THE WORLD'S FIRST FOILING ELECTRIC SPEED BOAT

WHY CANDELA?

A 7.5 m conventional planing boat consumes ***~15 times*** *more fuel than a family car*

Making boats run on electricity is inherently difficult. A 7.5 m long, planing recreational boat consumes ~15 times more fuel than a family car. At the same time, one kg of gasoline contains ~15 times more usable energy than one kg of the most energy dense batteries.

Because of this, electric boats have until now not been viable alternatives to combustion engine boats. Existing models are slow or have a much limited range.

Candela's pioneering approach to efficiency, software and structural design is radically changing the image and boundaries of electric boats.

Range in nautical miles at 22 knots:

50

Emissions per nautical mile*:

0

Top speed in knots:

30

RANGE AND SPEED

Candela has redefined what a boat is through creating the world's first electric boat with speed & range on par with a fossil boat. In rough seas, she behaves second to none, beating planing boats in comfort & silence. Simply the future of boating.

In 2014, the team behind Candela were determined to find ways to make electric boats with both range and speed. The group assembled contained some of the leading experts in the fields structural composite engineering, fighter jet flight control electronics, America's Cup hydrodynamics, truck transmission & hydraulics, dynamic modelling and drone control software.

At the end of 2016, a full-scale prototype was launched and, after some tuning, the target of more than 50 nautical miles per charge in 22 knots was reached.

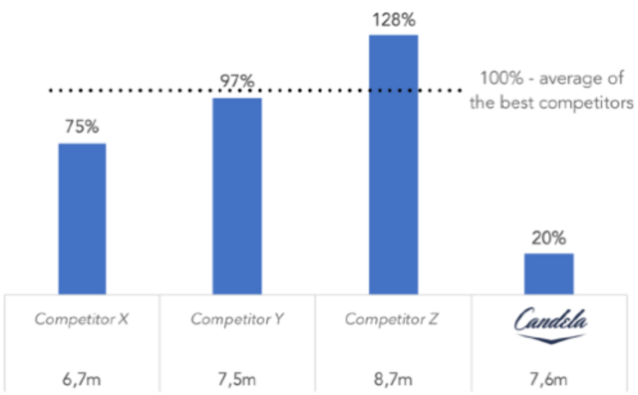
The achieved range is ~4 times longer than the best electric boats currently on the market and it is close to that of a combustion engine boat of the same size.

The 9 first customer deliveries have been completed as of March 2019.

*Assuming sustainably sourced electricity

THE EFFICIENCY FORMULA

Energy Consumption



A >75% energy reduction is achieved by the use of:

- Hydrofoils, which halve the friction compared to a planing boat
- An advanced automatic control system making the naturally unstable boat stable
- A very light design using carbon composites and design principles from the aviation industry

Since a combustion engine converts only some 25% of the chemical energy to mechanical energy while an electric drivetrain achieves approx 90% conversion, Candela has a stunning 15 times higher total efficiency than a traditional petrol boat.

$$
\begin{bmatrix} \dot{\boldsymbol{p}} \\ \dot{\boldsymbol{\Theta}} \\ \dot{u} \\ \dot{v} \\ \dot{w} \\ \dot{p} \\ \dot{q} \\ \dot{r} \end{bmatrix} = \begin{bmatrix} \boldsymbol{R}\boldsymbol{v} \\ \boldsymbol{T}\boldsymbol{\omega} \\ \frac{1}{m}\left(\begin{bmatrix} -D_{\Sigma}(\mathbf{v}, \boldsymbol{\omega}, D, \phi, \theta, \boldsymbol{\alpha}_C, \beta_C) \\ L_{S\Sigma}(u, v, \boldsymbol{\omega}, \beta_C) \\ -L_{F\Sigma}(u, w, \boldsymbol{\omega}, \boldsymbol{\alpha}_C) \end{bmatrix} + \mathbf{f}_P + \mathbf{f}_G \right) - \boldsymbol{S}(\boldsymbol{\omega})\boldsymbol{v} \\ \boldsymbol{I}_g^{-1}\left(\begin{bmatrix} \tau_{x\Sigma}(\mathbf{v}, \boldsymbol{\omega}, \alpha_{CR}, \alpha_{CL}, \beta_C) \\ \tau_{y\Sigma}(\mathbf{v}, \boldsymbol{\omega}, D, \phi, \theta, \boldsymbol{\alpha}_C, \beta_C) \\ \tau_{z\Sigma}(\mathbf{v}, \boldsymbol{\omega}, D, \phi, \theta, \boldsymbol{\alpha}_C, \beta_C) \end{bmatrix} + \mathbf{m}_p + \boldsymbol{S}(\boldsymbol{I}_g\boldsymbol{\omega})\boldsymbol{\omega} \right) \end{bmatrix} \tag{55}
$$

This can be further written out as:

$$
\begin{bmatrix} \dot{\boldsymbol{p}} \\ \dot{\boldsymbol{\Theta}} \\ \dot{u} \\ \dot{v} \\ \dot{w} \\ \dot{p} \\ \dot{q} \\ \dot{r} \end{bmatrix} = \begin{bmatrix} \boldsymbol{R}\boldsymbol{v} \\ \boldsymbol{T}\boldsymbol{\omega} \\ \frac{1}{m}\left(\cos\alpha_{CA}\cos\beta_C\ F_P - \sin\theta\ mg - D_{\Sigma}(\mathbf{v}, \boldsymbol{\omega}, D, \phi, \theta, \boldsymbol{\alpha}_C, \beta_C)\right) + rv - qw \\ \frac{1}{m}(\sin\beta_C\ F_P + \cos\theta\sin\phi\ mg + L_{S\Sigma}(u, v, \boldsymbol{\omega}, \beta_C)) + pw - ru \\ \frac{1}{m}(-\sin\alpha_{CA}\cos\beta_C\ F_P + \cos\phi\cos\theta\ mg - L_{F\Sigma}(u, w, \boldsymbol{\omega}, \boldsymbol{\alpha}_C)) + qu - pv \\ \frac{1}{I_{xx}}(-z_P\sin\beta_C\ F_P + \tau_{x\Sigma}(\mathbf{v}, \boldsymbol{\omega}, \alpha_{CR}, \alpha_{CL}, \beta_C) + (I_{yy} - I_{zz})qr) \\ \frac{1}{I_{yy}}((x_P\sin\alpha_{CA} + z_P\cos\alpha_{CA})\cos\beta_C\ F_P + \tau_{y\Sigma}(\mathbf{v}, \boldsymbol{\omega}, D, \phi, \theta, \boldsymbol{\alpha}_C, \beta_C) + (I_{zz} - I_{xx})pr) \\ \frac{1}{I_{zz}}(x_P\sin\beta_C\ F_P + \tau_{z\Sigma}(\mathbf{v}, \boldsymbol{\omega}, D, \phi, \theta, \boldsymbol{\alpha}_C, \beta_C) + (I_{xx} - I_{yy})pq) \end{bmatrix} \tag{56}
$$

MANAGING INSTABILITY

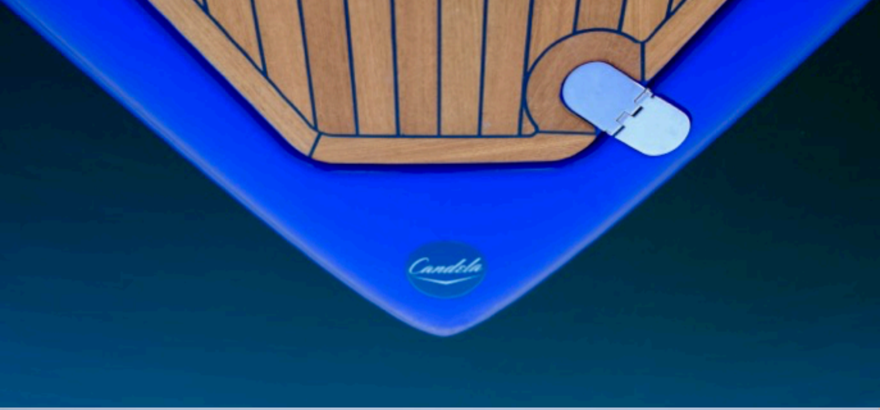
Hydrofoils can be designed in different ways with varying efficiencies and behaviour. At Candela we have opted for the most efficient solution possible - fully submerged foils. This however means that the boat is inherently unstable. Getting the boat stable with software and electronics allowed us to design the experience in rough sea and sharp turns.

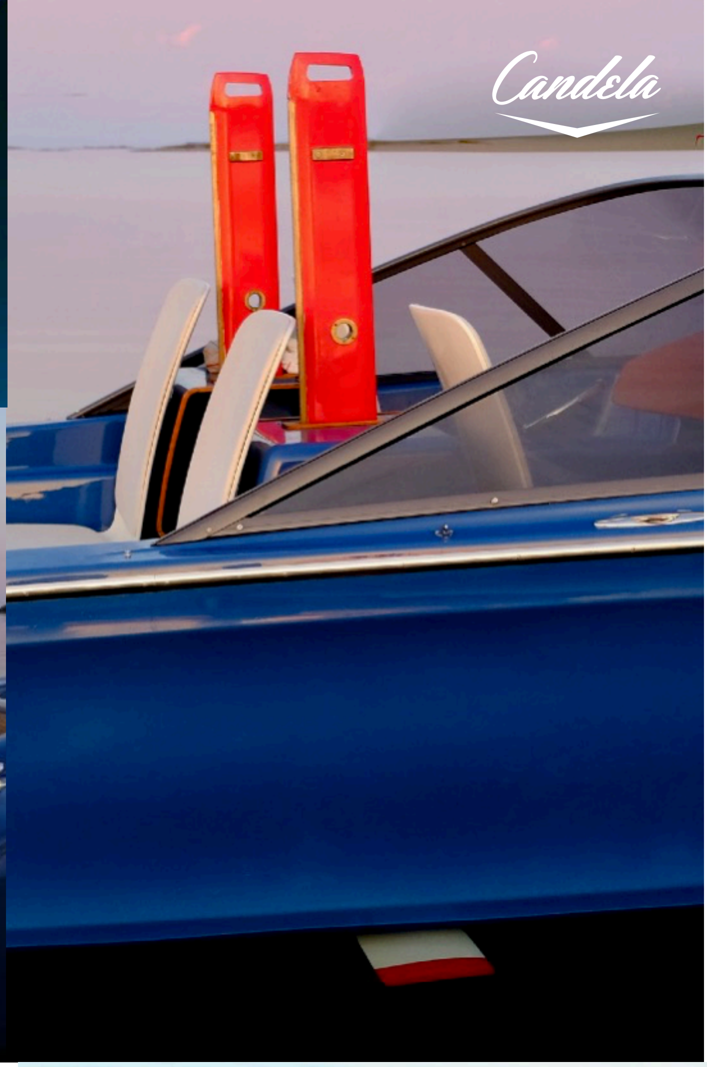
- **Six different sensor types** are used to measure positions, speeds and accelerations in six degrees of freedom
- **Sensor fusion algorithms** are used to minimize errors, bias and noise
- **Neural networks** will over time be deployed to continuously optimize the response to various sea patterns
- **The flight controller** is connected to the boat's other four main CPUs and eleven sub task CPUs over a common bus
- The boat is always **connected to the cloud** allowing for advanced data analytics, service, software updates and remote control through the Candela app
- **After 1000s of hours** of simulations, design iterations and sea trails, a mechanical solution has been found which is robust, fast and efficient. That was pretty hard!

A DIFFERENT EXPERIENCE

Once you have experienced Candela, it is hard to go back to a traditional noisy, smelly and bumpy petrol boat. Even turning is fun!

- A very smooth ride even in high waves
- Almost completely silent
- No wake generation
- When turning hard, the boat leans into the turn, making for a very exciting experience
- No more pollution & suffering at the gas station
- 95% lower operating cost





FORM AND FUNCTION

Designing a new product category means new challenges. For us it meant that the boat had to be built around the foil system and the large battery.

To maximize pitch stability we put the battery in the very front.

To enable shallow waters, beach landings and trailing, the foils had to be made fully retractable which put demands on where to locate the seats.

There was no propeller gear house efficient enough why we made it all from scratch.

All available navigators were complicated to use so we created one from the bottom up.

SPECIFICATION

CANDELA SEVEN

Material	Carbon fiber	**Speed**	22 kn cruise 30 kn top
Weight	1300 kg	**Motor**	55 kW
Length	7.70 m	**Battery**	40 kWh Lithium Ion NMC
Width	2.40 m	**Capacity**	Driver + 5 passengers
Range	50 NM at 22 kn + 8 NM at 5 kn in limp home mode	**Draft**	0.5 m in shallow water mode, 0.4 m while foiling 1.2 m while not foiling
Charging	230 V/16 A standard household outlet. 12 h for a full charge	**Colours**	Available in 9 different colours
Harbor cover	Available in various colours	**Others**	Navigation system, navigation light & fenders included
Sound	2 x Bowers & Wilkins Marine 6 waterproof speakers including audio playback via Bluetooth		
Connection	Connected to an app via 3G for checking the position, state of charge, receiving software updates, remote diagnosis, geofence in realtime		
Foils	Similar to a traffic airplane: a large flat foil close to centre of gravity and a small D shaped foil at the aft. Both are fully retractable for trailing, storage and shallow water operation		
Control	Take off, cruise and landing are all fully automated. Height, roll and pitch are controlled by sensor fusion, controllers, software and hydraulic actuators operating at 100-500 Hz update frequencies		
Optional	Dedicated trailer, cruiser cover and boat accessories available on your demand		