Numeric Simulation of Glider Winch Launches

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  - Main components
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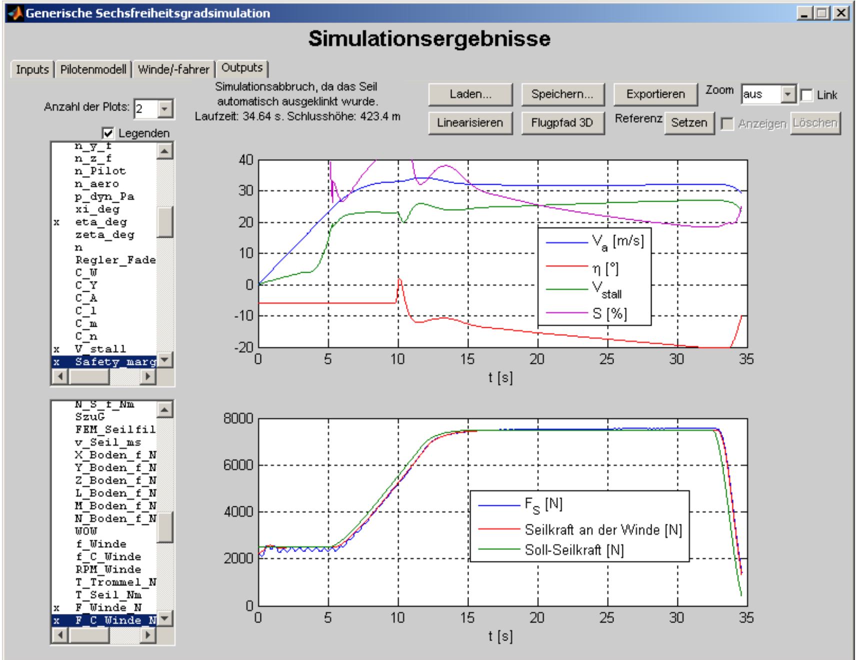
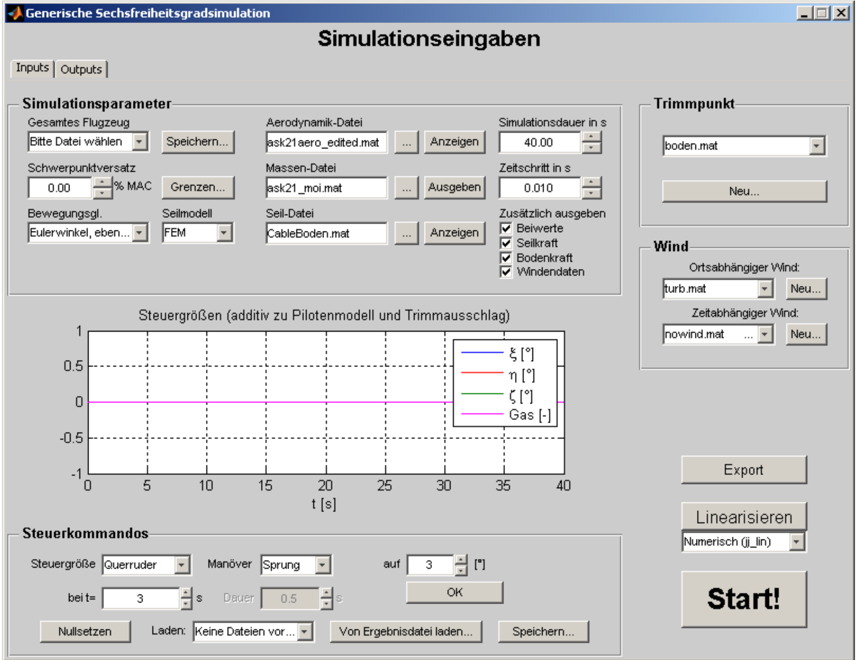
Simulation Tool: Framework

- Main simulation as block diagram in Simulink
- Matlab GUI for easy access



Outputs page

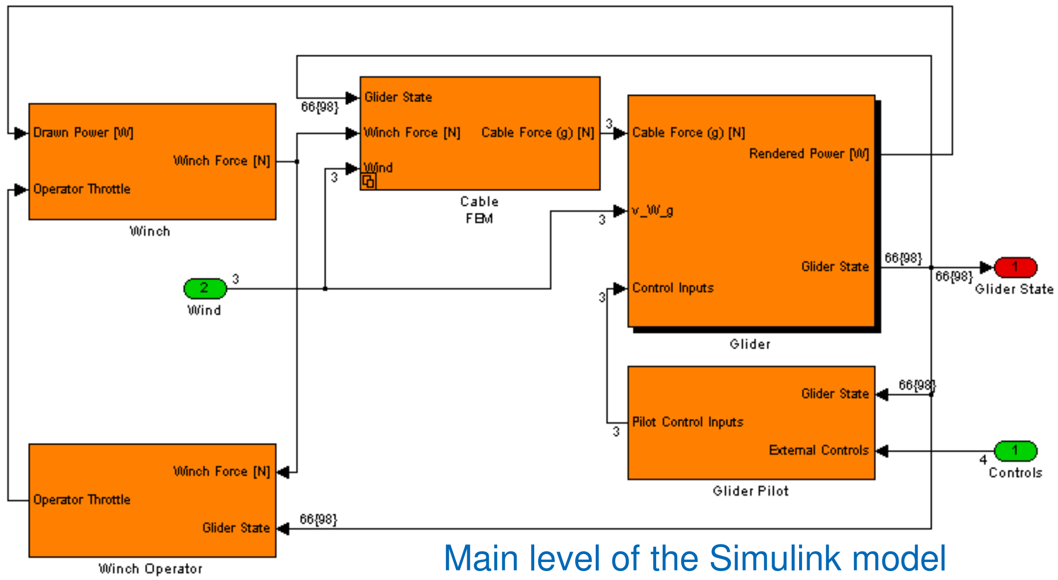


Inputs page

- Realized as a student's thesis
- Several extensions since then

Simulation Tool: Building Blocks

- Interaction of six main components:
  - Aircraft
  - Pilot
  - Cable
  - Winch
  - Winch operator
  - Atmosphere
- Each component as a subsystem
  - Atmosphere included in aircraft and cable



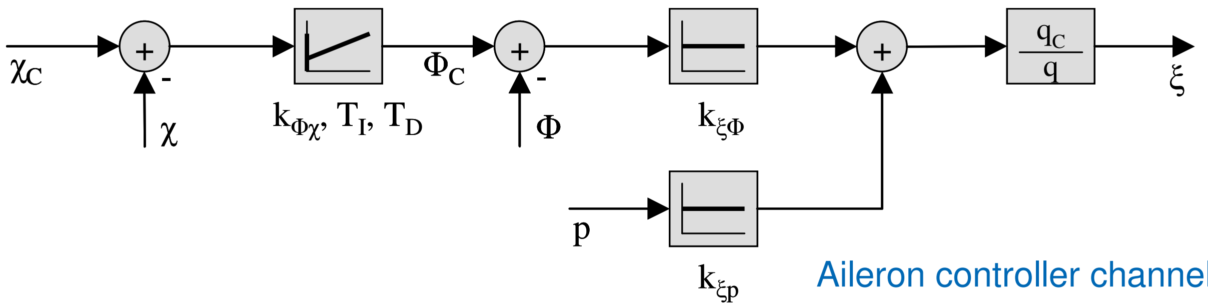
Main level of the Simulink model

Simulation Tool: Aircraft

- 6 degree of freedom, rigid body
- Flat, non-rotating earth
- Forces and moments arising from
  - Aerodynamics
  - Gravity
  - Cable
  - Ground reaction
- Aerodynamics formulated as lookup tables, including ground effect
- Model corresponds to a training two-seater (simplified ASK 21 data); different aircraft possible

Simulation Tool: Glider Pilot

- Approximation of human behavior by linear control theory
- Three separate channels:
  - Maintain airspeed with elevator
  - Maintain bank angle/ground track with aileron
  - Minimize angle of sideslip with rudder
- Gains scheduled by scaling with inverse dynamic pressure
- Human factors (neuro-muscular delay, reaction time)
- Faded in after reaching safety altitude



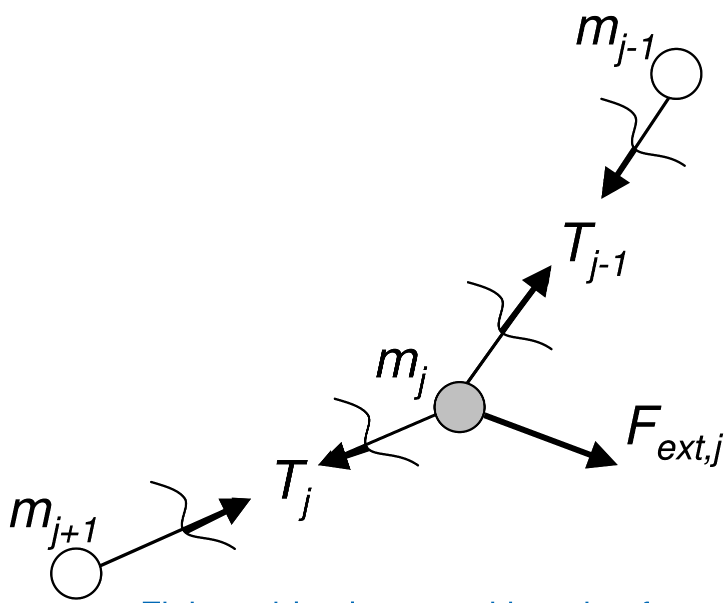
Aileron controller channel

Simulation Tool: Winch/Winch Operator

- Winch: Simple drive train model
- 400 hp Diesel engine simulated
- Operator controls force with the engine throttle
  - Measurement of cable force assumed
- Linear control theory, analogous to pilot model

Simulation Tool: Cable

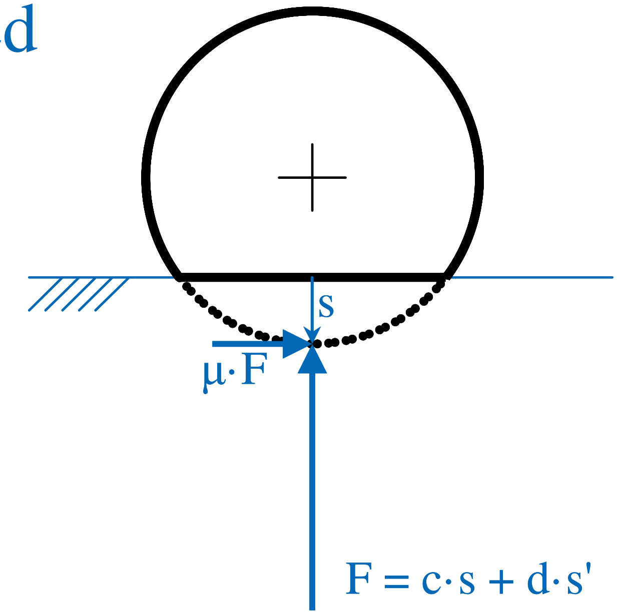
- Cable discretized into finite mass points, connected by massless cylinders
- Subject to weight, aerodynamic drag, ground reaction forces and internal cable tension
- Integration of equations of motion for all mass points
- Different types of cable (steel, synthetic) modeled by mechanic properties (mass, E modulus, …)



Finite cable element with acting forces

Simulation Tool: Ground Reaction Forces

- Spring/damper combination at predefined contact points
  - Wheels, skids
  - Exposed structure elements (wing tips)
  - Finite cable elements
- Spring deflection and deflection speed calculated from equations of motion
- Vertical reaction force (spring force) produces horizontal friction force



Forces acting on contact point

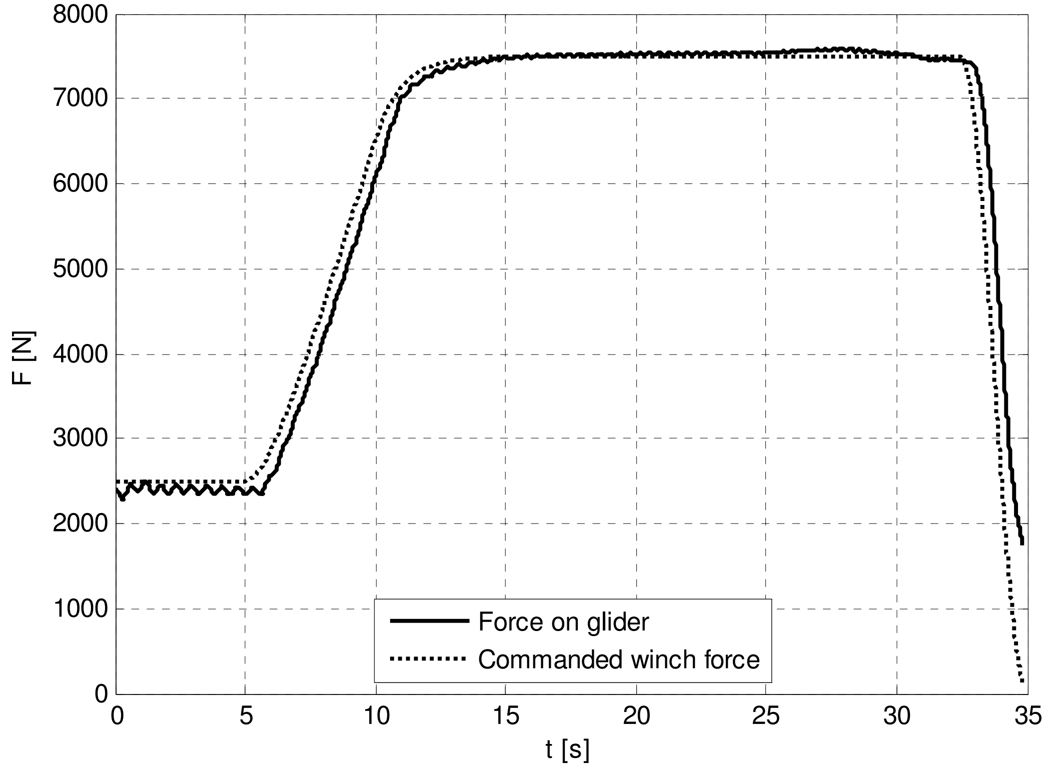
Simulated Procedure

- Launch with constant cable force during main climb phase
- Pilot controls airspeed, climb angle as result
- Recent discussion in Germany[1] indicates possible safety benefits with this procedure
- Winch operator needs to know actual cable force
  - Readily available with electric winches
  - Diesel winch: constant throttle, but operator experience required to find optimal setting
- Initial force low (~0.5×glider weight), increase to 1.5×weight after liftoff

[1]Eppler, R.: "Windenschlepp und optimale Ausklinkhöhe", Draft available from: www.daec.de/se/downfiles/2010/Windenstart_Prof_Eppler20100301.pdf

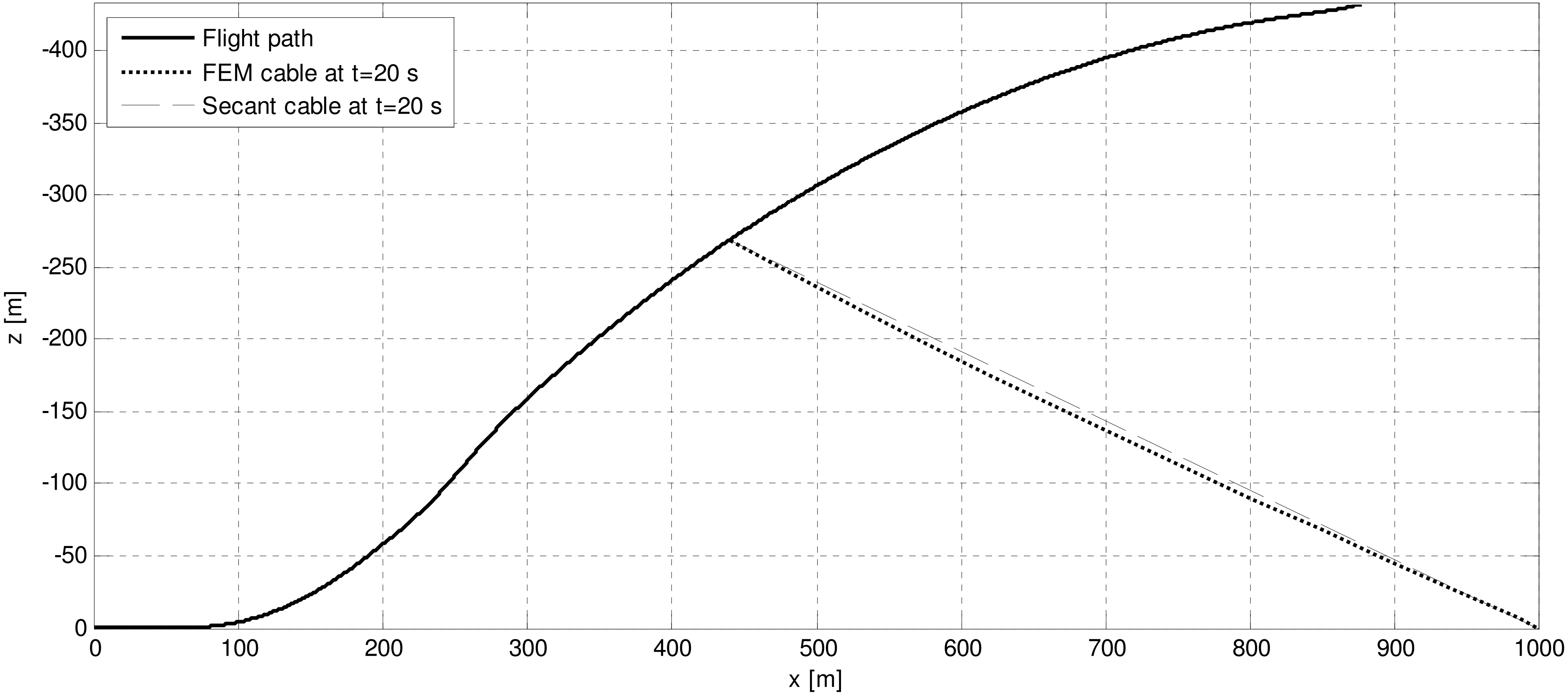
Reference Case

- 1000 m synthetic cable
- No wind
- Target airspeed 30 m/s (110 km/h)
- Glider weight ~5 kN
- Cable force as above
- Reaches 431 m after 35 s of winching



Time history of winch forces during reference launch

Reference Case: Flight Path



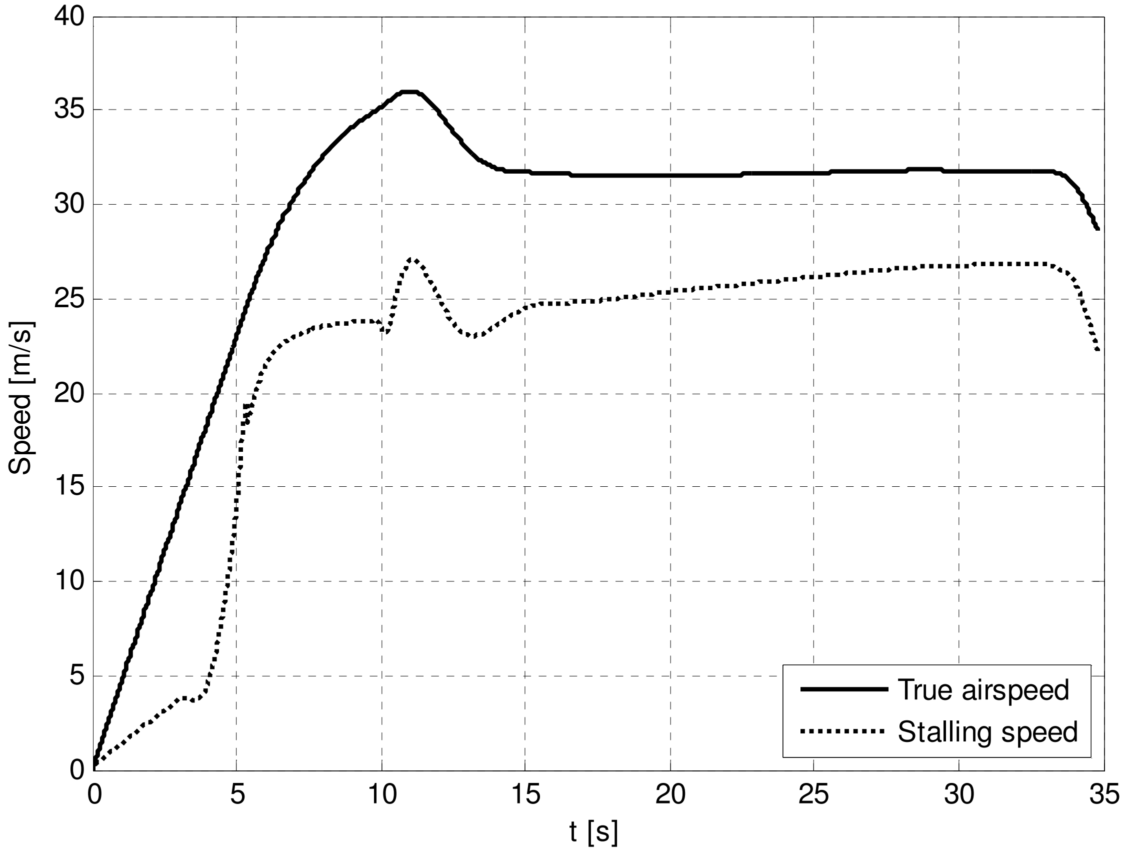
- Cable sag illustrated by difference between FEM and secant cables

Reference Case: Airspeed

- Airspeed safety margin is at least 25% during initial phase
- Drops to 18% shortly before force reduction
- Airspeed controller (pilot) gains authority at ca. t=10 s

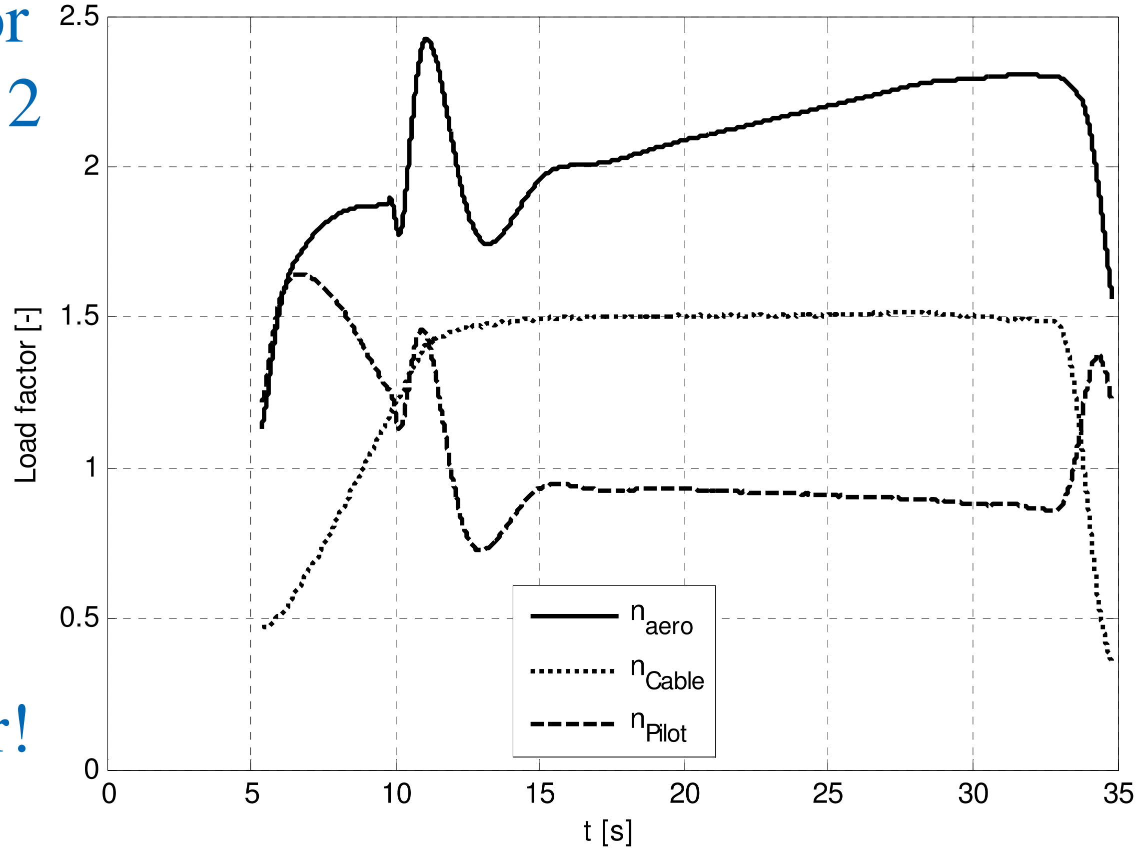
Safety margin defined as

$$S = \frac{V_{TAS} - V_{stall}}{V_{stall}} \cdot 100\%$$



Reference Case: Load Factors

- Aerodynamic load factor (lift/weight) well above 2
- But canceled by cable force: vertical acceleration perceived by pilot is close to 1g
- Stalling speed increases with square root of aerodynamic load factor!



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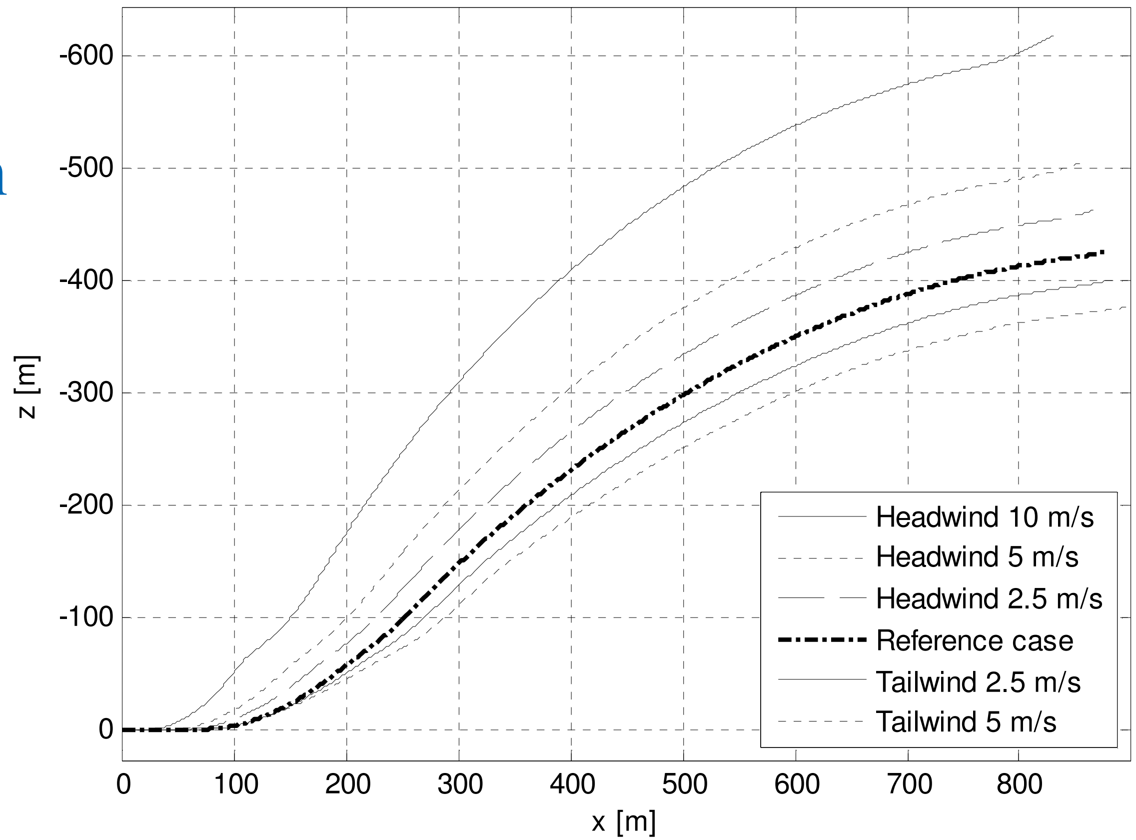
Wind Effects

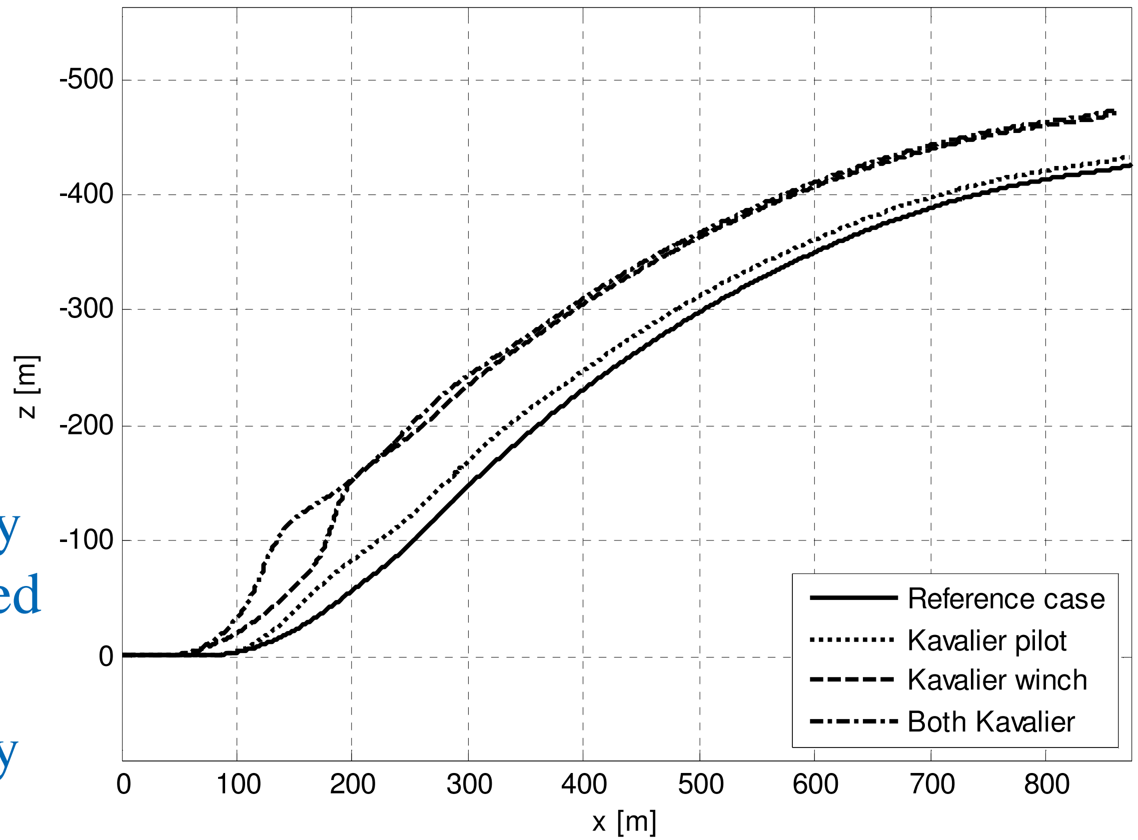
- Constant longitudinal wind
- About 5 m altitude gain per km/h headwind
- Controller maintains speed margin from reference case even with tailwinds
- Real life pilot has to consciously disregard groundspeed when controlling airspeed



Flight paths for head-/tailwind cases

Kavalierstart

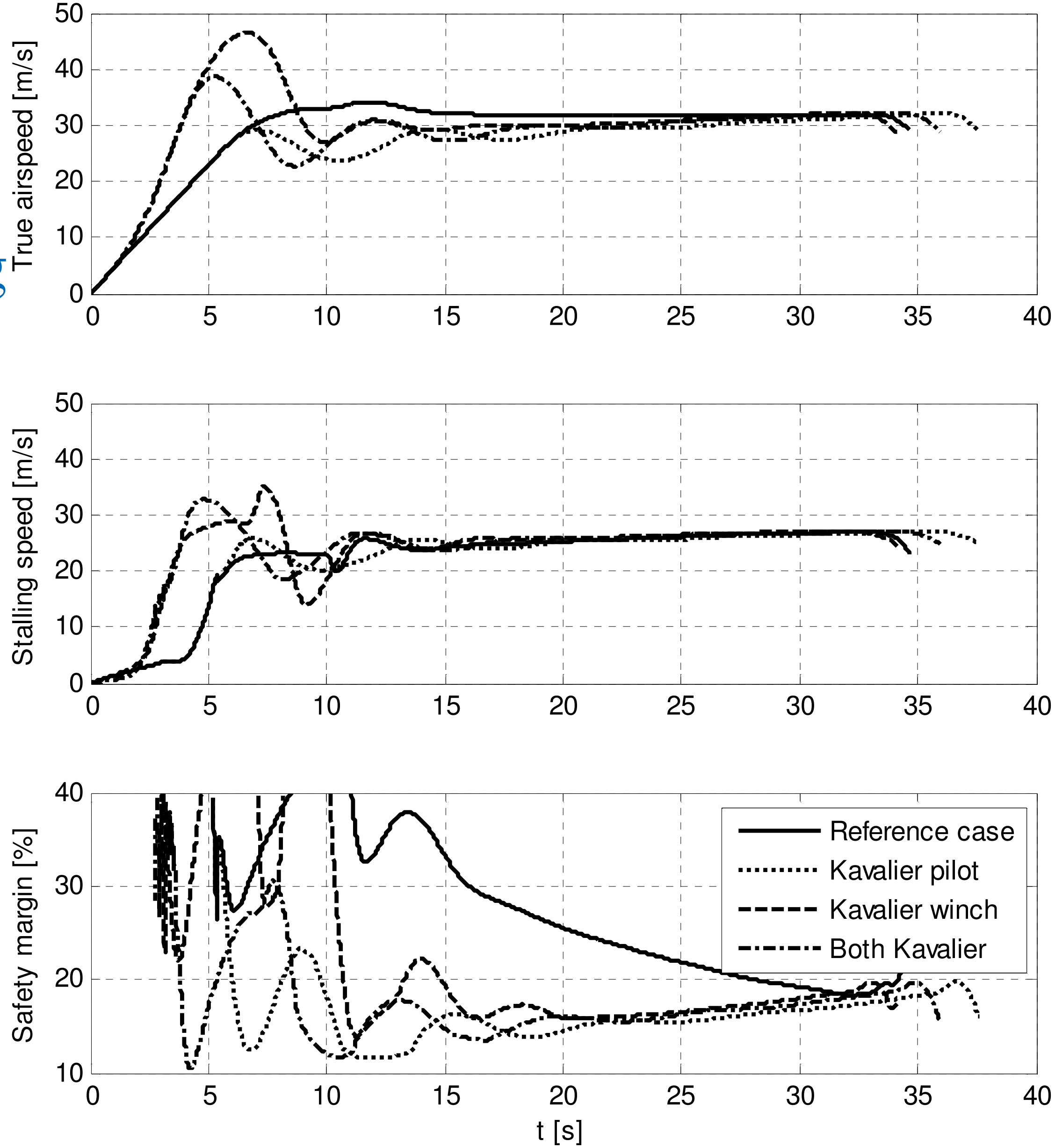
- Kavalierstart: excessively steep initial launch attitude
- May be caused by pilot (pulling too early) or winch operator (initial winch force too high for given glider)
- Altitude gain with Kavalier winch operator (more energy added to system), but reduced safety
- Kavalier pilot alone can only marginally increase altitude



Flight paths for Kavalierstart cases

Kavalierstart: Safety

- Safety margin to stalling speed significantly reduced in all cases
- Kavalier winch operator causes overshoot of allowable speed
- Pilot + operator both have responsibility for safe launch procedure



Summary

- Simulation framework realized for analysis of winch launches
  - Comprises aircraft, winch, pilot and winch operator as linear control theory models, cable as FEM model
- Reference launch with constant cable force
  - Safety of this procedure illustrated
- Safety reduction during Kavalierstart shown
  - Winch operator and pilot both take part in ensuring a safe launch

Outlook

- "Blade Element" aerodynamics model being realized to allow varying airflow in spanwise direction
  - Background: simulate roll-over accidents during early launch phase
- More sophisticated winch models to allow comparison of Diesel and electric winches

Thank you for your attention!