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**Ships and marine technology —  
Manoeuvring of ships —**

**Part 5:  
Submarine specials**

*Navires et technologie maritime — Manoeuvres des navires —  
Partie 5: Spécificités des sous-marins*

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## Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see [www.iso.org/directives](http://www.iso.org/directives)).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see [www.iso.org/patents](http://www.iso.org/patents)).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation on the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT) see the following URL: [www.iso.org/iso/foreword.html](http://www.iso.org/iso/foreword.html).

The committee responsible for this document is ISO/TC 8, *Ships and marine technology*, Subcommittee SC 6, *Navigation and ship operations*.

This second edition cancels and replaces the first edition (ISO 13643-5:2013), of which it constitutes a minor revision with the following changes:

- the numbering has been changed;
- in [Figure 1](#), key 2 has been changed from “boat dynamically unstable” to “boat dynamically stable”;
- in [Figure 1](#), key 5 has been changed from “dynamically unstable” to “dynamically stable”.

A list of all parts in the ISO 13643 series can be found on the ISO website.

# Ships and marine technology — Manoeuvring of ships —

## Part 5: Submarine specials

### 1 Scope

This document defines symbols and terms and provides guidelines for the conduct of tests to give evidence about the manoeuvring ability in the vertical plane of submarines and models. It is intended to be read in conjunction with ISO 13643-1.

### 2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 13643-1:2017, *Ships and marine technology — Manoeuvring of ships — Part 1: General concepts, quantities and test conditions*

### 3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- IEC Electropedia: available at <http://www.electropedia.org/>
- ISO Online browsing platform: available at <http://www.iso.org/obp>

#### 3.1

##### **meander test**

manoeuvring test to establish a submarine's manoeuvring characteristics and to verify the submarine's dynamic stability in the vertical plane

#### 3.2

##### **vertical overshoot test**

manoeuvring test to determine the effectiveness of the stern planes when initiating and terminating changes of depth

#### 3.3

##### **neutral level flight test**

manoeuvring test to determine the trim angle and the hydroplane angles at which the submarine maintains a constant dived depth at any given speed during submerged operation

Note 1 to entry: Neutral level flight is obtained

- for submarines with retracted bow planes by using a definite trim angle and a definite angle of stern planes, and
- for submarines with non-retractable bow planes, by using definite angles of the bow and stern planes for arbitrary trim angles (preferably  $\theta_S = 0^\circ$ ).

**3.4 critical speed test**

manoeuvring test to determine the speed at which the effect of the hydroplanes is reversed during submerged operation

**4 Test-related physical quantities**

Test-related physical quantities are according to [Table 1](#); general quantities and concepts are according to ISO 13643-1.

**Table 1 — Test-related physical quantities**

Symbol	CC-code	SI unit	Concept	
			Term	Definition or explanation
$a_1$	—	rad m <sup>2</sup> s <sup>-2</sup> a	Coefficient	For regression approximation
$a_2$	—	m <sup>2</sup> s <sup>-2</sup>	Coefficient	For regression approximation
$b_1$	—	rad m <sup>2</sup> s <sup>-2</sup> a	Coefficient	For regression approximation
$b_2$	—	m <sup>2</sup> s <sup>-2</sup>	Coefficient	For regression approximation
$C_c$	CCR	1	Damping ratio	Ratio between damping constant $\ln 2/t_{1/2}$ and eigenfrequency $2\pi/T_0$ of the undamped oscillation
$c_1$	—	rad m <sup>2</sup> s <sup>-2</sup> a	Coefficient	For regression approximation
$d_1$	—	rad m <sup>2</sup> s <sup>-2</sup> a	Coefficient	For regression approximation
$F_V$	FVC	N	Vertical force	—
MA	MAX	—	Main axis	(See ISO 13643-1)
$M_T$	MYT	Nm	Trim moment	—
$T$	TIP	s	Period of oscillation	Period of the damped oscillation, average of times $[t_{A(i+1)} - t_{Ai}]$
$T_0$	TIP0	s	Period of oscillation	Period of the undamped oscillation
$t_A$	TIA	s	Response time	For meander test: Times to achieve the trim amplitudes, $\theta_{Ai}$ , $i = 1, 2, 3, \dots$
				For vertical overshoot test: Time to change trim angle by $\Delta\theta_E$
$t_C$	TIC	s	Overshoot time	Time from putting the stern planes into the opposite direction until reaching maximum trim angle
$t_t$	TIT	s	Levelling-off time	Time from putting the stern planes into the opposite direction until reaching maximum depth change
$t_{1/2}$	T105	s	Time to half-value	Time elapsed before the envelope of time-dependent trim variation has decreased by half
$V_{CR}$	VCR	m s <sup>-1</sup> b	Critical speed	Speed at which the effect of the hydroplanes is reversed
$V_F$	VF	m s <sup>-1</sup> b	Final speed	Speed at the end of test (run)
$V_0$	V0	m s <sup>-1</sup> b	Initial speed	(See ISO 13643-1)
$V_{0i}$	VOI	m s <sup>-1</sup> b	Initial speed	For neutral level flight and vertical overshoot test: For individual runs of the test
$V_{0m}$	VOM	m s <sup>-1</sup> b	Mean test speed	—
$z_0$	Z0	m	Dived depth	Vertical coordinate in the earth-fixed axis system of the origin of the submarine (see ISO 13643-1:2017, Table 2) at any given time

<sup>a</sup> For angles, the unit ° (degree) may be used.

<sup>b</sup> The unit kn, common in navigation, may be used.

Table 1 (continued)

Symbol	CC-code	SI unit	Concept	
			Term	Definition or explanation
$z_{00}$	Z00	m	Initial dived depth	At the commencement of the test (run)
$\dot{z}_{0F}$	DZDTF	$m s^{-1}$ <sup>b</sup>	Rate of depth change	When constant trim angle, $\theta_F$ , has been reached
$\Delta z_{0E}$	DZ0E	m	Response depth change	Change of depth relative to $z_{00}$ when trim angle is changed by $\Delta\theta_E$
$\Delta z_{0F}$	DZ0F	m	Final change of dived depth	Under steady final conditions, only defined for a dynamically stable boat
$\Delta z_{0M}$	DZ0M	m	Levelling-off depth change	Maximum change of depth, relative to $z_{00} + \Delta z_{0E}$
$\Delta\delta_{Si}$	DANSI	rad <sup>a</sup>	Test stern plane angle	Relative to $\delta_{S0}$ ; if necessary, an equivalent stern plane angle shall be given, e.g. for submarines with X-planes: $\frac{1}{4} (\Delta\delta_{Ai1} + \Delta\delta_{Ai2} + \Delta\delta_{Ai3} + \Delta\delta_{Ai4})$ .
$\Delta\theta_E$	DTETPE	rad <sup>a</sup>	Execute change of trim angle	For meander test: $\theta_E - \theta_{S0}$ Specified change of trim angle relative to $\theta_{S0}$ at which the stern planes are returned to their initial settings $\theta_{S0}$
				For vertical overshoot test: $\theta_E - \theta_{S0}$ Specified change of trim angle relative to $\theta_{S0}$ at which the stern planes are applied in the opposite direction ( $\delta_{Si}$ )
$\delta_B$	ANB	rad <sup>a</sup>	Bow plane angle	(See ISO 13643-1)
$\delta_{B0}$	ANB0	rad <sup>a</sup>	Initial bow plane angle	For meander, vertical overshoot, and critical speed tests: Bow plane angle at the commencement of the test (valid for neutral level flight)
			Bow plane angle for neutral level flight	Result of neutral level flight test
$\delta_S$	ANS	rad <sup>a</sup>	Stern plane angle	(See ISO 13643-1)
$\delta_{SX}$	ANSX	rad <sup>a</sup>	Angle of stabilising fin or of the fixed post of a stern plane	Relative to the horizontal plane in MA, positive when leading edge tilts upwards
$\delta_{SX0}$	ANSX0	rad <sup>a</sup>	Angle of stabilising fin or of the fixed post of a stern plane, for neutral level flight	—
$\delta_{Si}$	ANSI	rad <sup>a</sup>	Test stern plane angle	Relative to $\delta_{S0}$ ; if necessary, an equivalent stern plane angle shall be given, e.g. for submarines with X-planes: $\frac{1}{4} (\delta_{Ai1} + \delta_{Ai2} + \delta_{Ai3} + \delta_{Ai4})$ .
$\delta_{S0}$	ANS0	rad <sup>a</sup>	Initial stern plane angle	For meander, vertical overshoot and critical speed tests: Stern plane angle at the commencement of the test (valid for neutral level flight)
			Stern plane angle for neutral level flight	Result of neutral level flight test: If necessary, an equivalent stern plane angle shall be given, e.g. for submarines with X-planes: $\frac{1}{4} (\delta_{A01} + \delta_{A02} + \delta_{A03} + \delta_{A04})$ .

<sup>a</sup> For angles, the unit ° (degree) may be used.

<sup>b</sup> The unit kn, common in navigation, may be used.

Table 1 (continued)

Symbol	CC-code	SI unit	Concept	
			Term	Definition or explanation
$\theta_A$	TRIMSA	rad <sup>a</sup>	Trim amplitude	Absolute value of the respective extreme $\theta_{Ai}$ , $i = 1, 2, 3, \dots$ of the change of trim with reference to $\theta_0$
$\theta_E$	TRIMSE	rad <sup>a</sup>	Execute trim angle	$\theta_{S0} + \Delta\theta_E$
$\theta_F$	TRIMSF	rad <sup>a</sup>	Trim angle at the end of run	Constant trim angle for the respective hydroplane settings
$\theta_S$	TRIMS	rad <sup>a</sup>	Trim angle	(See ISO 13643-1)
$\theta_{SS}$	TRIMSS	rad <sup>a</sup>	Overshoot angle	In the vertical plane after applying the stern planes in the opposite direction
$\theta_{S0}$	TRIMS0	rad <sup>a</sup>	Initial trim angle	For meander, vertical overshoot, and critical speed tests: Trim angle at the commencement of the test (valid for neutral level flight)
			Trim angle for neutral level flight	Result of neutral level flight test: Trim angle at which the submarine maintains a constant dived depth
<sup>a</sup> For angles, the unit ° (degree) may be used. <sup>b</sup> The unit kn, common in navigation, may be used.				

## 5 General test conditions

In addition to the general test conditions outlined in ISO 13643-1, the following specific test conditions shall be complied with.

- During the test, including the approach phase, each successive position of the ship shall be recorded at suitable time intervals (usually every second).
- The submarine shall be trimmed according to the results of the neutral level flight test (see [Clause 8](#)).
- Dived depth and water depth shall be sufficient (a clearance of at least one boat's length to the surface and to the bottom shall be maintained). For model tests, surface and bottom effects shall be excluded by the use of suitable measures.
- The bow plane angle shall remain unaltered.
- There shall be no relocation of mass (e.g. due to movements of the crew) during the conduct of any test. Unavoidable shifts of mass are to be compensated and recorded.

## 6 Test 5.1 — Meander test

### 6.1 Description

A series of tests for different initial speeds shall be conducted since damping and time constants of the motion of the submarine are speed-dependent, and a boat that proves to be stable at low speeds may become unstable at higher speeds.

For safety reasons, the series of tests shall be commenced with a low initial speed,  $V_0$ .

The submarine shall approach on a steady speed,  $V_0$ , before commencing the test. During the test, the propulsion plant settings shall remain unaltered and the heading kept as constant as possible. Heading and rudder movements shall be recorded throughout the test (ideally, at intervals of 1 s). If the submarine is equipped with planes acting simultaneously in the horizontal and the vertical directions

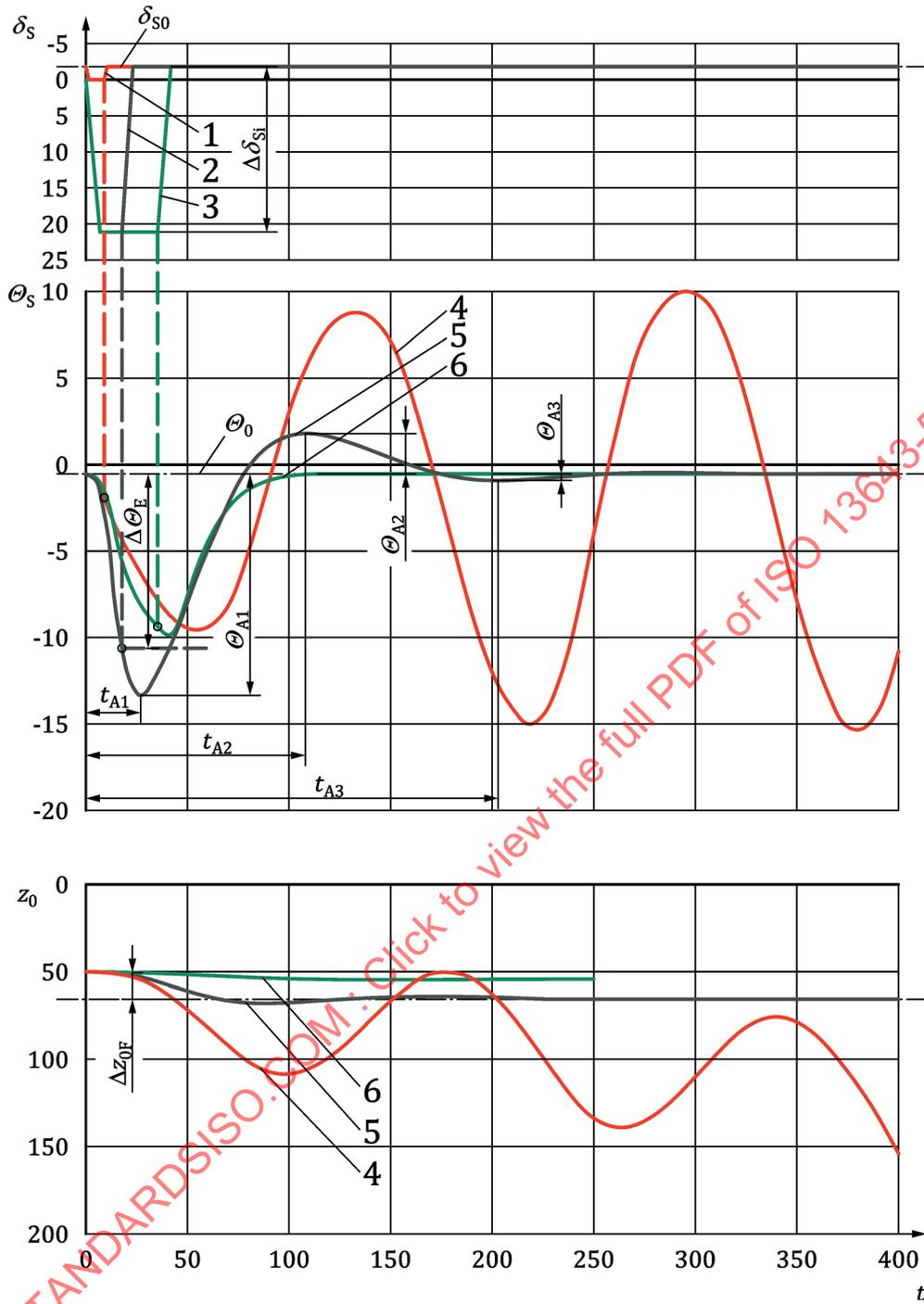
(e.g. X-planes), these planes should be controlled in such a way that a steady heading is maintained as a matter of priority.

After the submarine has been moving ahead for at least 2 min without significant movements of rudder and planes, the stern planes are set to the specified test stern plane angle,  $\Delta\delta_{Si}$ , as fast as possible and shall be held there until the trim angle has deviated from the initial trim angle,  $\theta_{S0}$ , by the specified execute change of trim angle,  $\Delta\theta_E$ . At this point, the stern planes are reversed to the initial position and held until the test is completed.

The stern plane impetus moves the submarine from its equilibrium condition. Test stern plane angle,  $\Delta\delta_{Si}$ , and execute change of trim angle,  $\Delta\theta_E$ , shall be selected in such a way that the stern plane impetus acts as quickly and powerfully as possible, and the submarine has at least three measurable trim amplitudes,  $\theta_A$ , in the case of a subsequent oscillation. Only data after completion of the stimulation are to be evaluated.

Because of the stern plane impetus, the submarine turns about its transverse axis and, in doing so, changes its trim and dived depth in the direction in which the planes were acting. Submarines with high damping approach a different dived depth without oscillation about the transverse axis. If the damping is less, the submarine starts to oscillate about the transverse axis. As long as the oscillation is damped, the submarine is stable and approaches a different constant dived depth. On the other hand, if the trim amplitude,  $\theta_A$ , increases, the submarine is dynamically unstable. The mean dived depth may alter also (see [Figure 1](#)).

If the submarine demonstrates pronounced instability, the test is to be stopped immediately for safety reasons.



**Key**

- |   |  |                      |                        |
|---|--|----------------------|------------------------|
| 1 | $V_0 = 14,0 \text{ kn}$ , $\Delta\delta_{Si} = 2^\circ$ , $\Delta\theta_E = 2^\circ$ (boat dynamically unstable)   | 6                    | supercritically damped |
| 2 | $V_0 = 6,0 \text{ kn}$ , $\Delta\delta_{Si} = 23^\circ$ , $\Delta\theta_E = 10^\circ$ (boat dynamically stable)    | $\delta_S, \theta_S$ | in $^\circ$            |
| 3 | $V_0 = 3,9 \text{ kn}$ , $\Delta\delta_{Si} = 23^\circ$ , $\Delta\theta_E = 9^\circ$ (boat supercritically damped) | $t$                  | in s                   |
| 4 | dynamically unstable   | $z_0$                | in m                   |
| 5 | dynamically stable   |                      |                        |

**Figure 1 — Time history**

## 6.2 Analysis and presentation of results of a meander test

### 6.2.1 Evaluation for subcritical damping

The following data are obtained from the test:

— mean test speed	$V_{0m}$
— trim amplitudes	$\theta_{Ai}, i = 1, 2, 3, \dots$
— response times to reach the trim amplitudes, $\theta_{Ai}$	$t_{Ai}, i = 1, 2, 3, \dots$
— period of oscillation	$T$
— time to half-value	$t_{1/2}$
— final change of dived depth	$\Delta z_{0F}$

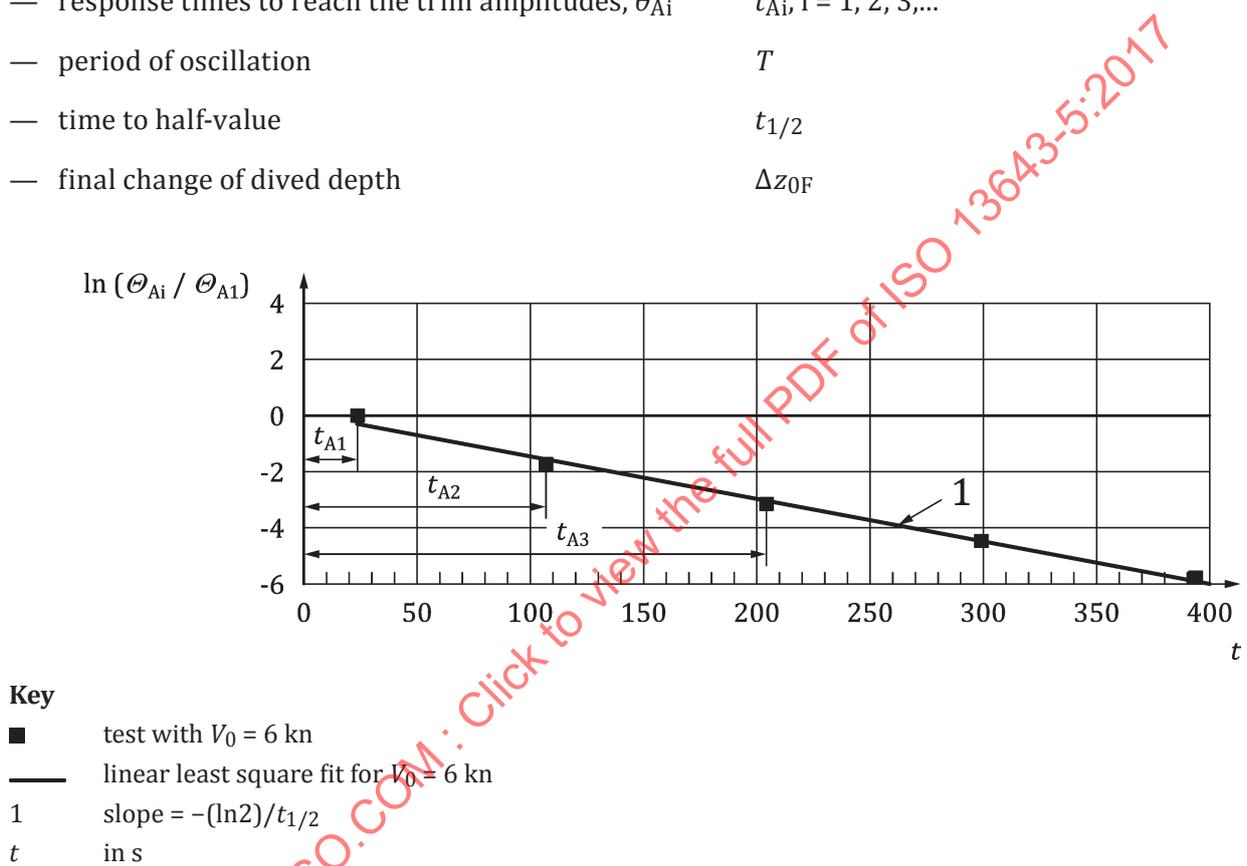
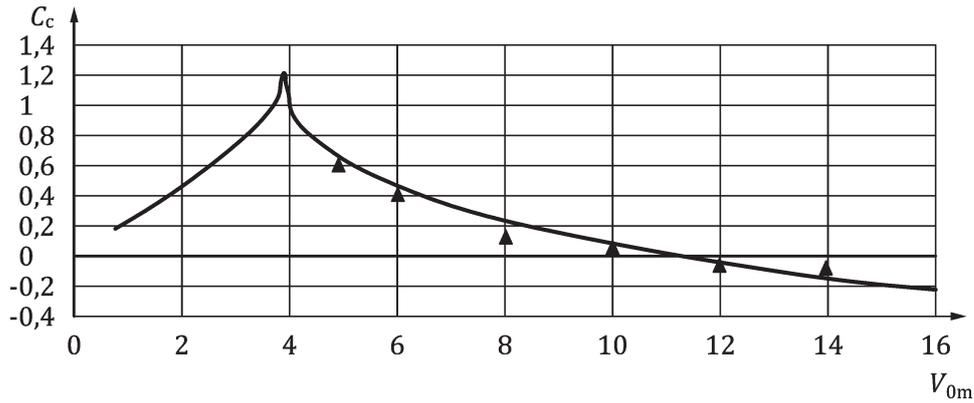


Figure 2 — Evaluation

### 6.2.2 Damping ratio

The damping ratios shall be plotted against the mean test speed,  $V_{0m}$ , as shown in [Figure 3](#).

$$C_c = \frac{1}{\sqrt{\left(\frac{2\pi t_{1/2}}{T \ln 2}\right)^2 + 1}} \quad (1)$$



**Key**  
 ▲ test results  
 — calculated from hydrodynamic coefficients  
 $V_{0m}$  in kn

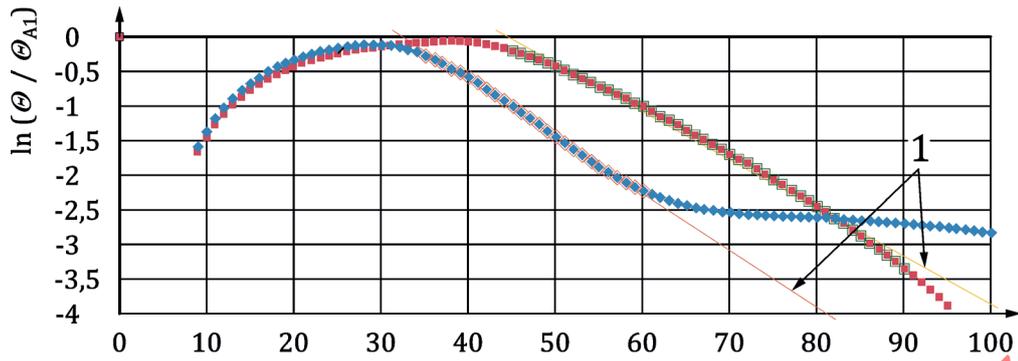
**Figure 3 — Damping ratio**

**6.3 Evaluation for supercritical or high damping**

The following data are obtained from the test:

- mean test speed  $V_{0m}$
- time to half-value  $t_{1/2}$
- final change of dived depth  $\Delta z_{0F}$

At supercritical or high damping, there are no measurable trim oscillations after completion of the stern plane impetus. If the submarine is dynamically stable, the trim angle reaches a maximum  $\theta_{A1}$  after the stern plane impetus and converges later asymptotically to the initial trim angle,  $\theta_{S0}$ . The trim angle according to Figure 4 divided by  $\theta_{A1}$  — and thereby non-dimensional — is plotted logarithmically against time. This is used to find the time to half-value,  $t_{1/2}$ .



**Key**

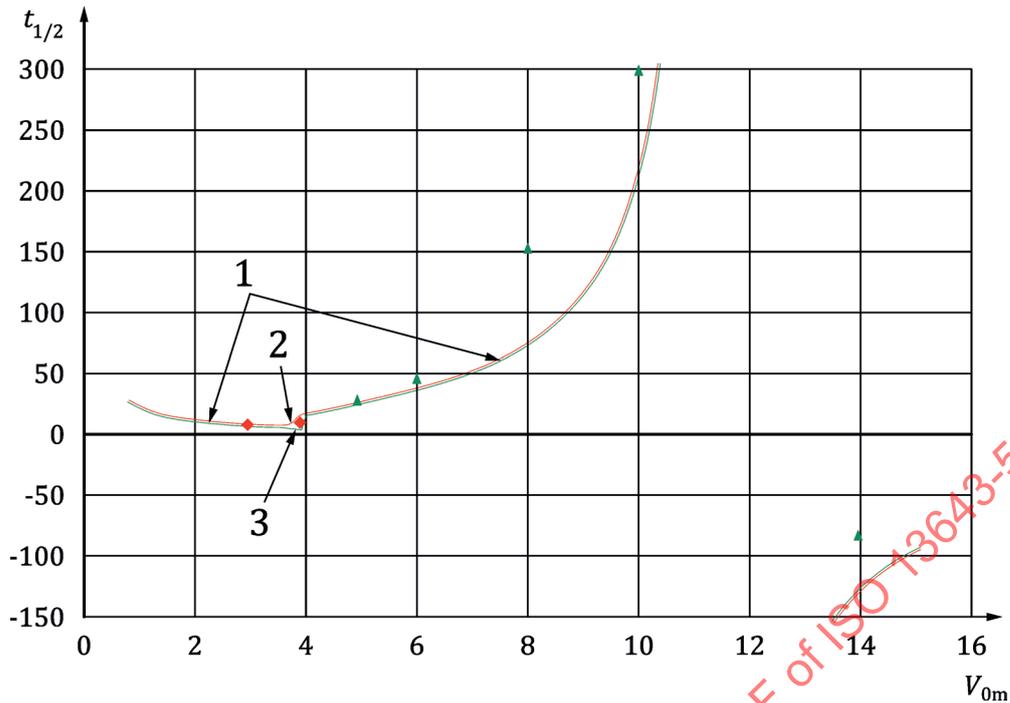
- ◆  $V_0 = 3 \text{ kn}; \Delta\delta_{Si} = 23^\circ; \Delta\theta_E = 5^\circ$
- ◇ points for linear curve fit
- $V_0 = 3,9 \text{ kn}; \Delta\delta_{Si} = 23^\circ; \Delta\theta_E = 9^\circ$
- points for linear curve fit
- 1 linear curve fit slope =  $-(\ln 2)/t_{1/2}$
- t in s

**Figure 4 — Decay of trim angle**

**6.4 Evaluation of the time to half-value**

The times to half-value,  $t_{1/2}$ , shall be plotted against the mean test speed,  $V_{0m}$ , as shown in [Figure 5](#).

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- Key**
- values for the first eigenform, calculated from model test data
  - values for the third eigenform, calculated from model test data
  - ▲ test results: evaluation according to [Figure 2](#)
  - ◆ test results: evaluation according to [Figure 4](#)
  - 1 identical values for first and third eigenform
  - 2 third eigenform
  - 3 first eigenform
- $t_{1/2}$  in s  
 $V_{0m}$  in kn

Figure 5 — Time to half-value

**6.5 Designation of a meander test**

Designation of a meander test according to ISO 13643-5 (5), Test 1 (1), conducted with an initial speed  $V_0 = 10$  kn (10), a test stern plane angle  $\Delta\delta_{Si} = 5^\circ$  (05), and an execute change of trim angle  $\Delta\theta_E = 5^\circ$  (05):

**Meander test ISO 13643 - 5.1 × 10/05/05**

**7 Test 5.2 — Vertical overshoot test**

**7.1 Description**

A series of tests shall be conducted with different initial speeds,  $V_0$ , test stern plane angles,  $\Delta\delta_{Si}$ , and execute change of trim angles,  $\Delta\theta_E$ .

For safety reasons, the series of tests shall be commenced with combinations of small values.

The submarine shall approach on a steady heading and at a constant speed,  $V_0$ , before commencing the test. During the test, the propulsion plant settings shall remain unaltered and the heading kept as constant as possible. Heading and rudder movements shall be recorded throughout the test (preferably

at intervals of 1 s). If the submarine is equipped with planes acting simultaneously in the horizontal and the vertical direction (e.g. X-planes), these planes should be controlled in such a way that a steady heading is maintained as a matter of priority.

After the submarine has been moving ahead for at least 2 min without significant movements of rudder and planes, the stern planes are set to the specified test stern plane angle,  $\Delta\delta_{Si}$ , as fast as possible and held there until the trim angle has deviated from the initial trim angle,  $\theta_{S0}$ , by the specified execute change of trim angle,  $\Delta\theta_E$ . At this point, the stern planes are reversed to the same test stern plane angle,  $\Delta\delta_{Si}$ , but in the opposite direction relative to the initial setting, and held until the submarine is levelled-off, i.e. the rate of change of dived depth reduces to zero (see [Figure 6](#)).

This completes the test for the selected parameters.

## 7.2 Analysis and presentation of results of a vertical overshoot test

The following data are obtained from the test:

— response time	$t_A$
— overshoot time	$t_C$
— levelling-off time	$t_t$
— overshoot angle	$\theta_{SS}$
— response depth change	$\Delta z_{0E}$
— levelling-off depth change	$\Delta z_{0M}$

Together with the test parameters  $V_0$ ,  $\Delta\delta_{Si}$ , and  $\Delta\theta_E$ , the above-mentioned data are used to assess the effectiveness of the stern planes.

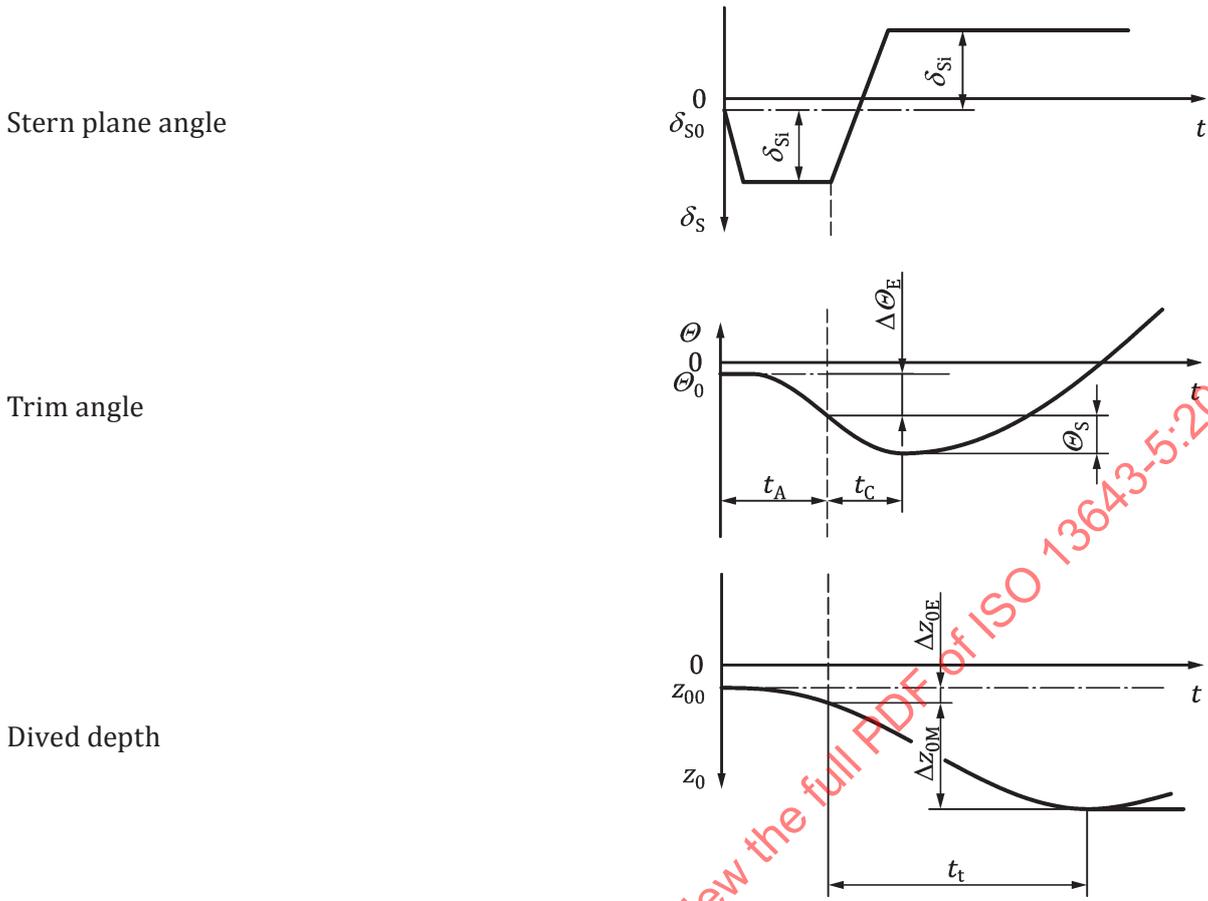


Figure 6 — Time history

7.3 Designation of a vertical overshoot test

Designation of a vertical overshoot test according to ISO 13643-5 (5), Test 2 (2), conducted with an initial speed  $V_0 = 10$  kn (10), a test stern plane angle  $\Delta\delta_{Si} = 5^\circ$  (05), and an execute change of trim angle  $\Delta\theta_E = 5^\circ$  (05):

Vertical overshoot test ISO 13643 - 5.2 × 10/05/05

8 Test 5.3 — Neutral level flight test

8.1 Description

8.1.1 Model test (M)

Moments and forces are measured at the supporting structure and recorded for the submerged submarine model, preferably initially on even keel when at a standstill with the stabilizing fins and stern planes set to  $\delta_{sx} = 0$  and  $\delta_s = 0$  (initial condition). Now the submarine model is accelerated to a test speed,  $V_0$ , at which the bottom and surface effects are still negligible. Then, the changes of the vertical force and the trim moment relative to the initial condition are measured and recorded.

In successive test steps with other trims, the initial condition at standstill is to be determined again.

The angles of the stabilizing fins and the stern planes, as well as the trim angles or bow plane angles, have to be varied in suitable increments (for instance, trim angle increments of 0,5°, stabilizing fin/hydroplane angle increments of 1°). For stern planes with fixed post and movable part, it is

recommended to set both to the same angle ( $\delta_{SX} = \delta_S$ ). The angles have to be selected so as to provide positive and negative values for the quantities of the vertical force and the trim moment when one parameter is maintained (trim angle or hydroplane angle), so that the zero value may be interpolated for evaluation purposes.

The angle of the stabilizing fin and/or fixed post of stern planes derived from the model tests according to 8.2.1 serves as input for the detailed design. The trim angle and/or hydroplane angles at which the submarine is assumed to maintain a constant dived depth at all speeds should be ascertained by full-scale tests.

## 8.1.2 Full-scale test (S)

### 8.1.2.1 General

A submerged cruising condition is to be found at which not only the total force and the total moment but also the difference between weight and buoyancy and the static trim moment are zero. At relatively high speeds, the difference between weight and buoyancy and the static trim moment have almost no influence on the dynamic behaviour of the boat. Therefore, the neutral level flight condition can be determined comparatively simply by extrapolation.

### 8.1.2.2 Submarines with retractable bow planes

The submerged submarine is compensated at a speed of about twice the critical speed,  $V_{CR}$  (see Clause 9), by use of the trimming and compensating systems, so that depth keeping is possible with retracted bow planes at a stern plane angle between  $\pm 1,5^\circ$  and a trim angle between  $-1^\circ$  and  $0^\circ$ . The actual quantity and the centre of gravity of compensating water have to be measured and recorded.

After that, the submarine shall be kept on a constant dived depth by use of the stern planes. Approaches at test speeds,  $V_{0i}$ , of about 50 %, 60 %, 65 %, 75 %, and 90 % of the maximum speed are conducted successively. These test speeds,  $V_{0i}$ , are selected such that an almost even distribution of test stern plane angles,  $\delta_S$ , and trim angles,  $\theta_S$ , is obtained when plotted as a function of the inverse square of the test speed,  $V_0$ . The test speed,  $V_{0i}$ , the related stern plane angle,  $\delta_S$ , and the resulting trim angle,  $\theta_S$ , shall be recorded.

After evaluation as per 8.2.2.1, the test speed is set again to about twice the critical speed,  $V_{CR}$ . The submarine is trimmed and compensated until it finally maintains a constant depth with a stern plane angle,  $\delta_{S0}$ , and trim angle,  $\theta_{S0}$ , for neutral level flight determined by the evaluation. The quantity and the centre of gravity of compensating water shall be measured and recorded.

In order to verify the angles  $\delta_{S0}$  and  $\theta_{S0}$  for neutral level flight, the submarine speed will be increased in increments up to a speed,  $V_{0i}$ , of 75 % of the maximum speed without changing the setting of the stern planes. Dived depth and trim angle are to be measured and recorded at suitable time intervals. After that, the stern plane is used to maintain depth, if necessary. In case the stern plane angle,  $\delta_S$ , or the related change of trim angle,  $\theta_S$ , differs by less than  $0,2^\circ$  from the stern plane angle,  $\delta_{S0}$ , and trim angle,  $\theta_{S0}$ , the test is completed.

Otherwise, the stern plane angle,  $\delta_S$ , and the related change of trim angle,  $\theta_S$ , for maintaining depth are to be determined at two additional speeds. The stern plane angles,  $\delta_S$ , and the trim angles,  $\theta_S$ , determined by the last three speeds together with the previously used angles for stern planes,  $\delta_{S0}$ , and trim,  $\theta_{S0}$ , are used for a renewed evaluation to determine the new values of  $\delta_{S0}$  and  $\theta_{S0}$ . After that, a further verification loop begins with compensating the submarine for a test speed of about twice the critical speed,  $V_{CR}$ .

### 8.1.2.3 Submarines with non-retractable bow planes

The submerged submarine is compensated at a speed of about twice the critical speed,  $V_{CR}$ , by use of the trimming and compensating systems so that depth keeping is possible for any pre-selected trim angle,  $\theta_S$  (preferably  $\theta_S = 0^\circ$ ), at a stern plane angle between  $\pm 1,5^\circ$  and a bow plane angle between  $\pm 4^\circ$ . The actual quantity and centre of gravity of compensating water are to be measured and recorded.

After that, the submarine shall be kept on a constant dived depth at the pre-selected trim angle,  $\theta_S = \theta_{S0}$ , by use of stern and bow planes. Approaches at test speeds,  $V_{0i}$ , of about 50 %, 60 %, 65 %, 75 %, and 90 % of the maximum speed are made successively. These test speeds,  $V_{0i}$ , shall be selected such that an almost even distribution of stern plane angles,  $\delta_S$ , and bow plane angle,  $\delta_B$ , is obtained when plotted as a function of the inverse square of the test speed,  $V_{0i}$ . The test speed,  $V_{0i}$ , the related stern plane angle,  $\delta_S$ , and bow plane angle,  $\delta_B$ , are to be recorded.

After evaluation as per 8.2.2.2, the test speed is set again to about twice the critical speed,  $V_{CR}$ . The submarine is trimmed and compensated until it finally maintains a constant depth with stern plane angle,  $\delta_{S0}$ , and bow plane angle,  $\delta_{B0}$ , determined by the evaluation for neutral level flight at trim angle,  $\theta_S = \theta_{S0}$ . Quantity and centre of gravity of compensating water have to be measured and recorded.

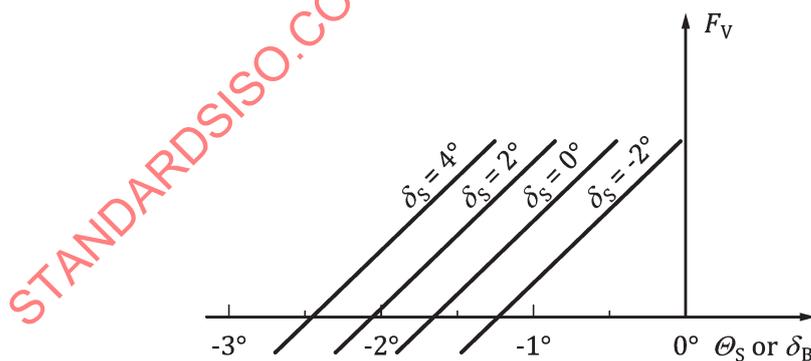
In order to verify the angles  $\delta_{S0}$  and  $\delta_{B0}$  for neutral level flight, the submarine speed is increased in increments up to a speed,  $V_{0i}$ , of 75 % of the maximum speed without changing the settings of the stern and bow planes. Dived depth and trim angle are measured and recorded at suitable time intervals. After that, the stern and bow planes are used to maintain depth and trim angle,  $\theta_{S0}$ , if necessary. If it is determined that the stern plane angle,  $\delta_S$ , or the bow plane angle,  $\delta_B$ , differs by less than 0,2° from the neutral level flight stern plane angle,  $\delta_{S0}$ , and the neutral level flight bow plane angle,  $\delta_{B0}$ , the test is completed.

Otherwise, the stern plane angle,  $\delta_S$ , and the related bow plane angles,  $\delta_B$ , for maintaining depth and trim angle,  $\theta_{S0}$ , are to be determined at two additional speeds. The stern plane angles,  $\delta_S$ , and the bow plane angles,  $\delta_B$ , determined by the last three speeds, together with the previously used angles for stern planes,  $\delta_{S0}$ , and bow planes,  $\delta_{B0}$ , are used for a renewed evaluation to determine the new values of  $\delta_{S0}$  and  $\delta_{B0}$ . After that, a further verification loop begins with compensating the submarine for a test speed of about twice the critical speed,  $V_{CR}$ .

## 8.2 Analysis and presentation of results of a neutral level flight test

### 8.2.1 Model test

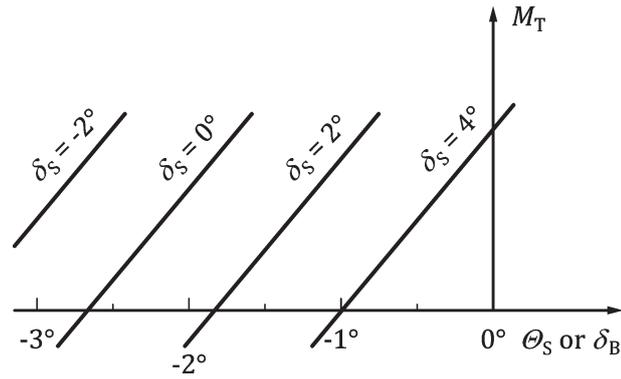
The vertical forces and trim moments according to 8.1.1 are plotted in a diagram as a function of the trim angle (or of the bow plane angle) for the different stern plane angles as parameters (example: Figure 7 and Figure 8) and as functions of the stern plane angle for the different trim angles (or of the bow plane angles) as parameters, respectively.



**Key**

$F_v$  in N

Figure 7 — Vertical force

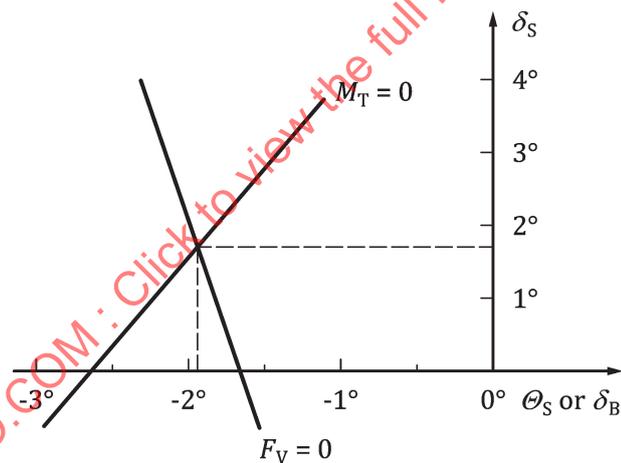


**Key**

$M_T$  in Nm

**Figure 8 — Trim moment**

The stabilizing fin/stern plane angles and the trim angles or bow plane angles for zero values of the vertical force,  $F_V$ , and the trim moment,  $M_T$ , are taken and plotted as curves in one diagram. The result of the test, i.e. the stabilizing fin angle,  $\delta_{S0}$ , and the stern plane angle,  $\delta_{S0}$ , and the trim angle,  $\theta_{S0}$ , (or the bow plane angle,  $\delta_{B0}$ ) for neutral level flight is given from the intersection of the two curves (example: [Figure 9](#)).



**Key**

$\delta_S, \theta_S, \delta_B$  in °

**Figure 9 — Analysis diagram**

**8.2.2 Full-scale test**

**8.2.2.1 Submarines with retractable bow planes**

The values for  $\delta_S$  and  $\theta_S$  according to [8.1.2.2](#) are plotted in a diagram as a function of the inverse square of the test speed  $1/V_0^2$ . The values for  $\delta_S$  and  $\theta_S$  shall be determined by the following linear regression approximations:

$$\delta_S = \delta_{S0} + a_1 \frac{1}{V_0^2} + a_2 \frac{\theta_S}{V_0^2} \tag{2}$$

$$\theta_S = \theta_{S0} + b_1 \frac{1}{V_0^2} + b_2 \frac{\theta_S}{V_0^2} \tag{3}$$

$\delta_{S0}$  and  $\theta_{S0}$  are the values of the extrapolated curves at  $1/V_0^2 = 0$  (example: [Figure 10](#)).

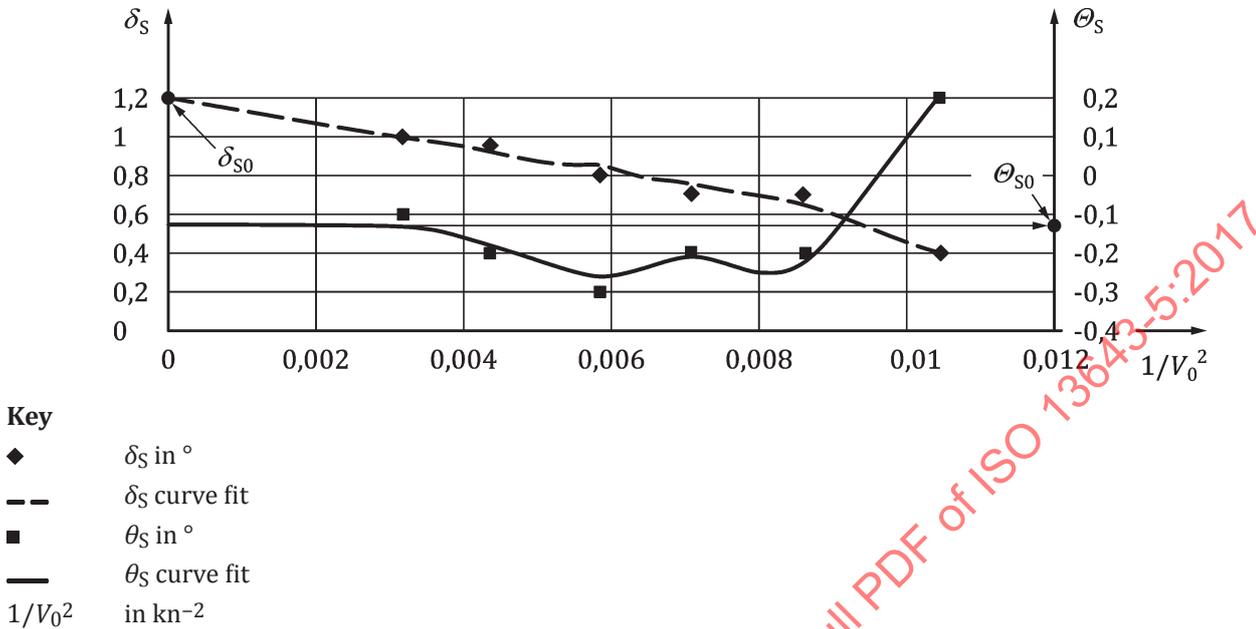


Figure 10 — Analysis diagram

8.2.2.2 Submarines with non-retractable bow planes

The values for  $\delta_S$  and  $\delta_B$  according to 8.1.2.3 are plotted in a diagram as a function of the inverse square of the test speed  $1/V_0^2$  and approximated by the following linear equations:

$$\delta_S = \delta_{S0} + c_1 \frac{1}{V_0^2} \tag{4}$$

$$\delta_B = \delta_{B0} + d_1 \frac{1}{V_0^2} \tag{5}$$

$\delta_{S0}$  and  $\delta_{B0}$  are the values of the extrapolated curves at  $1/V_0^2 = 0$  (example: [Figure 11](#)).