The Development of Ship Speed Verification Program Based on ISO 15016 Methodology for EEDI

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Verification of the Attained EEDI

• To verify reference speed of EEDI

\[
\text{Attained EEDI} = \frac{P \cdot C_F \cdot SFC}{f_i \cdot \text{Capacity} \cdot V_{\text{ref}} \cdot f_w}
\]

“Attained EEDI must be verified in a transparent, consistent and fair manner”

\( V_{\text{ref}} \) should be measured at sea trial condition and be analyzed to the standard condition. If sea trial cannot be conducted in max. load condition, the ship speed should be adjusted by an appropriate correction method.
Speed Trial Analysis Conditions

For the calm water and standard condition

- Wind
- Waves
- Shallow Water
- Current
- Disp. Dev.
- Surface Roughness
- Steering
- Drifting
- Water Density and Kinematic Viscosity
ISO 15016:2002 Standard

“ISO international standard exists that may be a starting point for the development of an EEDI verification procedure”
Develop the Computer Programme Complying with the ISO 15016

Use by Shipyards in Korea

Present at PRADS 8th Sep. 2001

Objectives of Speed Trial & Analysis

• To obtain powering performance data
• To obtain ship-model correlation allowance
• To determine the relationship between ship speeds and propeller revolutions
  ➡️ Ship Model Basin

• To fulfill contractual obligation at shipbuilding
  ➡️ Shipyard & Shipowner

• To verify reference speed of EEDI
  ➡️ IMO & Verifier
ISO 15016:2002
Guidelines for the assessment of speed and power performance by analysis of speed trial data
Contents of ISO 15016 Standard

1. Scope
2. Terms and definitions
3. Symbols and abbreviations
4. Trial conditions
5. Speed and power measurement
6. Analysis procedures
   Step 1: evaluation of acquired trial data.
   Step 2: correction of ship's performance for resistance increase.
   Step 3: correction of ship's performance for current.
   Step 4: correction of ship's performance for air resistance.
   Step 5: correction of ship's performance for shallow water.
   Step 6: final ship's performance.
## Analysis Methods of ISO 15016

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Resistance Increase due to Wind

- Model Test Results in Wind Tunnel, JTTC

\[ R_{AA} = \frac{1}{2} \rho_A C_{AA} (\psi_{WR}) A_{XV} V_{WR}^2 \]

(ISO 15016 Annex A
Resistance increase due to wind)

In cases where data are available covering ships of similar type, such data may be used instead of carrying out model tests.
Resistance Increase due to Ship Motion

• Maruo’s Method

\[ \Delta r = \frac{\rho}{4\pi} \left[ -\int_{-\infty}^{m_1} + \int_{m_2}^{m_3} + \int_{m_4}^{\infty} \right] \frac{k_u(m)(m-k \cos \chi)}{\sqrt{k_u^2(m) - m^2}} \left( |C(m)|^2 + |S(m)|^2 \right) dm \ (N/\text{m}^2) \]

\[ m_1 = -\frac{k_0}{2} \left( 1 + 2\tau \pm \sqrt{1 + 4\tau} \right) \]

\[ m_2 = \frac{k_0}{2} \left( 1 - 2\tau \mp \sqrt{1 - 4\tau} \right) \]

\[ k_u(m) = \frac{(m + k_0\tau)^2}{k_0} \]

\[ \tau = \frac{V_S \omega_e}{g} \]

It can be ignored in case of moderate sea conditions because ship motion appears at rough sea conditions.
Resistance Increase due to Wave Diffraction

- **Fujii-Takahashi’s Method** or
  \[
  \Delta r = \frac{1}{2} \rho g a_1 \zeta_A^2 (1 + a_2) \left[ \int_I \sin^2(\chi - \theta) \sin \theta \, dl + \int_{II} \sin^2(\chi + \theta) \sin \theta \, dl \right]
  \]

- **Faltinsen’s Method** or
  \[
  \Delta r = \frac{1}{2} \rho g a_1 \zeta_A^2 \left[ \int_I \left[ \sin^2(\chi - \theta) - \frac{2\omega V_s}{g} \{\cos \chi - \cos \theta \cos(\chi - \theta)\} \right] \sin \theta \, dl \\
  + \int_{II} \left[ \sin^2(\chi + \theta) - \frac{2\omega V_s}{g} \{\cos \chi - \cos \theta \cos(\chi + \theta)\} \right] \sin \theta \, dl \right]
  \]

- **Kwon’s Method**
  \[
  \Delta r = a^1 \cdot a^2 \cdot a^3 \cdot \frac{1}{2} \rho g \zeta_A^2 \int_{S_r} \left( \frac{\partial y}{\partial s} \right)^3 \, ds
  \]
Resistance Increase due to Irregular Waves

\[ R_{AW}(\chi) = 2\int_{-\pi}^{\pi} G(\alpha - \chi) \left[ \int_0^\infty S(f) \frac{\Delta r(f, \alpha)}{\zeta^2_A} df \right] d\alpha \]

for the frequency distribution of incident waves

- **ITTC Standard Spectrum for Sea Wave**
  \[ S(f) = \frac{0.11H_{1/3}^2T_{01}}{(T_{01}f)^5} \exp\left\{-\frac{0.44}{(T_{01}f)^4}\right\} \quad (m^2 \cdot s) \]

- **JONSWAP Spectrum for Swell**
  \[ S(f) = \frac{0.072H_{1/3}^2T_{01}}{(T_{01}f)^5} \exp\left\{-\frac{0.44}{(T_{01}f)^4}\right\} \times 3.3^{\exp\{-0.5(1.3T_{01}f-1)^2/\sigma^2\}} \quad (m^2 \cdot s) \]
Effect of Steering and Drifting

Effect of Steering for Course Keeping

- SR208 Report

\[ R_{\beta \beta} = \frac{1}{4} \pi \rho \, d^2 \, V_s^2 \, \beta^2 \]

Effect of Drifting

- SR208 Report

\[ R_{\beta \beta} = \frac{1}{2} \rho_A \, (1 - t_R) \, f_a(\lambda_R) \, A_R \, V_{eff}^2 \, \delta_R^2 \]
Effect of Water Temperature & Density

• Fundamental Method

\[ R_{AS} = R_{TS} \left( 1 - \frac{\rho_0}{\rho} \right) + \frac{1}{2} \rho S V^2 (C_F - C_{F0}) \]
Effect of Displacement Deviation

- Fundamental Method

\[ R_{ADIS} = 0.65 \ R_T \left(1 - \frac{\Delta O}{\Delta} \right) \]
Effect of Shallow Water

- Lackenby’s Method

\[
\frac{\Delta V_S}{V_S} = 0.1242 \left( \frac{A_M}{h^2} - 0.05 \right) + 1.0 - \left( \tanh \left( \frac{1}{F_n^2} \right) \right)^{0.5}
\]
Speed Loss from Resistance Increase

- Taniguchi & Tamura’s Method

\[ \Delta R = R_{AA} + R_{AW} + R_\delta + R_\beta + R_{AS} + R_{ADIS} \]

\[ \tau = \frac{K_T}{J^2} \]

\[ \Delta \tau = \frac{\Delta R}{R} \cdot \tau \]

\[ \tau_1 = \tau - \Delta \tau \]

\[ \tau_1 (\tau : K_Q) \Rightarrow K_{Q1} \]

\[ n_1 = n \cdot \frac{J}{J_1} \]

\[ n(n_1 : K_{Q1}) \Rightarrow K'_Q \]

\[ \Delta V_G = \frac{a \cdot D \cdot n \cdot (K'_Q - K_Q)}{(1 - w)_m} \]
Comprehensive Computer Programme
ST10
Complying with the ISO 15016 Speed Trial Analysis Guidelines
## Computer Programme ST10

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</tr>
<tr>
<td>Lackenby</td>
<td></td>
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<td>ITTC '78</td>
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</table>
Resistance Increase due to Wind

- Model Test, JTTC, Blenderman or Isherwood (Supplemented methods)

\[ R_{AA} = \frac{1}{2} \rho_A C_{AA} \left( \psi_{WR} \right) A_{XV} V_{WR}^2 \]
Effect of Hull Surface Roughness

Effect of Hull Surface Roughness can no longer be neglected, some methods may be available for correcting such effects.

- **ITTC-78 = Bowden’s Formula**
  (Supplemented methods)

$$R_{hull} = \frac{1}{2} \rho S V^2 \frac{105}{L^3} \left( k_{S_{real}}^{1/3} - k_{S_{standard}}^{1/3} \right) \cdot 10^{-3}$$
Effect of Propeller Surface Roughness

(ISO 15016  E.2 Hull and propeller surface roughness)

The effect of surface roughness can no longer be neglected, some methods may be available for correcting such effects.

- **ITTC-78 = Schlichting’s Formula**
  (Supplemented methods)

\[
K_{TSR} = K_{OTS} + \Delta C_D \ 0.3 \ \frac{P}{D} \ \frac{c}{D} \ Z
\]

\[
K_{QSR} = K_{OQS} - \Delta C_D \ 0.25 \ \frac{c}{D} \ Z
\]

where \( \Delta C_D = 2\left(1 + 2\frac{t}{c}\right)\left[\left(1.89 + 1.62 \log \frac{c}{k_{p0}}\right)^{-2.5} - \left(1.89 + 1.62 \log \frac{c}{k_p}\right)^{-2.5}\right] \)
## Interpolation Methods

<table>
<thead>
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<th>Interpolation Method</th>
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<td>V : t, w, $\eta_R$</td>
<td>2nd Degree Polynomial</td>
</tr>
<tr>
<td>J : $K_Q$</td>
<td>2nd Degree Polynomial</td>
</tr>
<tr>
<td>J : $\text{TAU} (=K_T/J^2)$</td>
<td>2nd Rational Function</td>
</tr>
<tr>
<td>N : $K_Q$</td>
<td>Least Square</td>
</tr>
<tr>
<td>Time : Current</td>
<td>Cubic Spline</td>
</tr>
<tr>
<td>V : $P_D$, N</td>
<td>Least square or Cubic Spline</td>
</tr>
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Flowchart of the Programme ST10

Main Programme (Trial Analysis)

**STEP 1: EVALUATION OF ACQUIRED TRIAL DATA**

- **SHIP PERFORMANCE:** VC, PDV, NV
- **TORQUE IDENTITY:** KQS > JQS
- **CALCULATION:** TAU/V, RTV
- **LOAD FACTOR:** TAUPV = TAU/V - DTAV
- **INTERPOLATION:** TAUPV > NV, KQV
- **FAIRING:** NS > (NV : KQV) > KQFV
- **SHIP PERFORMANCE:** VV, PDV, NS
- **CURRENT SPEED:** VC = VV - US
- **SHIP PERFORMANCE:** VC, PDV, NS
- **LOAD FACTOR:** TAUPA = TAU/A - DTAA
- **INTERPOLATION:** TAUPA > NA, KQA
- **FAIRING:** NS > (NA : KQA) > KQFA
- **SHIP PERFORMANCE:** VA, PDA, NS
- **SPEED LOSS:** VW = VA - DELV
- **FINAL PERFORMANCE:** VW, PDA, NS

**STEP 2: CORRECTION FOR CURRENT AT NO WAVES, VACUUM, NO STEERING, NO DRIFTING, CLEAN HULL, CORRECT DISPLACEMENT AND NO CURRENT**

**STEP 3: CORRECTION FOR CURRENT AT NO WAVES, VACUUM, NO STEERING, NO DRIFTING, CLEAN HULL, CORRECT DISPLACEMENT AND NO CURRENT**

**STEP 4: CORRECTION FOR AIR RES. AT NO WAVES, VACUUM, NO STEERING, NO DRIFTING, CLEAN HULL, CORRECT DISPLACEMENT AND NO CURRENT AND WIND FOR SELF SHIP SPEED**

**STEP 5: CORRECTION FOR SHALLOW W. AT NO WAVES, VACUUM, NO STEERING, NO DRIFTING, CLEAN HULL, CORRECT DISPLACEMENT AND NO CURRENT AND WIND FOR SELF SHIP SPEED AND DEEP SEA**

**PRE CALCULATION OF RESPONSE FUNCTION OF ADDED RESISTANCE IN REGULAR WAVES**

**DTAV FROM RESISTANCE INCREASE DUE TO WAVE (SEAS & SWELL), WIND, STEERING, DRIFTING, HULL ROUGH DISPLACEMENT CORRECTION**

**FAIRED CURRENT SPEED**

**DTAA DUE TO RESISTANCE INCREASE FOR WIND CORRESPONDING TO SHIP SELF SPEED**

**SPEED LOSS FOR SHALLOW WATER**

**Pre Programme (Res. due to ship motion in regular waves)**

**Post Programme (V-P Curves)**
Construction of Programme ST10

Pre Programme MOT (Response Function)

Main Programme ST (Trial Analysis)

Post Programme GRAPH (V-P Curves Various Draft)

Lines Data .MOT file

Resp. F. Data .ARM file

Sea Trial Data .INP file

Output Data .SST file

Model T. Data .MST file

V-P Curves Graphic file
Input of Main Programme
Run of Main Programme: \*.ARM+\*.INP→\*.SST
Run of Post Programme: .SST+.MST→Graph
Trial Performance of the ST10

Pre Programme MOT (Response Function)

Main Programme ST (Trial Analysis)

Post Programme GRAPH (V-P Curves Various Draft)
### Output of Main Programme .SST

#### Pre Programme MOT
(Response Function)

#### Main Programme ST
(Trial Analysis)

#### Post Programme GRAPH
(Graphical Results)

### Sea Trial Data .INP file

### Model T. Data .MST file

### Lines Data .MOT file

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### SPEED TRIAL ANALYSIS PROGRAM ST10E62 : INPUT DATA

**FILE NAME**: 360001.inp  36001.inp  
**DATE**: 19.05.89  19.05.89  
**TIME**: 15.00  15.00  
**RUNNER**: 1800  1800  
**REV. (RPM)**: 83.90  83.90  
**B.SPEED**: 20.770  20.770  
**SPEED (KNOT)**: 20.770  20.770  
**RUNNING DIRECTION**: 20.0  20.0  
**INNING TIME (HOUR)**: 9.0  9.0  
**BEAUFORT NUMBER**: 0.0  0.0  
**SPEED TRIAL RESULTS**

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### Waterline Offsets : X(METER:FP=0)/Y(METER:B/2)

<table>
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<tr>
<th>Step</th>
<th>X(METER)</th>
<th>Y(METER)</th>
</tr>
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<tbody>
<tr>
<td>1</td>
<td>0.250</td>
<td>0.250</td>
</tr>
<tr>
<td>2</td>
<td>0.150</td>
<td>0.150</td>
</tr>
<tr>
<td>3</td>
<td>0.980</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>0.740</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>0.660</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>0.580</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>0.500</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>0.420</td>
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</tbody>
</table>

### WS : 0.250 0.250 0.250 0.250 0.250 0.250 0.250 0.250

---

### Program Output

**D, KRISO** 2D SCALE = 30.0000

**DELCF** = 0.72

---

### Programme Steps

**STEP I** : EVALUATION OF SEA WAVE AND SWELL RESISTANCE

**STEP II** : CORRECTION FOR VARIOUS RESISTANCE INCREASE

**STEP III** : CORRECTION FOR CURRENT

**STEP IV** : CORRECTION FOR WIND RESISTANCE DUE TO SELF SPEED

**STEP V** : CORRECTION FOR SHALLOW WATER EFFECT

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### Model T. Data

**SHIP**: K3600  **PROP. NAME**: K3600  **WEATHER**: CLOUDY
Output of Post Programme  V-P Curves

\[ P \cdot C_F \cdot SFC \]

\[ f_i \cdot \text{Capacity} \cdot V_{\text{ref}} \cdot f_w \]
Evaluation of the Computer Programme

- to comply with the ISO 15016 procedure
- to contain all of the ISO 15016 methods
- to supplement few reliable methods
- to emphasize the graphic user interface and automatic calculation from input data
- to implement the evident reporting form
- to confirm the good agreement with the example of ISO 15016 standard values
Verification of the EEDI

- Verification process of reference speed (Vref) is a technical issue and one of the targets of the EEDI.

\[
\text{Attained EEDI} = \frac{P \cdot C_F \cdot SFC}{f_i \cdot \text{Capacity} \cdot V_{\text{ref}} \cdot f_w}
\]

- The ISO 15016 speed trial analysis guidelines which has already been developed by ISO is known to be a very sophisticated method that can consider various effects, such as wave, wind, steering, drifting, water temperature, salt content, shallow water and various vessel conditions.

- The computer programme complying with the ISO 15016 standard could be a solution for the consistent verification process of the reference speed from the sea trial condition of any draft condition to the standard condition of maximum design load condition.
The Development of Ship Speed Verification Program Based on ISO 15016 Methodology for EEDI

If you have any questions, please contact:
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Thank you very much