PROPULSION DYNAMICS

A CO_2 Maintenance Index

(Hull and Propeller Performance)

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Ship Efficiency Conference
Hamburg, September 2009

Introduction

“Many ships are not operating at most profitable propulsion conditions, due to problems checking the speed and consumption” -- Torben Munk, Motorship 1999

“The shipping industry is faced with new challenges and demands accurate prediction of resistance and propulsion efficiency…” Classification Society 2007

“Hull Resistance Management”…”Performance monitoring for hull conditions and fouling” -- SEEMP 2009

Hull Condition and Emissions

Assessment of CO2 Emission Performance of Ships Marintek, 2005

"Reasons behind variation in CO_2 index …hull and propeller fouling… Establishing benchmark is key challenge to make use of index..."

GHG for Shipping and Implementation Guidance for the Marine Fuel Sulphur Directive IMO Report, CE Delft, 2006

"…Indicators utilizing ship specific resistance curves, draft, speed and consumption are more suitable to monitor hull performance…"

List of Early Action Measures to Reduce GHG EPA, 2007

"…These measures include methods of hull maintenance and advanced coatings to reduce fouling…"

Hull Performance Factors

Age of ship
Time in port
Service speed
Water temperature
Port water (fouling pressure)
Loading conditions (changes in draft/duration)

Factors in your control (ranked)

- Frequency/efficiency of planned maintenance?
- Pre-treatment of hull surface: Spotblast? Fullblast?
- Hull coating selection in drydock
- Coating selection at newbuild
- Drydock time interval: 3 year? 5 year? 6 year?

The CASPER® Service

(Computerized Analysis of Ship PERformance)

A system of data collection and onshore analysis.

No additional software or instruments required.

In active use on hundreds of ships since 2003 with over 1,000 ship-years experience.

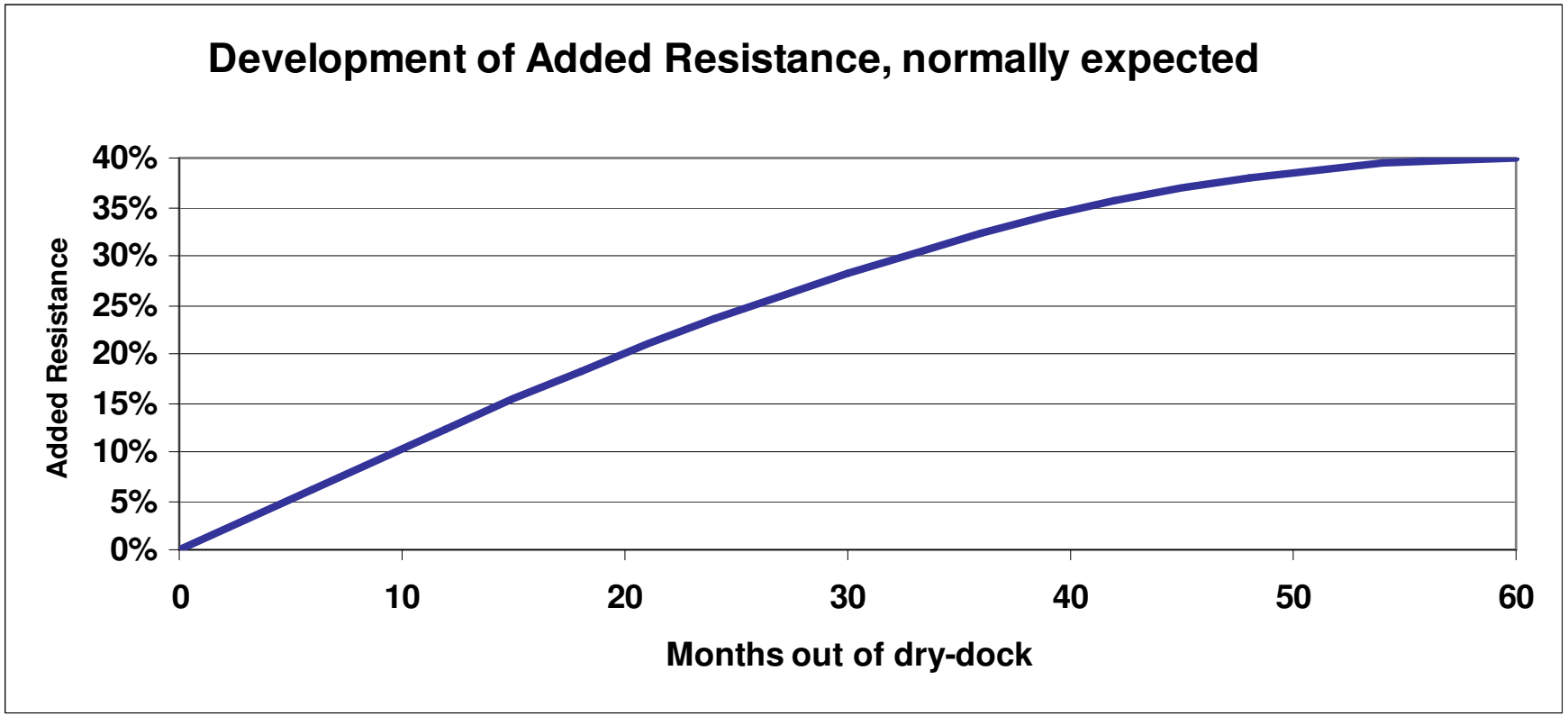
(tankers, bulkers, ro-ro's, boxships).

Compatible with all performance monitoring and data recording systems.

Results of analysis is calculation of added resistance

Definition of ”Added Resistance”

The virtual resistance caused by degrated hull and propeller condition, at design draft and design speed, as a percentage of the ”new ship” total resistance.



Hydrodynamic Techniques

[Revolutions used to calculate speed through water]

Theoretical Model

- Length
- Breadth
- Draft
- Displacement
- Design Speed
- Propeller Design and RPM

Trial Trip data adjusts this model

Actual "Performance Model"

Observations (evidence-based)

We find the three added resistances:
1) Weather: wind and waves
2) Residual: trim, nozzles, engine degr.
3) Fouling: affects resistance/wake

Step 1: Trial data is used to correct the wake and the resistance values.

Step 2: Constants for added resistance and weather resistance are adjusted.

Step 3: Ongoing statistical analysis of data to refine the mathematical model.

Unique Aspects of ‘Observation’

Vessel in steady-state

(no changes in heading or power for 2-hour interval)

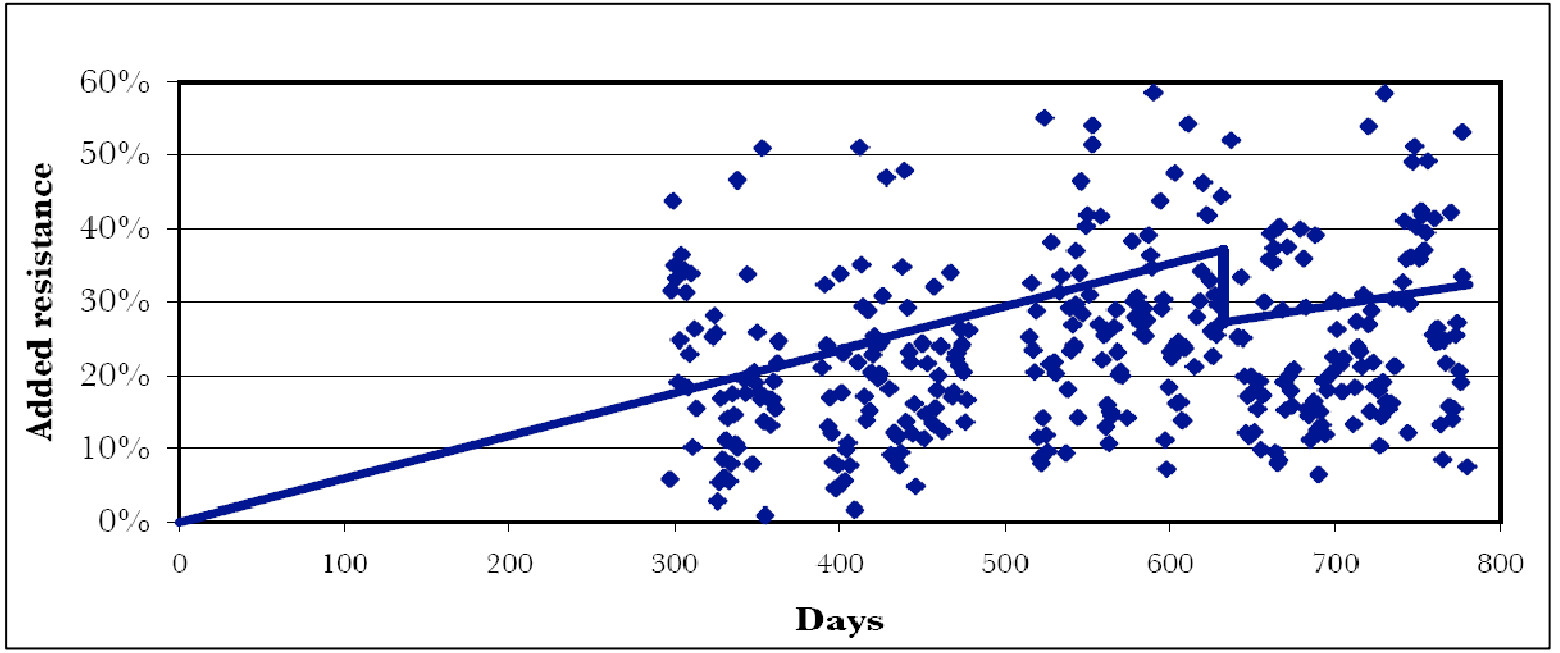
Performance Observations should be recorded

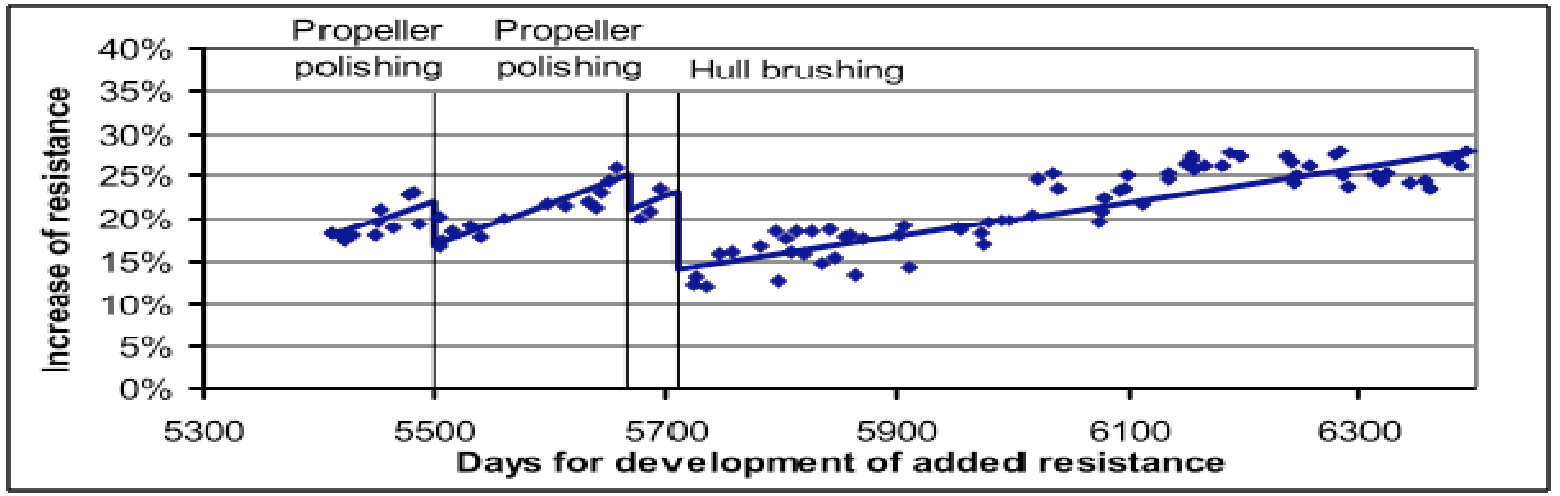
- any sea state < BF9
- any loading condition
- any speed

Speed Log reading is not used in calculation

Noon Data vs Careful Data

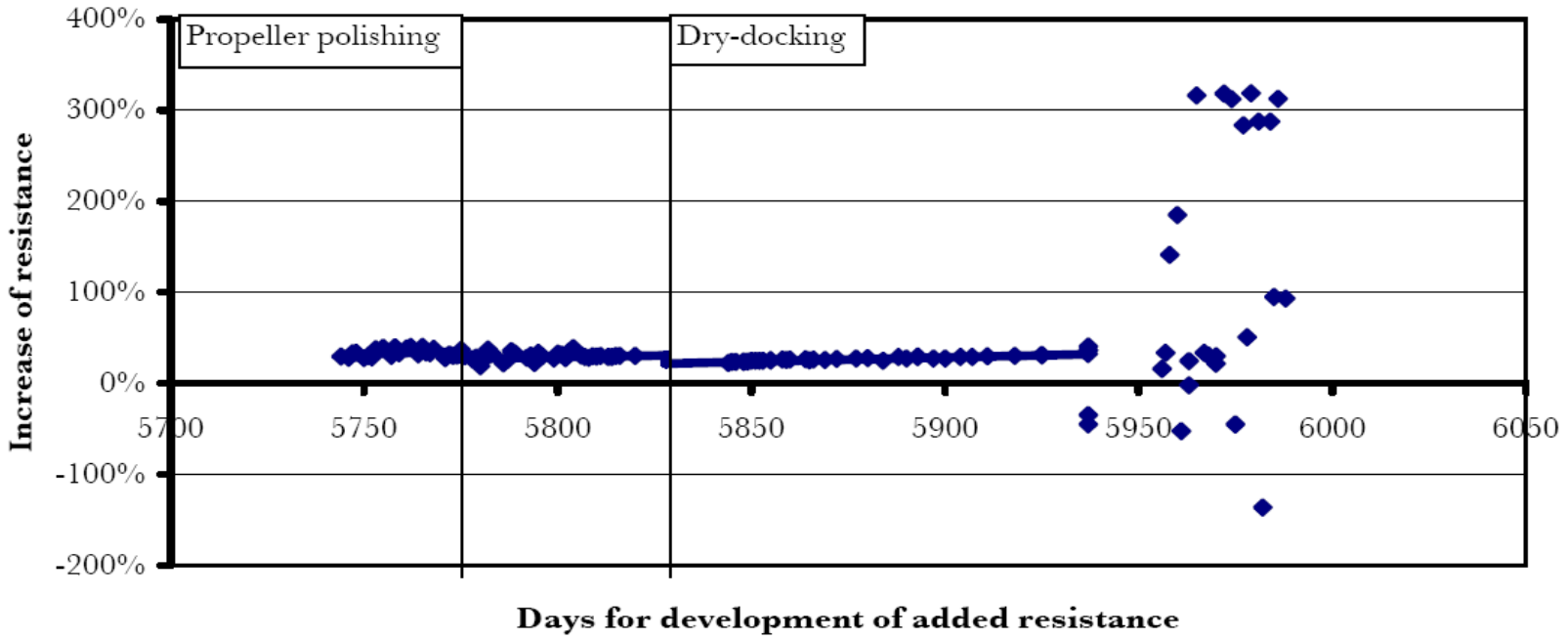
(not the same ships, but illustrating scatter in noon-data)



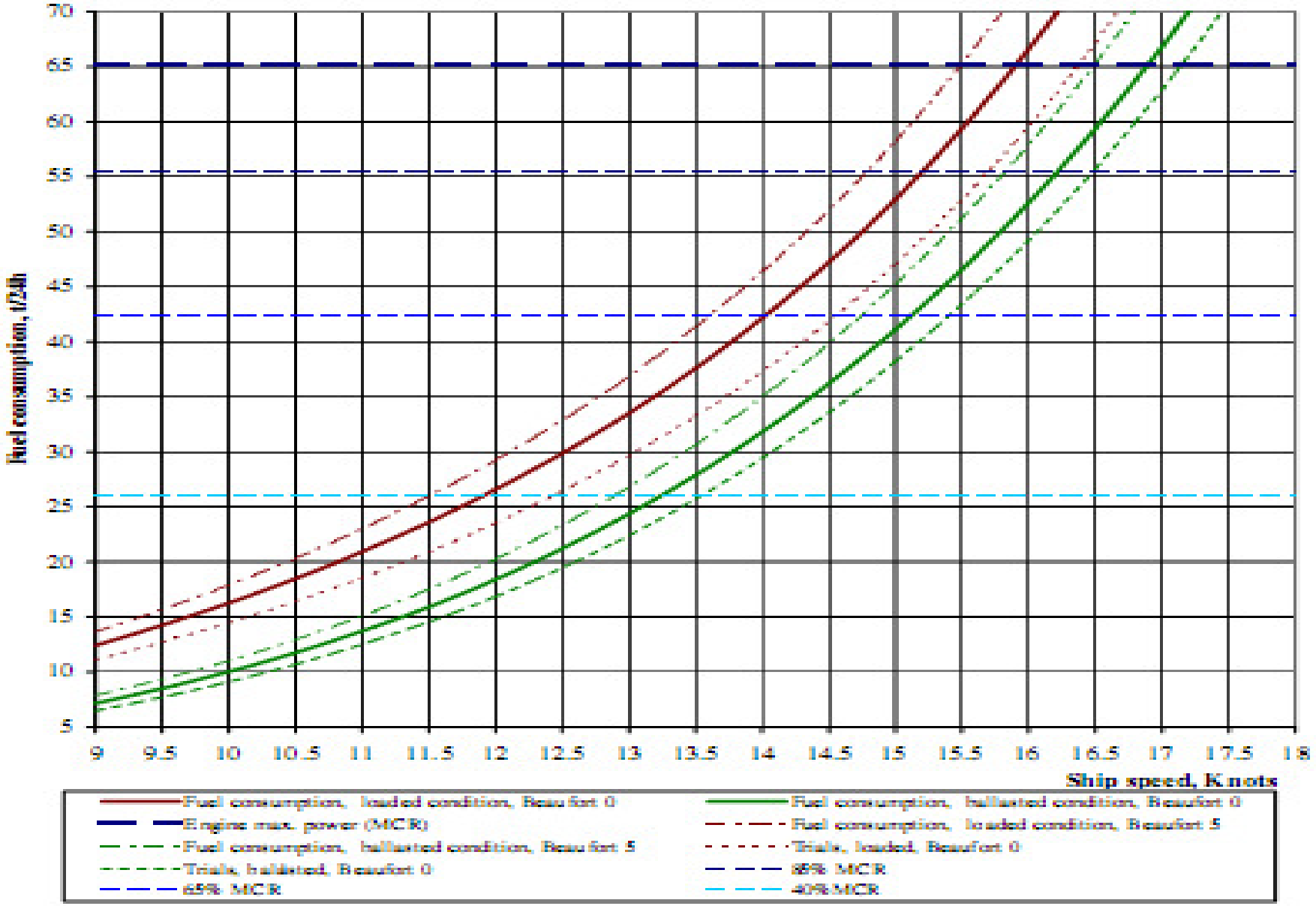


Observation errors are detected

3. Long term development of hull/propeller added resistance

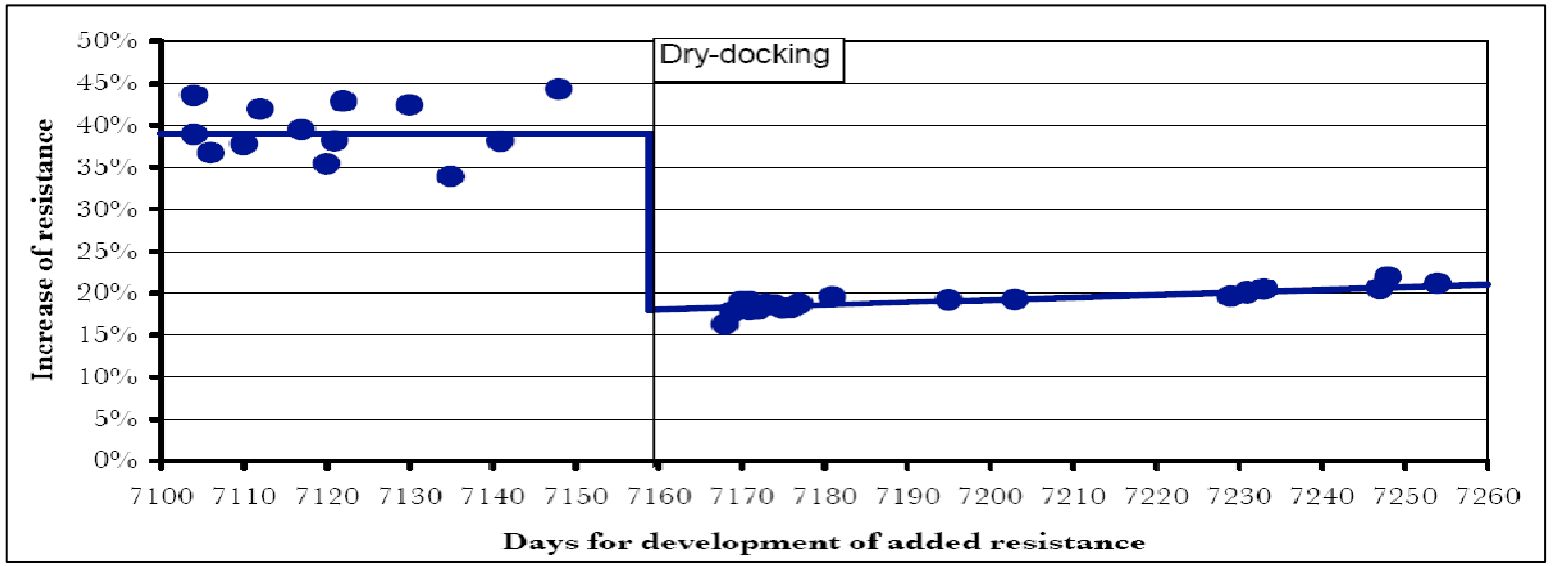


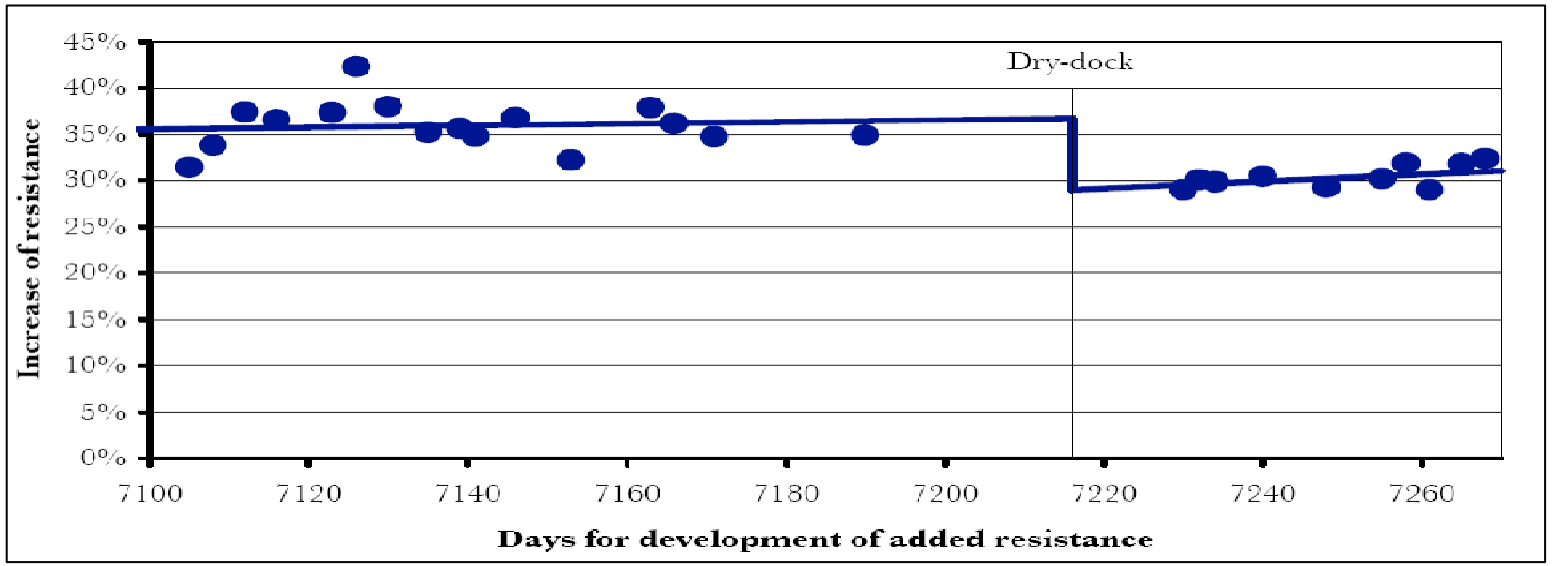
Speed/fuel consumption curves calculated from added resistance



Post-docking Analysis (sisters)

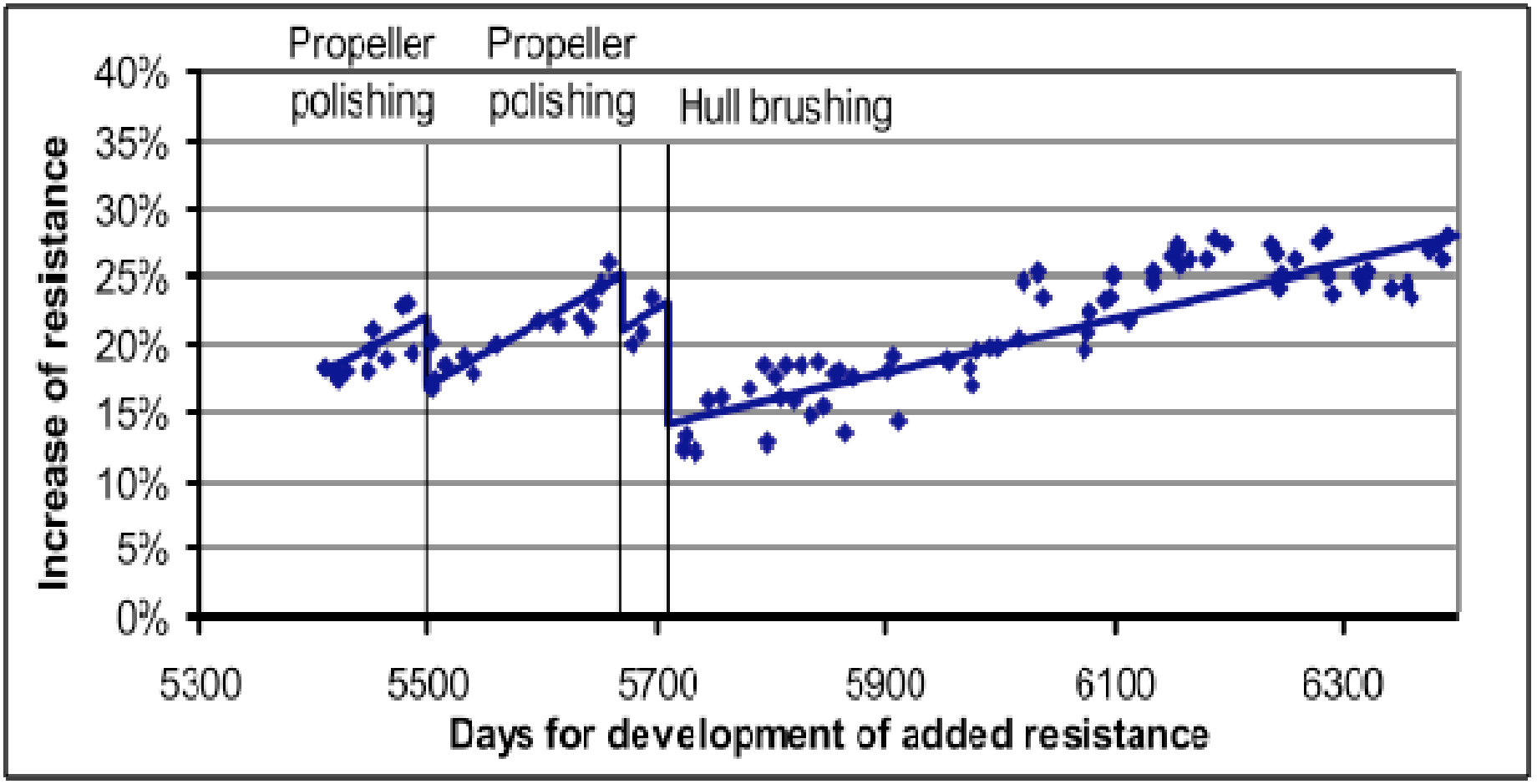
(low cost hull pre-treatment = higher resistance outdocking)



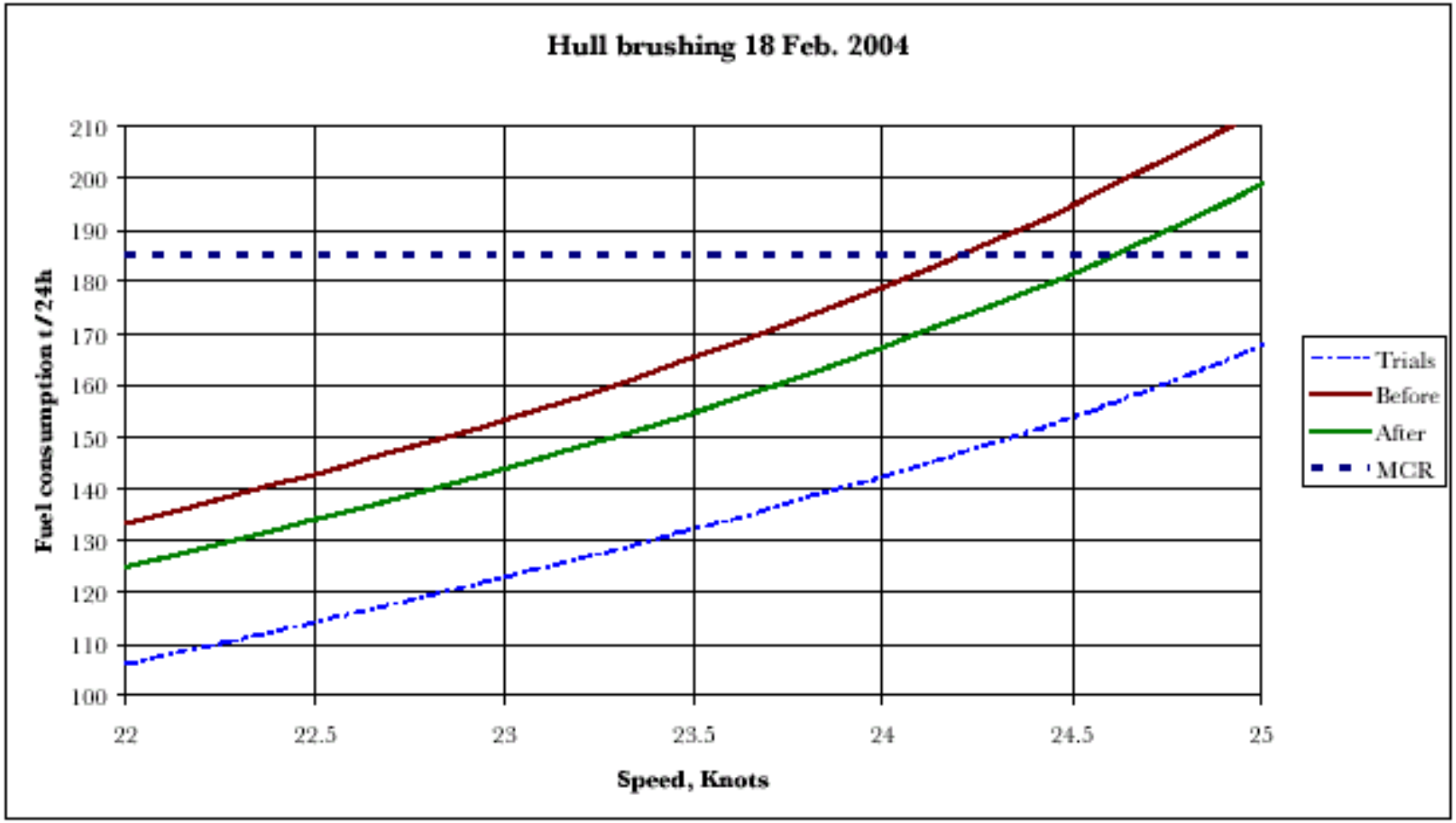


Cost-benefit metrics of hull/prop maintenance

(Prop polishing equates 5 tons per day saving, hull cleaning 12 tons per day)

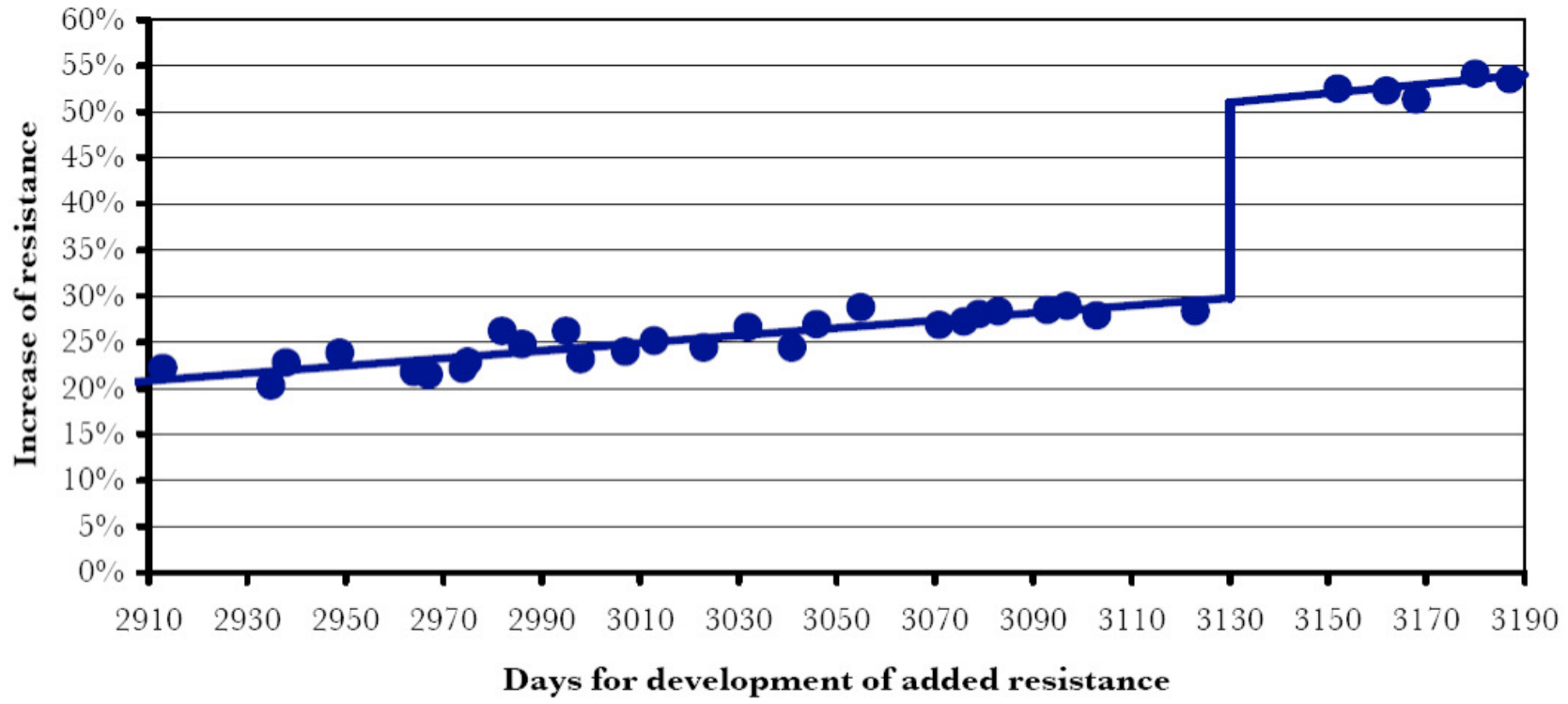


Cost-benefit of Hull Cleaning (prior slide)

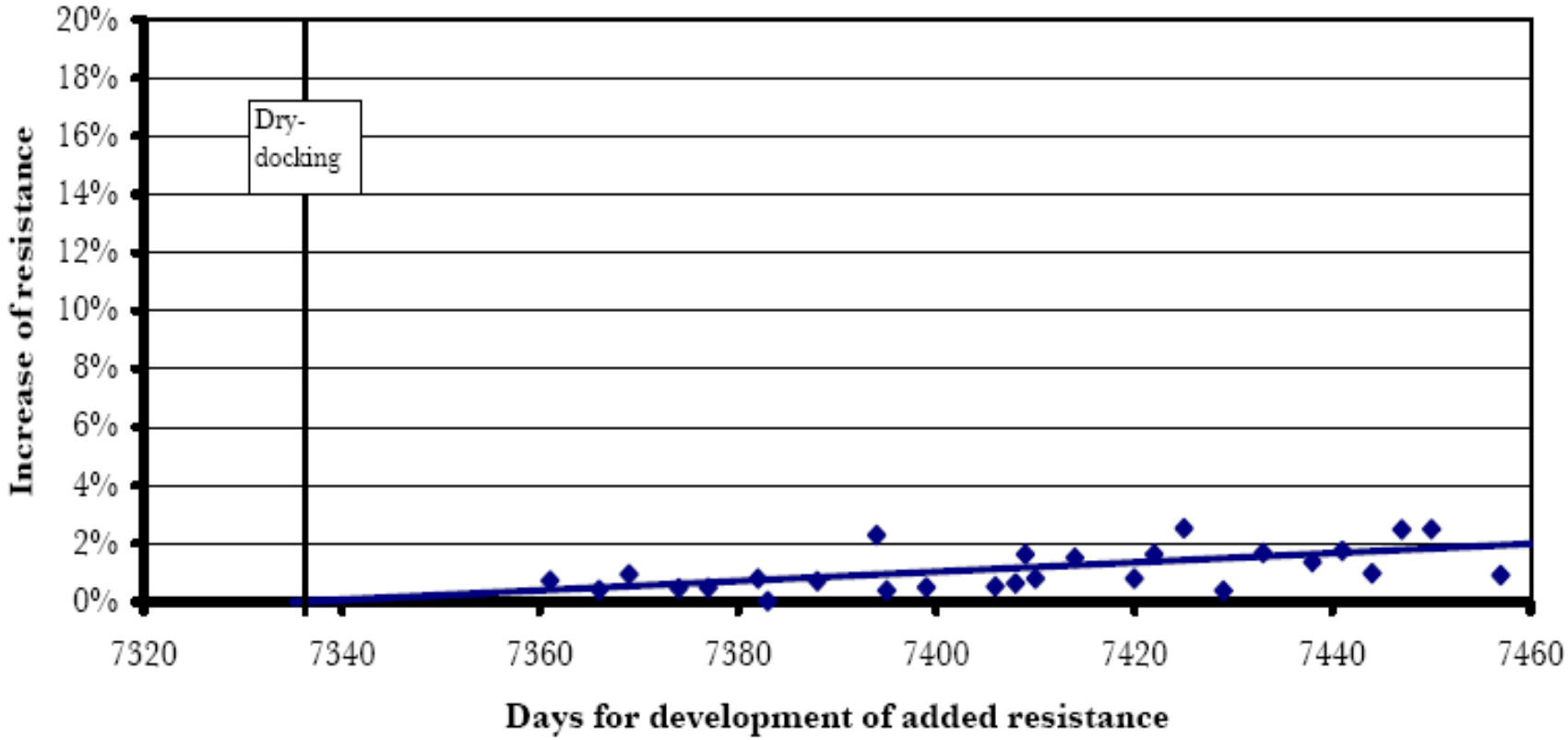


Long Port Stay

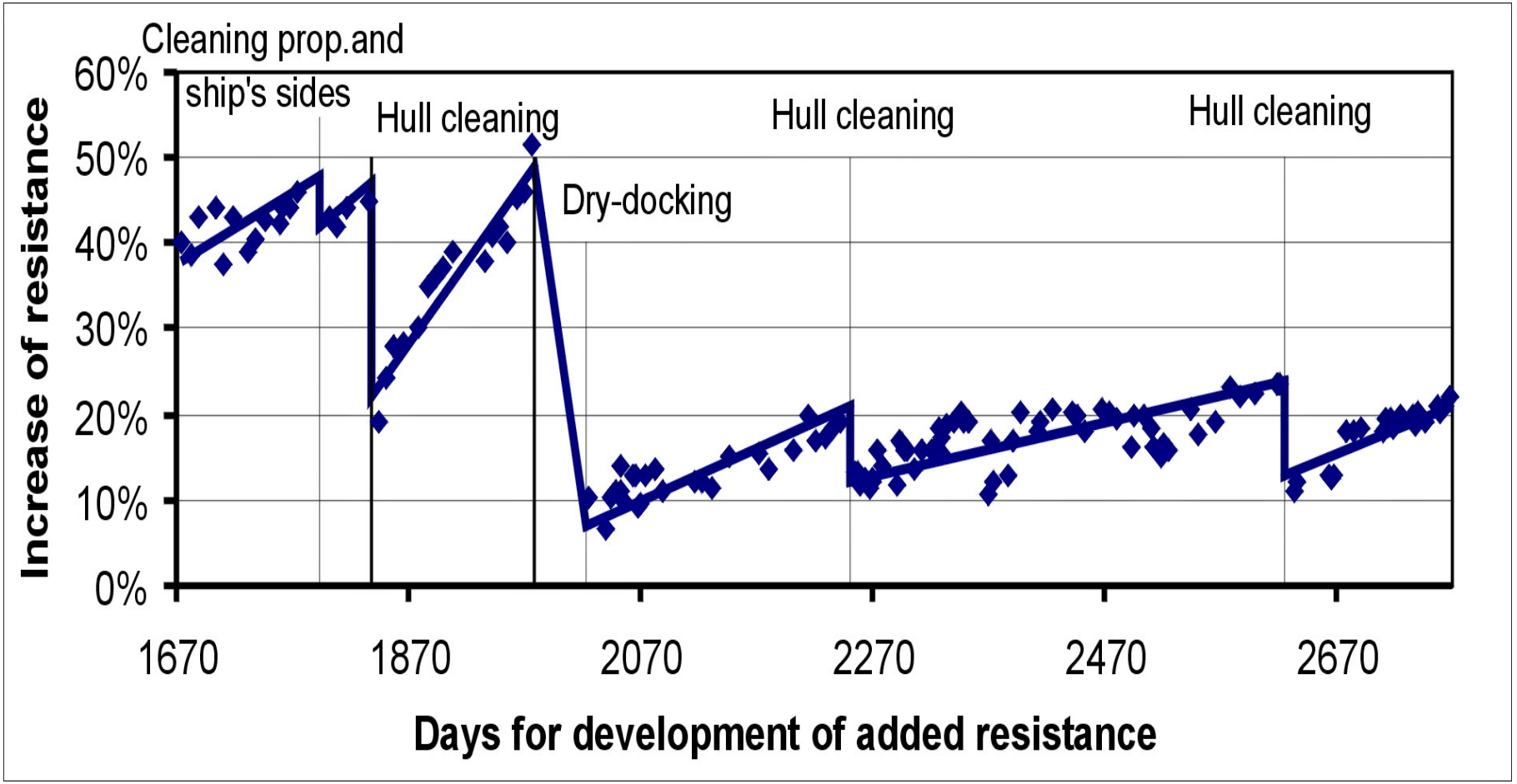
20% increase in hull resistance after 4-week stay
(speed loss approximately 0.9 kn or increase in fuel use 8 tons/day)



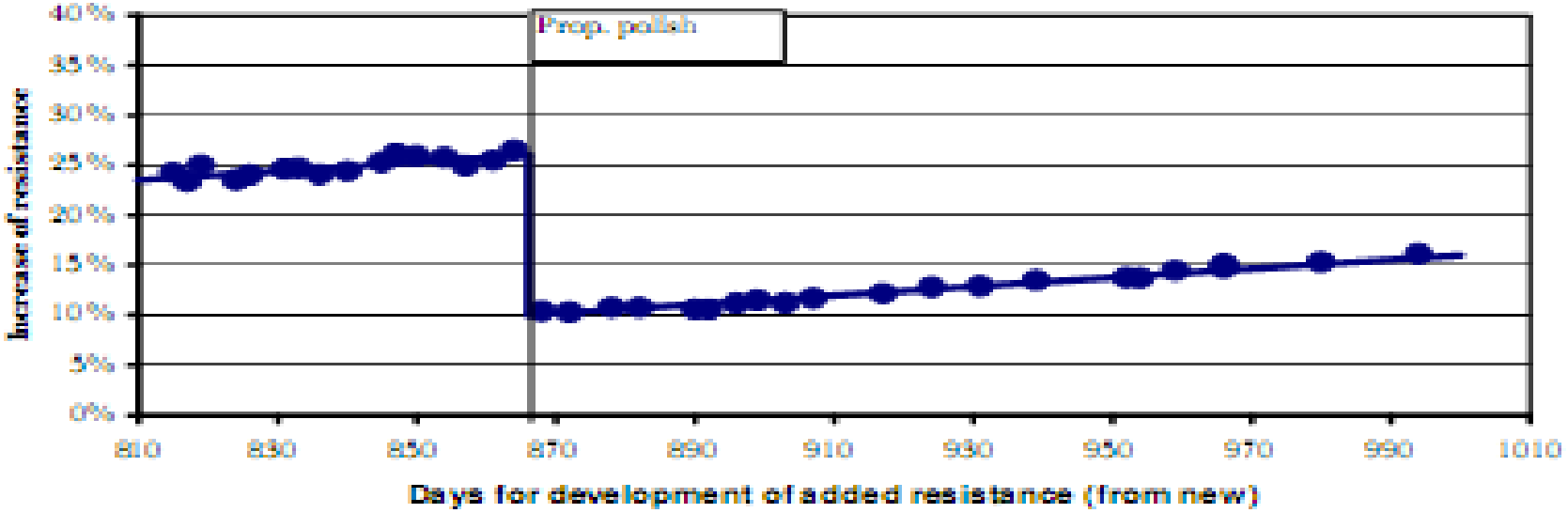
Full hull blast can make major difference in hull/prop condition

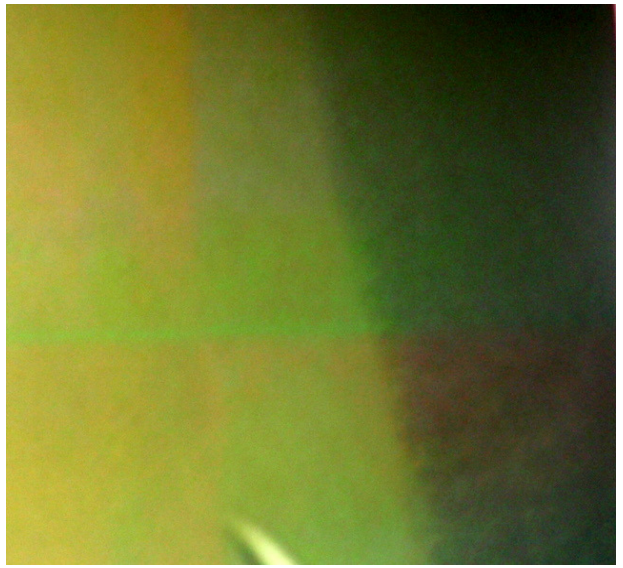


Time history of added resistance

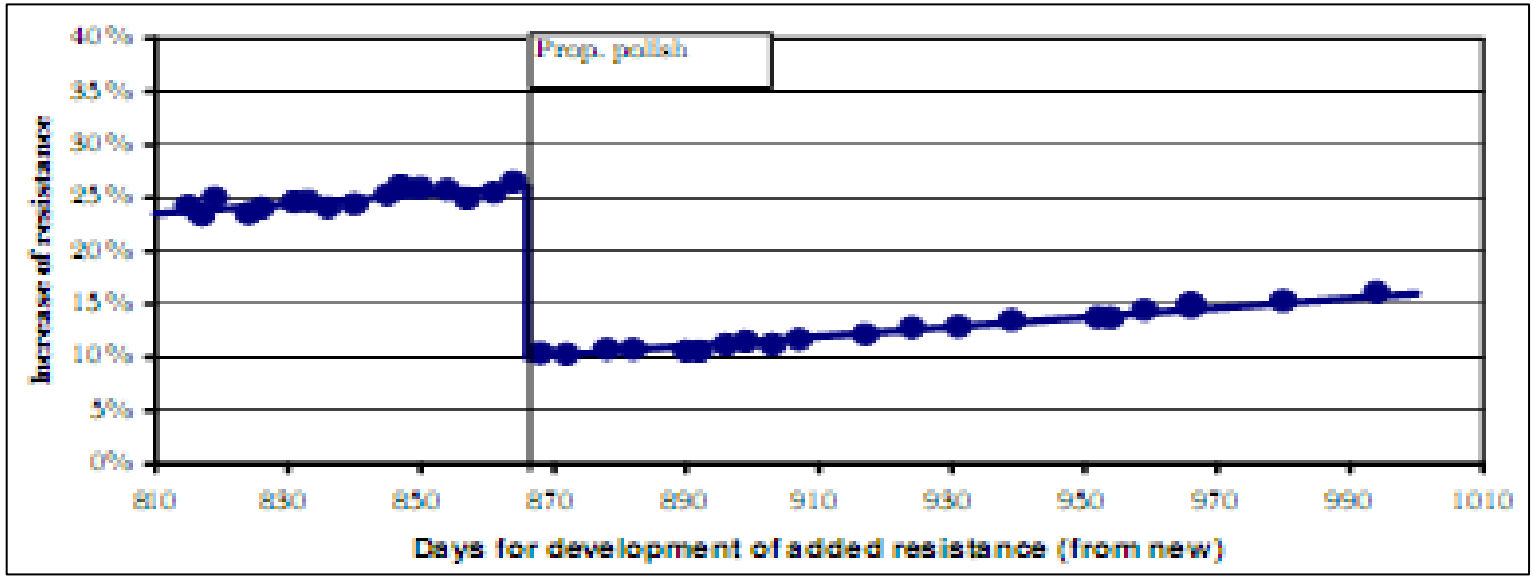


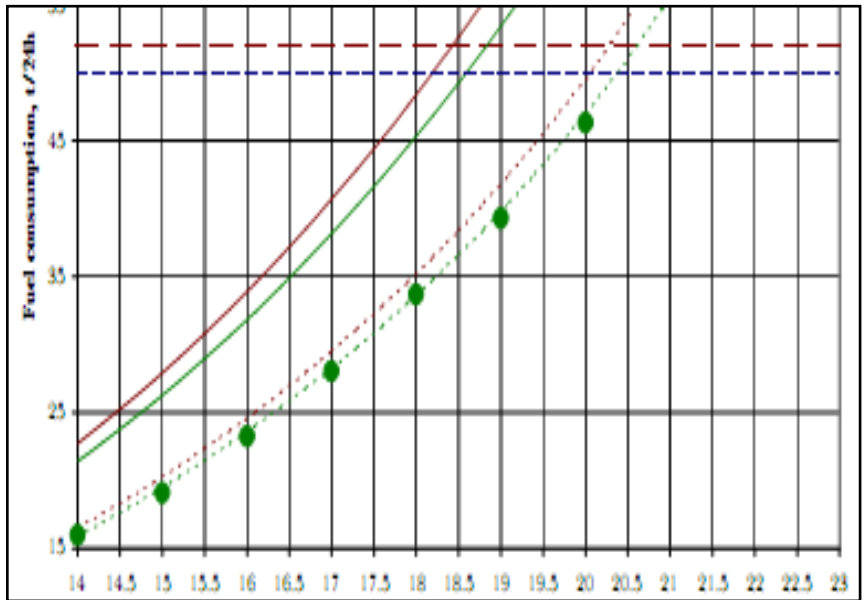
Slime = Fuel Loss



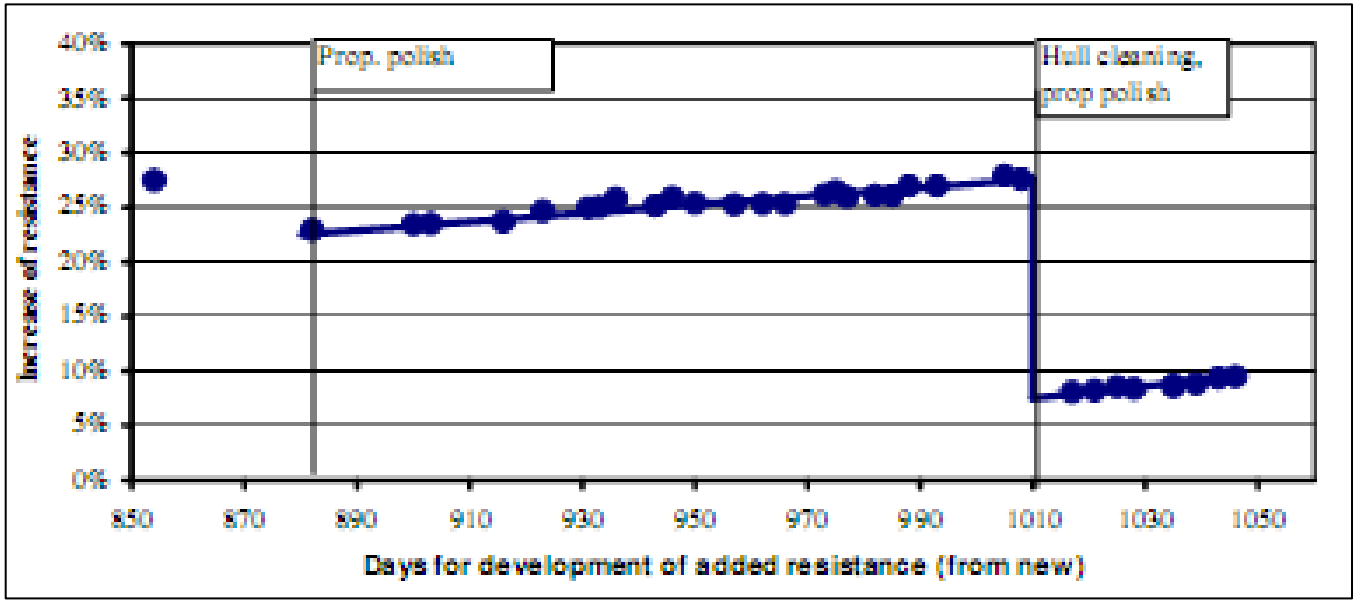


Slime Removal - 5 t/day @ 17.5 kn



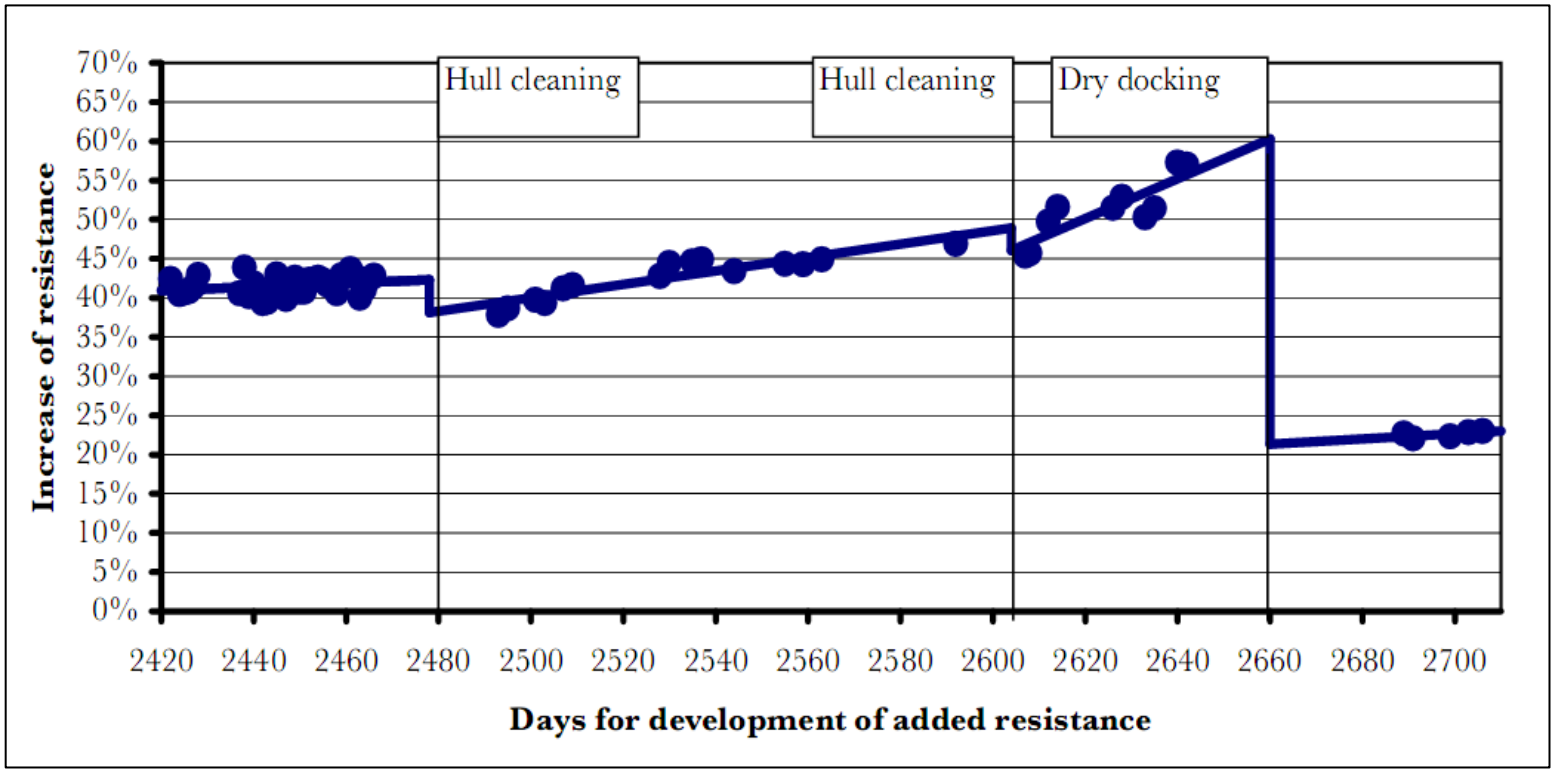


Hull + Prop Cleaning



Hull condition – at what cost?

Full blasting in dock



CO_2 index used (design)

Definition: Gram CO_2 per tons displacement per nautical mile

$$I_{CO_2} = k_1 \times D_d^{2/3} \times c_t \times v^3 / \eta_{tot} / D_d / v$$

$$= k_1 \times (v^2 / D_d^{1/3}) \times c_t / \eta_{tot}$$

$$= k_2 \times F^2 \times c_t / \eta_{tot}$$

D_d	Displacement at design draft
v	Design service speed (at design draft)
F_d	Froude's number, based on displacement ($F = v / D^{1/6}$)
c_t	Total resistance coefficient, design draft, design speed
η_{tot}	Total propulsion efficiency, (towing power / fuel power)
$k, k_1, k_2 \ldots$	constants

F is a measure of the relative speed and draft

c_t is a measure of the expediency of the hull form

η_{tot} is a measure of the expediency of the propulsion system

CO_2 index used (total)

$$I_{CO2,\ service} = I_{CO2,design} \times s$$

$$s = D_d^{1/3} \times v_{actual}^2 / (D_{actual}^{1/3} \times v_d^2) \times (1+\text{actual virtual added resistance factor})$$

$$I_{total} = I_{design} + I_{operation} + I_{maintenance}$$

Beyond Benchmarking - Driving down C02

Fleet Hull and Propeller Performance							
Using 'CASPER'							
Ship	Days Out of Dock	Maintenance Activity		Added Resistance	Variance from Benchmark (25%)	Fuel Savings Laden	CO_2 Index Laden
		Hull	Propeller	%	%	MT	gms/tons disp./mile
1	228			9.07	-15.93	1.13	3.75
2				30.29	5.29	8.13	3.28
3	194			25.62	0.62	2.21	3.50
4	1345	25-May-08		78.94	53.94	12.16	3.89
5	630	10-Jul-07	10-Jul-07	13.96	-11.04	2.78	3.67
6			12-Feb-09	50.61	25.61	12.45	3.79
7	526			22.41	-2.59	2.51	3.63
8	669			22.06	-2.94	2.41	3.62
9	730	01-Apr-07	15-Jan-09	16.95	-8.05	0.00	3.48
10	502	15-Nov-07	15-Nov-07	14.84	-10.16	3.39	3.67
11	1293		15-Dec-06	21.46	-3.54	4.87	3.60
12	472			29.08	4.08	2.05	3.82
13	441	15-Jan-08	15-Mar-09	2.10	-22.90	0.00	3.60

The CO2 Maintenance Index
Hull and propeller condition

grams/tons disp./nautical mile

Fuel / CO2 Index	**Laden**	**Ballast**
Design Index, Fuel	**1.024**	**2.168**
Maintenance Index	***0.233***	***0.220***
Total Index	**1.257**	**2.388**
Design Index, CO2	**3.225**	**6.829**
Maintenance Index, CO2	**0.735**	**0.693**
Total Index	**3.960**	**7.522**

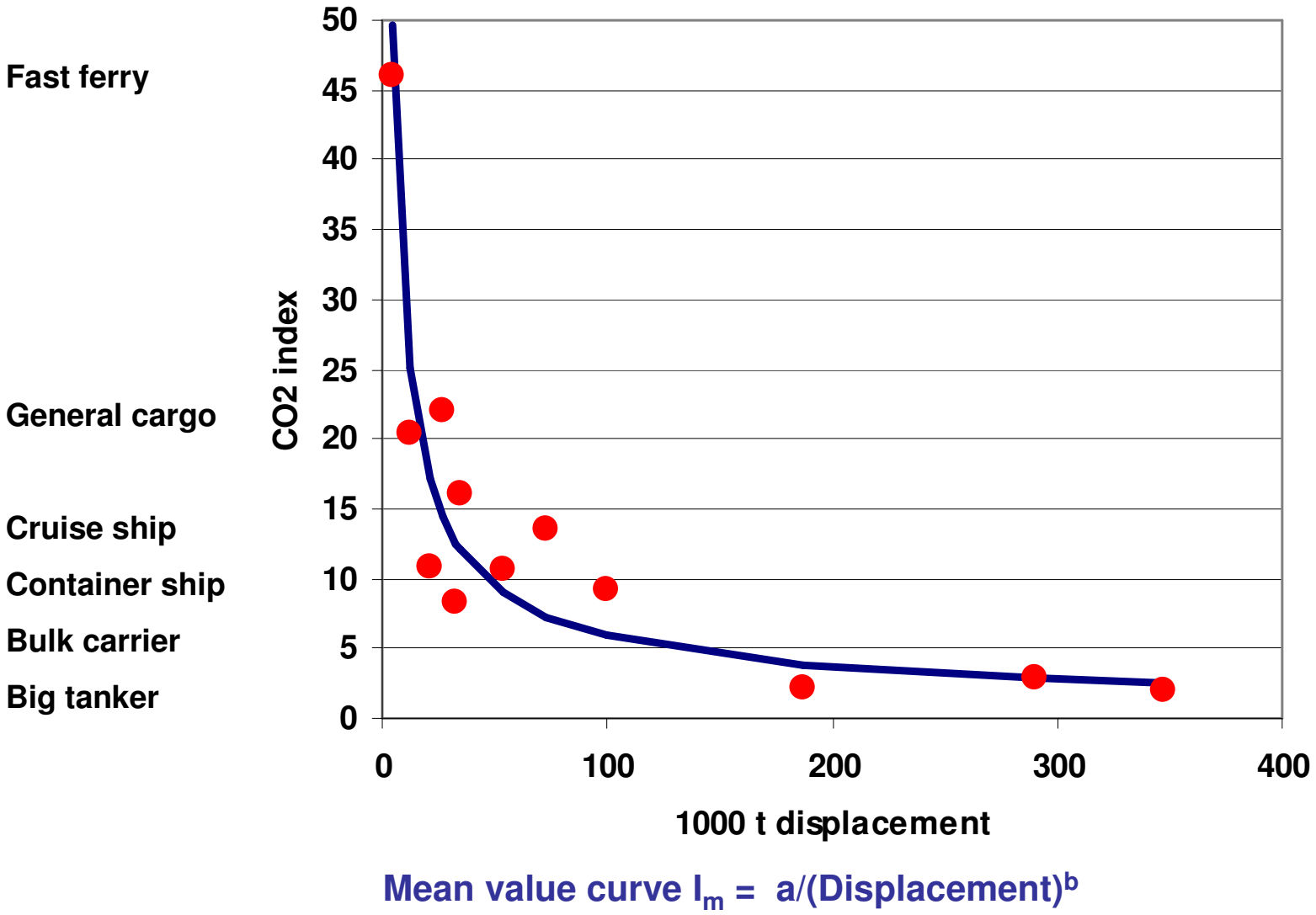
Sustaining hull/prop performance

Simplest CO2 Reduction
1. **Propeller polish intervals** (low cost, little risk)
2. **Hull Cleaning, condition-based** (higher cost, higher risk)
3. **Full hull blast in DDX** (high cost, 10+ year old ships)
4. **Hull Coating Selection** (higher quality within supplier's range)

Greatest C02 Reduction
1. **Full hull blast in DDX** (higher cost, 10+ year old ships)
2. **Propeller Polish intervals** (low cost, little risk)
3. **Hull Cleaning, condition-based** (higher cost, higher risk)
4. **Hull Coating Selection** (high quality coating)

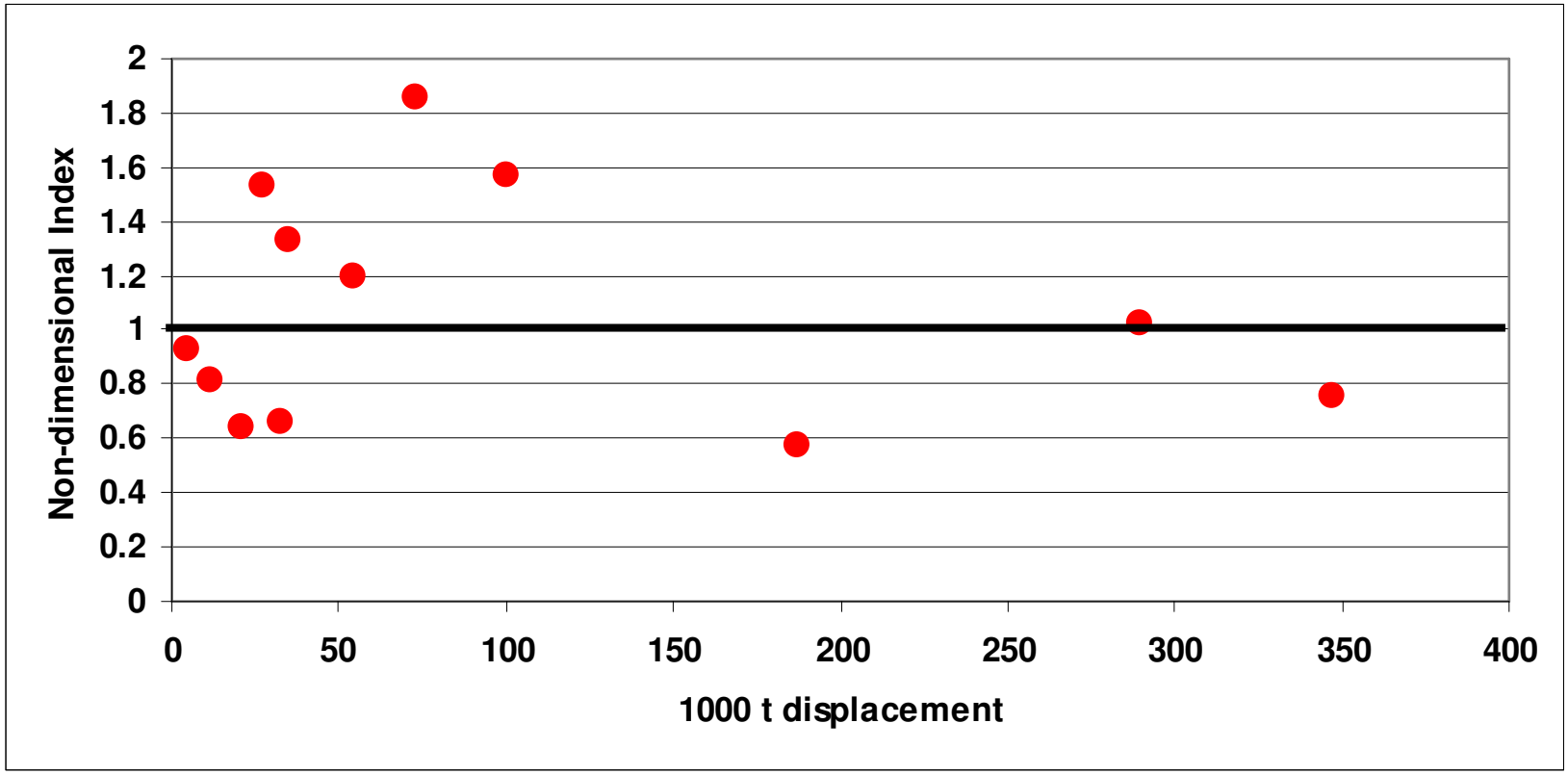
Depends on age of fleet, FOC, docking intervals, etc.

Examples of Index values for different ships



Mean value curve $I_m = a/(\text{Displacement})^b$

Non-dimensional Index = I/Im




Thank you for your attention