TITLE: Assessing the Hydrodynamic Performance of Fouling-Release Surfaces
(ONR Research Contract # N00014-07-WR-2-0213)

INVESTIGATOR: Associate Professor Michael P. Schultz, Naval Architecture & Ocean Engineering Department

BACKGROUND: The primary purpose of a ship antifouling system is to limit the increase in drag that will be incurred with fouling settlement on the hull. Ineffectiveness in this endeavor will lead to an increase in energy consumption and a platform that is unable to meet its mission. Non-toxic, fouling-release coating systems have been introduced as alternatives to traditional biocide-based antifoulings. However, for these systems to serve as viable alternatives to traditional biocide-based systems, their hydrodynamic performance must compare favorably with traditional systems over the entire coating life cycle. At present, few data are available to make these fundamental comparisons.

OBJECTIVE: The technical objectives of this research are to:

- Develop effective, generic roughness scaling parameters for a continuum of hull conditions.
- Implement this scaling to predict performance penalties of U.S. Navy ships.
- Collaborate with NSWCCD to incorporate these predictions with fleet operational data to perform a rigorous economic analysis of the cost of hull roughness and fouling to the Navy.

METHOD AND RESULTS: The technical approach of this research is to (see Figure 1 below):

- Develop roughness scaling parameters for a range of hull conditions based on hydrodynamic experiments by the PI (*i.e.* Schultz (2004)).
- Employ boundary layer similarity analysis to determine the increase in frictional drag at ship scale.
- Predict powering and speed penalties for the *Oliver Hazard Perry*-class frigate (*FFG*-7) and the *Arleigh Burke*-class destroyer (*DDG*-51) Naval surface combatants using model test data and frictional drag predictions.
- Collaborate with NSWCCD to carry out a rigorous cost/benefit analysis for hull roughness and fouling for the U.S. Navy combining the aforementioned powering predictions with data for ship operational profiles from the fleet.

# Report Documentation Page

*Form Approved*
*OMB No. 0704-0188*



| | | |
|---|---|---|
| 1. REPORT DATE<br>**2007** | 2. REPORT TYPE | 3. DATES COVERED<br>**00-00-2007 to 00-00-2007** |

| | |
|---|---|
| 4. TITLE AND SUBTITLE<br>**Assessing the Hydrodynamic Performance of Fouling-Release Surfaces** | 5a. CONTRACT NUMBER |
| | 5b. GRANT NUMBER |
| | 5c. PROGRAM ELEMENT NUMBER |
| 6. AUTHOR(S) | 5d. PROJECT NUMBER |
| | 5e. TASK NUMBER |
| | 5f. WORK UNIT NUMBER |
| 7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)<br>**United States Naval Academy (USNA),Naval Architecture & Ocean Engineering Department,Annapolis,MD,21402** | 8. PERFORMING ORGANIZATION REPORT NUMBER |
| 9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) | 10. SPONSOR/MONITOR'S ACRONYM(S) |
| | 11. SPONSOR/MONITOR'S REPORT NUMBER(S) |

12. DISTRIBUTION/AVAILABILITY STATEMENT
**Approved for public release; distribution unlimited**

13. SUPPLEMENTARY NOTES

14. ABSTRACT

15. SUBJECT TERMS

| 16. SECURITY CLASSIFICATION OF: | | | 17. LIMITATION OF ABSTRACT | 18. NUMBER OF PAGES | 19a. NAME OF RESPONSIBLE PERSON |
|---|---|---|---|---|---|
| a. REPORT<br>**unclassified** | b. ABSTRACT<br>**unclassified** | c. THIS PAGE<br>**unclassified** | **Same as Report (SAR)** | **7** | |

**Standard Form 298 (Rev. 8-98)**
Prescribed by ANSI Std Z39-18

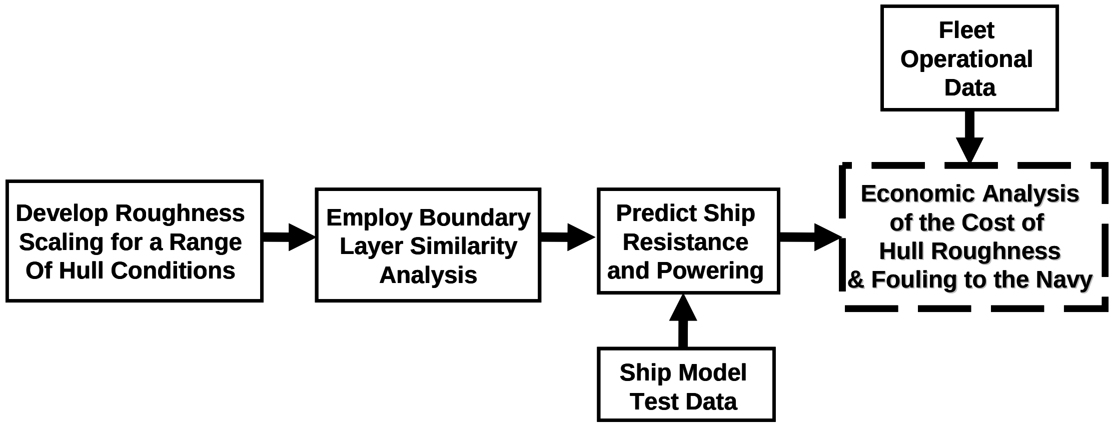


Figure 1 – Flow chart illustrating the technical approach employed the present research.

The following progress has been made in the 2007 fiscal year:

- Generic roughness and fouling scaling parameters have been developed for a range of hull conditions (Table 1).
- Predictions of the increase in total drag at cruising speed and near top end have been made for the *Oliver Hazard Perry*-class frigate *FFG*-7 (Tables 2 & 3) and the *Arleigh Burke*-class destroyer *DDG*-51 (not shown).
- Estimates of powering and speed penalties have been carried out for the *Oliver Hazard Perry*-class frigate *FFG*-7 (Figures 2 & 3) and the *Arleigh Burke*-class destroyer *DDG*-51 (not shown).
- Comparisons with full-scale ship trials data in the literature indicate that the present predictions are reliable (Figures 4 & 5).
- Collaboration is currently underway with NSWCCD to carry out a rigorous cost/benefit analysis for hull roughness and fouling for the U.S. Navy using combining the aforementioned powering predictions with data for ship operational profiles from the fleet.

Table 1 – Roughness scaling parameters for a range of hull roughness and fouling conditions. Note that the NSTM rating is the Navy hull fouling rating based on the Naval Ships' Technical Manual (NSTM, 2002), $k_s$ is the equivalent sand roughness height, and $Rt_{50}$ is maximum peak-to-trough roughness height over a 50 mm transect.

| **Description of Condition** | **NSTM Rating*** | **$k_s$ (μm)** | **$Rt_{50}$ (μm)** |
|---|---|---|---|
| hydraulically smooth surface | 0 | 0 | 0 |
| typical as applied AF coating | 0 | 30 | 150 |
| deteriorated coating or light slime | 10 - 20 | 100 | 300 |
| heavy slime | 30 | 300 | 600 |
| small calcareous fouling or weed | 40 - 60 | 1000 | 1000 |
| medium calcareous fouling | 70 - 80 | 3000 | 3000 |
| heavy calcareous fouling | 90 - 100 | 10000 | 10000 |

* NSTM (2002)

Table 2 – Increase in total drag for the *FFG*-7 class frigate at a cruising speed of 15 kts (7.7 ms$^{-1}$) for a range of hull roughness and fouling conditions.

| **Description of Condition** | **$\Delta R_T$ @ $U_s$ = 7.7ms$^{-1}$ (kN)** | **% $\Delta R_T$ @ $U_s$ = 7.7ms$^{-1}$** |
|---|---|---|
| hydraulically smooth surface | -- | -- |
| typical as applied AF coating | 4.6 | 2% |
| deteriorated coating or light slime | 23 | 11% |
| heavy slime | 41 | 20% |
| small calcareous fouling or weed | 69 | 34% |
| medium calcareous fouling | 105 | 52% |
| heavy calcareous fouling | 162 | 80% |

Table 3 – Increase in total drag for the *FFG*-7 class frigate at a speed of 30 kts (15.4 ms$^{-1}$) for a range of hull roughness and fouling conditions.

| **Description of Condition** | **$\Delta R_T$ @ $U_s$ = 15.4ms$^{-1}$ (kN)** | **% $\Delta R_T$ @ $U_s$ = 15.4ms$^{-1}$** |
|---|---|---|
| hydraulically smooth surface | -- | -- |
| typical as applied AF coating | 46 | 4% |
| deteriorated coating or light slime | 118 | 10% |
| heavy slime | 192 | 16% |
| small calcareous fouling or weed | 305 | 25% |
| medium calcareous fouling | 447 | 36% |
| heavy calcareous fouling | 677 | 55% |

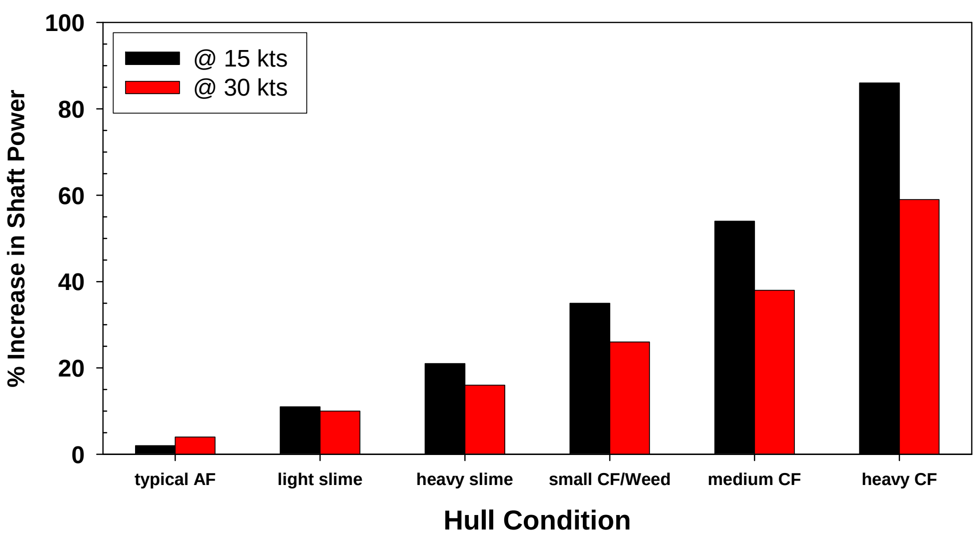


Figure 2 – Increase in required shaft power for the *FFG*-7 class frigate at 15 and 30 kts (7.7 and 15.4 ms$^{-1}$) for a range of hull roughness and fouling conditions.

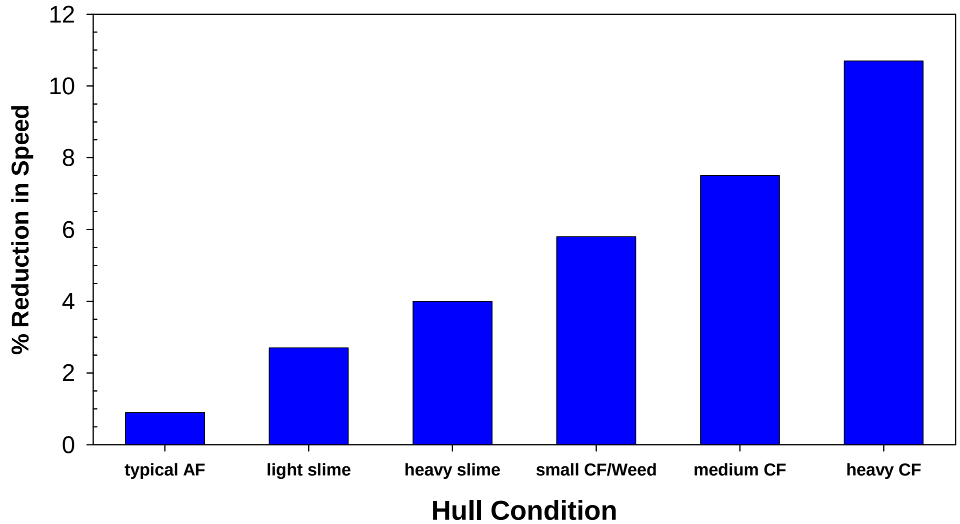


Figure 3 – Reduction in top end speed for the *FFG*-7 class frigate at a fixed input power corresponding to that required at 30 kts for a hydraulically smooth hull.

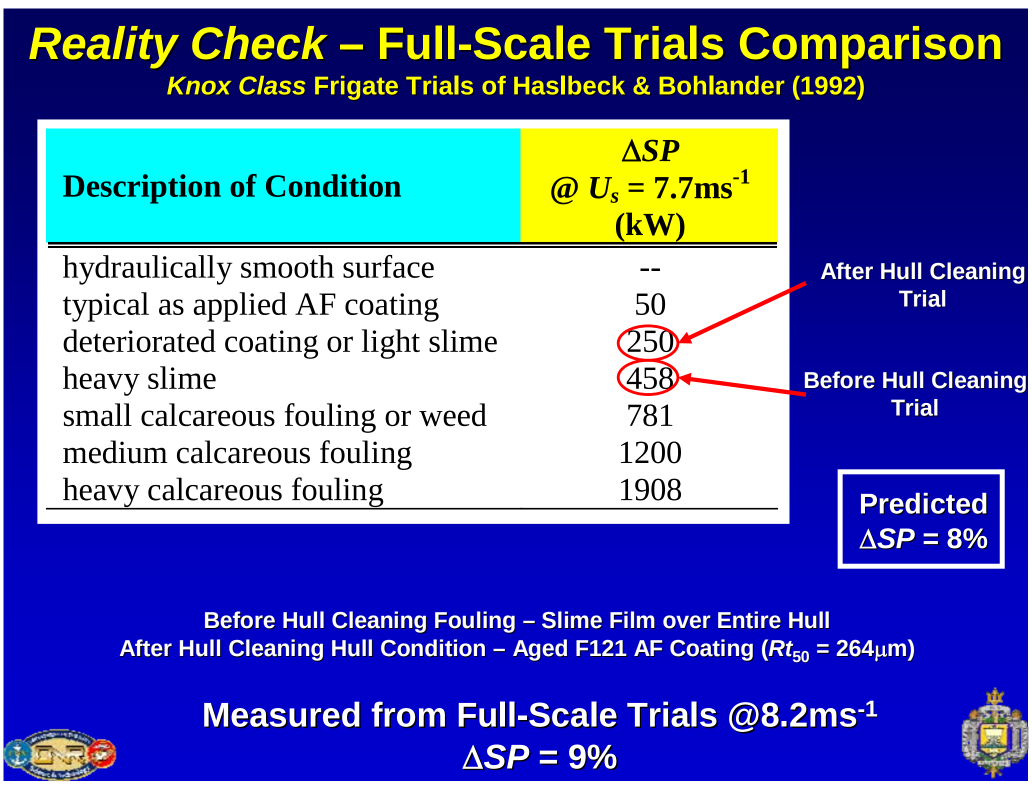


Figure 4 – Comparison of the present predictions to the results of Haslbeck & Bohlander (1992).

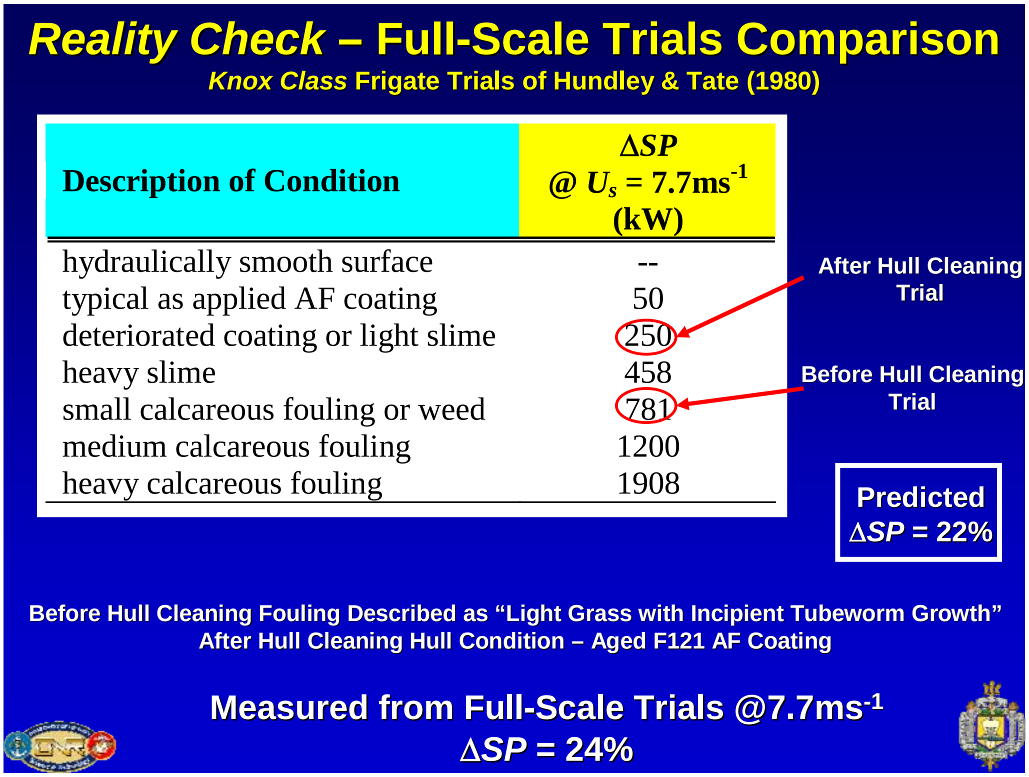

Figure 5 – Comparison of the present predictions to the results of Hundley & Tate (1980).

### ***References***

Haslbeck E G, Bohlander G. 1992. Microbial biofilm effects on drag - lab and field. *Proceedings SNAME Ship Production Symposium.* Paper No. 3A-1. 7p.

Hundley L L, Tate C W. 1980. Hull-fouling studies and ship powering trial results on seven FF 1052 class ships. D W Taylor Naval Ship Research and Development Center Report # DTNSRDC-80/027. 111 p.

Naval Ships' Technical Manual. 2002. *Chapter 081 - Waterbourne underwater hull cleaning of Navy ships*. Publication # S9086-CQ-STM-010/CH-081R4. Naval Sea Systems Command. 31 p.

Schultz M P. 2004. Frictional resistance of antifouling coating systems. *ASME Journal of Fluids Engineering* **126**: 1039-1047.

PUBLICATIONS:

1. M.P. SCHULTZ & K.A. Flack (2007), "The Rough-Wall Turbulent Boundary Layer from the Hydraulically Smooth to the Fully Rough Regime," Journal of Fluid Mechanics, Vol. 580, pp. 381-405.

2. K.M. Womack, R.J. Volino, & M.P. SCHULTZ (2007), "Measurements in Film Cooling Flows with Periodic Wakes," Journal of Turbomachinery in press.

3. K.M. Womack, R.J. Volino, & M.P. SCHULTZ (2007), "Combined Effects of Wakes and Jet Pulsing on Film Cooling," Journal of Turbomachinery in press.

4. M.P. SCHULTZ (2007), “Effects of Coating Roughness and Biofouling on Ship Resistance and Powering,” Biofouling in press.

5. K.A. Flack , M.P. SCHULTZ, & J.S. Connelly (2007), “Examination of a Critical Roughness Height for Wall Similarity,” Physics of Fluids in press.

6. R.J. Volino, M.P. SCHULTZ, & K.A. Flack (2007), “The Turbulence Structure in Rough- and Smooth-Wall Boundary Layers,” revision submitted to Journal of Fluid Mechanics.

PRESENTATIONS:

1. K.M. Womack, R.J. Volino, & M.P. SCHULTZ (2007), “Measurements in Film Cooling Flows with Periodic Wakes,” ASME Paper 2007-GT-27917.

2. K.M. Womack, R.J. Volino, & M.P. SCHULTZ (2007), “Combined Effects of Wakes and Jet Pulsing on Film Cooling,” ASME Paper 2007-GT-27921.

3. K.A. Flack & M.P. SCHULTZ (2007), “The Rough-Wall Turbulent Boundary Layer from the Hydraulically Smooth to the Fully Rough Regime,” Proceedings of the 5th International Symposium on Turbulence and Shear Flow Phenomena (TSFP-5).

4. R.J. Volino, M.P. SCHULTZ, & K.A. Flack (2007), “The Turbulence Structure in Rough and Smooth Wall Boundary Layers,” Proceedings of the 11th European Turbulence Conference (ETC-11).

5. M.P. SCHULTZ & K.A. Flack (2006), “The Rough-Wall Turbulent Boundary Layer from the Hydraulically Smooth to the Fully Rough Regime,” Bulletin of the American Physical Society: Division of Fluid Dynamics 59th Annual Meeting, Vol. 51, No. 9, pp. 238-239.

6. K.A. Flack, M.P. SCHULTZ, & R.J. Volino (2006), “Development of Roughness Scaling Parameters,” Bulletin of the American Physical Society: Division of Fluid Dynamics 59th Annual Meeting, Vol. 51, No. 9, p. 43.

7. R.J. Volino, M.P. SCHULTZ & K.A. Flack (2006), “The Turbulence Structure in Rough and Smooth Wall Boundary Layers,” Bulletin of the American Physical Society: Division of Fluid Dynamics 59th Annual Meeting, Vol. 51, No. 9, p. 240.

8. M.P. SCHULTZ (2006), “Frictional Drag of Ship Hull Coating Systems,” 13th International Congress on Marine Corrosion and Fouling, Rio de Janeiro, Brazil, 2006.

August 12, 2009