RECENT DESIGN PROGRAMS, DDG 51

Since the introduction of the USS ARLEIGH BURKE Class (DDG 51) into the fleet in 1991, the Hydromechanics Directorate (Code 50) of the Naval Surface Warfare Center Carderock Division (NSWCCD) has explored several advances in technology and design which could improve the hydrodynamic and operational performance of this combatant. These innovations are presented in detail by Cusanelli, Jessup, and Gowing, [Ref. 1], and excerpts are presented herein:

· New Blade Section Propeller: To reduce propeller cavitation, lessen cavitation erosion damage
· Twisted Rudder: To improve rudder cavitation performance, lessen cavitation erosion damage
· Retrofit Bow Bulb: Integrated into a bow which houses a sonar dome, to reduce power
· Stern Extension with Stern Flap: Stern flap developed in parallel with a lengthened transom
· Integrated Wedge-Flap: Combination stern flap and transom wedge, to reduce power

New Blade Section Propeller:
Developed to increase cavitation inception speed, suppress propeller cavitation, and reduce cavitation erosion damage. New blade section technology tailors the blade surface pressure distributions to minimize blade surface cavitation, [Ref. 2]. The new sections are thinner, incorporating high camber (mildly "cupped") at the trailing edge, (Fig 1).

Fig 1a. New Blade Section Propeller

Fig 1b. New Section: T/C = 0.0755

Fig 1c. Standard NACA66: T/C = 0.1007

Cavitation tunnel results on a model scale 16 in (40.6 cm) diameter new blade section propeller showed a 2 - 3 knot increase in cavitation inception speed, and reduced extent of cavitation, especially at high speeds, (Fig 2), compared to the standard fleet DDG 51 propeller, [Ref. 3]. Ship trials on the USS BARRY (DDG 52) with the new blade section propeller confirmed the improvements in propeller cavitation performance exhibited at model scale.

Fig 2a. Standard propeller, model cavitation test

Fig 2b. New Blade Section Propeller, model cavitation test

The onset of cavitation at the bolt counter-bores was increased by 6 knots, full-scale, on the USS BARRY (DDG 52). This improvement in cavitation was made by incorporating low profile blade attachment bolts, and bolt covers matched to local blade surface contour, into the full-scale new blade section propeller design, (Fig 3).


Fig 3. Low profile bolts and bolt covers, DDG 52

Full-scale experience indicates reduced cavitation erosion damage tendencies on the blade surface for the new blade section propeller compared to the standard fleet DDG 51 propeller. After 2 years of ship operations, the new propellers were inspected, and found to have no erosion damage. Speed/Power performance maintained throughout speed range (no changes to propulsion system), and top speed was increased via reduced propeller thrust breakdown.

Twisted Rudder:

Designed to reduce rudder erosion damage, and provide for cavitation-free operation during normal course keeping maneuvers. A rudder operates in the propeller slipstream, which contains swirl (rotation). Swirl produces varying angles of attack along the rudder span, which causes it to cavitate. Rudder cavitation can be reduced or avoided [Ref. 4] if the rudder is aligned with the local incoming flow, (Fig 4).

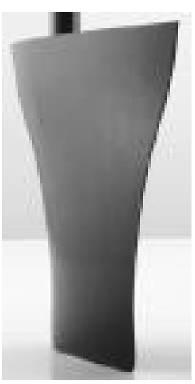
Fig. 4. Twisted rudder

Model experiments in the Large Cavitation Channel (LCC) confirmed that cavitation on the standard rudder could be significantly reduced when aligned with inflow, (Fig 5). Reduced rudder cavitation results in reduced erosion damage tendencies. The cavitation performance of the twisted rudder provides for a 7 degree increase in the cavitation-free operating envelope over that of the standard DDG 51 rudder.

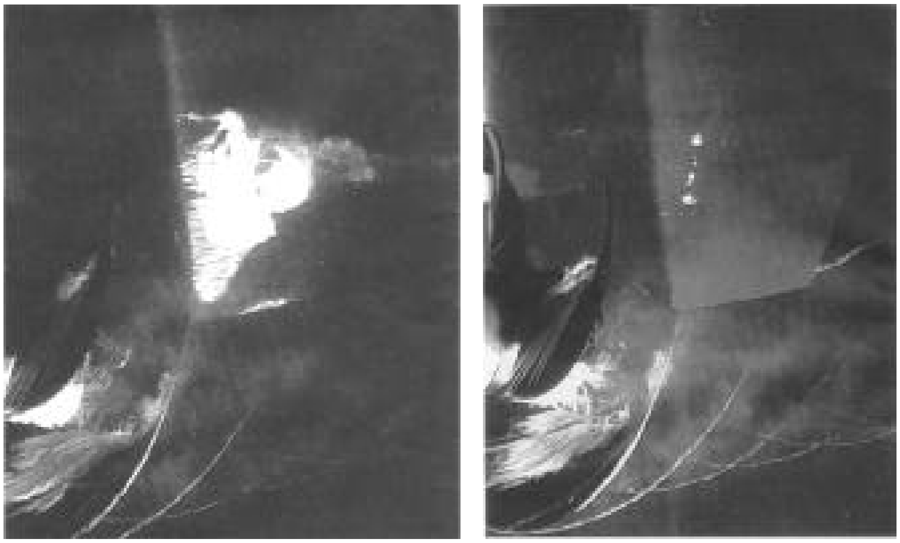

Fig 5. Fleet rudder (left), Twisted rudder (right): Cavitation tests at 31 knots, zero rudder angle

Force measurements showed that turning performance will be equal or slightly better than that of the standard DDG 51 rudder.

Retrofit Bow Bulb:

Integrated into the existing bow, which houses a sonar dome, with the design purpose of reducing propulsion power requirements [Ref 5]. Bulbous bows (bow bulbs) are appendages designed to hydrodynamically reduce the ship's resistance, and are generally placed (or extend) well above the baseline of the ship. The bow bulb’s nabla shape (inverted tear drop), location near the free surface, and the reduced size, volume, and beam-to-height ratio, (Fig 6), are in direct contrast to the geometry of the sonar dome located beneath it. A U.S. Patent "Combined Bulbous Bow and Sonar Dome for a Vessel", has been awarded for this concept, [Ref. 6].

Fig 6. Retrofit bow bulb installed on model

The bow bulb design was refined so that power reduction was maintained throughout calm water and rough water' [Ref. 7]. Several bulb shape variations, all of which retained the equivalent bulb volume and length parameters, were model tested, (Fig. 7).


Fig 7. Bow bulb shape variations

Ship performance was projected across several sea states. Ship performance improvement was projected for the entire ship speed range across all sea states tested, resulting in significant annual fuel savings.
Analysis of seakeeping data and extreme sea wave load tests indicate that the bow bulb had no significant impact on ship motions or hull girder loads. Acoustic transfer function tests data from a vibracoustic model concluded that the bow bulb should have little noticeable impact on the sonar self-noise levels.

Stern Extension with Stern Flap:
In order to increase helicopter flight-deck area, the stern of the initial DDG 51 was lengthened by 5 ft (1.52 m), increasing the ship LWL to 471 ft (143.6 m). A stern flap was developed in parallel with the lengthened transom, and the resultant design is referred to as the DDG 51 Flight IIA sub-class, (Fig 8).


Fig 8. DDG 51 Flight IIA, under construction

The stern flap was designed specifically for performance enhancement' [Ref. 8]. It is projected to decrease annual propulsion fuel consumption resulting in significant cost savings, and as an added benefit, the stern flap will also increase the maximum ship speed by 0.3 knots.

Integrated Wedge-Flap:

The DDG 51 integrated wedge-flap design program investigated whether a stern flap, installed in addition to the hull's transom wedge, could further reduce the ship's powering requirements, [Ref. 9]. This program was unique because it represented the initial model evaluation (Fig. 9) of a wedge and flap combination, the two of which were previously viewed as exclusive devices. A U.S. patent is pending for this design concept, [Ref. 10].

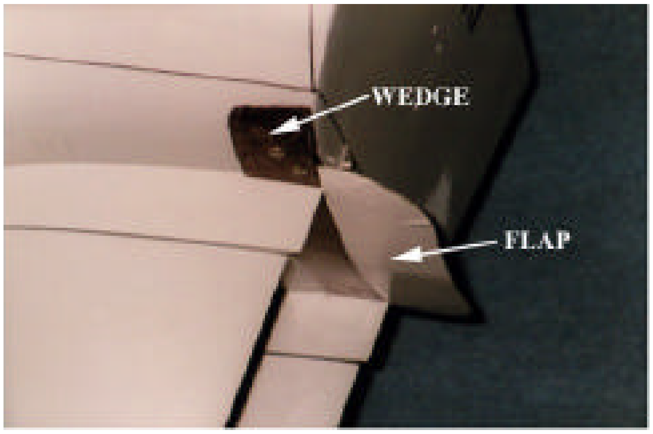

Fig 9. Integrated wedge-flap on model

The stern flap, as a retrofit to the existing ship with the wedge, forming the integrated wedge-flap, is projected to decrease annual propulsion fuel consumption resulting in significant cost savings. The stern flap will also increase the maximum ship speed by 0.4 knots.

ADDITIONAL INFORMATION

New Blade Section:	Stuart Jessup, NSWCCD Code 5400 Voice: (301) 227-5080, eMail: JessupSD@nswccd.navy.mil
Twisted Rudder:	Scott Gowing, NSWCCD Code 5400 Voice: (301) 227-2633, eMail: GowingS@nswccd.navy.mil
Bow Bulb, Stern Flaps, Integrated Wedge-Flap:	Dominic S. Cusanelli, NSWCCD Code 5200 Voice: (301) 227-7008, eMail: CusanelliDS@nswccd.navy.mil

REFERENCES

[1] Cusanelli, D.S., S.D. Jessup, and S. Gowing, "Exploring Hydrodynamic Enhancements to the USS Arleigh Burke (DDG 51)", FAST'99, Fifth International Conference on Fast Sea Transportation, Seattle, WA (Aug 1999)

[2] Bailar, J. , Jessup, S. and Shen, Y., "Improvement of Surface Ship Propeller Cavitation Performance Using Advanced Blade Sections," 23rd ATTC Conference, New Orleans, LA, 1992.

[3] Jessup, S., W. Berberich, and K. Remmers, "Cavitation Performance Analysis of Naval Surface Ship Propellers with Standard and New Blade Sections," 20th Symposium on Naval Hydrodynamics, Santa Barbara, CA, (1994).

[4] Shen, Y.T., C.W. Jiang, and K.D. Remmers, "A Twisted Rudder for Reduced Cavitation," Journal of Ship Research, Vol. 41, No. 4, (Dec. 1997).

[5] Cusanelli, D.S., “Development of a Bow for a Naval Surface Combatant which Combines a Hydrodynamic Bulb and a Sonar Dome,” ASNE Technology Innovation Symposium, Pittsburgh, PA, (Sept 1994).
[6] Cusanelli, D.S. and G. Karafiath, U.S. Patent number 5,280,761, "Combined Bulbous Bow and Sonar Dome for a Vessel," (Jan. 1994).
[7] Cusanelli, D.S., “Performance of Near-Surface Bow Bulbs in Irregular Waves,” 25th ATTC, Iowa City, IA, (Sept 1998).
[8] Karafiath, G., D.S. Cusanelli, and C.W. Lin, “Stern Wedges and Stern Flaps for Improved Powering - U.S. Navy Experience”, 1999 SNAME Annual Meeting, Baltimore, MD (Sept 1999)
[9] Cusanelli, D.S., and G. Karafiath, “Integrated Wedge-Flap for Enhanced Powering Performance,” FAST ‘97, Sidney, Australia, (July 1997).
[10] Cusanelli, D.S. and G. Karafiath, U.S. Patent Case number 78,104, "Combined Wedge-Flap for Improved Ship Powering” (1997).