



Photo: Vendée Globe

AKER ARCTIC TECHNOLOGY

How to engineer a keel for an IMOCA 60 sailboat?

2023-02-16

Ville Valtonen

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Aker Arctic
The Ice Technology Partner

Background



$$\vec{a} \cdot \vec{b} = -\sin \xi \cos^2 \alpha \sin \beta + \cos \xi \sin \alpha \cos \alpha \sin \beta$$

$$|\vec{a}| = \sqrt{\cos^2 \alpha + \sin^2 \alpha} = \sqrt{1} = 1$$

$$|\vec{b}| = \sqrt{\sin^2 \xi \cos^2 \alpha \sin^2 \beta + \cos^2 \xi \cos^2 \alpha \sin^2 \beta + \cos^2 (\xi - \alpha) \cos^2 \beta}$$

$$= \sqrt{\cos^2 \alpha \sin^2 \beta + \cos^2 (\xi - \alpha) \cos^2 \beta}$$

$$\Omega = \cos^{-1} \left(\frac{-\sin \xi \cos^2 \alpha \sin \beta + \cos \xi \sin \alpha \cos \alpha \sin \beta}{\sqrt{\cos^2 \alpha \sin^2 \beta + \cos^2 (\xi - \alpha) \cos^2 \beta}} \right)$$

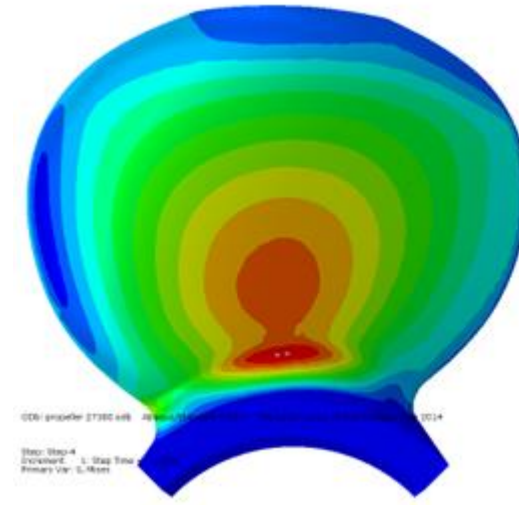
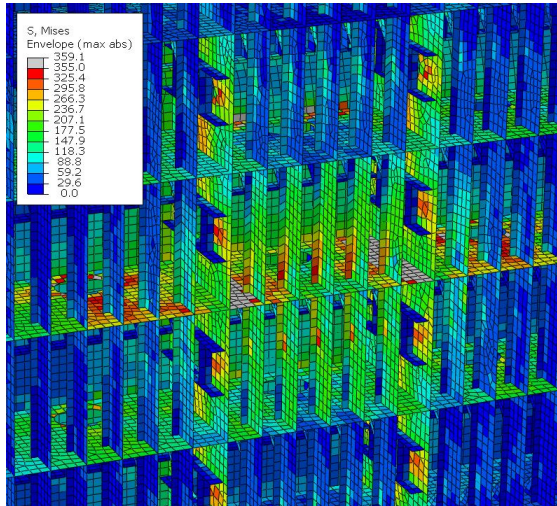


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"If they've never engineered a keel for a yacht before, a canting keel IMOCA 60 might be an ambitious point to start"

A racing boat – what does that mean in practical terms?

Cruising sailboat (Hallberg-Rassy 62)

- Displacement 33 t
- Sail area 203 m²



Photo: Hallberg Rassy

IMOCA 60 Stark

- Displacement 8.5 t (26 %)
- Sail area 337 m² (166 %)



Photo: Ari Huusela

The environment - the design loads

Le Vendée Globe : édition 2020-2021

— Parcours du Vendée Globe

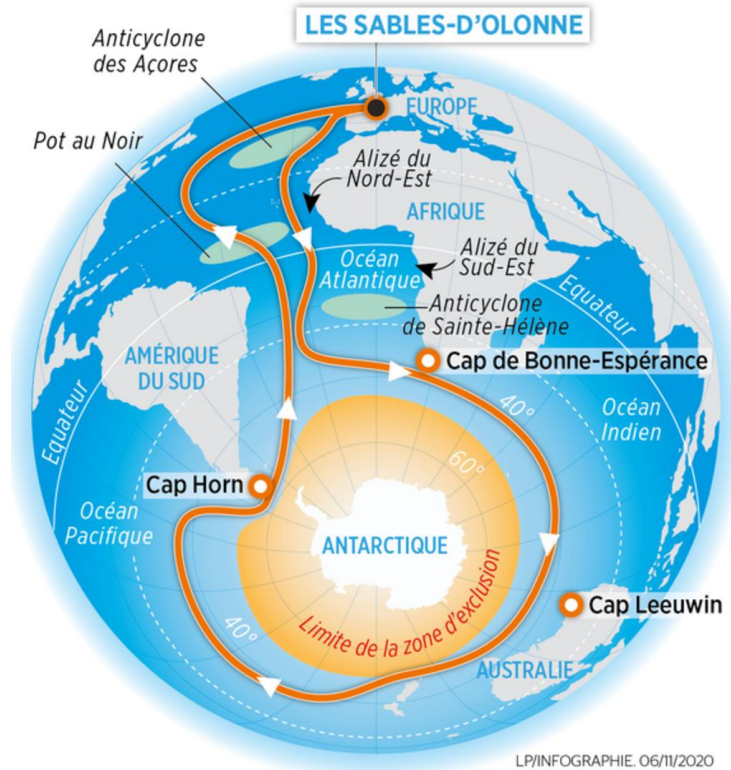


Photo: Ari Huusela



Photo: Christophe Launay



Photo: OnEdition

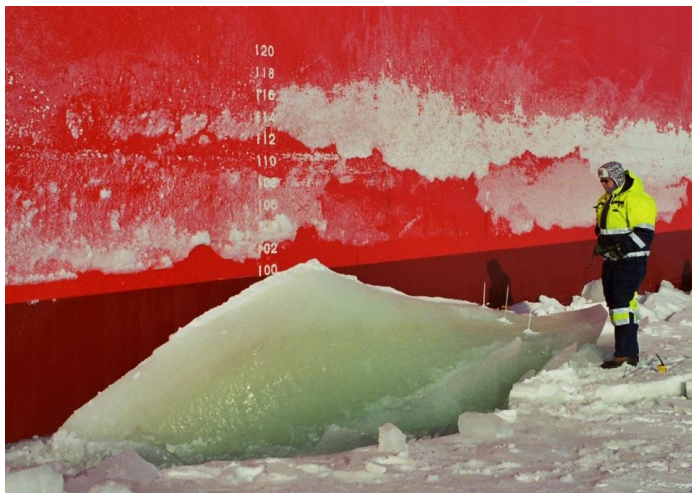
The reliability

- Solo, non-stop race
- Keel failure is not an option



The requirements

- Rules changed after 2012 Vendee Globe
 - No welded structures or composites
 - Keel has to be machined from single billet



- Design loads from IMOCA Class Rules
 - Boat at 90° heel, 5 G gravity load
 - Grounding, 27 t load at keel bulb nose
- Material forged stainless steel
 - Yield min. 800 MPa
 - Available from 2 manufacturers in the whole world



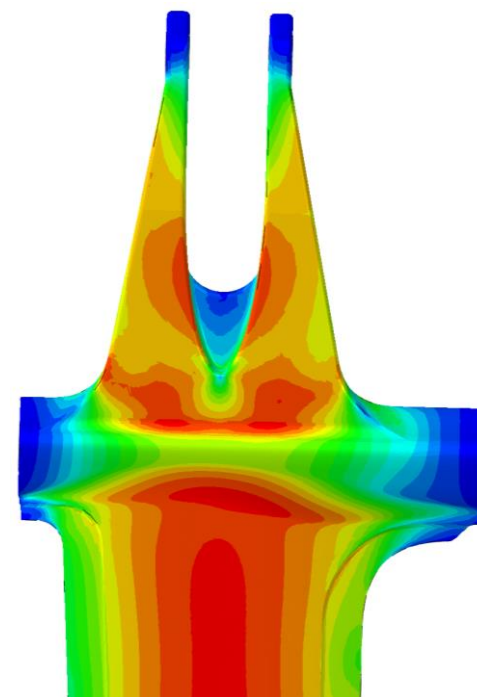
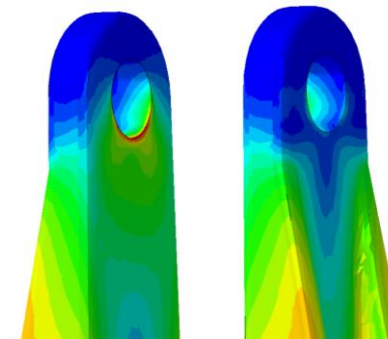
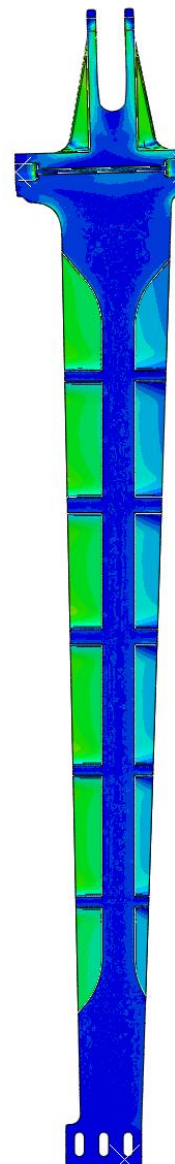
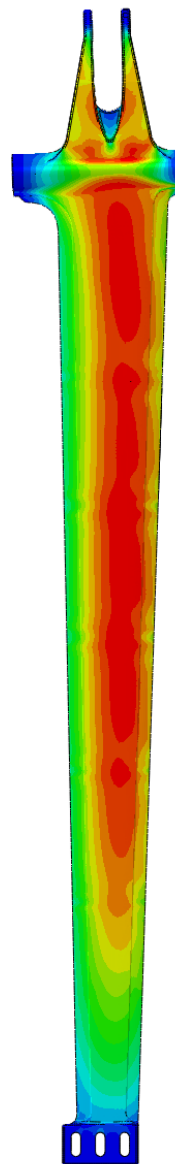
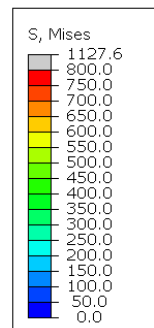
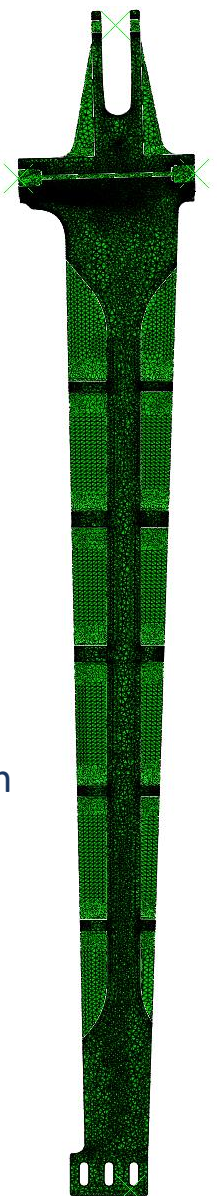
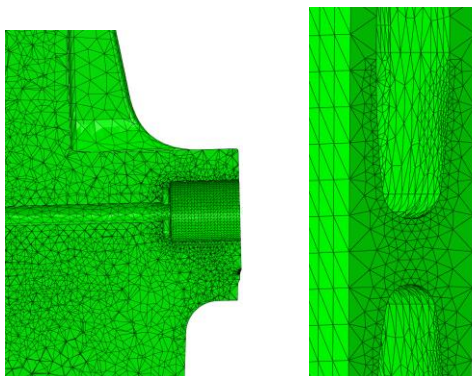
© Marine Nationale / Nefertiti - # Vendee Globe



Photo: Vapillon

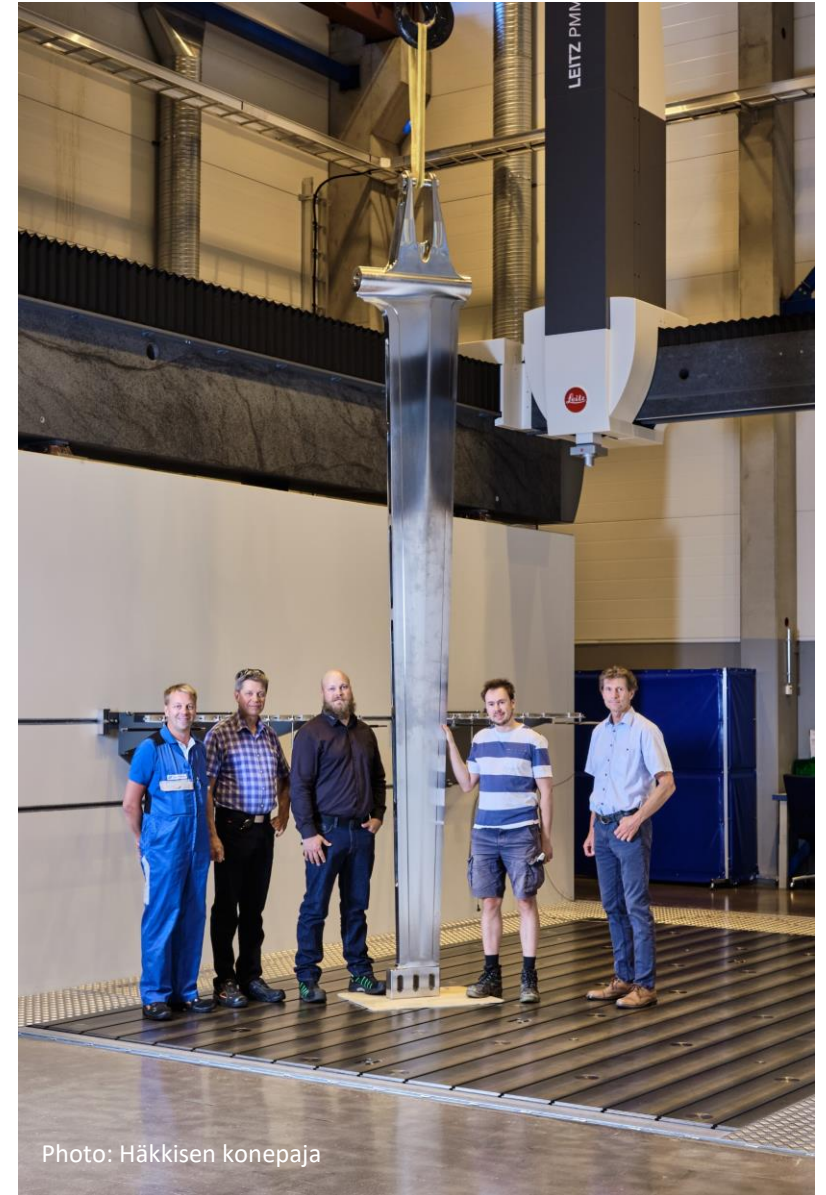
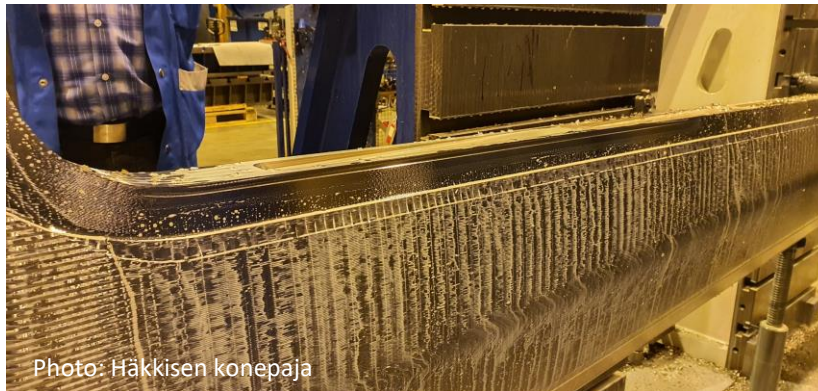
The analysis

- Foil section and hydro from Merf Owen
- Finite element analysis with Abaqus
- Extremely dense mesh
 - Quadratic elements
 - 20 mm mesh in general
 - 4 mm mesh at details
 - 657344 elements
- Close co-operation with Häkkisen konepaja on producibility
- 30 iteration rounds to find optimal design



The keel fin

- Machined from single billet in Häkkisen konepaja
- ~4500 kg slab
~960 kg keel fin
~3500 kg shavings



The keel fin



Photo: Häkkisen konepaja



Photo: Häkkisen konepaja

The keel fin



Photo: Häkkisen konepaja



Photo: Häkkisen konepaja

The keel fin



Photo: Häkkisen konepaja

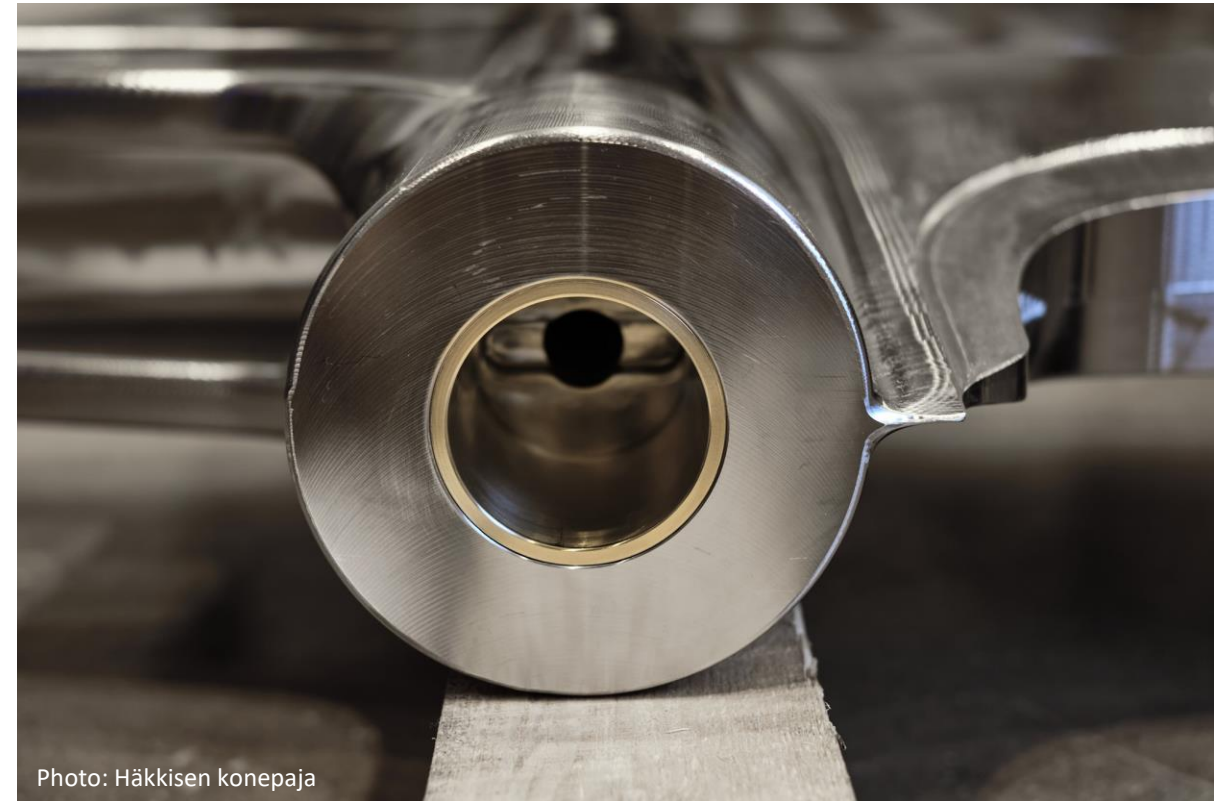


Photo: Häkkisen konepaja

End result



Photo: Ari Huusela



Photo: Vendée Globe



THANK YOU

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