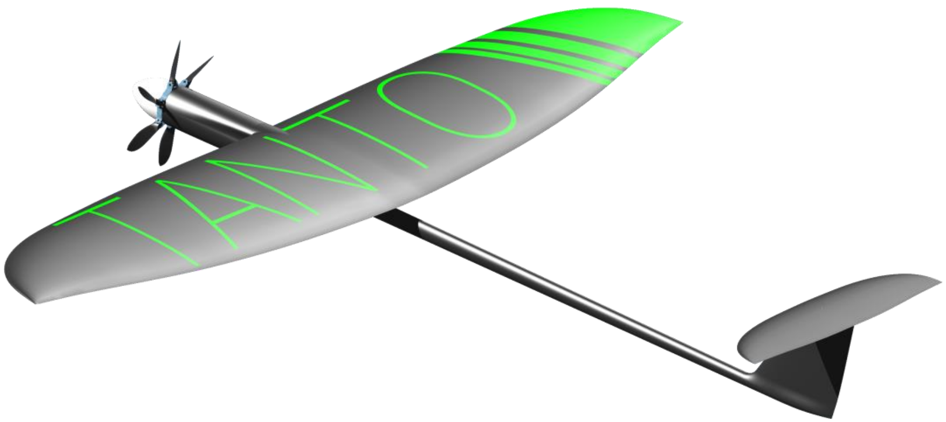
On the design of a 500 km/h electrically driven Mini-UAV

Dr.-Ing. Christian Rößler



Institute of Aircraft Design

01.July 2015

Contents

UAS Research

Research at the Institute for Aircraft Design at TU München focuses on

- derivation of consistent UAV concepts from operational requirements through an integrated conceptual design of airvehicle and mission payload
- exploration and design of modular/multi-mission capable air vehicles
- exploration, design and test of novel energy and propulsion concept for increased operational performance, incl. requirements derived from civil operations (e.g. noise and visual signature, emissions)
- provision of demonstrators (ground and airborne) for verification of systems and operations

Integrated Design Environment

To optimize UAV the Institute of Aircraft Design works on:

- An integrated UAV design environment
- The integration of propulsion systems in coherence with airframe design
- The integration of general avionics and mission systems in coherence with airframe design
- The operational analysis of UAV designs (performance, sensor integration, environmental impact) in the operational context

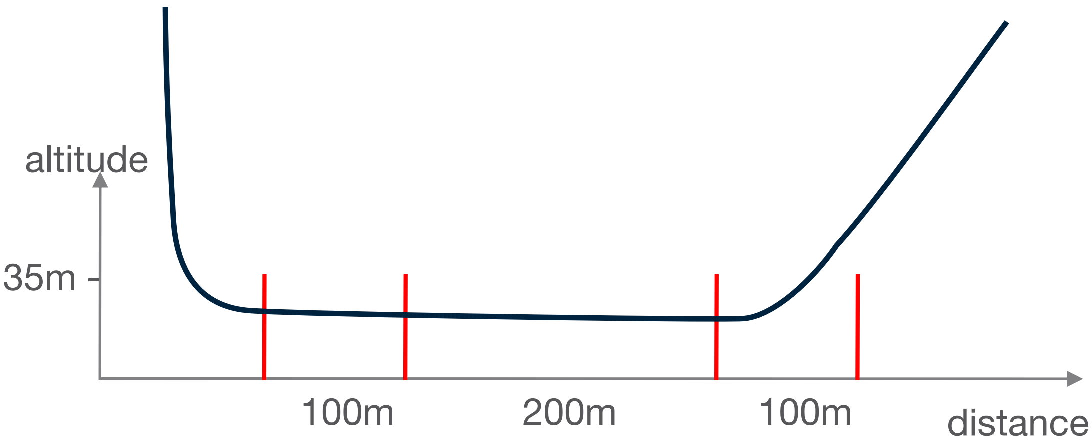
On the design of a 500 km/h electrically driven Mini-UAV

Goal:

Set a new speed world record for electrically powered airplanes!

Rules (FAI sub-class 175):

- Max. wing loading 75 g/dm²
- Max. Takeoff weight 5 kg
- Max. Voltage 72 V
- Timeframe 4 min
- Average of fastest flight over 200m distance from both directions



Current Speed World Records

Manned electric speed records

10.06.2009	Maurizio Cheli	SkySpark	250 km/h
05.09.2010	Hugues Duval	MC15E CriCri "E-Cristaline"	262 km/h
25.06.2011	Hugues Duval	MC15E CriCri "E-Cristaline"	283 km/h
19.07.2012	**Chip Yates**	**modified Rutan Long-EZ**	**324 km/h**
06.10.2013	Chip Yates	modified Rutan Long-EZ	347 km/h

Officially approved speed records electrical motor rechargeable sources (model airplanes) (from Fédération Aéronautique Internationale (FAI) - the governing body for aviation records)

10.06.2007	David Dzida	361.0 km/h
27.08.2009	Jakob Karpfinger	420.24 km/h
17.09.2011	David Dzida	439.14 km/h
15.09.2013	**Niklas Kahlich**	**477.3 km/h**

Actual speed record combustion engine category F3

17.09.2011	Dag Cammann-Walczak	405.30 km/h

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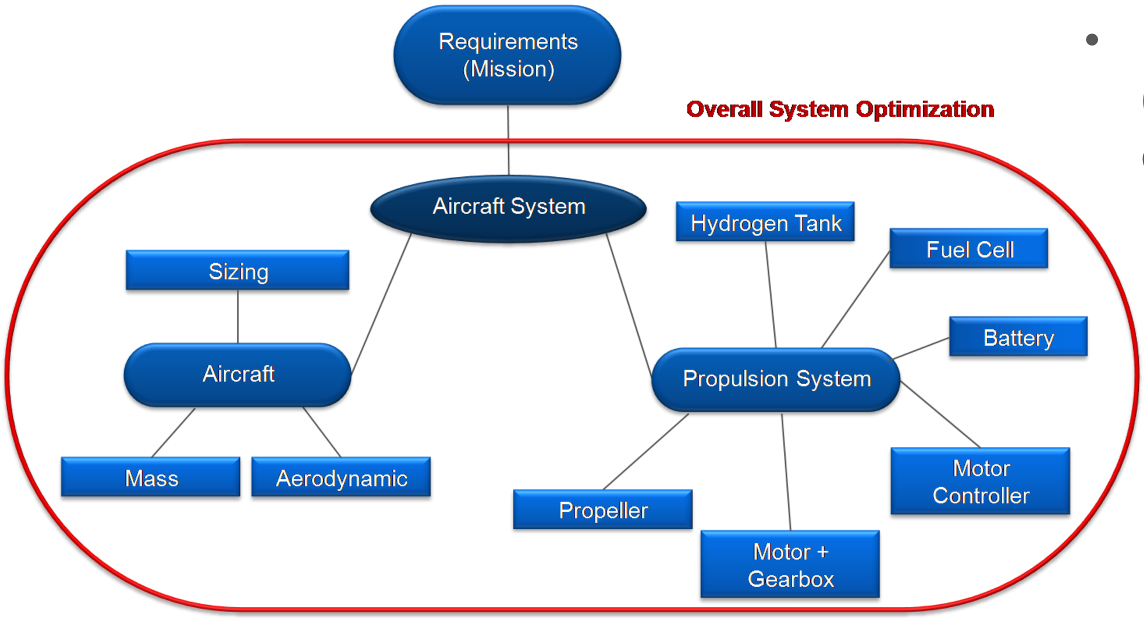
Hybrid Propulsion UAVs – Design Methodology for small UAV

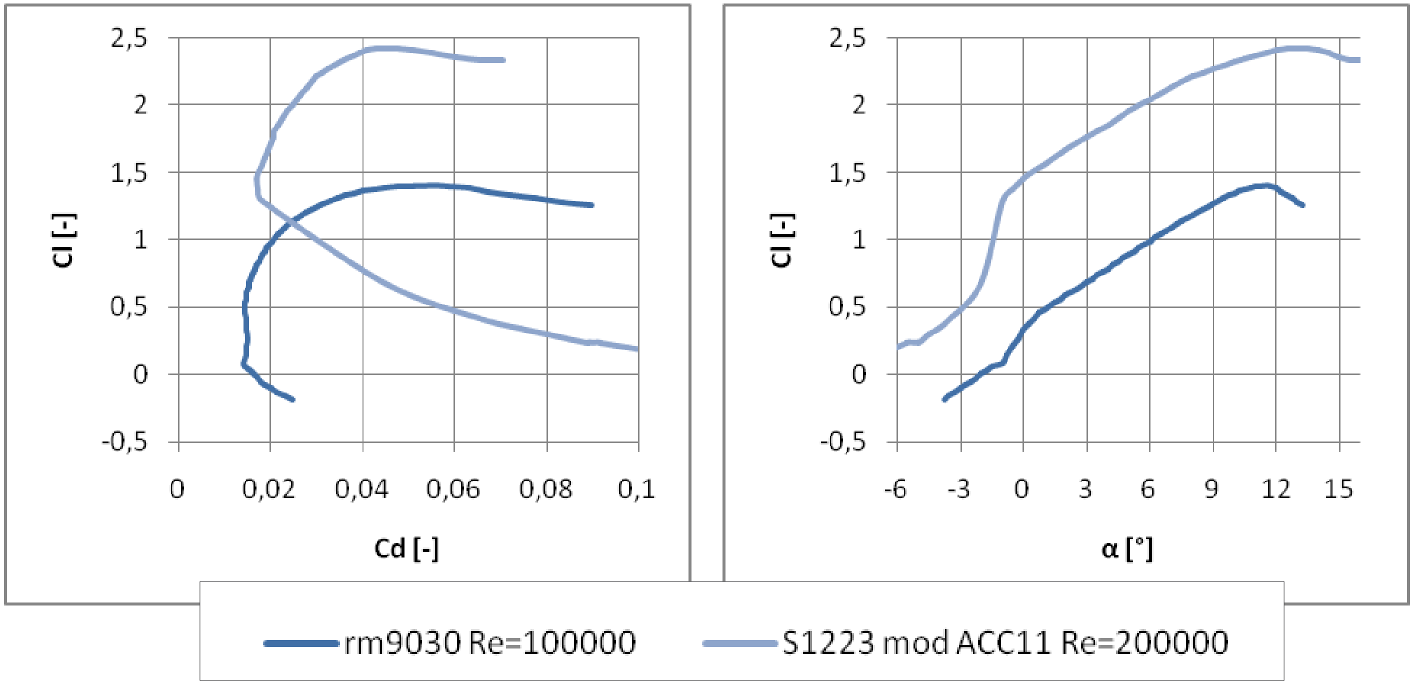
- Integrated Design Methodology mandatory
- Model matching from off-the-shelf and generic systems



Design models required and developed for:

- Aerodynamics
- Structure / mass estimation
- Weight and balance
- Electric propulsion (incl. motor and propeller efficiency matching

Aerodynamic

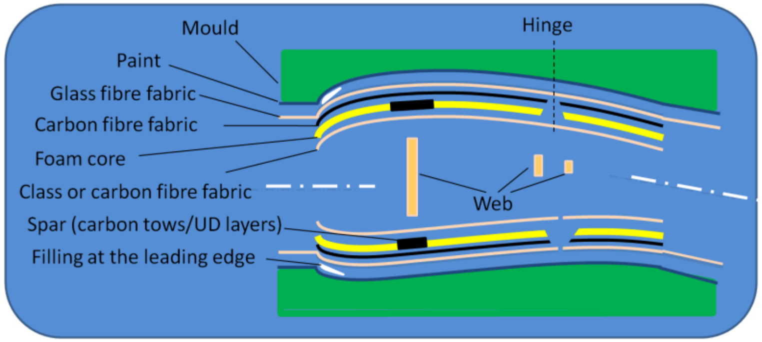


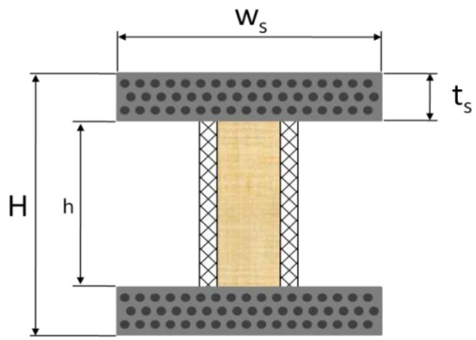
- PAWAT: Extended lifting line theory combined with viscous airfoil data from xfoil or wind tunnel

➡ Non - linearity because of viscous effects due to low Reynolds numbers can be modeled

Mass calculation

- Combination of sizing of components (spar, wing shell) …





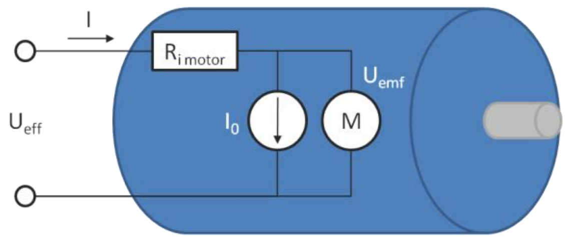
- And empirical measurement results (paint, glue)

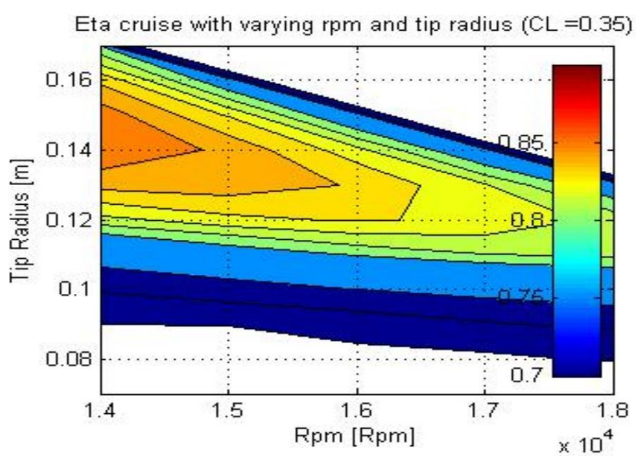
Name	Value and Unit	Normalized by
Filling at the Leading Edge	36 g/m/m	Span [m], Chord [m]
Bonding Leading Edge	4 g/m/mm	Span [m], Core Material Thickness [mm]
Bonding Trailing Edge	5 g/m	Span [m]
Bonding Webs	4 g/m/mm	Span [m], Web Width [mm]
Paint	54 g/m²	Surface [m²]

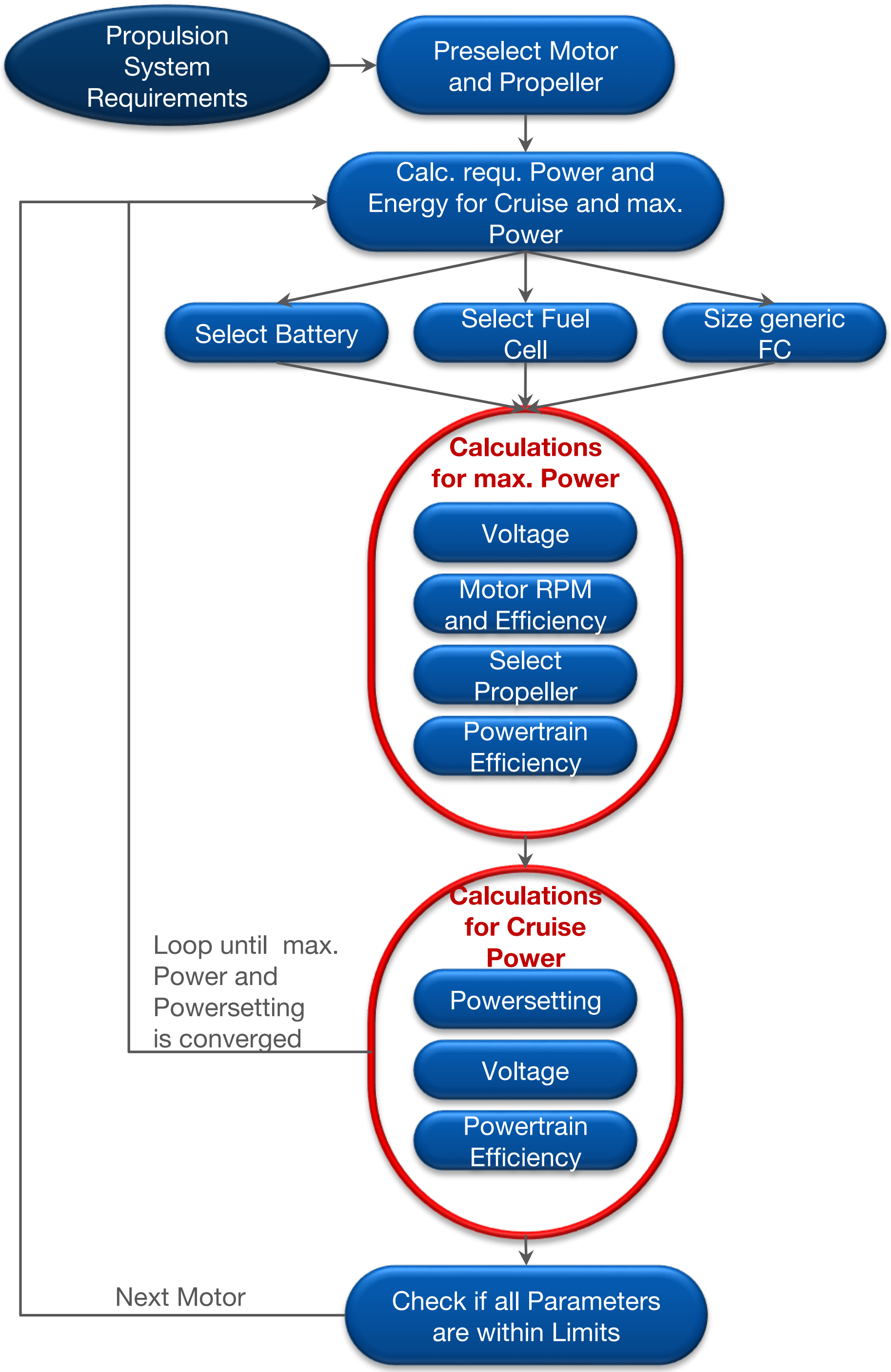
Summarizing of all masses: $$m_{component} = \sum m_{sized} + \sum k_{empirical} \cdot D$$

Propulsion System

- Matching of components is important
- Finding the lightest propulsion system to match the requirements

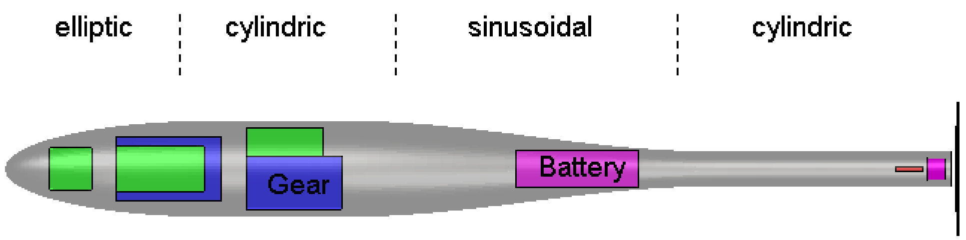


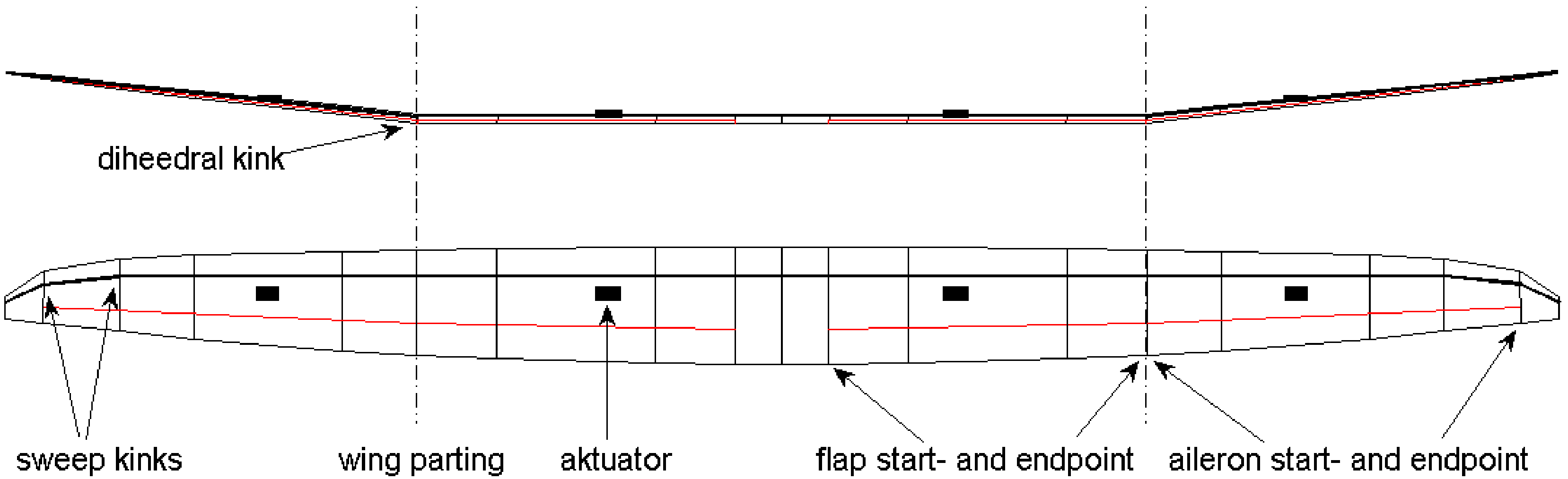




Sizing

- Alignment of components
- Adjustment of center of gravity
- Fuselage sizing
- Empennage sizing





Configuration design is only possible iteratively

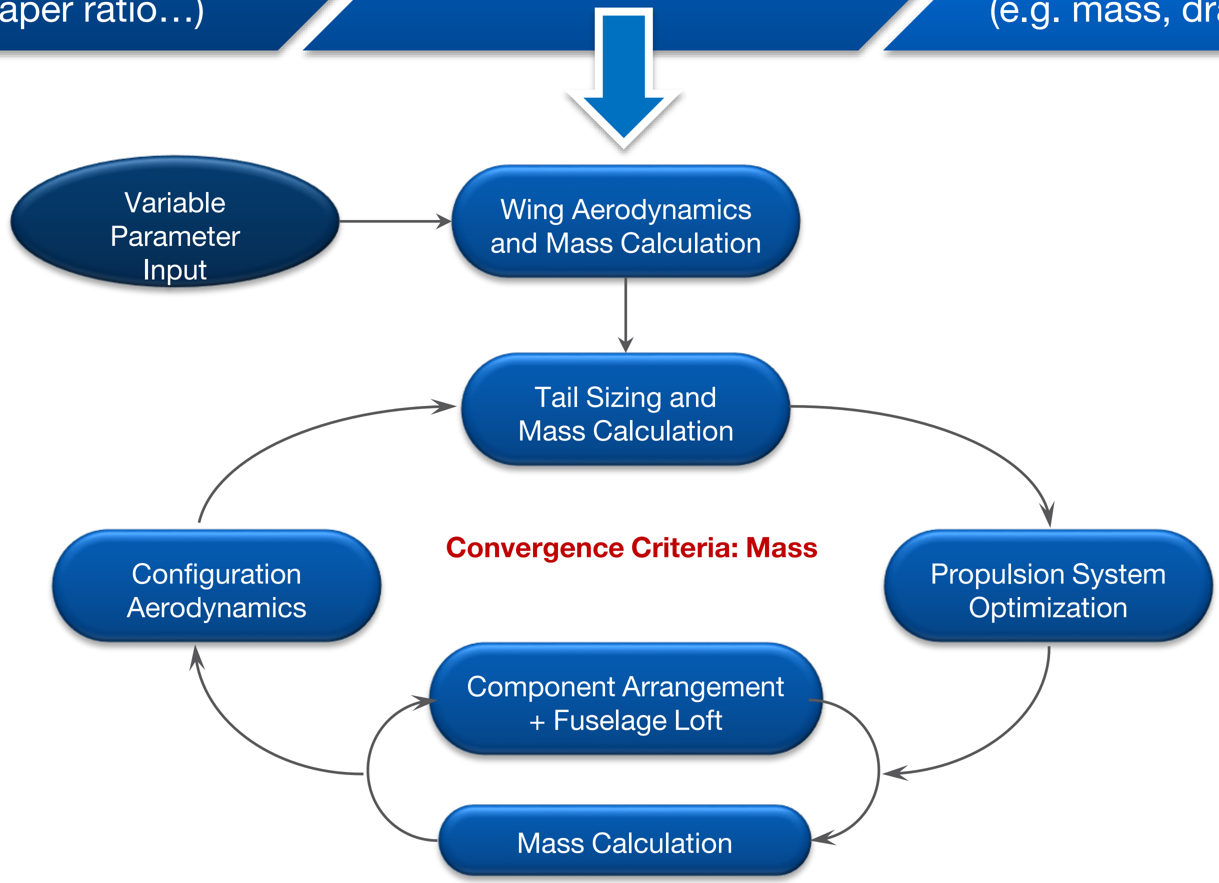
Design variables

(e.g. wing surface, aspect ratio, taper ratio…)

Configuration design

Evaluation of the objective funktion

(e.g. mass, drag, speed…)



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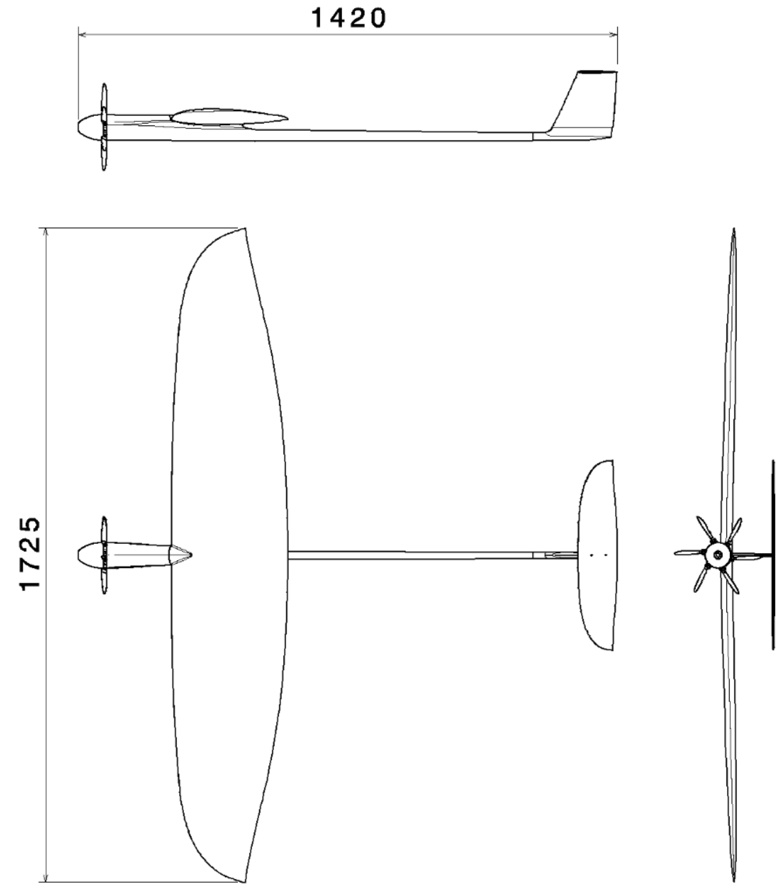
F3S Airplane Tanto – Technical Data

Take off weight:	**3.5 kg**
Wing loading:	**74.9 g/dm²**
Span:	**1.73 m**
Aspect ratio:	**7**
Wing surface:	**0.43 m²**
Horizontal tail surface:	**0.04 m²**
Vertical tail surface:	**0.018 m²**

Max. speed > 500 km/h ~ 140 m/s



F3S Airplane Tanto – Propulsion System

Technical Data:

Design cruise power 13 kW

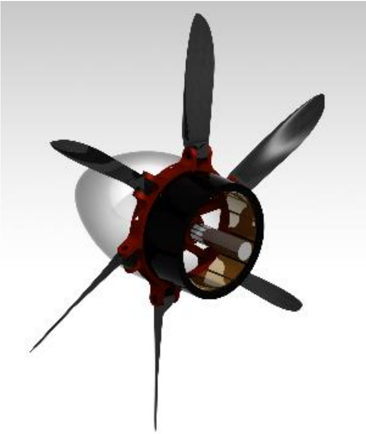
Propeller:
- Self made 6 blade 9.5 x 26 inch

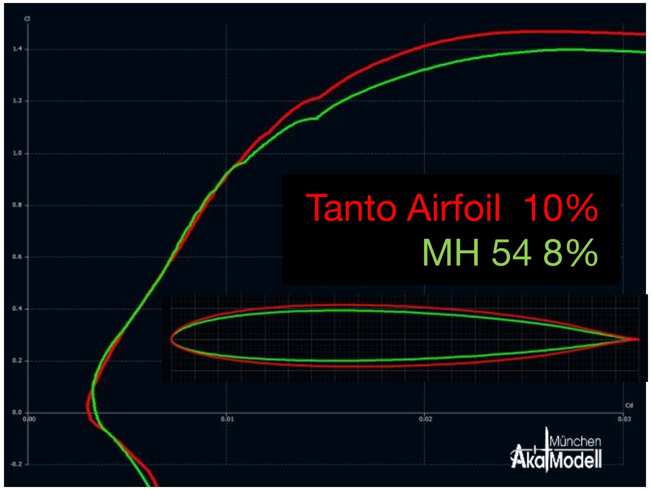
Motor:
- Kontronik Pyro 800 modified
- Mass 540 g

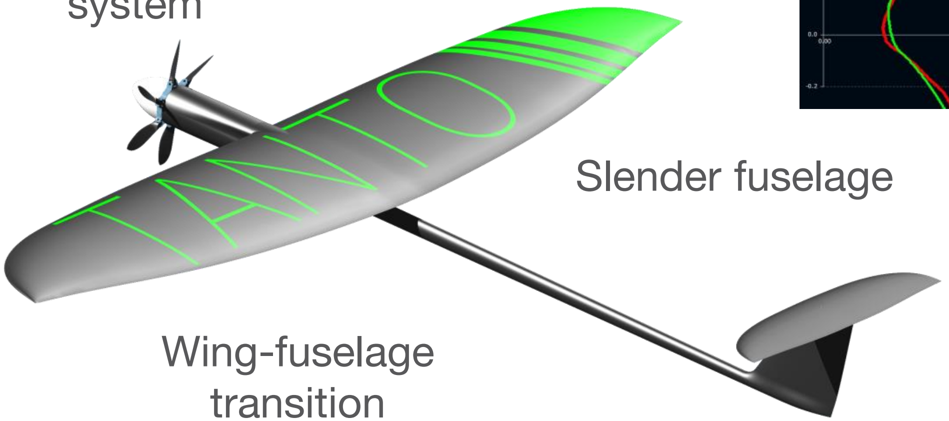
Controller
- Kontronik Kosmik 200 HV+
- Mass 290g

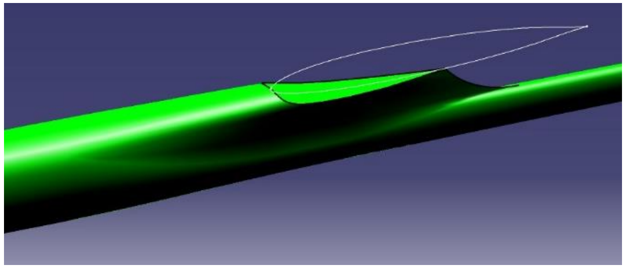
Batteries
- 13S 4000 mAh GensAce 60/120C
- Mass 1.7 kg

F3S Airplane Tanto - Features









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The Team

Akademic Aeromodelling Group of Munich

→ Association of students and academic researchers of Universities in Munich

Our Motto: **Design, build and fly!**

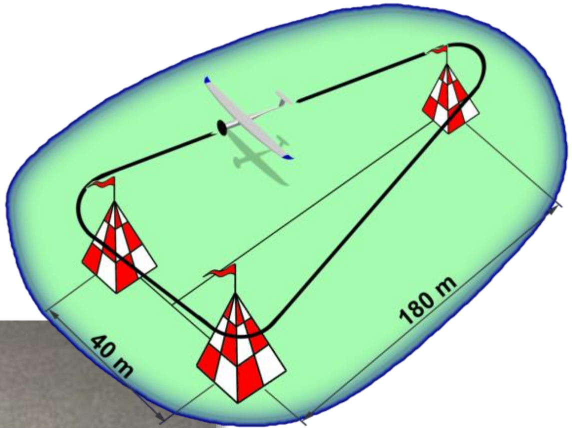
One new project every year:

- Model Competition Airplanes: F5D, F3K
- Student Competitions: Air Cargo Challenge
- Research: Airfoil Development, Building methods etc.
- Fun projects: Aircombat flying wing, Aero towing airplane etc.

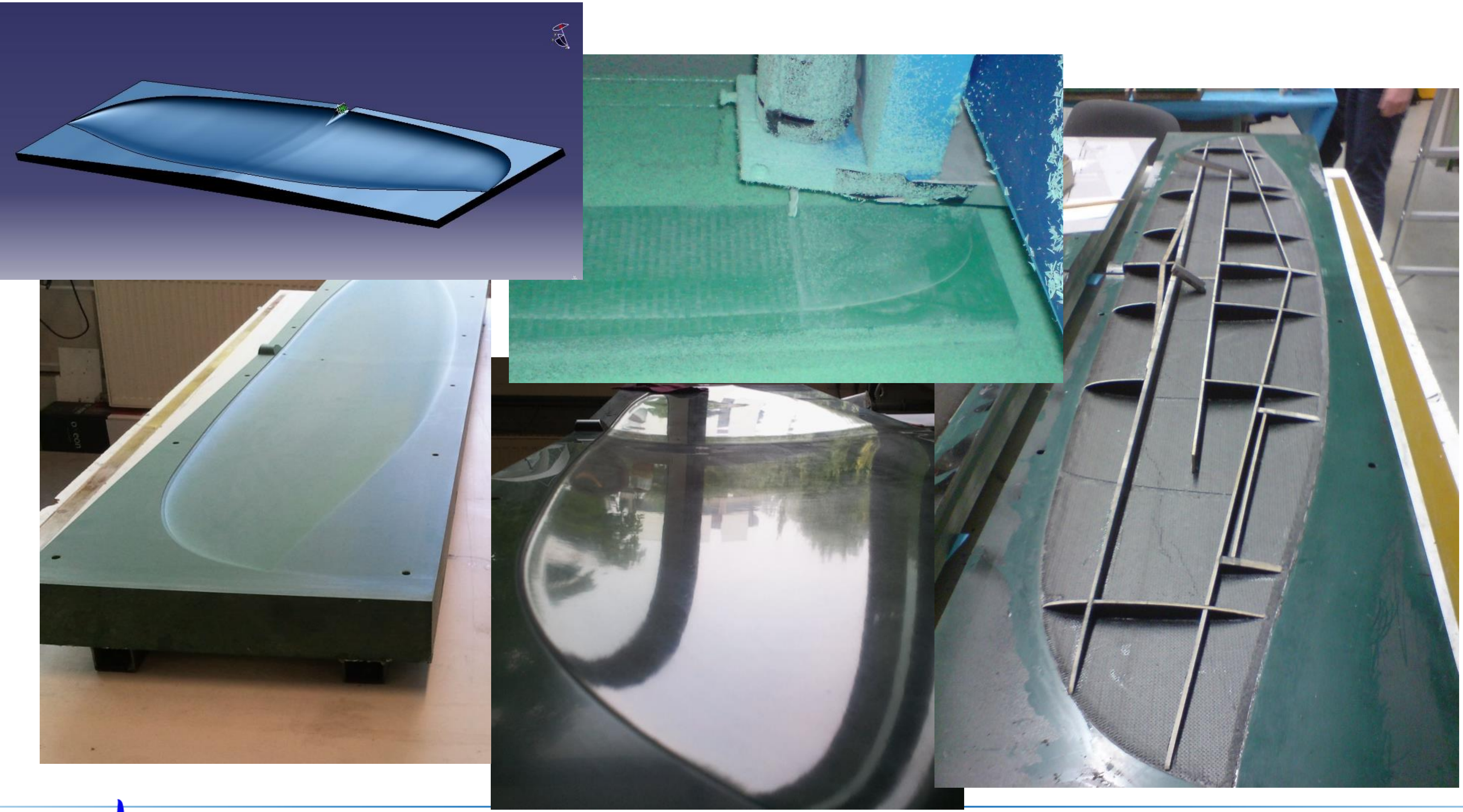
Previous Experience

F5D: Electro-Pylonracing

- 10 rounds in a triangular course – the fastest wins
- Speeds over 300 km/h
- 50 g turns
- **World champion** 2006
- New **World record** with 63,4 seconds



F3S Airplane Tanto – Manufacturing



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F3S Airplane Tanto – Current State

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Outlook

- Test Flights up to 6 kW of power and 420 km/h
- Ground tests for 9 kW successful
- Ground tests up to 13 kW successful (30s)
- More funding required
- Flight tests
- World record attempt


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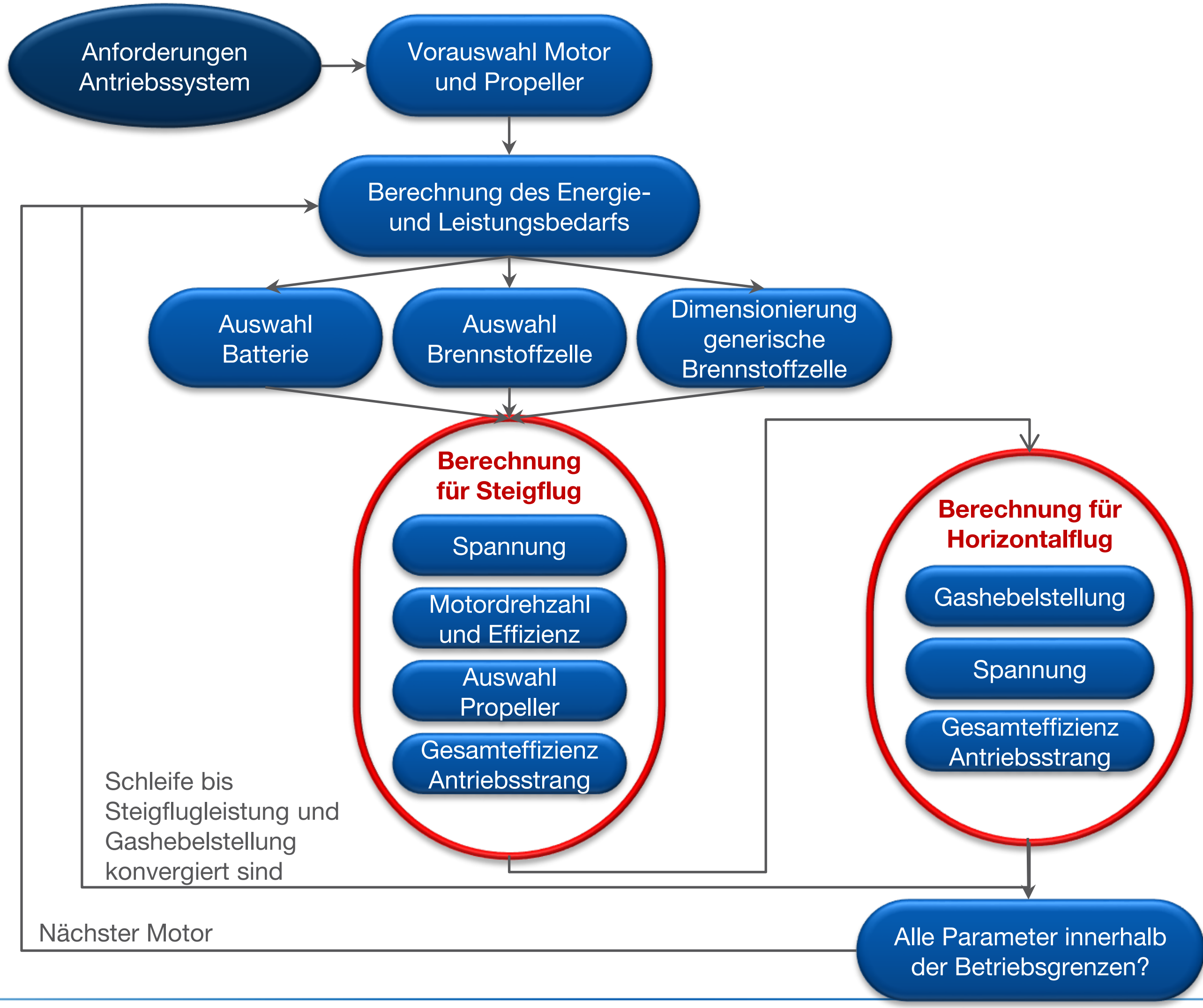
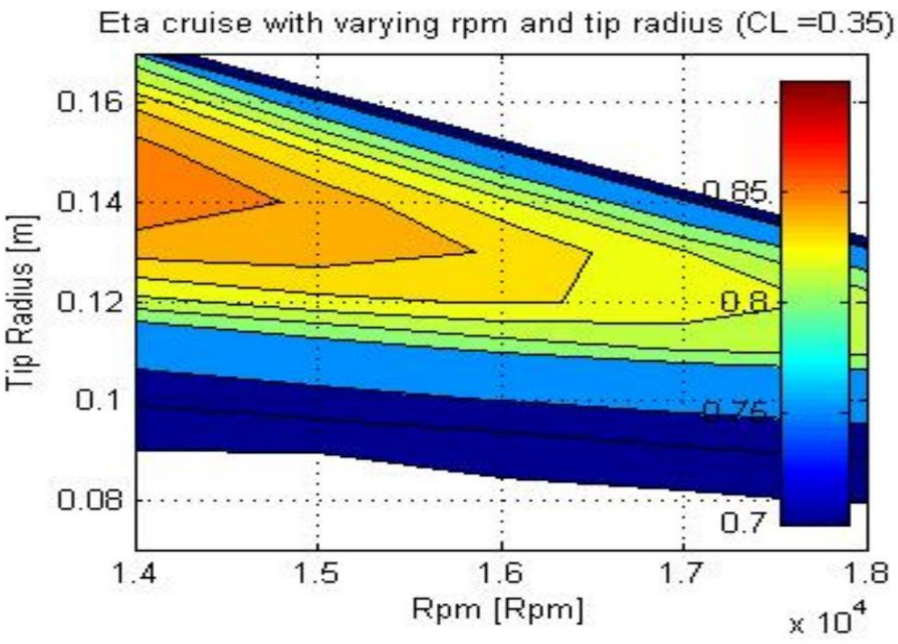
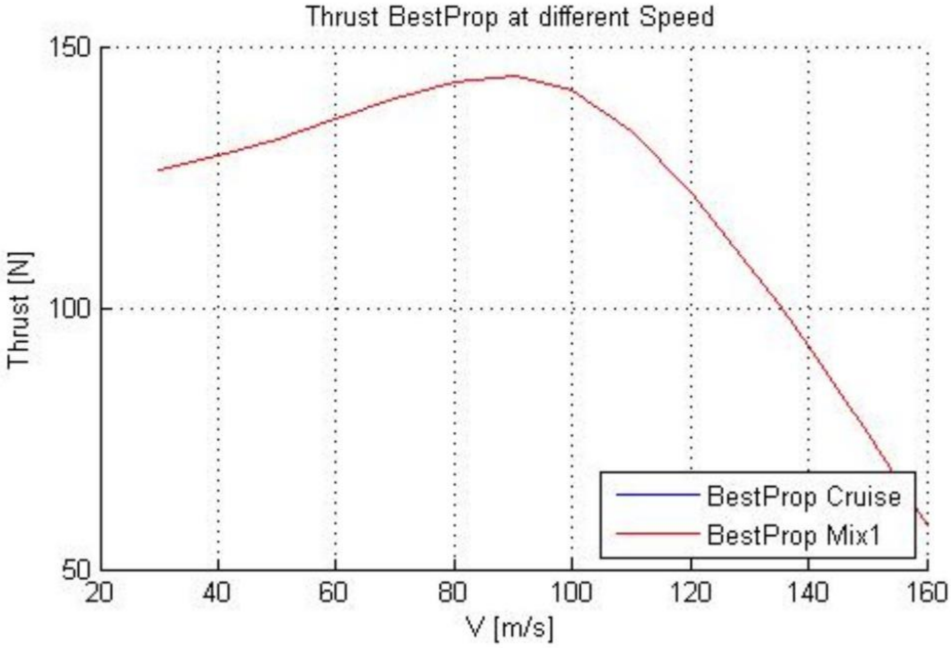
Antriebssystem



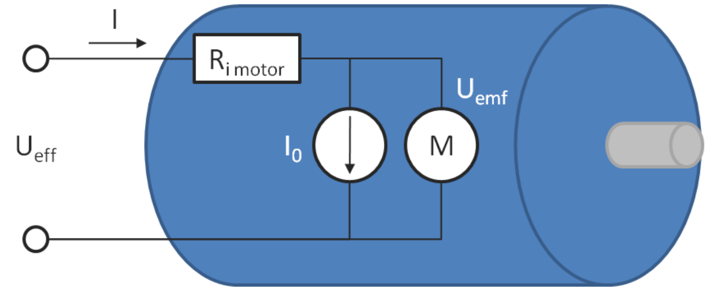

Eta cruise with varying rpm and tip radius (CL =0.35)
0.16
0.14
0.12
0.1
0.08
Tip Radius [m]
0.85
0.8
0.75
0.7
1.4
1.5
1.6
1.7
1.8
Rpm [Rpm]
x 10^4

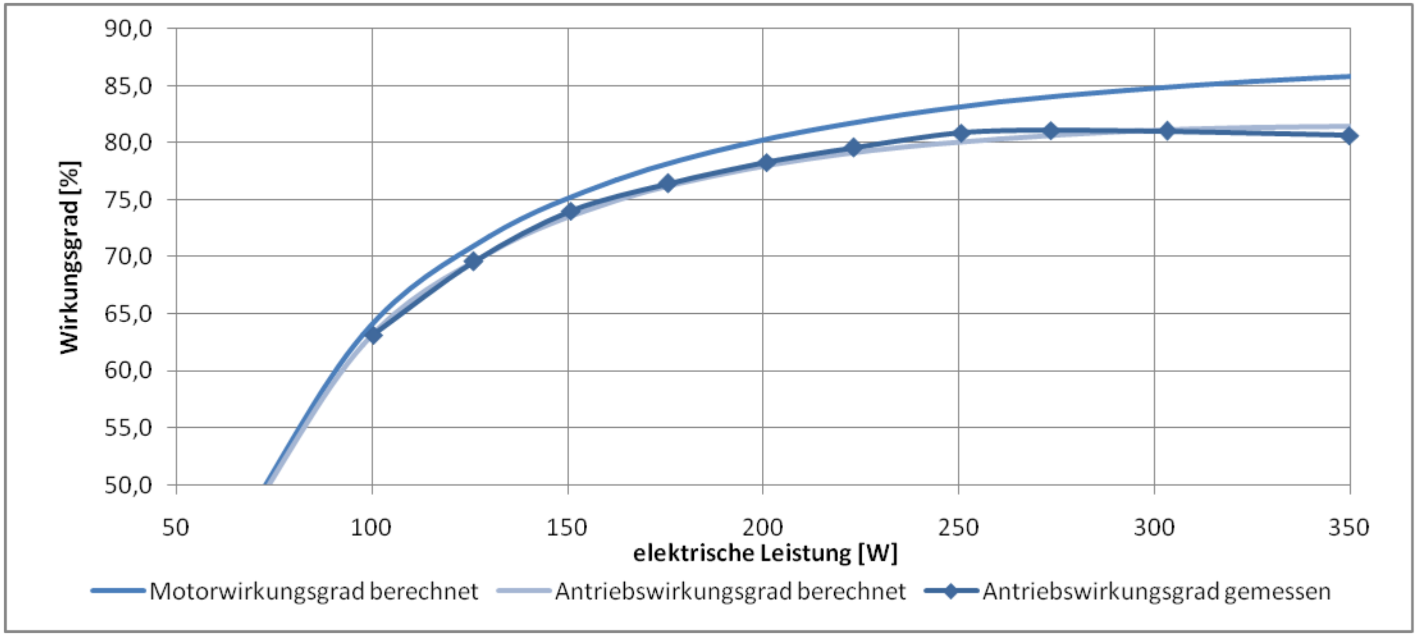

Thrust BestProp at different Speed
150
100
50
Thrust [N]
20
40
60
80
100
120
140
160
V [m/s]
BestProp Cruise
BestProp Mix1

Berechnungsmethode für elektrische Antriebe

Vollgas:

- Motorparameter durch drei Motorkonstanten (R_i , I_0 *und* K_v) berechenbar
- Motorregler durch zusätzlichen Innenwiderstand erfassbar

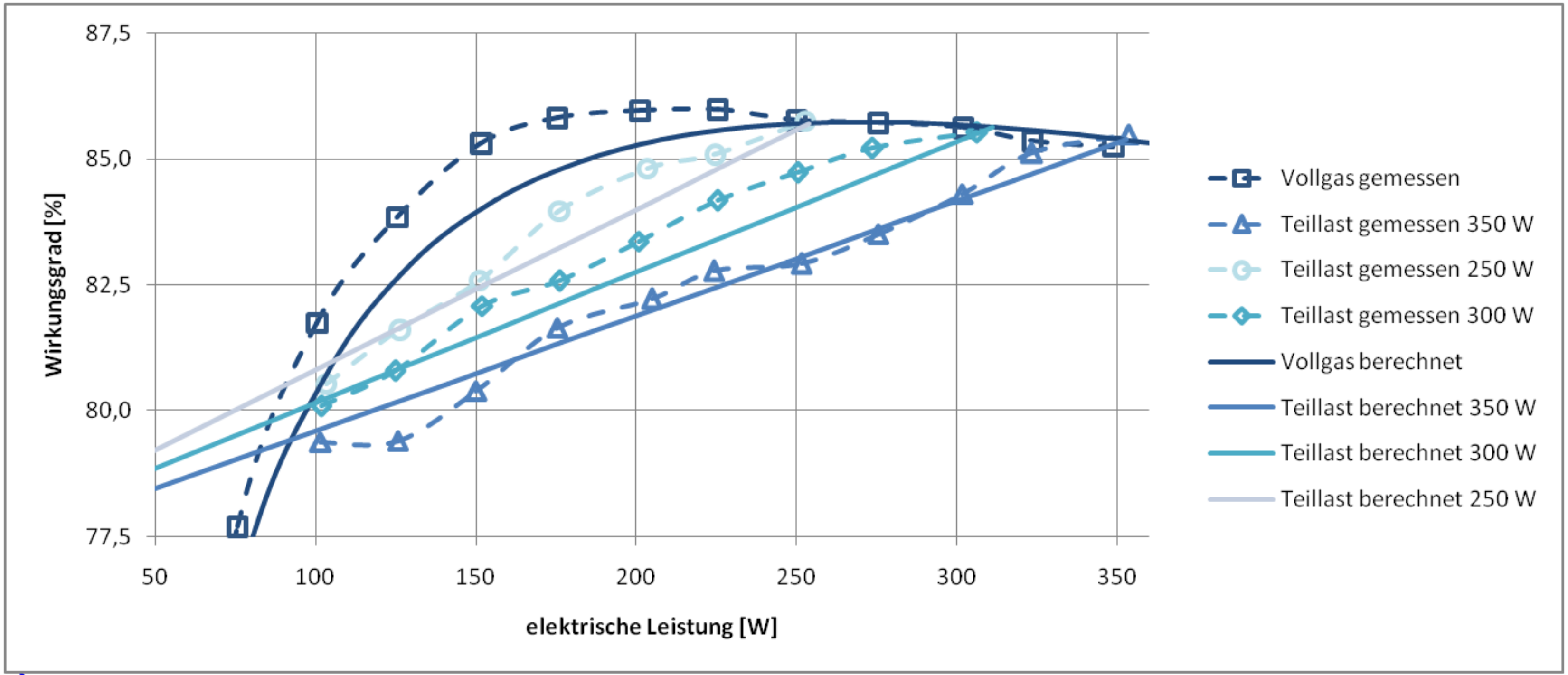




Berechnungsmethode für elektrische Antriebe

Teillast

- Messungen am Motorprüfstand
- Zusätzliche Verluste, hauptsächlich durch Schaltvorgänge im Regler
- Ableitung eines mathematischen Zusammenhangs



Stress Test

- Sand sacks and weights
- Design limit at -2/+5 g
- Test limit at 4.2 g due to extensive sag

➡ Stress test passed

+126 kg

4.2g