4.0%, corresponding to \$395K
- Dependant on the ship monitoring systems to determine accurately the pitch of each propeller blade
- Blade pitch as registered by the ship is frequently in error by 2 to 5% (a 5% pitch offset can reduce the propeller performance by 1%)

Requirement: Direct, Accurate Pitch Measurement System

- Reliability and long term viability of previously installed in-hub pitch sensors have been poor
- Development of a direct propeller blade pitch sensor system that provides accurate pitch data, in water, while the ship is operational and underway at speed will be undertaken
- Technologies such as direct in water distance measurement with a laser or an acoustic measurement system will be evaluated

Updated Stern Flap

Reduce fuel consumption

Stern Flap: Extension of the hull surface aft of the transom

Transom Wedge: Located under and forward of the transom

Three Stern Configurations of the DDG 51 Class:

(1) *Flight I/II **Transom Wedge** (DDG 51-78), original design in 1984:*

- 13-degree, 3.2 ft chord length, inlayed into the hull plating
- 0.8% reduction in annual fuel, \$77K in fuel savings

(2) *Flight IIA **Stern Flap** (DDG 79-122), 1989:*

- Designed in combination with 5 ft Transom Extension
- 15-degree, 3.2 ft chord length, 23.6 ft span
- 4.5% reduction in annual fuel, \$443K in fuel savings

(3) *Flight I/II **Retrofit Stern Flap** (DDG 51-78), 1996:*

- Designed to be installed behind existing transom wedge
- 13-degree, 4.7 ft chord length, 24 ft span
- 5.3% reduction in annual fuel, \$525K in fuel savings

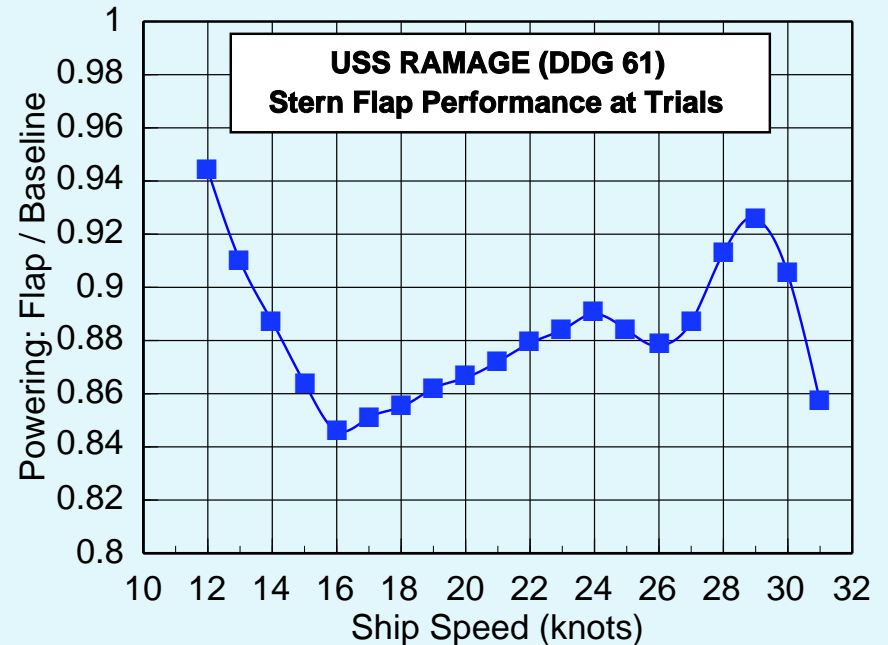
Updated Stern Flap

Reduce fuel consumption

RAMAGE (DDG 61) Trials Results:

- Fuel consumption reduced by 3002 bbls/yr (5.3%); fuel cost savings of \$525K
- Top speed increased 0.9 knots

Retrofit on all 28 Flight I/II ships

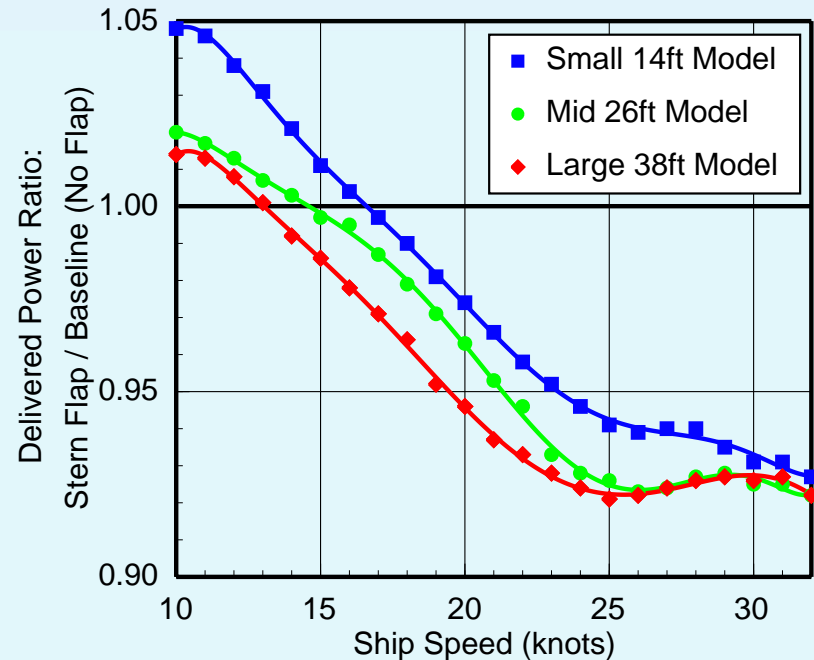


Ship modifications, displacement increase, and the likelihood of altered mission profiles, would indicate that a re-evaluation of the existing Flight IIA stern flap the design and a new flap for Flight III are in order.

Updated Stern Flap

Reduce fuel consumption

It has been determined at NSWCCD that the use of a substantially large model is required for the accurate determination of performance of these types of transom appendage configurations.



Through model tests, CFD, and full-scale trial performance comparisons, stern flap scaling effects were firmly established.

- A proprietary flap scaling analysis tool was formulated

Hull and Propeller Cleaning

Reduce fuel consumption

The cleaning of biofouling off the hull and propeller is an important practice in maintaining good ship performance

- Severity is greater on unpainted surfaces such as propellers, as well as on the hull, struts and rudders in areas where the paint coating has become degraded



Cleaning of the hull and propellers has the potential for fuel cost avoidance far in excess of the potential of any appendage addition.

- Current U.S. Navy cleaning threshold, FR 40 over 20% of hull, still allows for a 12-18% increase in power due to biofouling

Degree of biofouling may be to some extent controlled:

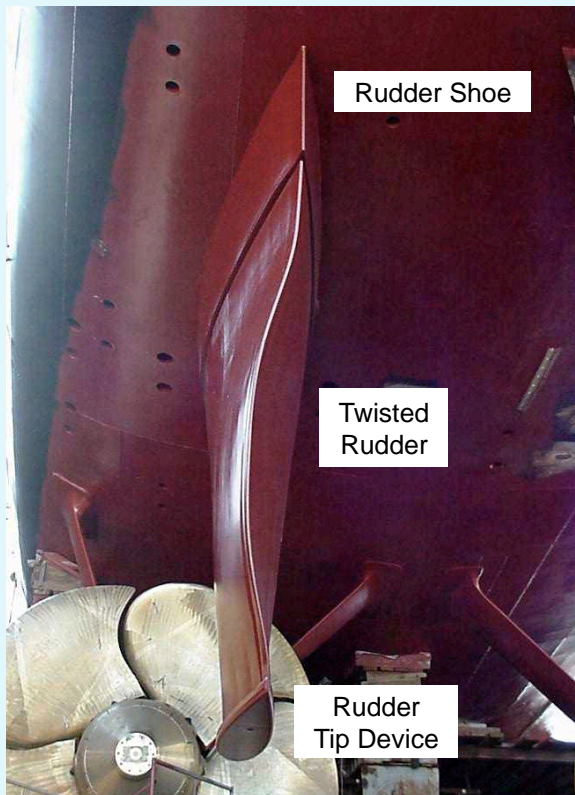
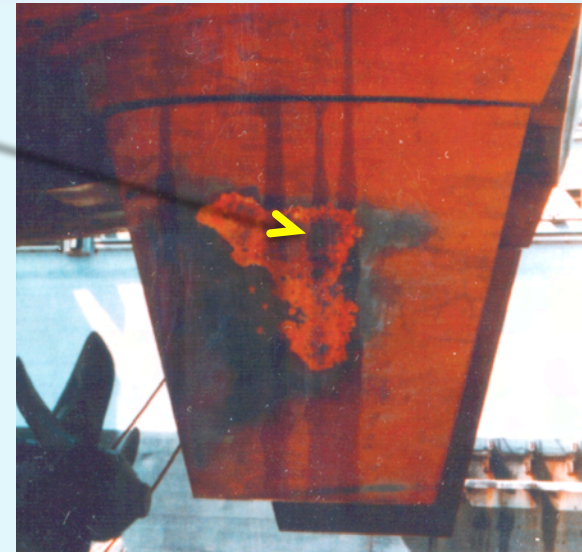
- Development of an onboard, automated propeller cleaning system
- Development and adoption of a condition-based cleaning policy

Twisted Rudder

Reduce maintenance costs

Rudder cavitation has led to severe erosion damage on the DDG 51 Class

- This has become a maintenance issue, requiring periodic repair



Twisted Rudder Developed

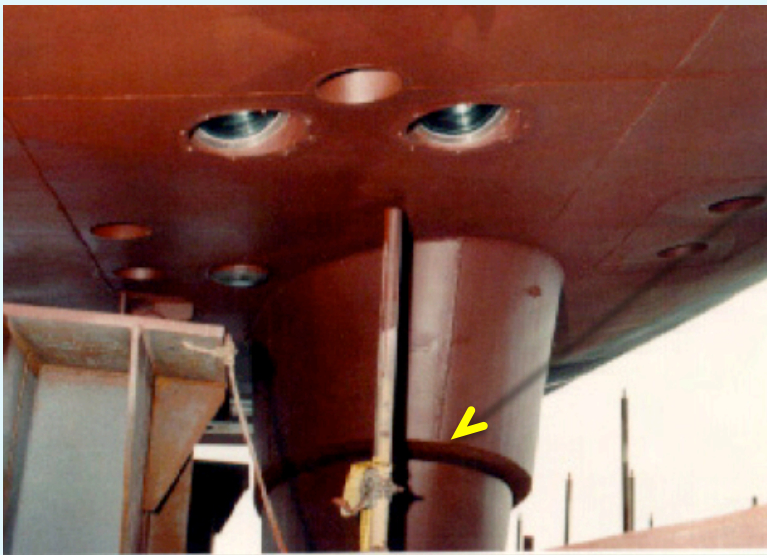
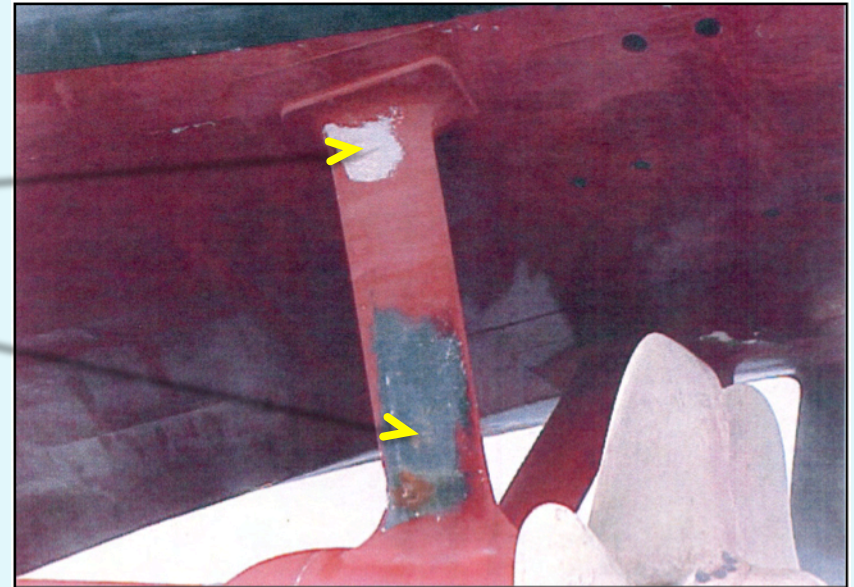
- Installed on BULKELEY (DDG 85)
- Showed significant cavitation improvement over the fleet rudder
- Installation of the rudder tip device appears to mitigate steady state tip cavitation
- Scheduled for installation on the remaining Flight IIA hulls beginning with DDG 103

Additional Issues

Reduce maintenance costs

Shaftline support strut cavitation has also become a maintenance issue.

- Small area of cavitation at top of strut is yet to be studied
- Available alignment correction could alleviate the cavitation over lower half of strut



The width and length of the rudder shoe was increased to accommodate the rudder bearing, creating a mismatch between it and the top of the rudder

- For the prevention of gap cavitation, this rudder-shoe interface should be modified

Summary / Conclusions

DDG 51 Class will total 72 destroyers and possibly 96.

It would be highly desirable for the new ships to adopt many of the design efforts discussed in this paper, and for the design changes to be retrofit to existing ships where they are economically feasible.

Costs are expected to be recouped through fuel savings:

- 18 ft Diameter propeller - design and increased manufacturing cost
- Bow Bulb - continued design and installation cost
- Stern End Bulb - R&D in progress
- Readjusting the stern flap design - minor effort
- Condition Based Cleaning - design and implementation costs

A relatively moderate fuel cost savings of \$300K per ship (3%) represents a total ownership cost savings of \$735 Million when applied over a minimum of 70 ships and 35-year service life.

Costs are expected to be recouped through reduced maintenance:

- Twisted Rudder - (implemented) increased manufacturing cost
- Strut & Rudder Shoe - design and installation costs

Questions / Comments

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