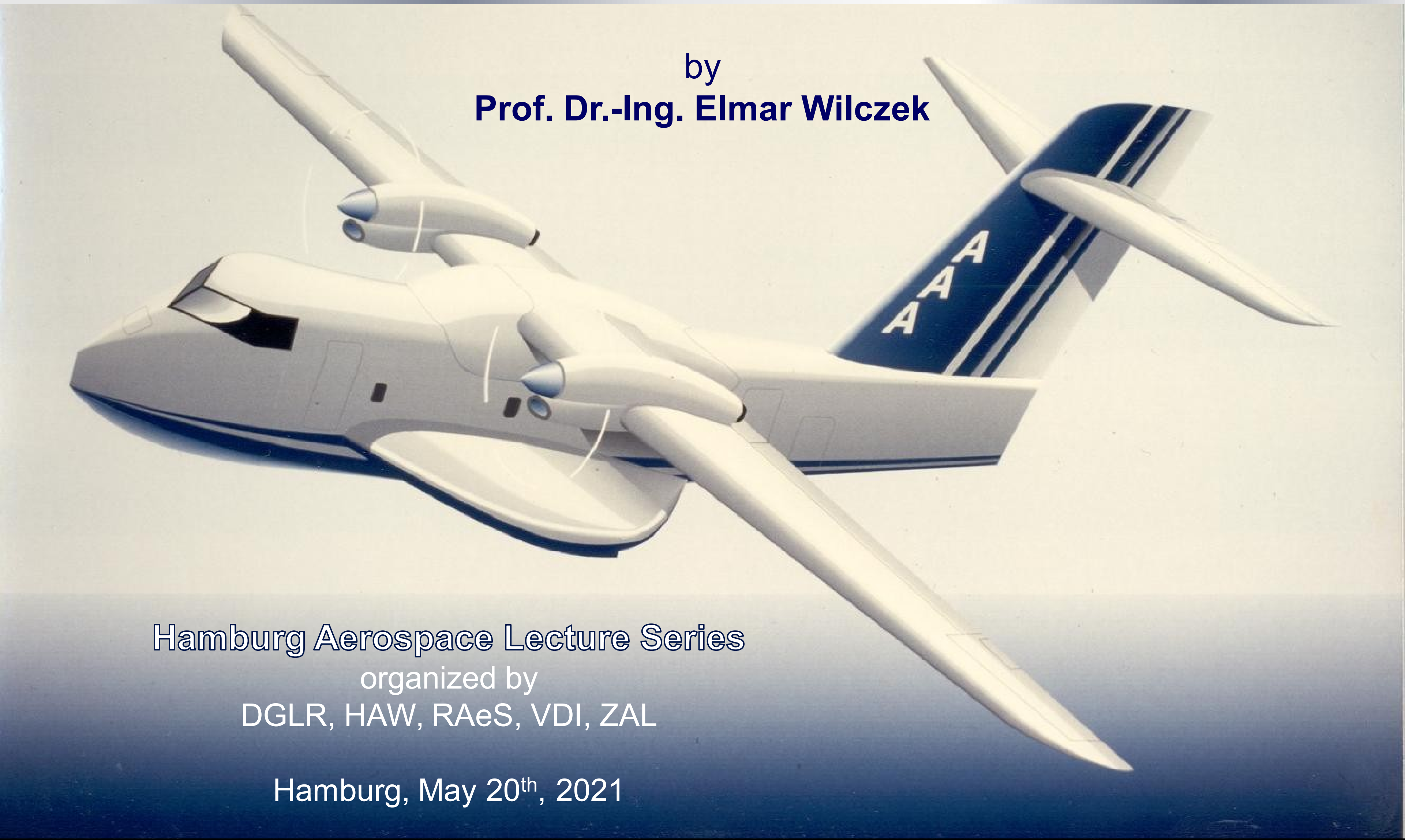
Seaplane Design - a Forgotten Art



by
Prof. Dr.-Ing. Elmar Wilczek

Hamburg Aerospace Lecture Series
organized by
DGLR, HAW, RAeS, VDI, ZAL

Hamburg, May 20th, 2021

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Hamburg Aerospace Lecture Series

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DGLR in cooperation with the RAeS, HAW Hamburg, VDI, & ZAL invites you to a lecture

Seaplane Design - A Forgotten Art

Prof. Dr.-Ing. **Elmar Wilczek**, Expert in Marine Aviation

Lecture followed by discussion
No registration required !
Online Zoom lecture

Date: Thursday, 20 May 2021, 18:00 CEST

Online: http://purl.org/ProfScholz/zoom/2021-05-20

Beriev Be-200 Altair – Courtesy of United Aircraft Corporation (UAC)

A seaplane gives the ultimate freedom of flight with theoretically endless take-off and alighting possibilities along the coast, on lakes and rivers – and not to forget on the open seas. The design of seaplanes is based on the knowledge of aircraft design and speedboat design. The craft must meet buoyancy and lift requirements. Hydrostatic and -dynamic stability has to be matched with the longitudinal and lateral static and dynamic stability in the air. The structure has to withstand water and air loads. Crucial are hydrodynamic resistance at take-off as well as the lift-to-drag ratio in flight and particularly the water loads in defined sea states.

Sea plane design has a glorious past, but much of the knowledge is buried in dusty archives. It is even worse if knowledge is lost forever and needs to be reinvented.

Elmar Wilczek has taught seaplane design for decades. In his presentation he will focus on particular research results among others: the importance of water spray for hydrodynamic resistance, scale effects, hydrodynamic elasticity for seaworthiness, length-to-beam ratio for hydrodynamics and aerodynamics. He advocates the conservation of seaplane design knowledge and is very open to share the information he has diligently collected.

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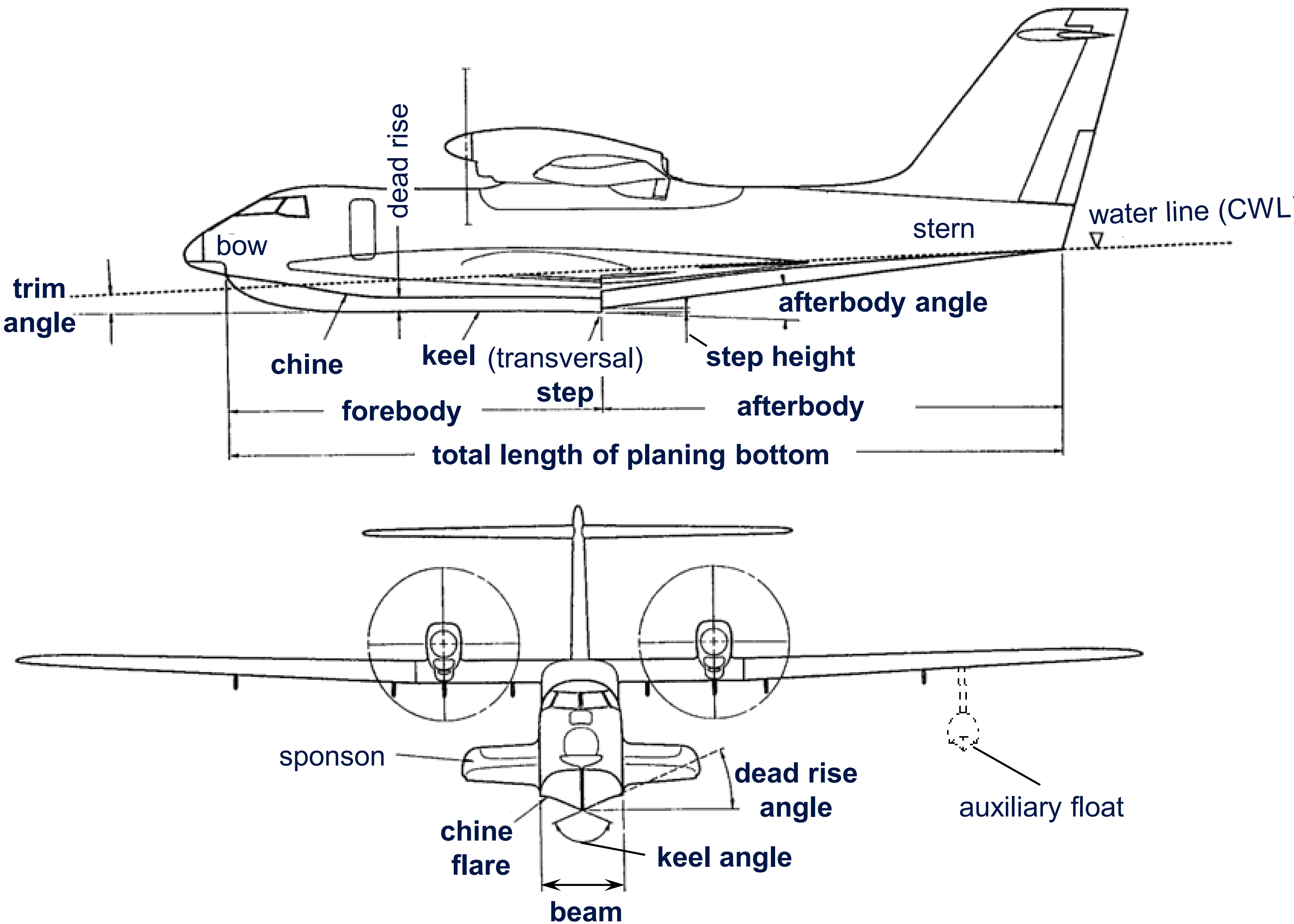
Modern Seaworthy Seaplanes

***AVIC AG 600 Kunlong**, maiden flight December 24th, 2017*

***Beriev Be 200** Altair, maiden flight 1999*

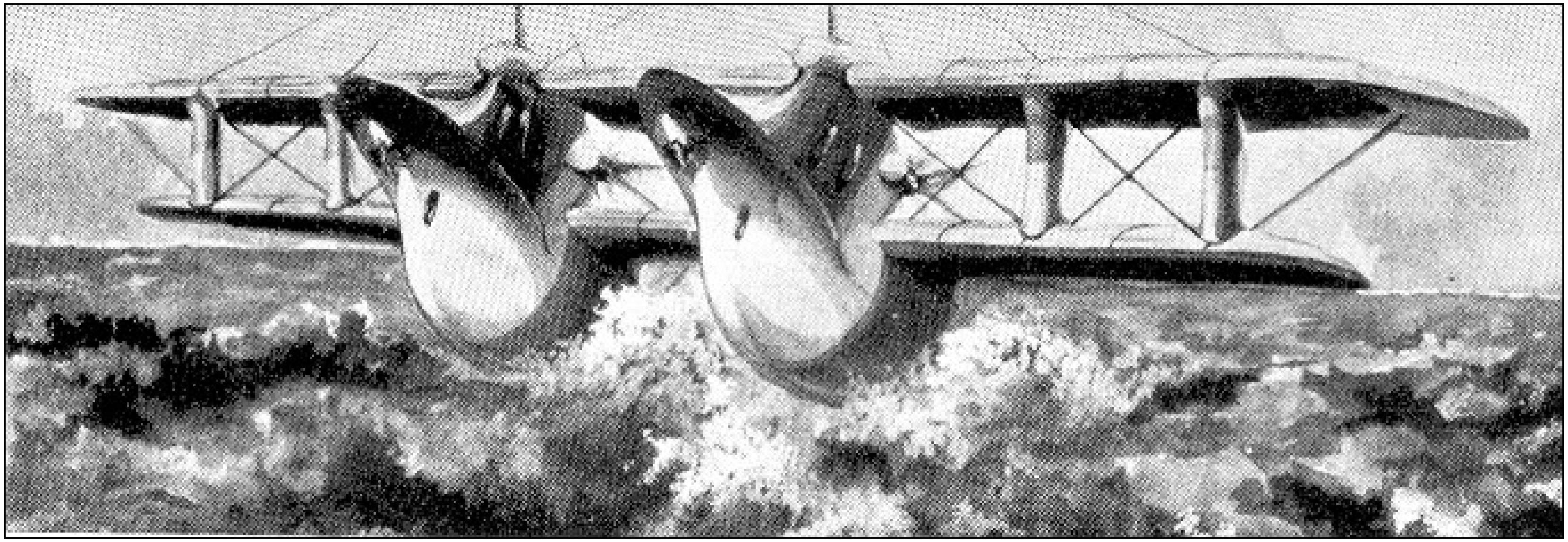
***ShinMaywa US-2**, delivered to JMSDF in February 2009*

Hull Bottom Definitions of Seaplanes (Flying Boat)



Design of a High-Seaworthy Seaplane

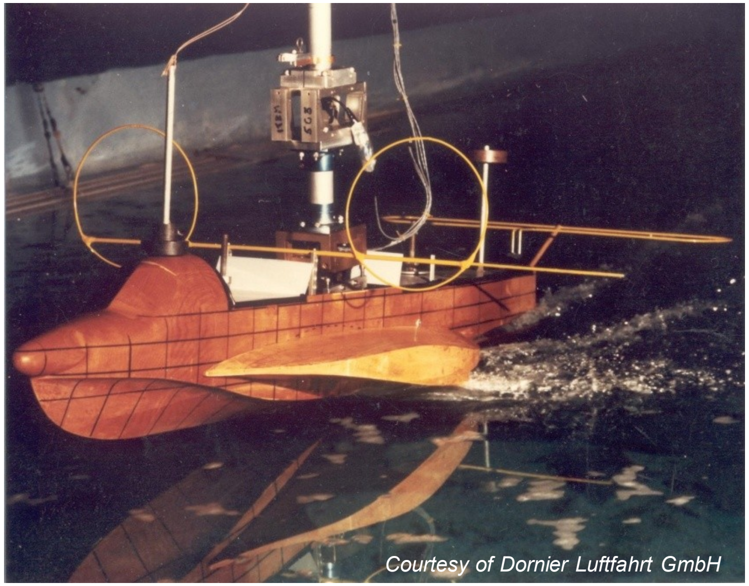
by Konrad Detert 1916



- ***Hydrodynamics***
- ***Spray Protection***
- ***Seaworthiness***
- ***Sea Strength***
- ***Buoyancy***

Main Requirements of a Seaplane

- ***Low water resistance***
- ***Low spray water production***
- ***Low impact loads*** during take-off and alighting at ***defined seaworthiness***
- ***No tends of oscillations around the pitch axis*** – ***no porpoising***
- ***Weather-cock stability*** and ***stability around all horizontal axis at drifting*** by cross wind according to required seaworthiness
- ***Quick reaction*** of the seaplane's ***air and water rudders during manoeuvring***
- ***Low aerodynamic drag***

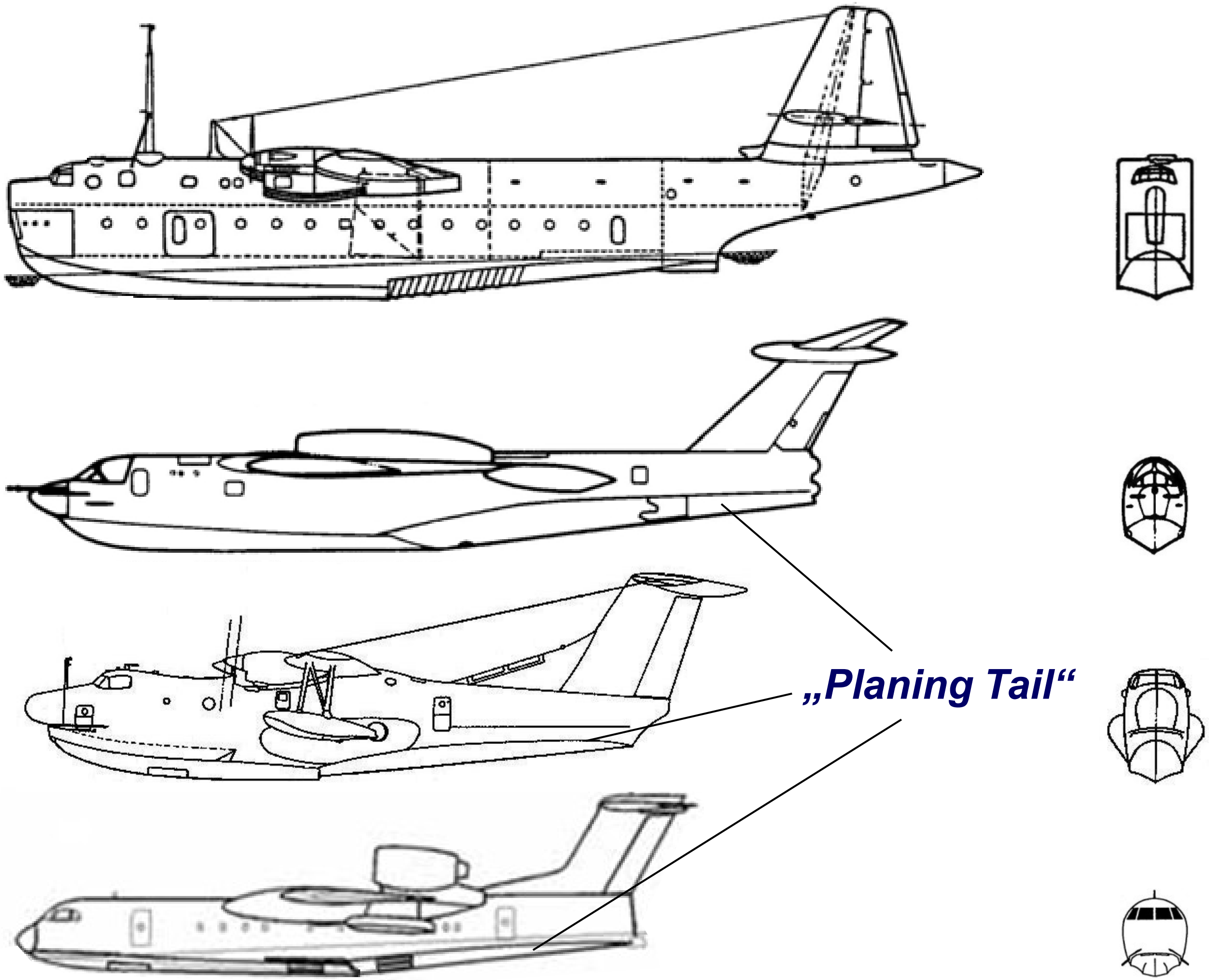

Courtesy of Dornier Luftfahrt GmbH

<u>Essential Towing Tank Testing:</u>
Dornier AAA model,
Stevens Institute of Technology

Low Water Resistance Hull

Advanced Slender Hulls

- High **length-to-beam ratio** l_L/b_{St} **= 10 to 15**
- High **beam loading** $c'_a = \frac{A^+}{\gamma \cdot b_{st}^3}$ = » **2** to **3**



Blohm & Voss
BV 238 V1 (1944)

l_L/b_{St} = 9.3; c_a‘ = 2.1 (2.2)

Martin
P6M SeaMaster (1959)

l_L/b_{St} = 15; c_a‘ = 3.1

Shin Meiwa
SS-2A (1968)

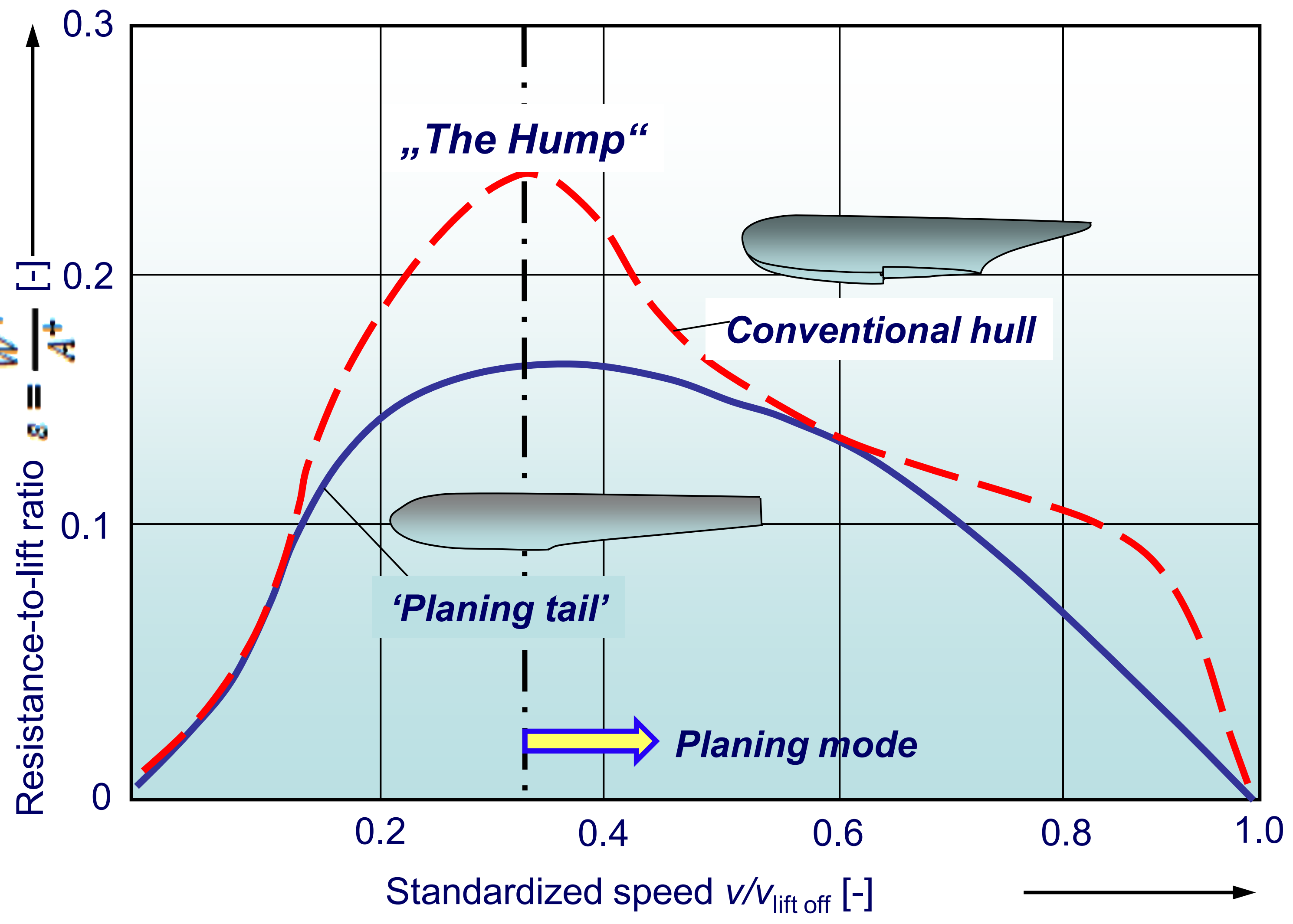
$l_L/b_{St} \cong$ 11.6; c_a‘ = 3.1

Beriev
Be-200 (1999)

$l_L/b_{St} \cong$ 13; c_a‘ = 3.8

Low Water Resistance Hull

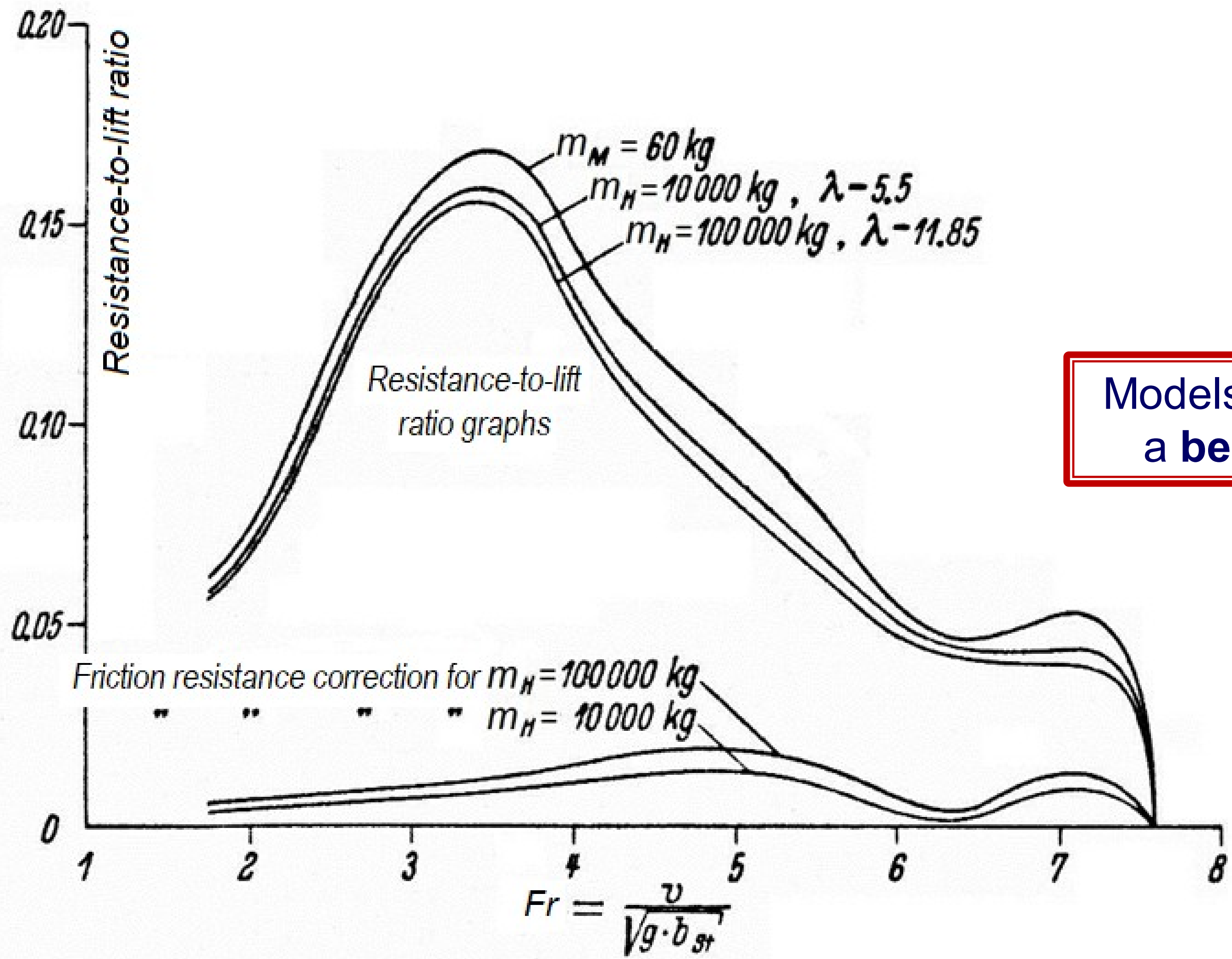
Comparison of Resistance Between Conventional and Planing Tail Hull Bottom



Low Water Resistance Hull

Towing Tank Results with Scale Effect (Sottorf)

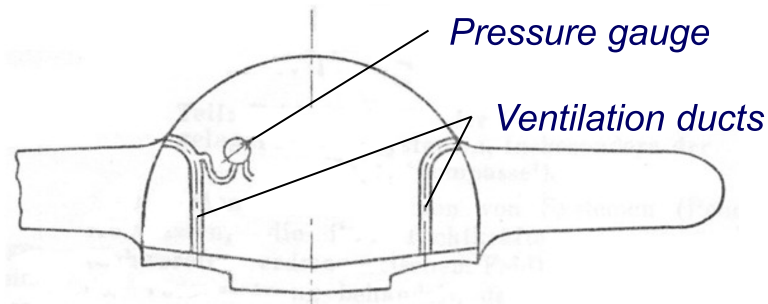
Higher model resistance by neglecting friction scale effect (Reynolds number)



Models should **<u>never</u>** have a **beam below 20 cm**!

Low Water Resistance Hull

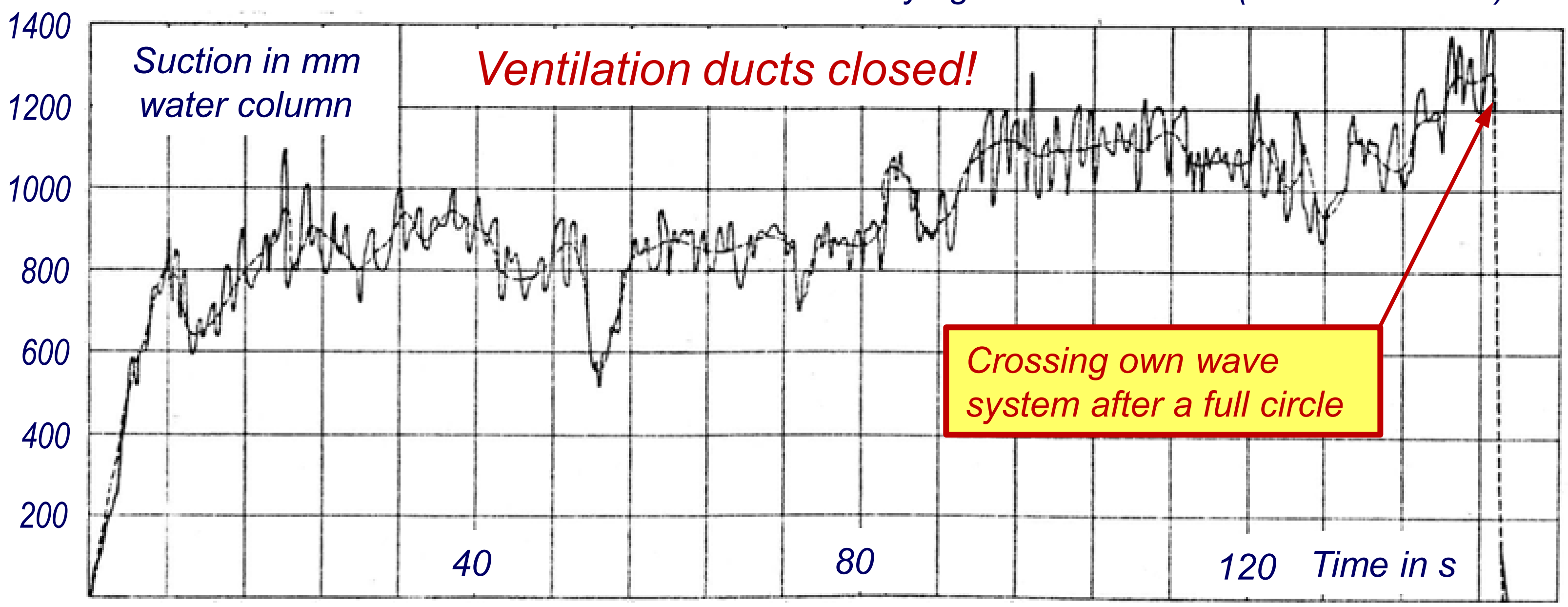
Step/Afterbody Ventilation Tests on Dornier Do 18 (Full, 1939)



Step ventilation of a Dornier Do 18 flying boat with sponsons

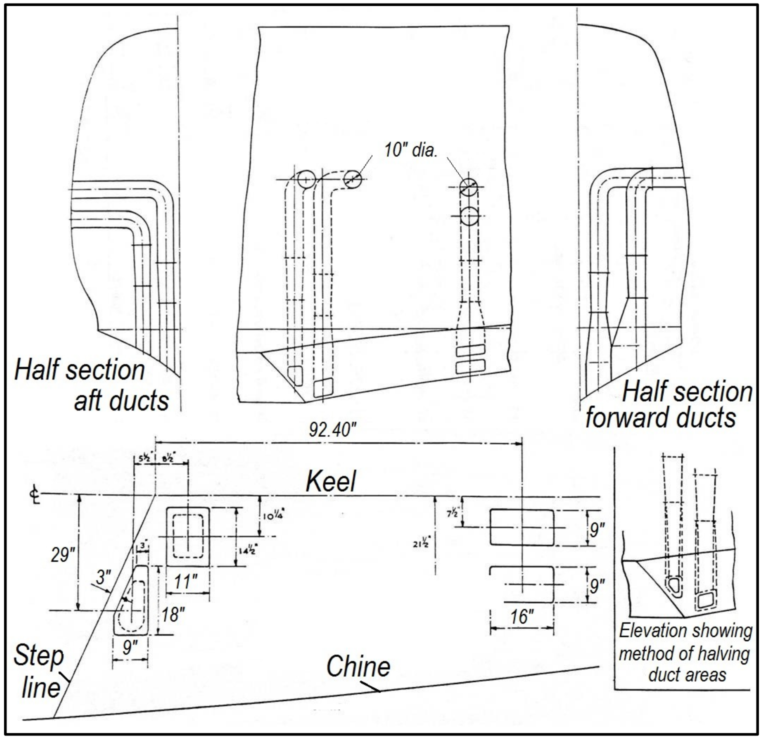
- Ventilated step on **FF floatplanes**
- Glassy water: **Take-off problems** with sponsons if **no ventilation**
- Even **Do 26** equipped with ventilation

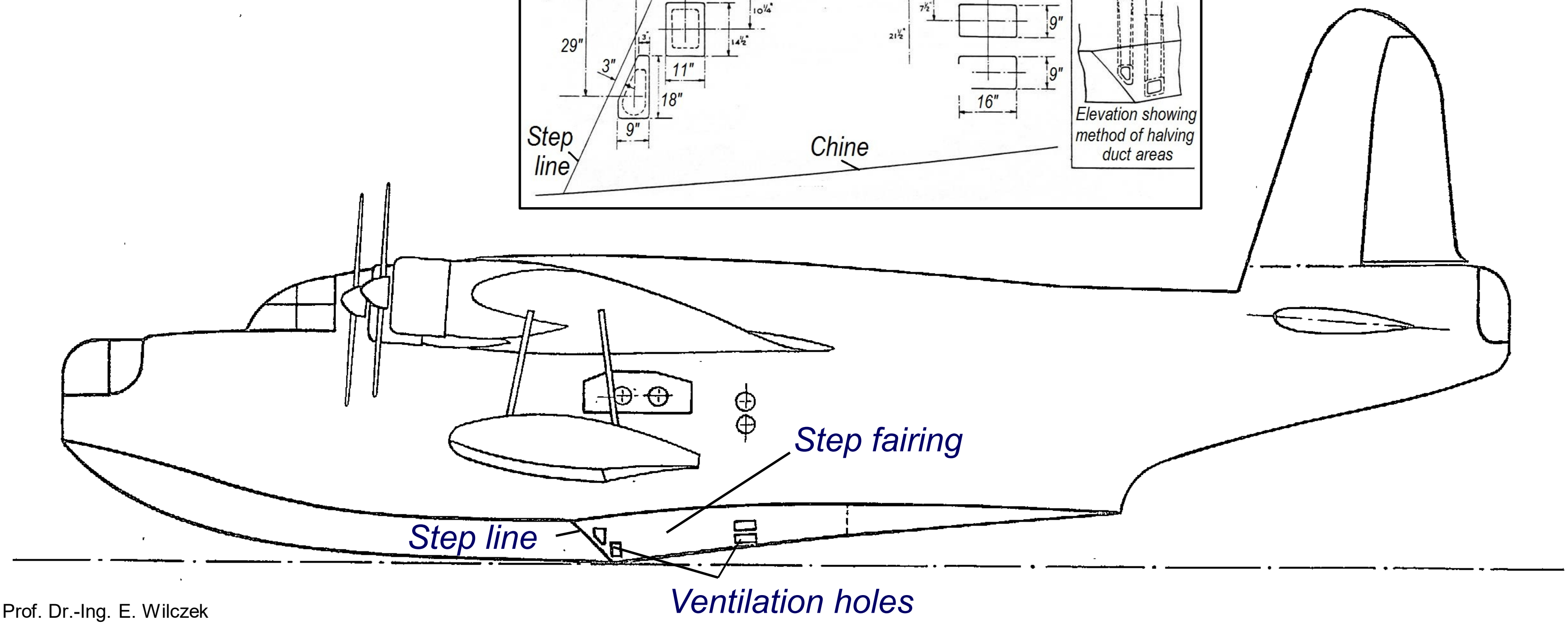
Suction curve in the ventilation duct of the step during take-off run of the Do 18 D-ATEY flying boat at no wind (circular take-off)



Low Water Resistance Hull

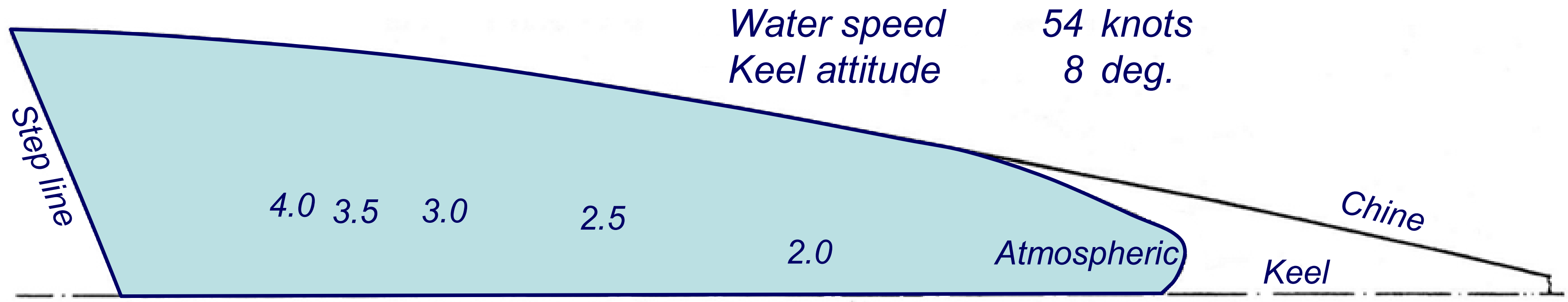
Step & Afterbody Ventilation Tests on Sunderland (1952)



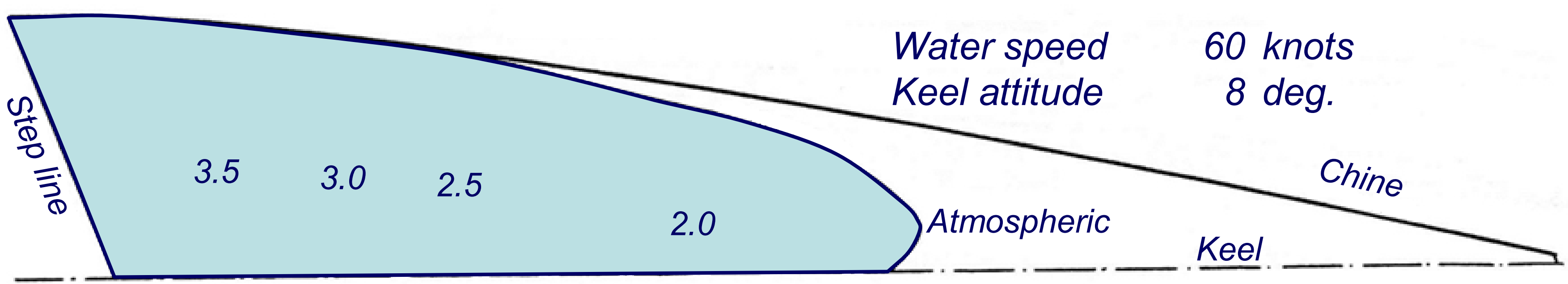


Low Water Resistance Hull

Step/Afterbody Ventilation Tests on Sunderland (1952)



Afterbody pressure distribution during a **take-off (above)** and an **alighting skip (below)**.
Step sharp. All vents sealed
All pressures in pounds/sq. in. negative below atmospheric.

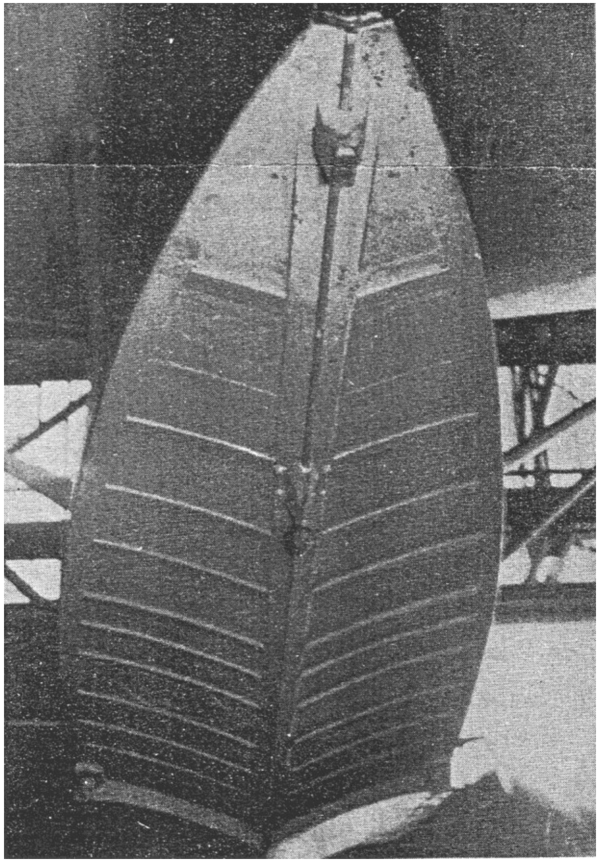


Test Results:

- **No suction** and **skipping** if step is fully faired and **ventilated**
- Step must be a **sharp** break between fore- and afterbody
- **Reduction** of **drag** and **resistance** and
- **Improved directional stability**

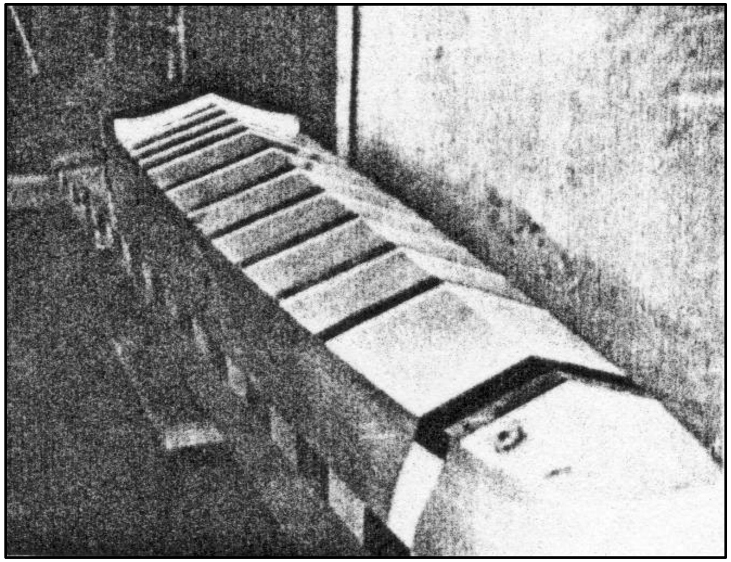
Low Water Resistance Hull

Reduced Resistance by Afterbody Steplets or Wedges (Full/Sottorf)

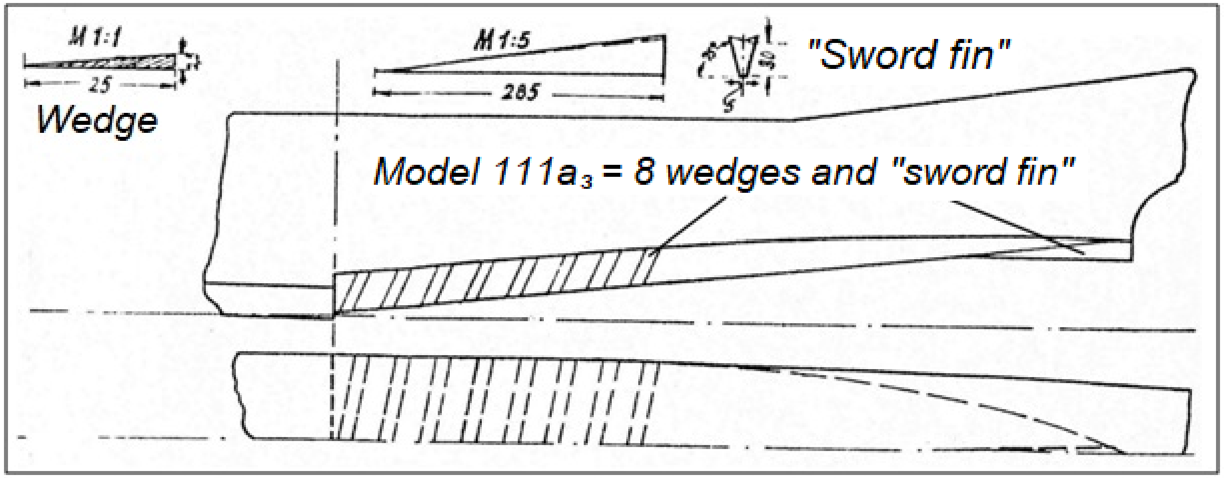


Full scale trials on ***Arado Ar 196*** *floats*

Blohm & Voss BV 222 *towing tank model with steplets or wedges on afterbody*



- *Up to* ***45% of resistance reduction*** *before lift-off*
- *Almost* ***no upper stability limit***



Blohm & Voss BV 238 *afterbody equipped with wedges or steplets and "sword fin" (Schwerthacke)*

Low Water Resistance Hull

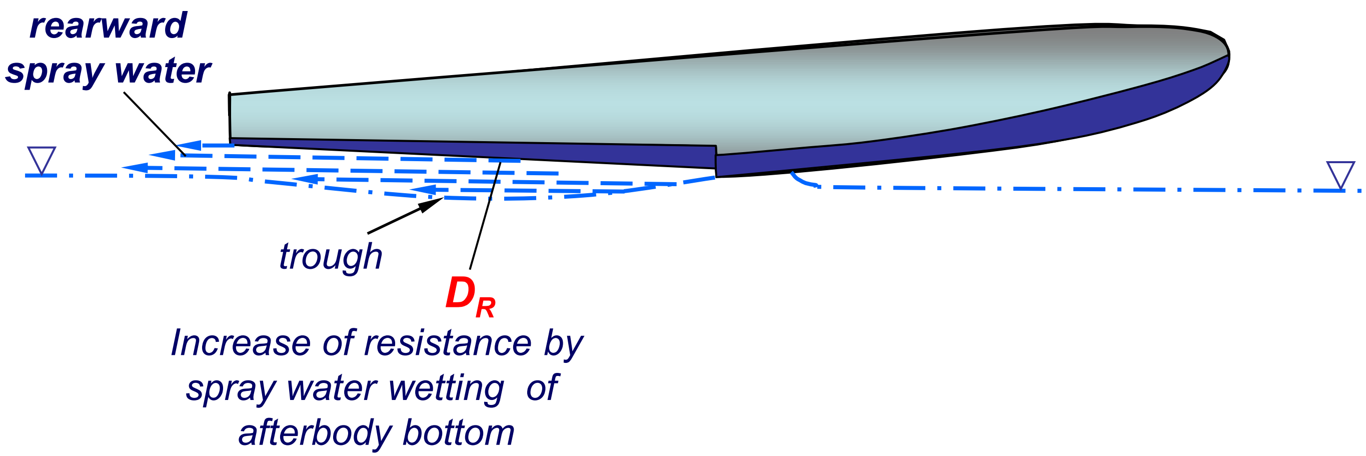
Reduced Resistance by Afterbody Steplets

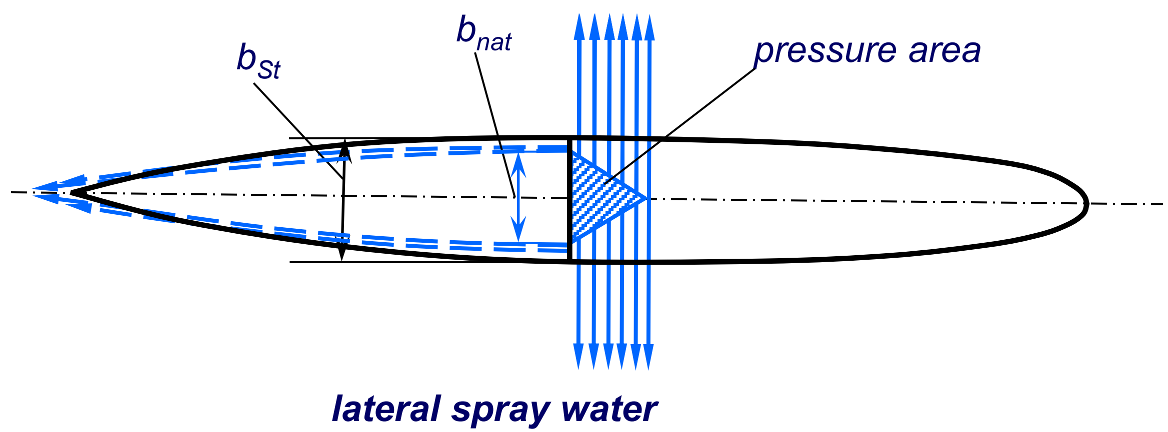
Wedge on afterbody of ***Beriev A-40***

Low Spray Generation

Principal Sketch of Spray on a Seaplane Hull/Float (Sottorf)

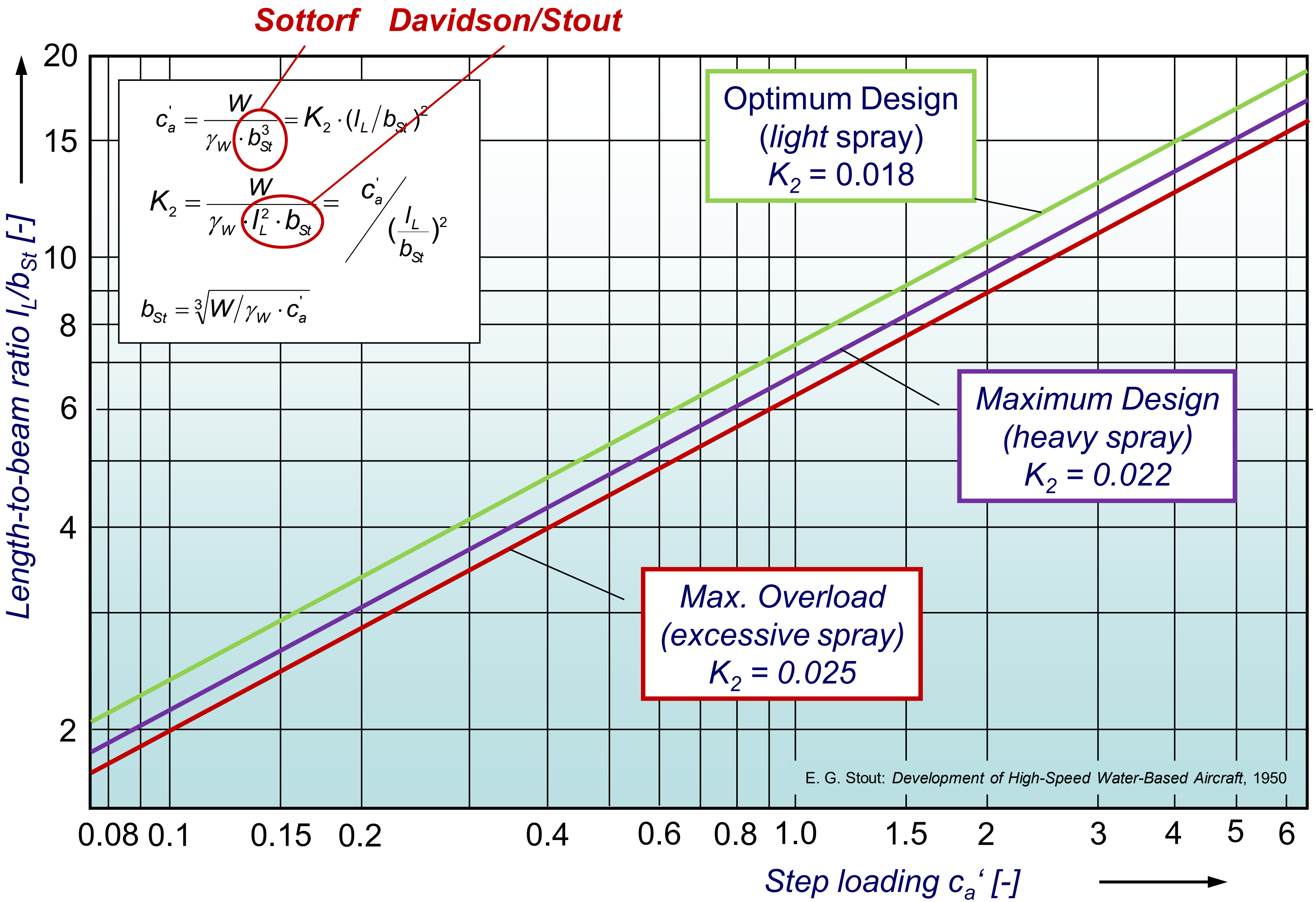
Planing mode





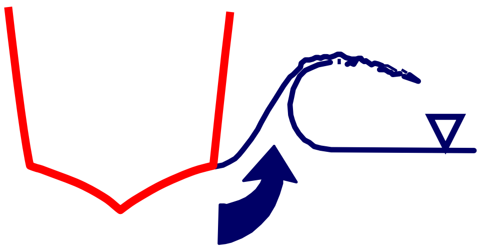
Low Spray Generation

Spray Intensity Depending on Step Loading and Length-to-Beam Ratio

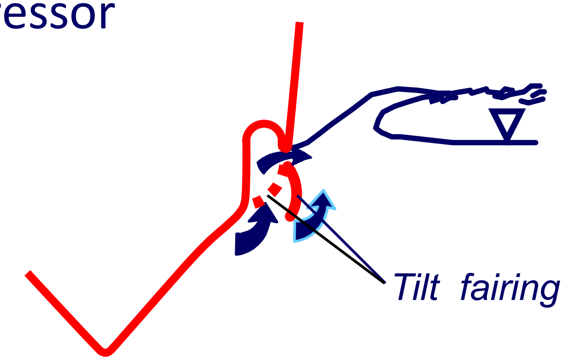


Low Spray Generation

Groove Type Spray Suppressor



Conventional hull bottom frame shape (with chine flare)



Bottom with Groove Type Spray Suppressor and fairing

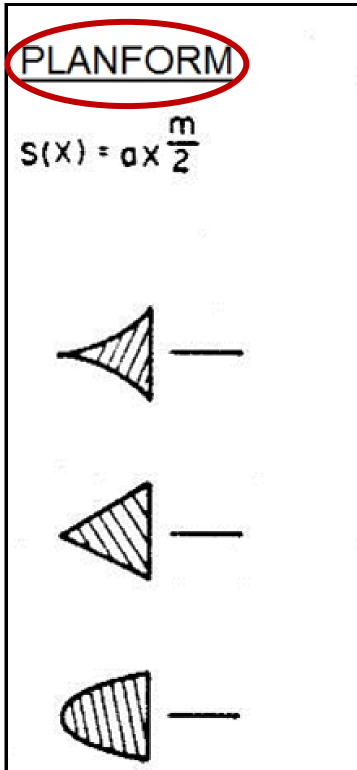
Additional **resistance** and **drag, impact load?**

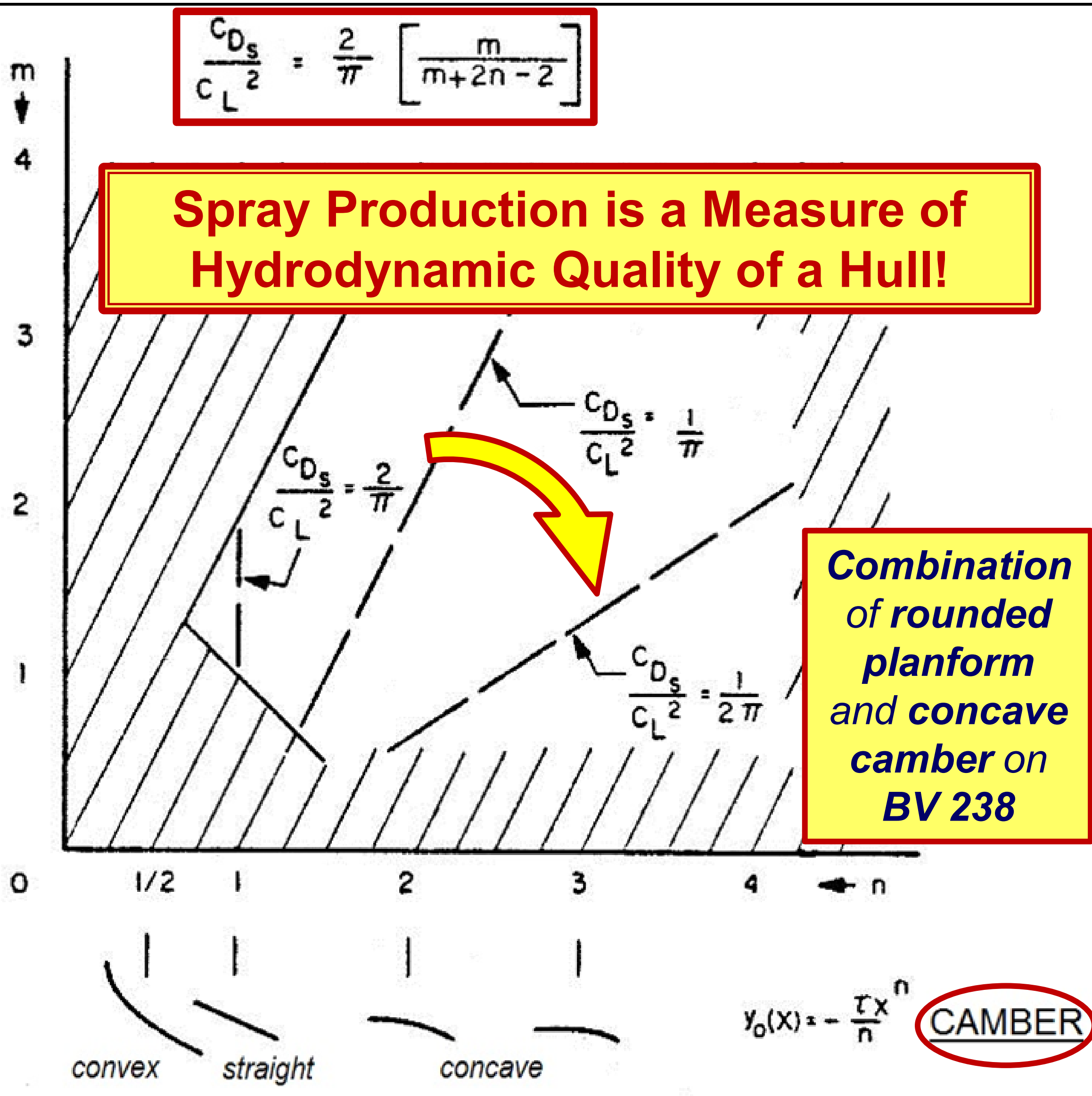
Forebody of ***ShinMaywa US-2*** *with GTSS*

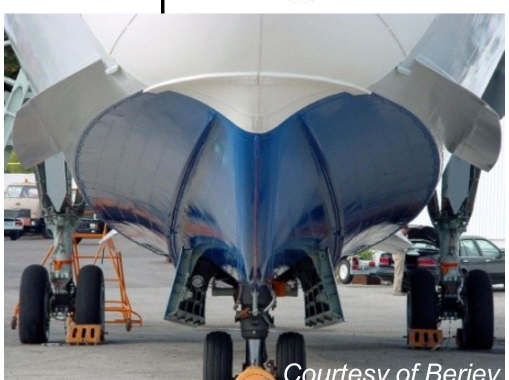
Unknown source

Low Spray Generation

Influence of Planform and Camber on Spray Drag (Tulin/Wagner)





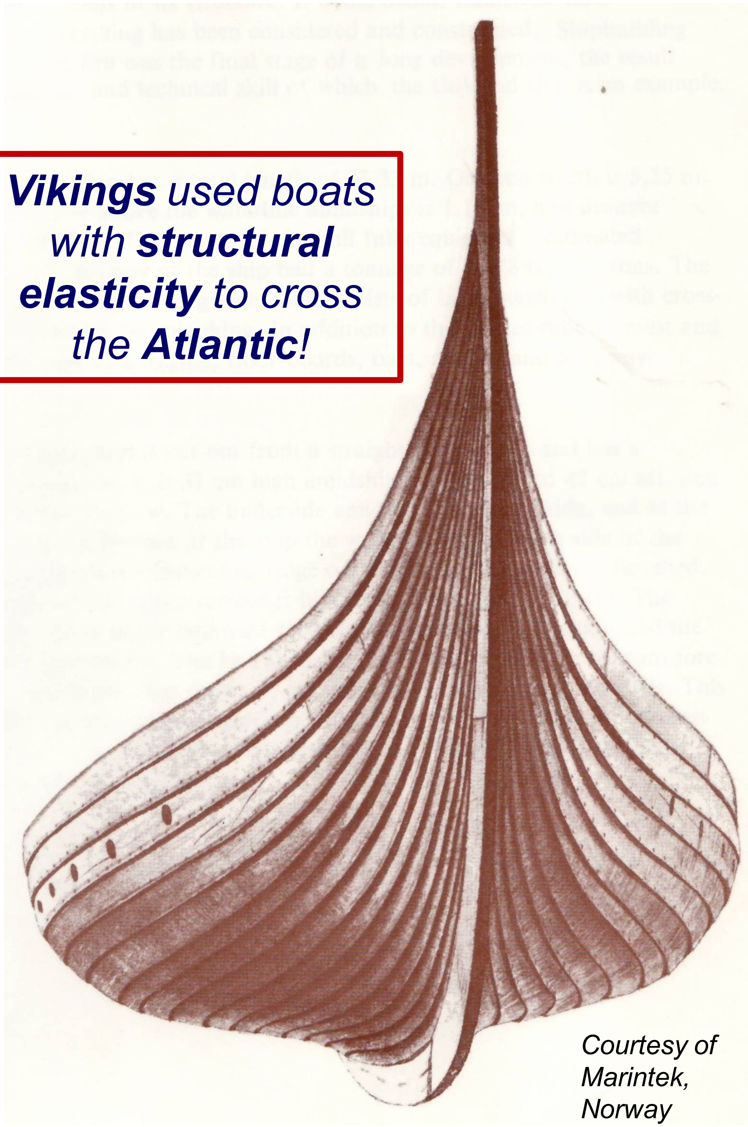


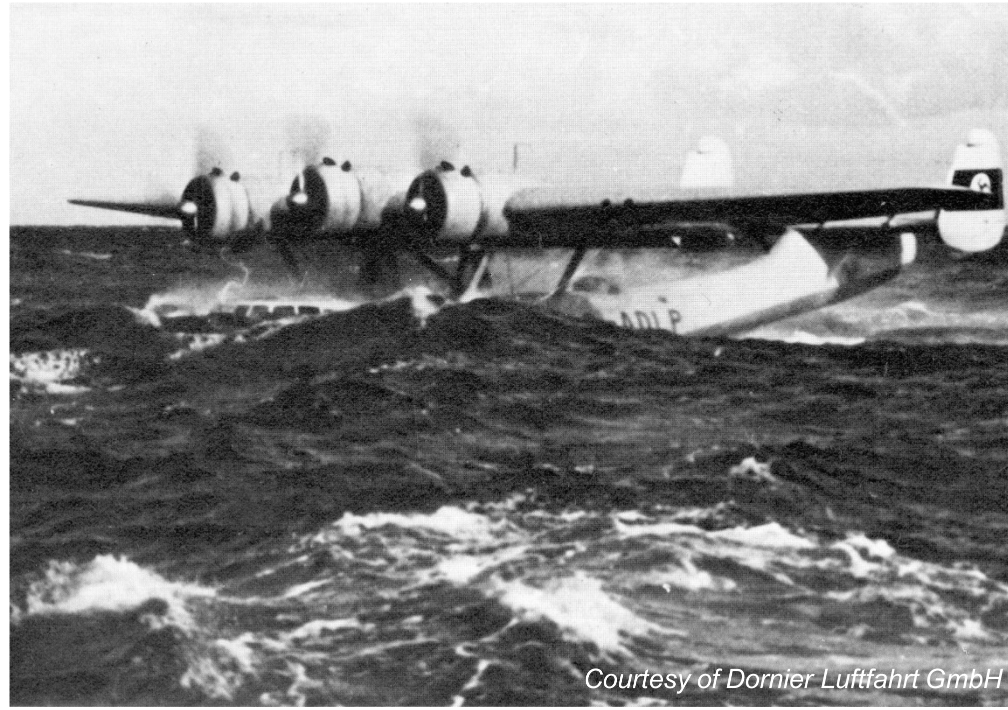
Round keel at bow of Be-200

Low Water Impact Loads

Structural Elasticity (Viking Boats) and High Seaworthiness

Vikings *used boats with* ***structural elasticity*** *to cross the* ***Atlantic****!*



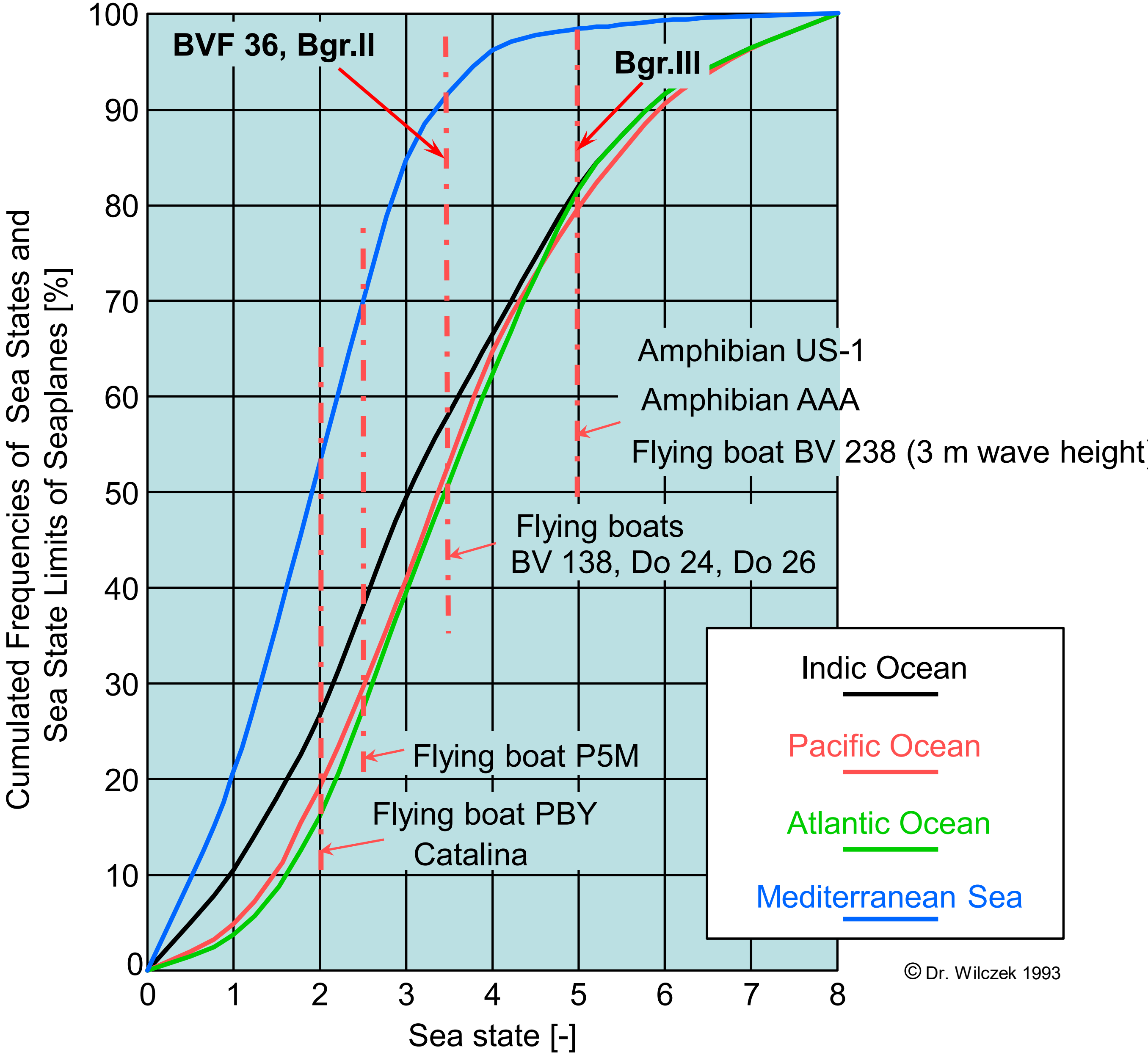


Dornier Do 24 *at sea trials, North Sea 1937 (****sea state 4****)*

No model tests allowed due to **Cauchy‘s Law**!

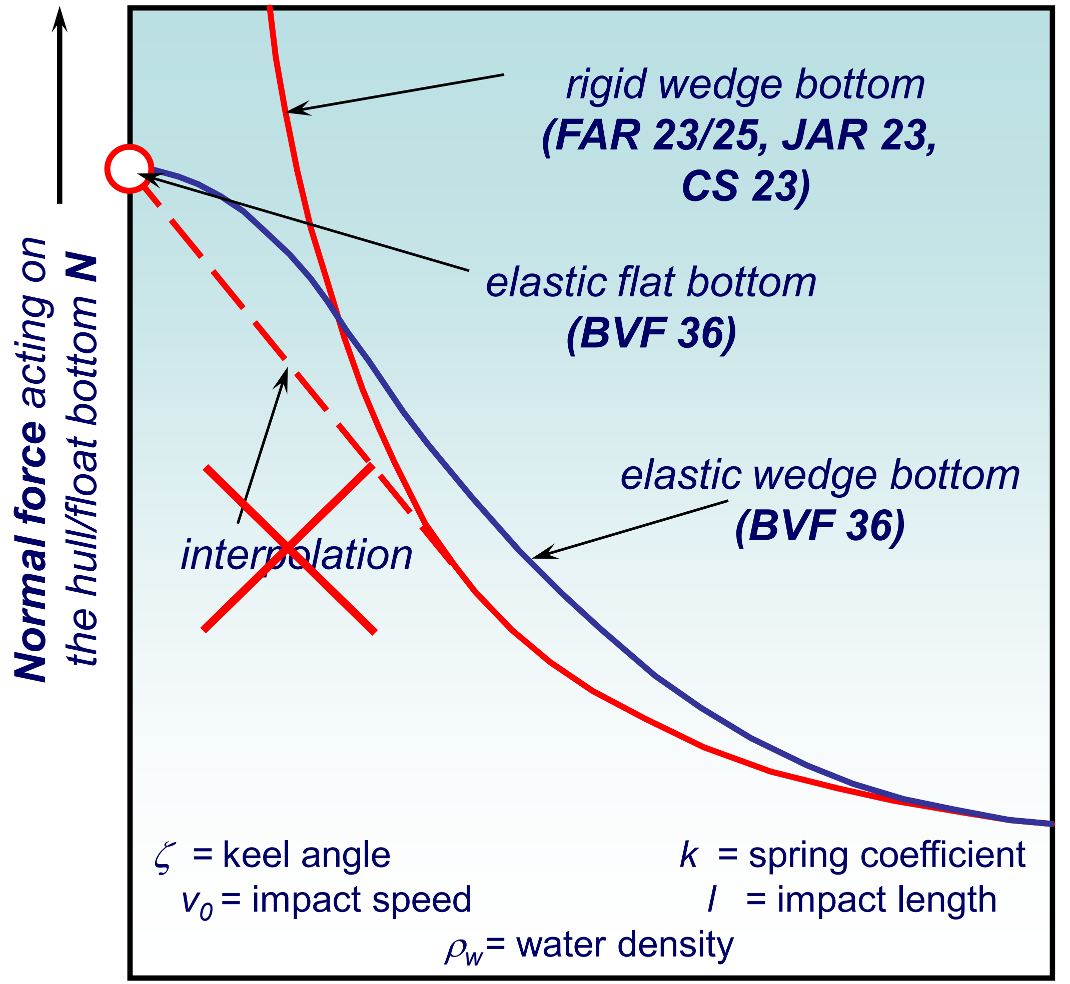
Low Water Impact Loads

Sea State Statistics & Limitations



Low Water Impact Loads

Influence of Elasticity and Deadrise on Alighting Impact (Ebner/Sydow)



$$\frac{\pi-\zeta}{\zeta}\,\frac{\sqrt{k}}{v_0\sqrt{\rho_w l}}$$

Ebner's water load formula *being introduced into the* ***German BVF 36***

$$P_{zx} = m_{red}\cdot\left(c_0\cdot c_1\cdot c_2\cdot v^{1.5}\right)$$

m_{red} = mass reduced to point of impact

c_0 = weight coefficient

c_1 = "sea state" limitation coefficient

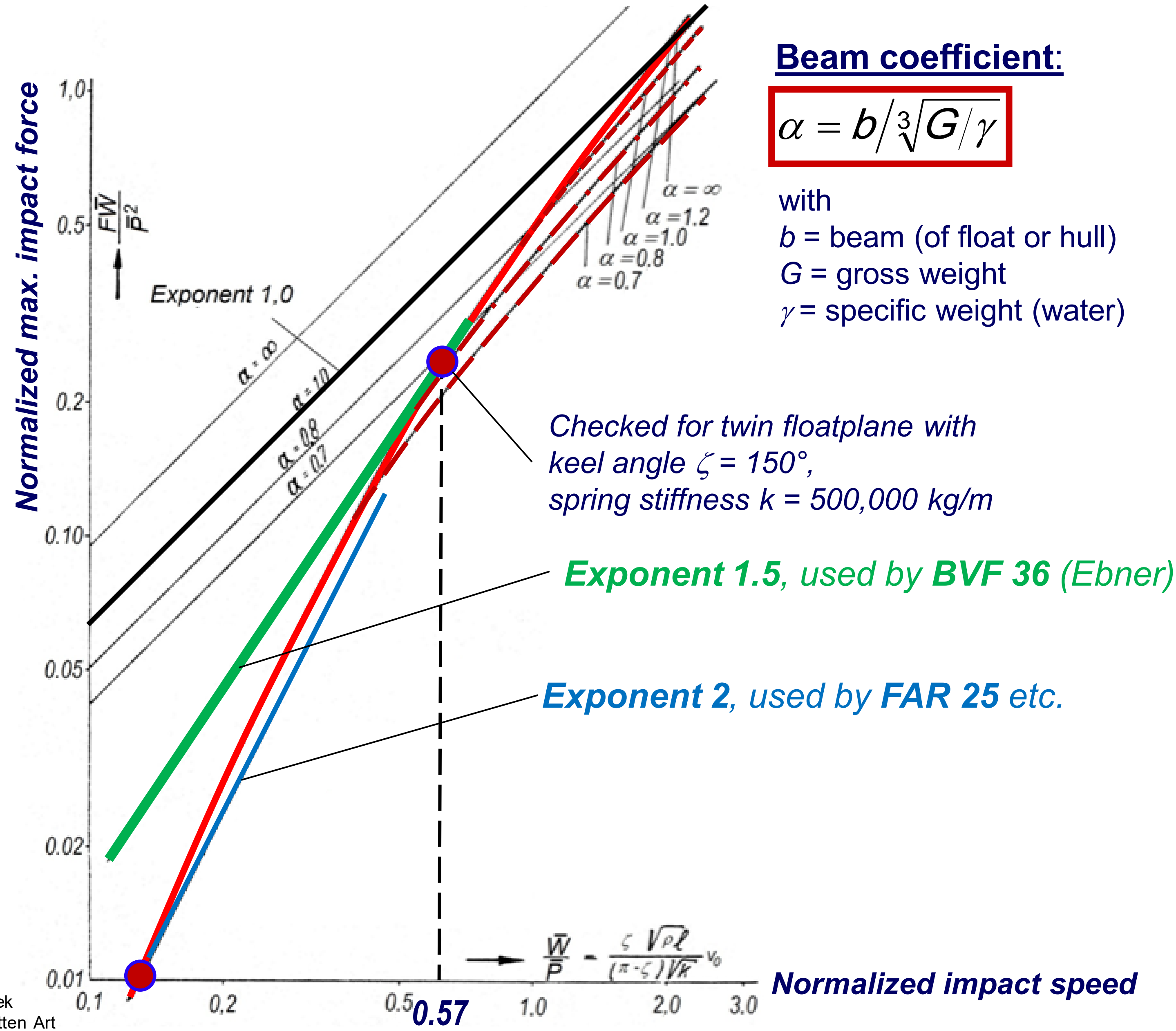
c_2 = keel shape coefficient

v = alighting speed

A ***steep wedge*** *increases considerably the* ***hydrodynamic resistance****!*

Low Water Impact Loads

Water Loads Depending Exponentially from Impact Speed (Sydow/Schmieden)



Beam coefficient:

$$\alpha = b \big/ \sqrt[3]{G/\gamma}$$

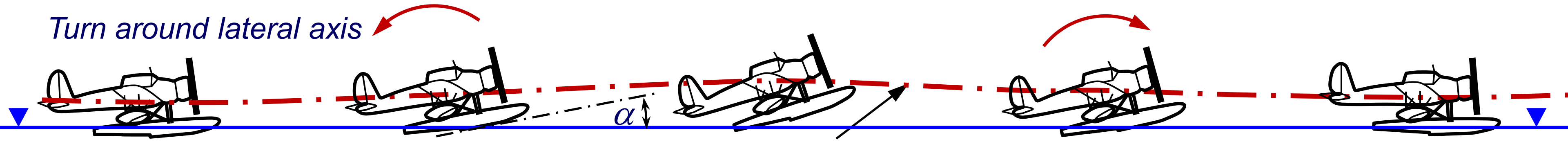
with
b = beam (of float or hull)
G = gross weight
γ = specific weight (water)

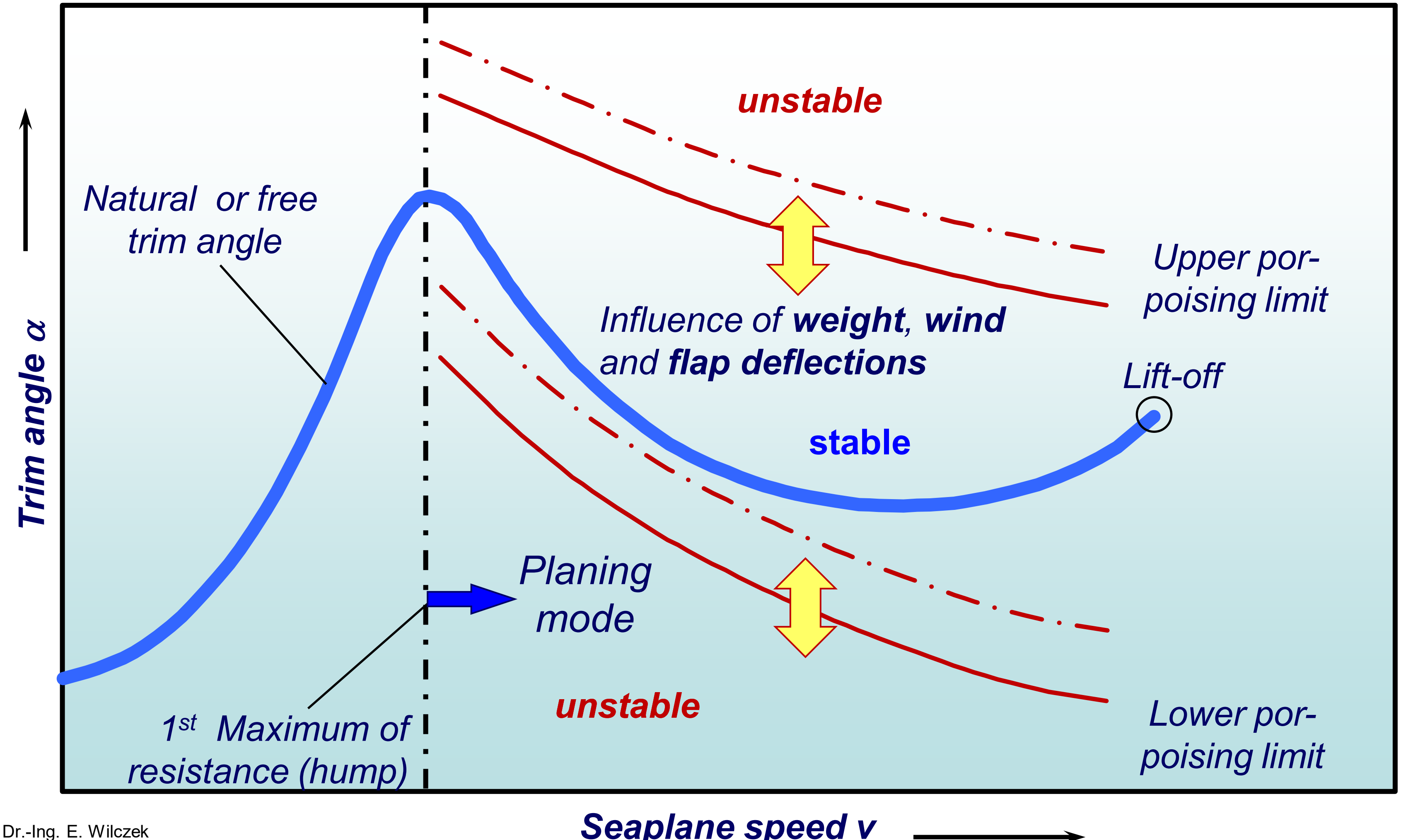
NO TENDS OF OSCILLATIONS AROUND THE PITCH AXIS – NO PORPOISING

https://images.app.goo.gl/dJVEwQ76EAvVfbbd6

No Tends of Oscillations Around the Pitch Axis – No Porpoising

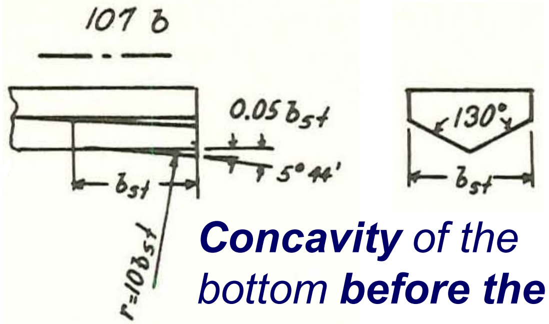
Porpoising Limits of a Seaplane (Full/Lechner/Sottorf)



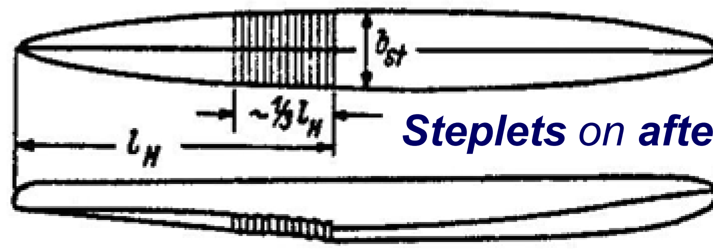


No Tends of Oscillations Around the Pitch Axis – No Porpoising

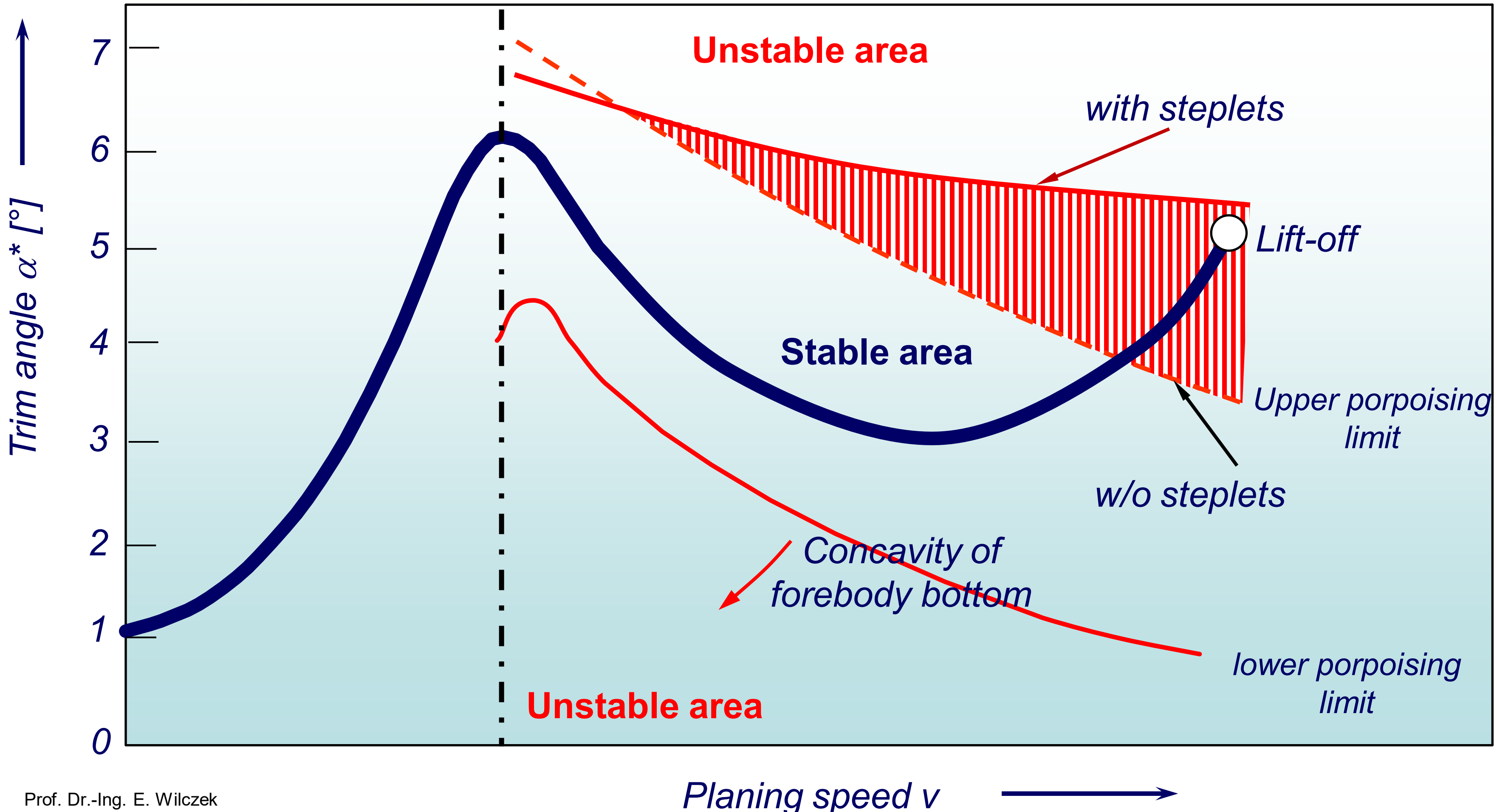
Influence of Modifications of Fore- and Afterbody (Sottorf)



Concavity** of the bottom **before the step



Steplets** on **afterbody



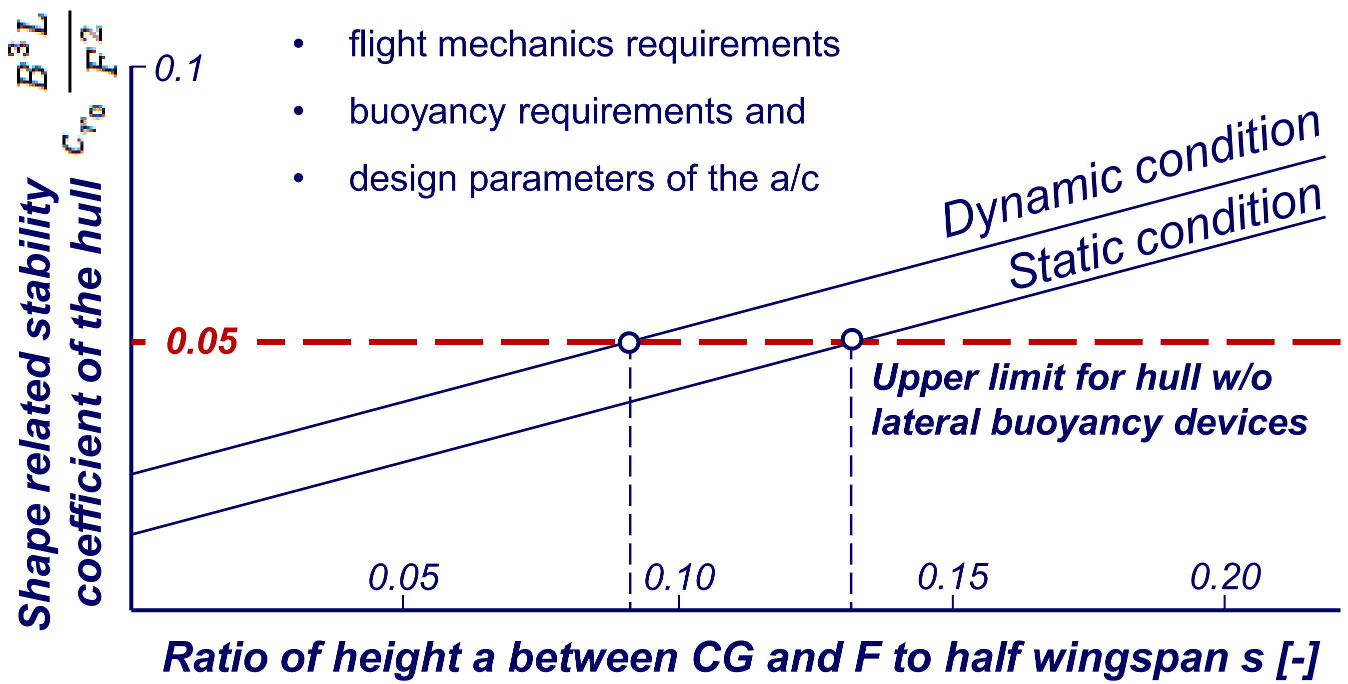
Weather-Cock Stability and Stability Around All Horizontal Axis

Characteristics at Different On-Water Operations

- **Static stability with regard to capsizing**
- **Weather-Cocking at mooring**

Correlation between Wing Span – Mass Density – Stability (Wenk)

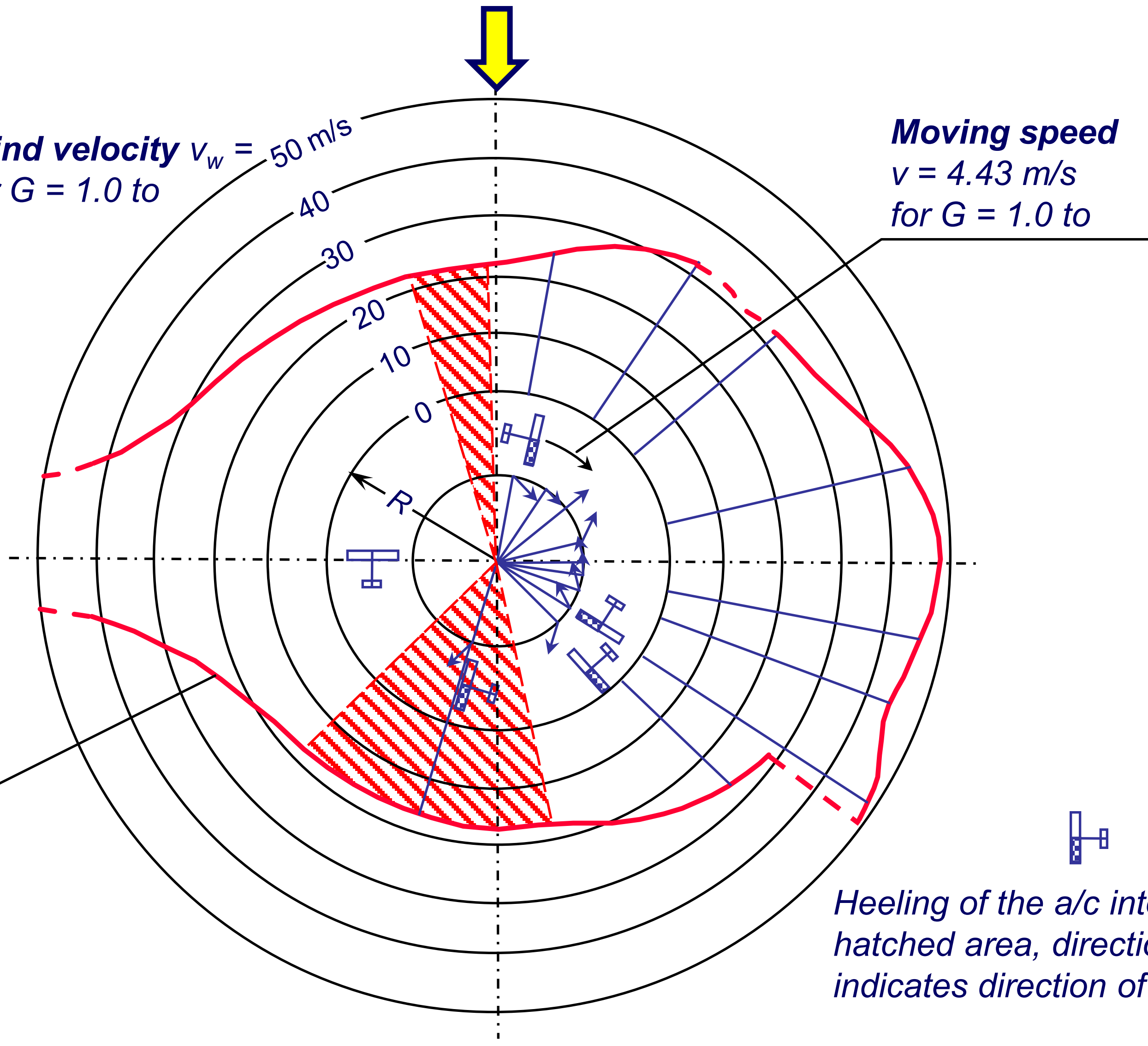
- seaworthiness requirements
- flight mechanics requirements
- buoyancy requirements and
- design parameters of the a/c



Weather-Cock Stability and Stability Around All Horizontal Axis

Maximum Wind Speeds for 1-t-Aircraft When Taxiing in a Circle without Crabbing

(Laute)

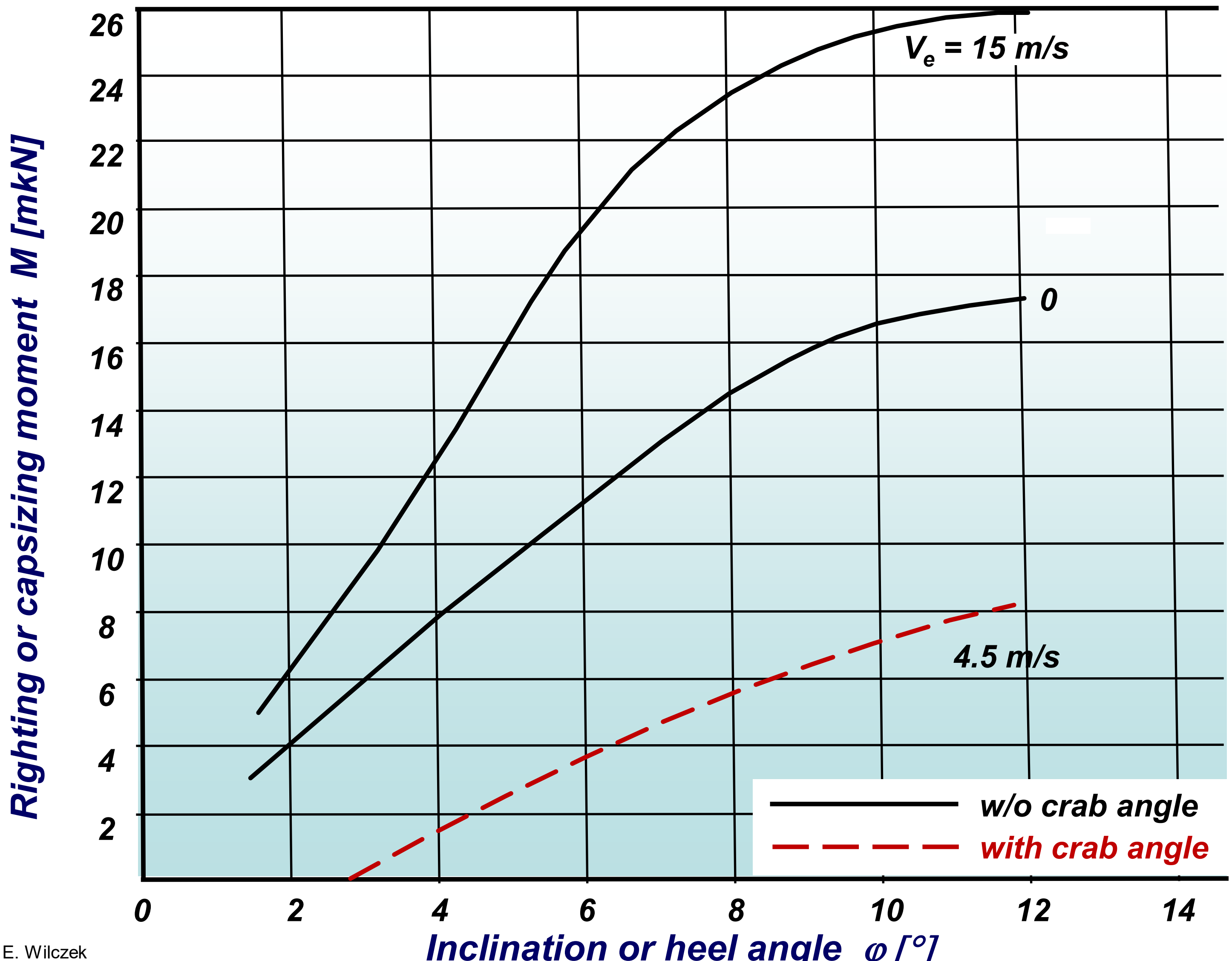


Heeling of the a/c into direction of hatched area, direction of arrows indicates direction of capsizing.

Weather-Cock Stability and Stability Around All Horizontal Axis

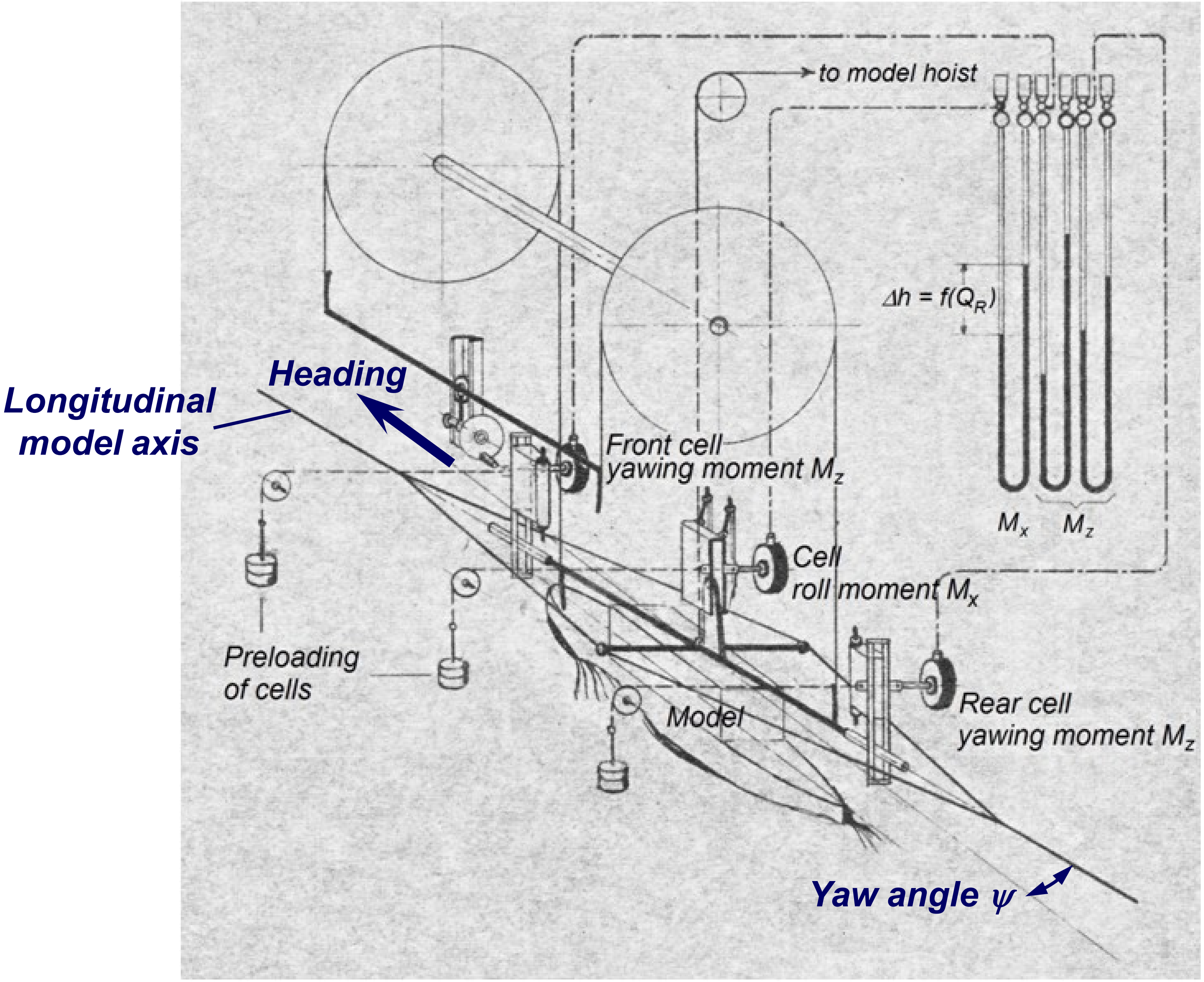
Lateral Stability of a Taxiing Twin Floatplane (Ebner/Full)

(w/o and with crab angle (10°); V_e = floatplane velocity)



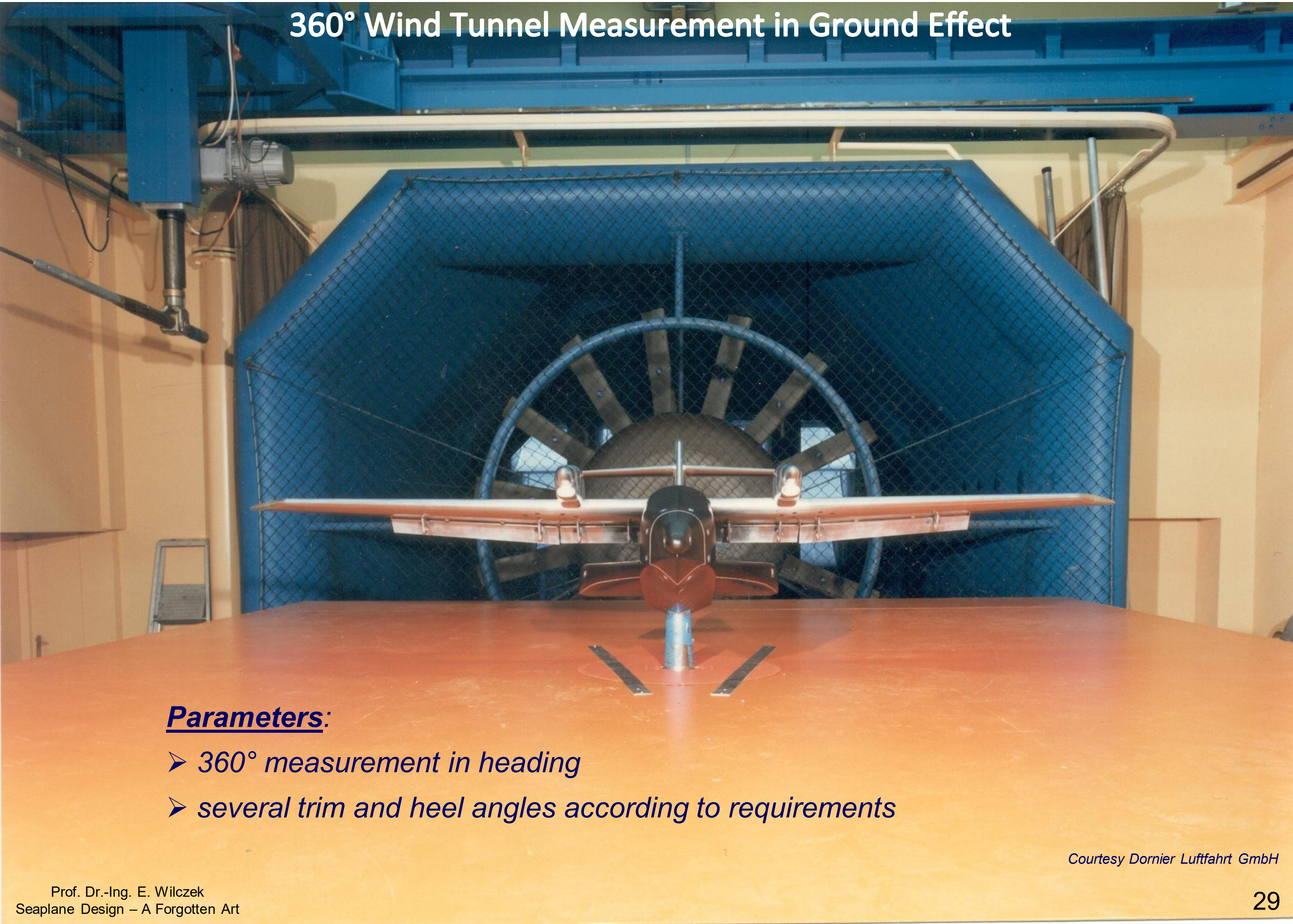
Weather-Cock Stability and Stability Around All Horizontal Axis

Oblique Towing Test Apparatus Measuring Transversal Force, Yawing and Rolling Moment (IfS)



Weather-Cock Stability and Stability Around All Horizontal Axis

360° Wind Tunnel Measurement in Ground Effect



Parameters:

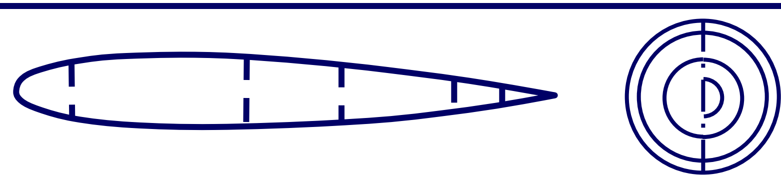
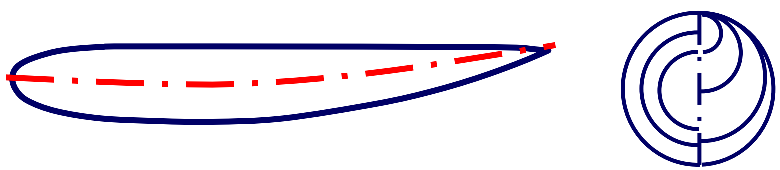
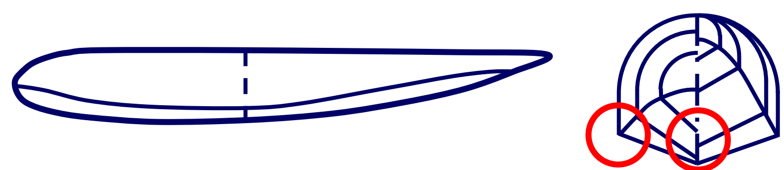
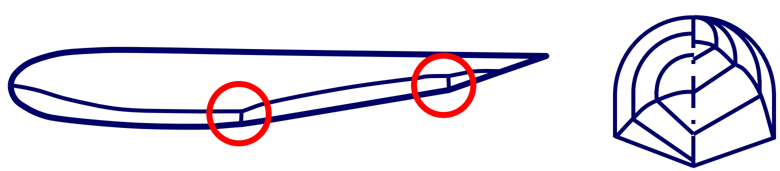
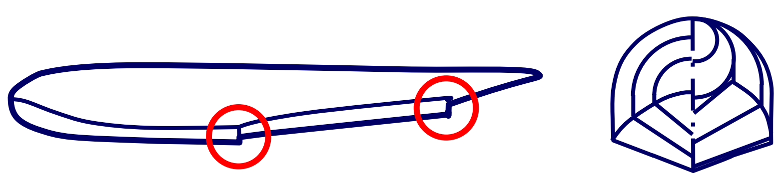
- *360° measurement in heading*
- *several trim and heel angles according to requirements*

Courtesy Dornier Luftfahrt GmbH

Low Aerodynamic Drag

Aerodynamic Drag of Conventional Hulls/Floats

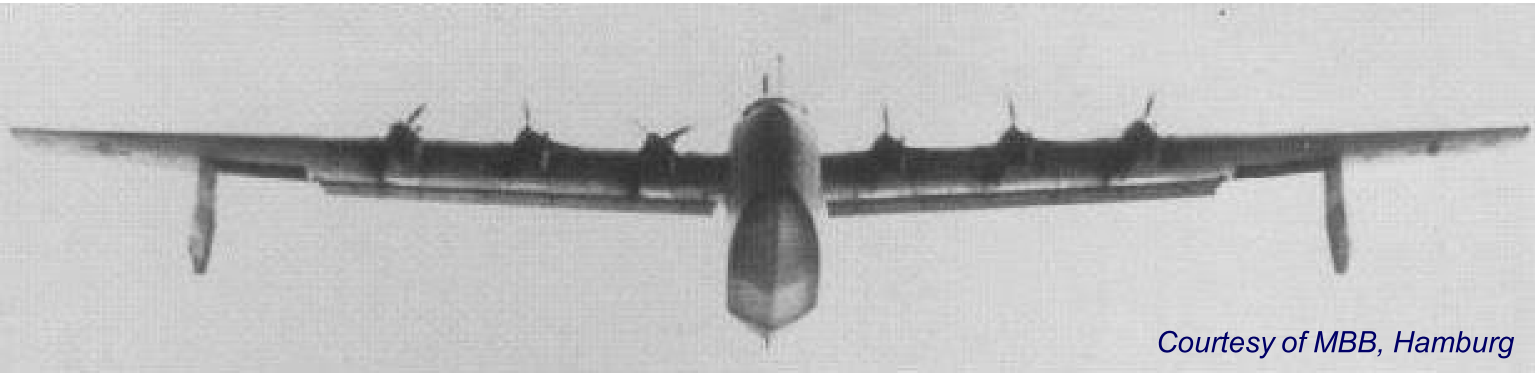
- **Features creating drag**

Features creating drag	Drag ratio to seaplane	Development phase
	*69%*	*Aerodynamic body circular cross sections*
	*78%*	*stern upwards circular cross sections*
	*83%*	*V-shaped planing bottom*
	***85%***	*Flying-boat* ***w/o steps***
	***100%***	*Flying-boat* ***with steps***

Prof. Dr.-Ing. E. Wilczek
Seaplane Design – A Forgotten Art

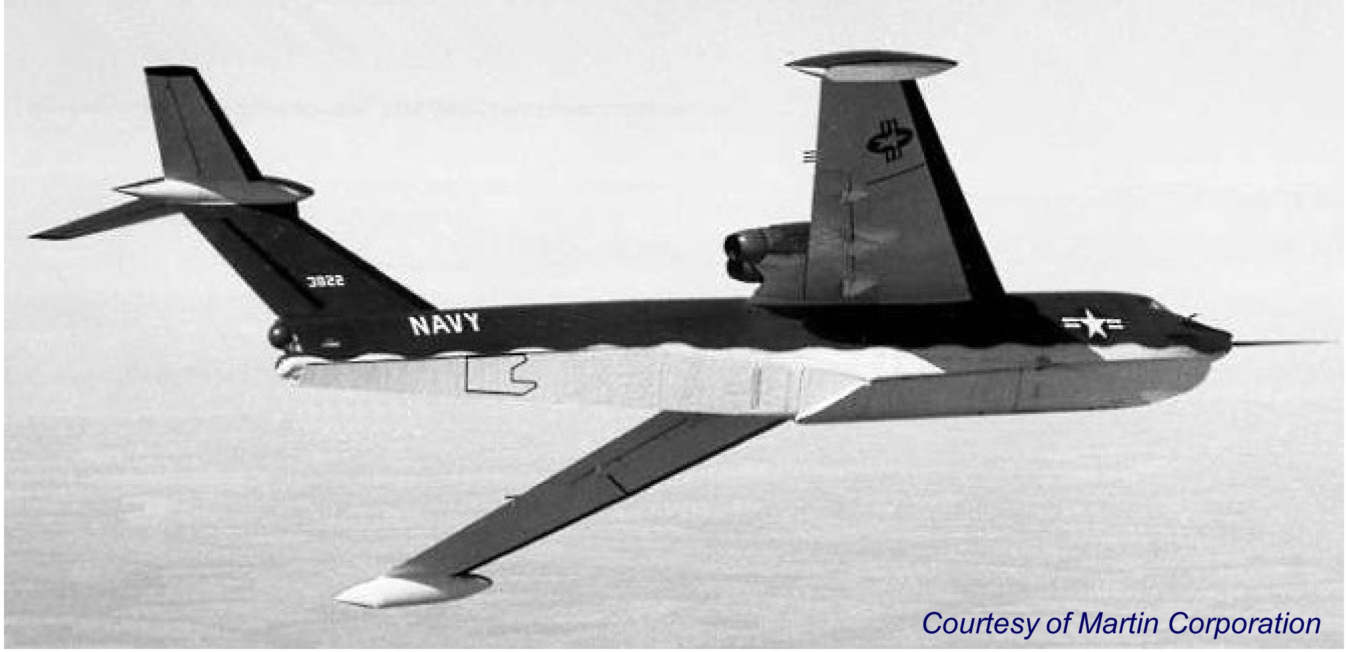
Low Aerodynamic Drag

Advanced Slender Hull Bottoms



Courtesy of MBB, Hamburg

Blohm & Voss BV 238 V1 (1944)
l/b_{St} = 9.3



Courtesy of Martin Corporation

Martin YP6M-1 SeaMaster (1959)
l/b_{St} = 15

Courtesy of Dornier Luftfahrt GmbH