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SIMULATION OF A GLIDER WINCH LAUNCH

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ABSTRACT

The question of the optimized winch launch arises from the current advancements in glider performance and increase in glider mass. As a first step in modeling the winch launch, a winch, cable and pilot model is introduced into an existing six-degrees-of-freedom glider simulation in MATLAB/Simulink already developed at the Chair of Flight Dynamics. These models are enhanced with manufacturer and flight test data to gain a more detailed insight into the highly dynamic process of a glider winch launch. The ensuing variation of winch launch parameters and models provides clues on how to optimize this method of glider launching. Data resulting from these variations is then interpreted in regard to flight operations and flight safety. Recommendations for optimizing flight performance and flight safety are also given.

SYMBOLS

$C_{D,C}$	Cable Drag Coefficient
E_C	Cable Modulus of Elasticity
$F_{C,W}$	Winch Force Exerted onto Cable
$F_{G,C}$	Force Induced from Cable into Glider
F_T	Target Force
$M_{G,C}$	Moment Induced from Cable into Glider
S	Safety Margin
S_{min}	Minimum Safety Margin
V_a	Glider's Airspeed
V_S	Glider's Stall Speed
$V_{S,1g}$	Glider's Steady State Stall Speed
d_C	Cable Diameter
h	Altitude
h_{Release}	Release Altitude
$\Delta h_{\text{Release}}$	Change in Release Altitude
h_{Safety}	Safety Altitude
n_0	Initial Number of Mass Points
n_z	Vertical Load Factor
$p_{\text{dyn},T}$	Target Dynamic Pressure
t	Time
t_{Release}	Release Time
α	Angle of Attack
α_S	Stalling Angle of Attack
η_P	Pilot-Commanded Elevator Deflection
η_{Trim}	Elevator Trim Deflection
ρ_C	Mean Cable Density
6DoF	Six-Degrees-of-Freedom
CG	Center of Gravity
FEM	Finite Element Method
ISA	International Standard Atmosphere
PID	Proportional, Integrating & Differentiating

1 INTRODUCTION

When analyzing the introduction of new technologies in the field of gliding over the last decades it becomes apparent that most technological development has gone into refinement of the aircraft. Developments such as laminar flow airfoils and composite construction techniques have significantly contributed to an increase in flight performance while the introduction of low-cost anti-collision devices is significantly promoting flight safety. A significant driving force behind these developments are competitive considerations arising from soaring contests.
However, the design of glider winches - which provide one of the most popular and low-cost methods of launching gliders - lacks such a driving force. The general increase in glider mass over the past decades has caused a trend of using more powerful internal combustion engines on winches, yet few other technologies have come to widespread acceptance by winch operators. Also, the technical research in winch launching has been very low-key, providing only little written analysis on the nature of this launch type. While the available research was mostly theoretical, to date little time has been spent on applying the modern methods of flight simulation to the winch launch.

2 SIMULATION SETUP AND MODELS

For the purpose of this simulation the problem of the glider winch launch has been broken down into three interfaced primary components - winch, cable and glider - which interact through their outputs with each other. In order to depict the influence of human operators on the winch and aircraft and to achieve closed loop control over these primary components, rudimentary pilot and winch operator models are integrated as feedback loops. This interaction of the five independent models is depicted in the block diagram of FIG. 1. Methods regarding standard atmospheric influence are integrated into the relevant models, making the International Standard Atmosphere (ISA) the sixth model used in this simulation.

2.1 Aircraft Model

From a developmental standpoint this simulation is the enhancement of a generic six-degrees-of-freedom (6DoF) flight simulation in MATLAB/Simulink which has been previously developed at the Chair of Flight Dynamics.[1] The actual aircraft analyzed is a Schleicher ASK 21 primary training glider. This composite two-seat training glider is in widespread use worldwide and its aerodynamics and flight performance are similar to other aircraft of the composite primary training fleet. For the purpose of this simulation, the ASK 21 is said to be representative of this fleet. Also, the availability of a flight mechanics model, drawn from previous research with the ASK 21 at the Chair of Flight Dynamics, was a factor in selecting this glider type.
Within this simulation the aircraft is modeled as a rigid body using the Newtonian Equations of Motion. While this results in the disregard of aeroelastic effects, the errors made by this approximation are said to be minor. Furthermore, the non-linear aerodynamic coefficients only regard quasi-static, incompressible and obstruction-free airflow around the glider. This causes the aircraft's behavior during the phases of flight in which it is exposed to strong ground effect - namely the take-off run in this simulation - not to be depicted accurately. As soon as the "virtual glider" reaches its initial climb attitude and an altitude of approximately one wingspan above ground level, the aerodynamic results are said to be within acceptable accuracy.
The original aircraft model has not been designed to regard acting external forces, except aerodynamic lift and drag, thrust and gravity. Yet, the force being exerted by the tow cable onto the glider is the primary means of increasing the glider's sum of potential and kinetic energy. The Newtonian Equations of Motion, as presented by Brockhaus,[2] therefore have to be modified by the introduction of additional terms for the force $\boldsymbol{F}_{G,C}$ induced from the cable into the glider as well as the corresponding moment $\boldsymbol{M}_{G,C}$. A cable release mechanism which terminates the simulation at the moment of automatic cable release from the glider is also introduced.

2.2 Winch Model

Using the methods of automotive engineering of Kiencke and Nielsen,[3] the winch is represented by a driveline and engine model. The most prominent variations in winch design are in the used engine - being either operated on gasoline or diesel fuel - as well as the use of a torque converter, or lack thereof, in the driveline. Due to the availability of data, it was decided to represent a driveline without torque converter being powered by a supercharged diesel engine. The driveline itself is said to consist only of the following rotating elements: the camshaft, an ideal gearbox, one cable drum and a shaft connecting the cable drum to the gearbox.
Whereas there is only a limited number of glider types in widespread operation, the design of winches often varies. This causes the general validity of the winch model to be lower than that of the aircraft model.

2.3 Cable Model

A detailed description of the tow cable's deformation is necessary to accurately determine the cable tow force $\boldsymbol{F}_{G,C}$ acting on the glider. Due to the non-conservative nature of the aerodynamic forces acting on the cable, in addition to the conservative gravitational influence, the cable is modelled by the means of a dynamic finite element method (FEM).
The used model is based upon the works of Williams, Lansdorp and Ockels[4] and has been originally developed for the simulation of tethered kites in electric power generation through a laddermill. Due to the high dynamic similarity between a tethered kite - which in a laddermill is reeled in and out at low frequency - and a glider being launched, this model is adequate.
The description by means of FEM implies that the cable is discretized into n_0 lumped masses at the beginning of the simulation. A weightless elastic cylinder connects two neighboring mass points and the tension within each cylinder is determined through the use of a linearly damped form of Hooke's law.
In total, it is said that three different types of forces are acting upon the cable:

- cable tension (internal force)
- aerodynamic forces (external forces)
  - Drag as well as lift are modelled. Components of each force act in radial and axial directions of the cable.
- gravity (external forces)

An illustration of forces acting on the cable is given in FIG. 2. Due to the fact that the cable is reeled onto the winch drum during the launch, the number lumped masses is continuously reduced. This behavior is accounted for in a separate reeling unit script.
In the presented model the basic cable properties such as mean cable density ρ_C, cable diameter d_C, modulus of elasticity E_C and drag coefficient $C_{D,C}$ are kept constant across the length of the cable. In practice, this assumption is deeply violated by the placement of a drag chute and other auxiliary equipment between the actual tow cable and the glider's center of gravity (CG) tow hook. Another source of errors is the behavior of the cable model

during the ground roll and initial climb phases of the winch launch. The actual cable will be dragged over the surface of the airfield, which is not implemented into the simulation. However, in the course of the simulation (FIG. 3) it was shown that the cable behaves adequately.

2.4 Human Controller Models

2.4.1 Winch Operator Model

The purpose of the winch operator model is to stabilize the winch force $F_{C,W}$ exerted onto the tow cable around a given target force F_T. In order to achieve this goal, the winch operator has been modeled to act as a compensatory single-loop controller, adjusting the winch's throttle in an attempt to stabilize the aforementioned force. It is presumed that operating the winch is a similar task to the longitudinal speed control of a motor vehicle. Kiencke and Nielsen state that in automotive control modeling, human driver behavior is often modelled as that of a controller with proportional, integrating and differentiating command components[3] (PID controller).

The mentioned target force F_T is time-variant to regard several real-life effects in operator behavior. Usually, the winch force is gradually increased in a differentiable manner to a maximum and then smoothly decreased again. This allows the glider's acceleration near the ground not to be excessive while permitting higher forces in the main climb phase. The following decrease of winch force is performed to prevent excessive load changes on the glider at the moment of cable release.

It should be mentioned that modelling the winch operator as a force controller is only a rough first-order approximation. The force exerted onto the cable by the winch is usually not directly obvious to the winch operator. An actual operator will usually regard multiple other influences such as cable sag, engine noise and vibration, camshaft revolution speed and wind. All of these influences, together with the operator's experience, will determine his or her actions on the throttle. However, the winch operator model presented above will provide sufficiently smooth force transitions for the purpose of this simulation and is taken to be acceptable.

2.4.2 Pilot Model

During the winch launch longitudinal motion dominates and makes the pilot's elevator control input η_P the primary control input during the launch. In the presented pilot model all other inputs in remaining flight controls, such as rudder, ailerons and speed brakes, are not considered.

Quite similar to the winch operator model, the pilot model's goal is to stabilize the glider around a (time-invariant) target dynamic pressure $p_{\text{dyn},T}$. Dynamic pressure / airspeed control is achieved through the use of a further PID controller providing elevator deflection commands. At the same time, the pilot serves in the role of a pitch damper to lessen or suppress the glider's phugoid motion. This is regarded with a proportional pitch damper - being routed parallel to the PID airspeed controller - that also provides elevator deflection commands.

A problem which arises with pure airspeed control in the manner described is that the pilot would command the aircraft to climb at excessive angles of pitch at low altitude. Most flight training curricula strongly discourage such a maneuver, due to the insufficient recovery altitude available in the event of a cable break at low altitude. It is more typical for a pilot to leave the flight controls near a trimmed neutral position during initial climb and only to make minor adjustments in pitch and pitch speed. Only once a perceived safety altitude is reached, the pilot then transitions into controlling airspeed.

To emulate this behavior, all pilot-commanded elevator inputs η_P are multiplied with the output of a fading function, which activates only once a safety altitude h_{Safety} is reached. The given fading function makes certain that flight control inputs, except for a trim deflection η_{Trim}, are suppressed at low altitudes. Due to the location of the CG tow hook and the resulting moment $\boldsymbol{M}_{G,C}$ induced by the cable force $\boldsymbol{F}_{G,C}$, the aircraft will gently pitch up during the early climb phase. Additional airspeed control and pitch damping will be faded online only once a safety altitude is reached, steepening the climb angle.

2.4.3 Comments on Human Controller Models

Through his research in human-machine interfaces Johannsen[5] recommends augmenting human commanded actions with an additional transfer function to regard neuromuscular first order delays, psychological anticipation and delay times. This has also been incorporated in both human controller models. The effects of this transfer function is minor in comparison to the transfer function of the PID controller representing the human decision process, though a slight effect on the stability of the controlled systems remains.

Human controller models of the presented type are very rudimentary in comparison to the complexity of the human decision making process involved in controlling technical processes. The multitude of influences on human behavior is still often difficult to regard adequately for cybernetic consideration.

Especially in regard to the fact that the three-dimensional control of a glider in a winch launch - with all available flight control surfaces - is a high work load situation for the pilot which demands his or her utmost attention, the presented PID model is very basic.

The prognosis of the control parameters in human controller models, such as control factors, derivative and integrating times, is equally challenging. These parameters have been determined manually by operating each controller (winch operator and pilot) at first in an unstable, oscillating manner and then iteratively adjusting the parameters to stabilize the controller. This operation in the vicinity of the stability limit is assumed to regard the human decision process accurately enough.

2.5 Atmospheric Model

As mentioned previously, the international standard atmosphere is implied in all aerodynamic considerations of the glider and cable models. It is also possible to provide the developed simulation with a three-dimensional wind vector field to analyze the influence of different atmospheric motions on the winch launch.

3 RESULTS AND ANALYSES

The ensuing analyses are based on a multitude of numeric data required for the respective model equations to be solved. As already described the aerodynamic data was made available through previous flight testing at the Chair of Flight Dynamics. Geometric values were gathered from technical drawings of the ASK 21 where necessary. If not otherwise indicated, the cable parameters represent a synthetic cable of Rosenberger Tauwerk GmbH of Lichtenberg, Germany. Winch data was provided by Tost Startwinden GmbH of Assling, Germany. However, characteristic diagram of the implemented diesel engine is based on freely available data sets of the General Motors Corporation of Detroit, Michigan, USA.

3.0.1 Safety Margin

One of the primary concerns during the presented work was to analyze potentially critical situations, as they might occur while winch launching. It is deemed especially critical if the glider reaches a stalled state during the launch process. Due to this, the relative difference between the aircraft's airspeed V_a and stall speed V_S is defined as the safety margin S.

(1) $$S := \frac{V_a - V_S}{V_a}$$

One should bear in mind that the aircraft's stall speed is proportional to the square root of the vertical load factor n_z and the aircraft's stall speed in steady flight $V_{S,1g}$. The safety margin follows as:

(2) $$S = \frac{V_a - V_{S,1g} \cdot \sqrt{n_z}}{V_a} = 1 - \frac{V_{S,1g} \cdot \sqrt{n_z}}{V_a}$$

This also means that the safety margin is an expression for the angle of attack α. If the glider reaches its stalling angle of attack $\alpha_S = 8°$ - which is also the angle of the maximum lift coefficient - then the wing is completely stalled and the safety margin has reached a value of $S = 0$.
Bear in mind that the vertical load factor is scalar ratio of lift to weight. Due to the fact that the cable force also acts on the glider during the winch launch it is not possible to directly convert the vertical load factor into a vertical acceleration. This is in contrast to the influence of the load factor in free flight.

3.1 Reference Configuration

For the purpose of identifying the influence of parameter changes on the winch launch a reference launch condition was defined. This reference configuration is placed at a "virtual airfield" with 1000m of available tow distance at seal level under standard atmospheric and wind-free conditions to approximate conditions as they exist on many general aviation airfields. Remaining parameters were selected in a similar manner to provide the most generic results where possible.
The simulation of the reference configuration supplies a flight path of the glider as presented in FIG. 3. In this case, the glider will reach a release altitude of $h_{\text{Release}} = 439m$ at $t_{\text{Release}} = 33s$. For illustrative purposes, the deformed cable at the moment of $t = 15s$ has been plotted into the mentioned flight path diagram. A cable deflection due to acting external forces can clearly be seen against the connecting straight line between the glider and winch. This deflection seems reasonable and shall serve as partial validation of the cable model.
A plot of safety-relevant parameters during the reference winch launch is given in FIG. 4 which also implicitly supplies the safety margin S. The initial peak of the angle of attack α at $t = 0.9s$ corresponds with the decreasing distance between airspeed V_a and stall speed V_S, resulting in a minimum safety margin $S_{\text{min}} \equiv 2.7\%$ at this moment. This is partially due to the glider's descending flight path within the simulation's first second (recall that in the given simulation no ground or ground effect model has been implemented so far), yet also corresponds with the necessity for rotating into a nose-up attitude for the initial climb. In practical measurements, it is expected that S_{min} would be larger than the given value, since the aircraft would not have a negative climb angle below ground level. Instead, the glider will continue its ground roll. This serves to lessen the acting angle of attack and decrease the load factor and stall speed, making the actual launch safer in regard to the safety margin S.

3.2 Wind Influence

Most flight regulations such as the German "Glider Operation Regulations"[6] limit tailwind glider launch operations to very small values of wind speed or prohibit them completely. Due to this, it was expected that the release altitude of a launch conducted in tailwind conditions would decrease more strongly than that of a launch in an equally strong, yet opposing, headwind.
The simulated flight path, visualized in FIG. 5, cannot support this hypothesis. The glider flying in a $2.5m/s$ tailwind will release at $\Delta h_{\text{Release}} = -26m$ below the refer-

ence launch and a $2.5m/s$ headwind will cause a gain of $\Delta h_{\text{Release}} = 28m$. Though the safety plot of FIG. 6 for the tailwind condition shows a stalled situation in the interval of $0.6s < t < 1.2s$ where the stalling angle of attack α_S is exceeded slightly, this has to be interpreted cautiously. A more detailed look at the flight path during this interval reveals, that the glider has descended to an altitude of $h < 0m$, due to the lack of a ground model. This cannot be interpreted as being physically meaningful, but much rather should be seen as a continuation of the ground roll. Only once sufficient airspeed is reached will the glider lift off which is expected to occur at a time, when the angle of attack α is again below its stalling value. To provide a more meaningful safety analysis of the situation during which the glider takes off in a slight tailwind, the inclusion of proper ground-effect and ground models are necessary. However, the increased duration of a lower dynamic pressure acting on the aircraft becomes apparent in FIG. 6. A pilot transitioning into the climb too early - by not properly regarding the decreased airspeed at the beginning of the launch - still runs the risk of stalling the glider. A glider launch in tailwind conditions is safely possible only if the decrease in airspeed is accounted for and the pilot is not distracted by the visual and inertial impressions of a higher groundspeed.

3.3 Aggressive Pilot Behavior

In a further analysis the benefit and risks associated with an aggressive winch launch, as performed by some pilots, is looked at. During such an aggressive winch launch, the pilot will pitch the glider to a steep pitch angle while still in close proximity to the ground, intending to maximize the altitude gain. Before the launch, he or she will usually have placed the elevator trim in an aft position.

To allow for this maneuvering, the pilot model has been modified by commanding higher elevator deflections throughout the launch. Therefore higher rotating speeds in the pitch axis, which are necessary to reach the higher pitch and climb angles of the aggressive launch, are made possible. At the same time, the pilot already begins to track and control airspeed close to the ground. Both of these behaviors are thought to be adequate representations of actual aggressive pilot behavior. Also, the elevator trim angle has been set to $\eta_{\text{Trim}} = -7.0°$, corresponding to approximately $1/3$rd aft stick position.

The altitude gain brought by this behavior is plotted in FIG. 7 and has a value of $\Delta h_{\text{Release}} = 22m$. Especially the higher climb gradient close to ground level is prominent in the plot where the flight paths of the reference launch and the aggressive launch quickly diverge.

A comparison of the airspeed and stall speed clearly discloses the risk associated with this pilot behavior. FIG. 8 shows that during the time frame of $0.7s < t < 1.3s$ the stall speed and airspeed coincide. In the same interval, the stalling angle of attack $\alpha_S = 8°$ is exceeded. This causes the safety margin to shrink to a value of $S \equiv 0\%$ during this interval.

While the flight path plot of FIG. 7 shows that the glider will climb at a steeper angle during the initial climb phase when the pilot flies the winch launch aggressively, FIG. 8 reveals that the glider is actually stalled during this flight phase and illustrates how risky this maneuver is. In the event of a cable break during or near the stall, the aircraft would immediately pitch down, as defined by its natural stability. Yet, the altitudes at which this might occur are more than insufficient for recovery and the glider is expected to crash uncontrollably into the ground. The inherent risk of loss of hull, and more importantly the risk of loss of life of the crew, is obvious.

3.4 Influence of Varying Cable Models

In an attempt to gain a more detailed understanding of the physical mechanisms governing the influence of the tow cable on the release altitude of the glider, the standard model presented in section 2.3 is modified. Particularly, the flight paths of the following cable models are determined and presented in FIG. 9:

FEM with Tension, Gravity and Drag is the model described in section 2.3 and regards all presented inertial, internal and external forces.

FEM with Tension and Drag, no Gravity selectively disregards the influence of gravity as it would act on the cable while retaining the effects of internal and inertial forces and aerodynamic drag.

FEM with Tension and Gravity, no Drag selectively disregards the influence of aerodynamic drag on the cable.

FEM with Tension, no Gravity and Drag completely disregards the external forces acting on deforming the cable. Cable deformation is only due to internal and inertial forces.

Secant Model is the physical limit case of a massless ideal cable without aerodynamic drag. It is reached by orienting the winch force along a connecting straight line between the winch an the glider's CG hook.

The flight path plot of FIG. 9 shows two distinct sets of flight paths, the changing influence between the sets being the aerodynamic drag. At the same time, the flight paths regarding gravity lay below the corresponding flight paths without gravitational influence on the cable. This said, it can be estimated that the gravitational influence causes a release altitude loss of $\Delta h_{\text{Release}} \approx -2m$ whereas the drag influence is $\Delta h_{\text{Release}} \approx -32m$. It is peculiar to note that the flight paths of the ideal **secant model** and the **FEM with tension, no gravity and drag** model are identical for all practical purposes. These negligible differences in the trajectory serve to show that the inertial forces acting on the cable in the launch are also negligible.

It is evident that drag seems to more directly influence the cable than gravity does. The introduction of synthetic cables into winch launching has primarily modified the cable material density while the cable cross section remains circular to oval with similar diameters to the steel cable. For the future, it is thought to be likely that more prominent gains in release altitude will be reached by reducing the cable diameter and causing lower aerodynamic cable drag. This, however, can only be realized with the availability of cable fibers able to withstand the higher tension in the cable caused by a reduced cross section.

4 SUMMARY

The presented simulation illustrates some of the basic mechanisms governing the winch launch as it is practiced at many gliding sites worldwide. Whereas several comprehensive cybernetic models are coupled in this simulation, areas still in need of improvement within each model are pointed out for future enhancements.
Through the variation of significant parameters in the winch launch process the influence of these parameters is appraised. A winch launch in tailwind conditions will serve to marginally increase the risk of stalling during the early launch phase. At the same time pilot behavior is much more critical in influencing the risk of stalling. While analyzing an aggressively flown winch launch it becomes obvious that a period of stalled flight might exist, this being a major risk in the event of a cable break. By varying the influence of different physical forces on the cable, through the use of modified cable models, aerodynamic cable drag is identified as another major influence on release altitude.
Whereas only selected cases of analysis are presented, many other significant phenomena can be analyzed in their regard to aircraft stability and control, flight safety and design optimization with the aid of the developed winch launch simulation. These include

- analysis and optimization of pilot and winch operator behavior,
- optimization of the cable (including cable diameter, strength of weak links and cable mass)
- optimization of the glider (tow hook position and other design parameters) and the winch (engine, drive train, etc.)

The author hopes that the results of such studies will provide an impulse for future technical development of winches, gliders and cables. For pilots the analysis of the highly critical aggressive pilot behavior during winch launching hopefully serves to sensitize about the inherent risks of this maneuver and how it can be reduced.

REFERENCES

[1] GÄB, Andreas: *Generische Simulation*. Lehrstuhl für Flugdynamik, RWTH Aachen, 2007

[2] BROCKHAUS, Rudolf: *Flugregelung*. 2. Springer Verlag, 2001

[3] KIENCKE, Uwe ; NIELSEN, Lars: *Automotive Control Systems*. Springer Verlag, 2000

[4] WILLIAMS, Paul ; LANSDORP, Bas ; OCKELS, Wubbo: *Modeling and Control of a Kite on a Variable Length Flexible Inelastic Tether*. August 2007

[5] JOHANNSEN, Gunnar: *Mensch-Maschine-Systeme*. Springer Verlag, 1993

[6] SEGELFLUGKOMMISION, DEUTSCHER AEROCLUB E. V. (Hrsg.): *Segelflugsport-Betriebs-Ordnung*. Segelflugkommision, Deutscher Aeroclub e. V., 2003

APPENDIX

Section 1: INTRODUCTION

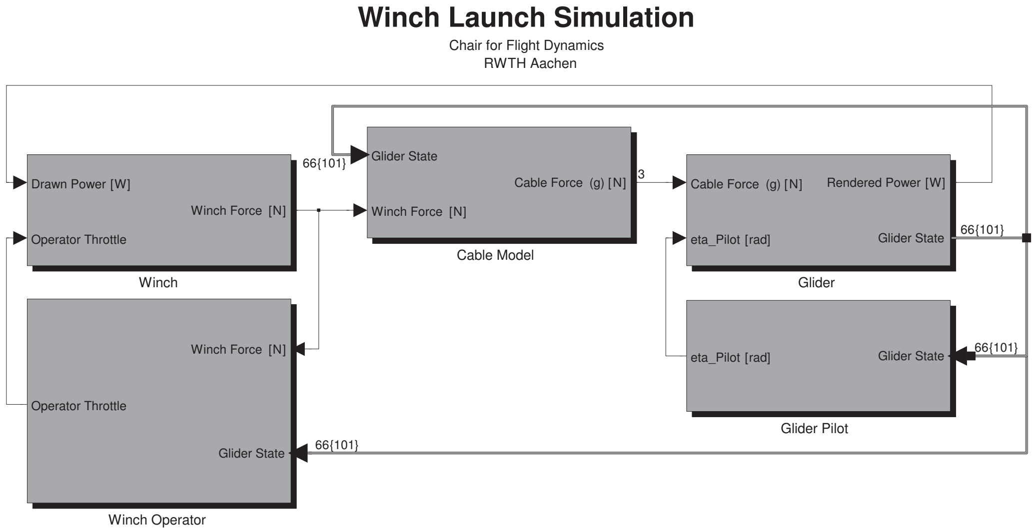

FIG. 1: Block Diagram of the Simulation

Section 2: SIMULATION SETUP AND MODELS

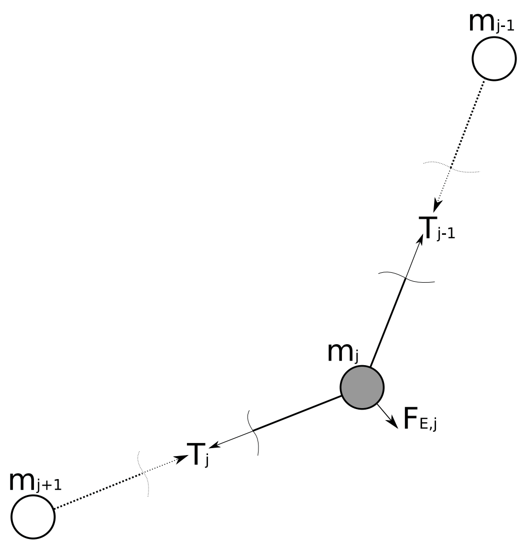

FIG. 2: Illustration of Forces Acting on the jth Discrete Cable Mass

Section 3: RESULTS AND ANALYSES

Section 3.1: Reference Configuration

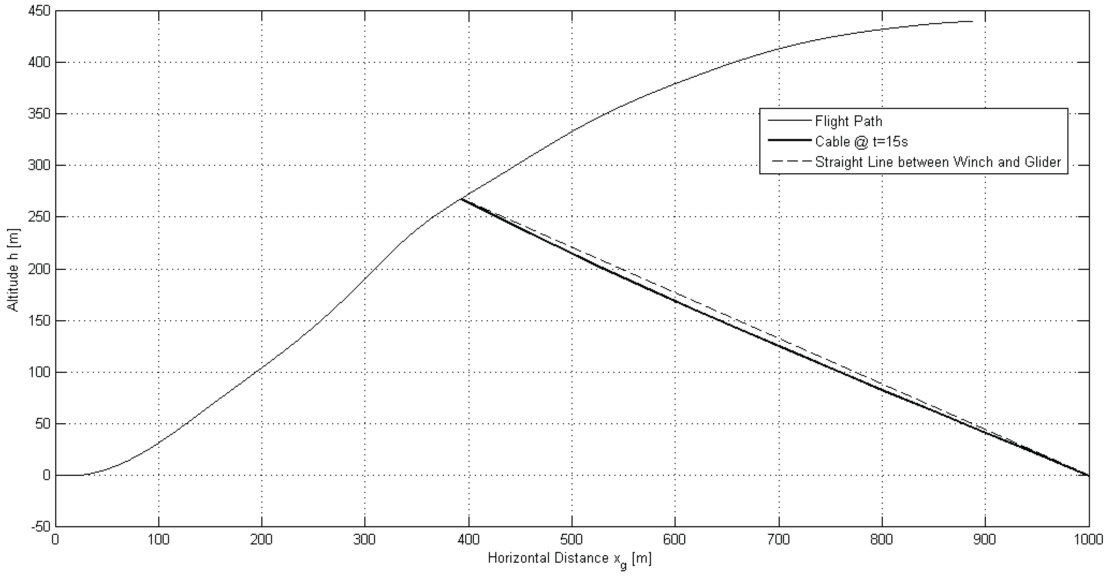

FIG. 3: Flight Path of the Reference Configuration

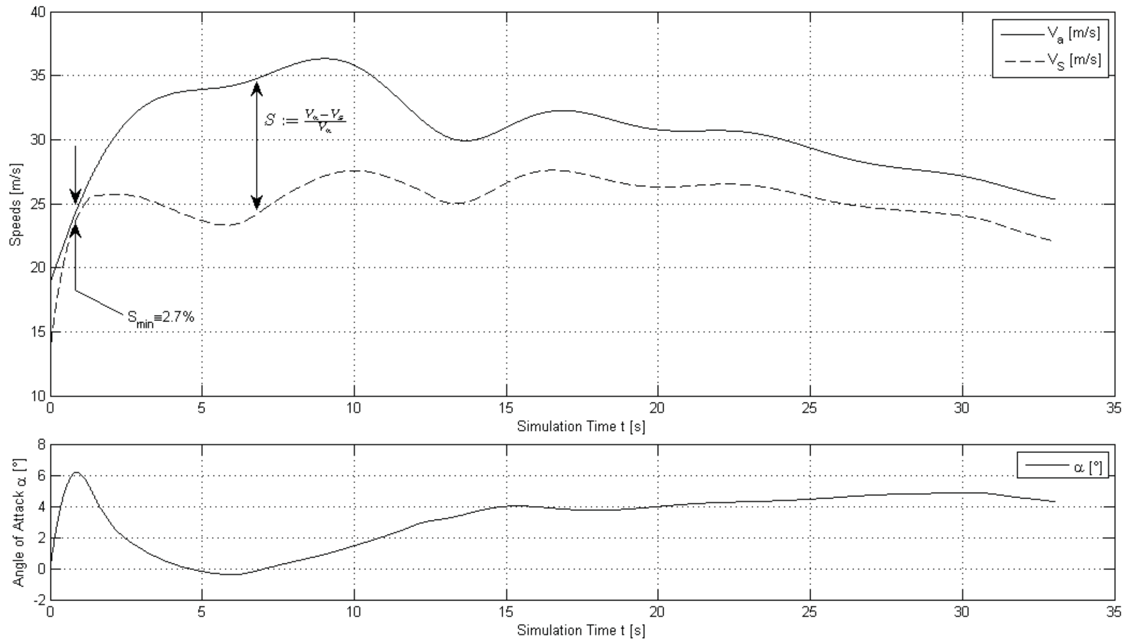

FIG. 4: Safety-relevant Parameters during Reference Launch

Section 3.2: Wind Influence

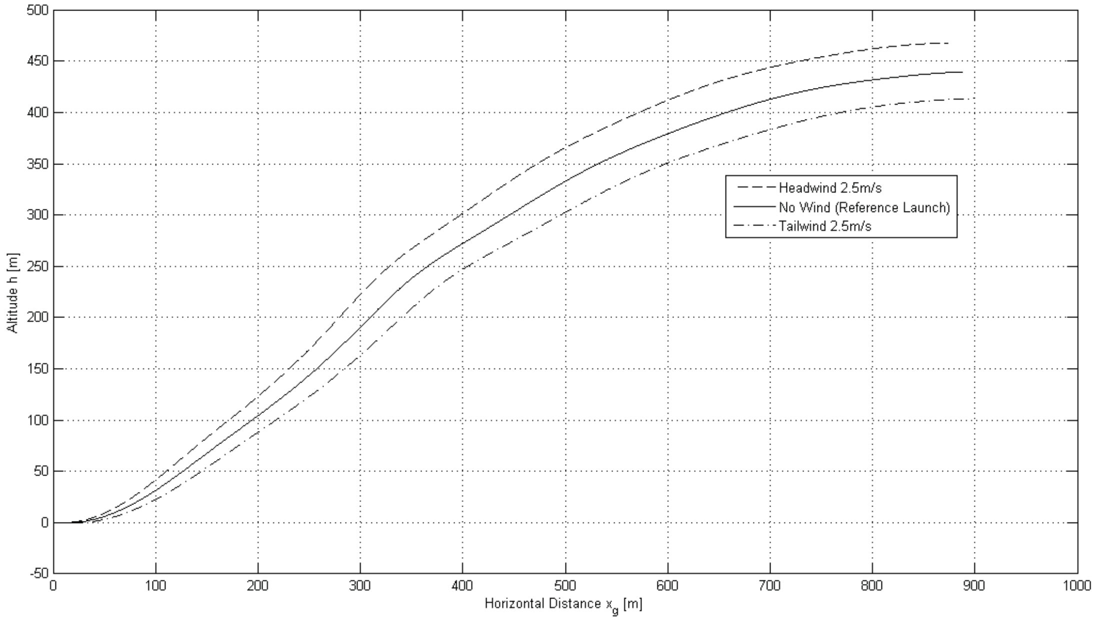

FIG. 5: Flight Paths with Acting Steady Winds

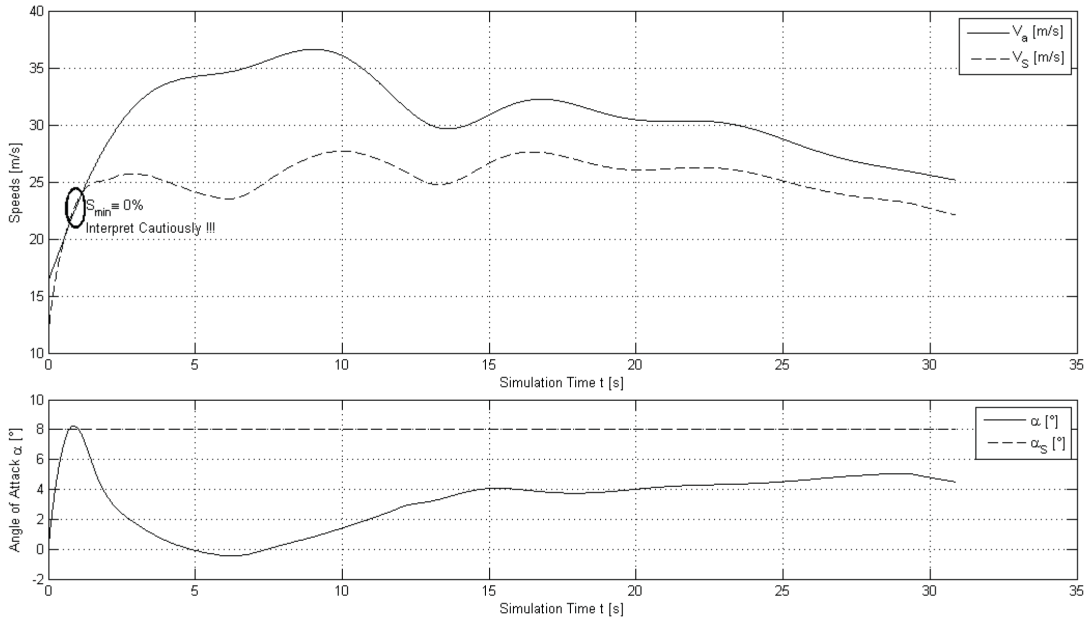

FIG. 6: Safety-relevant Parameters with $2.5 m/s$ Tailwind

Section 3.3: Aggressive Pilot Behavior

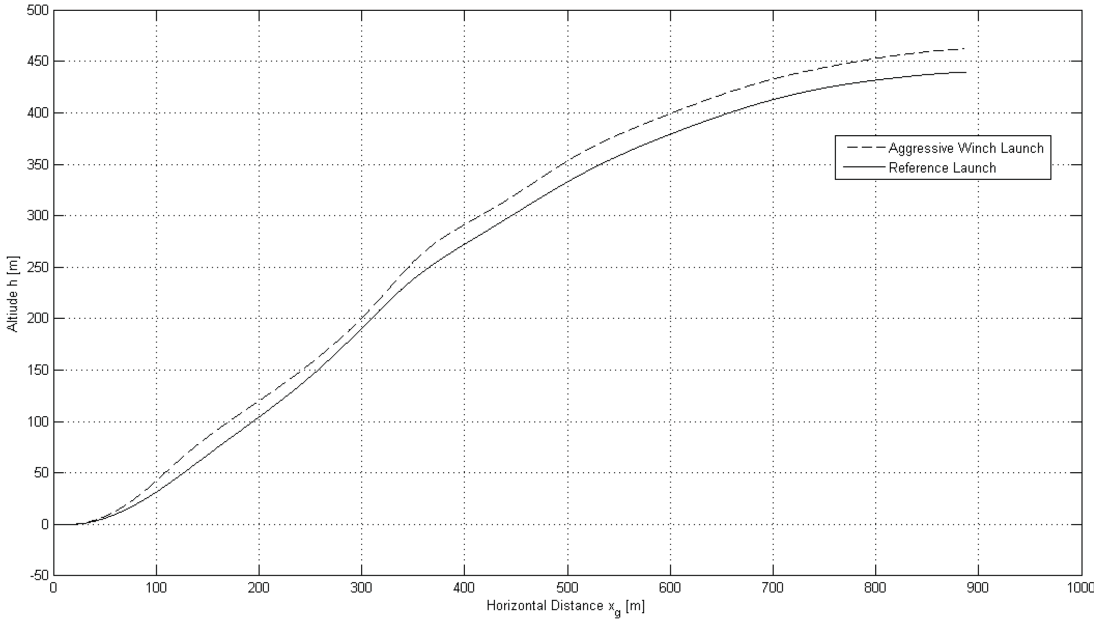

FIG. 7: Flight Path of Aggressively Flown Winch Launch

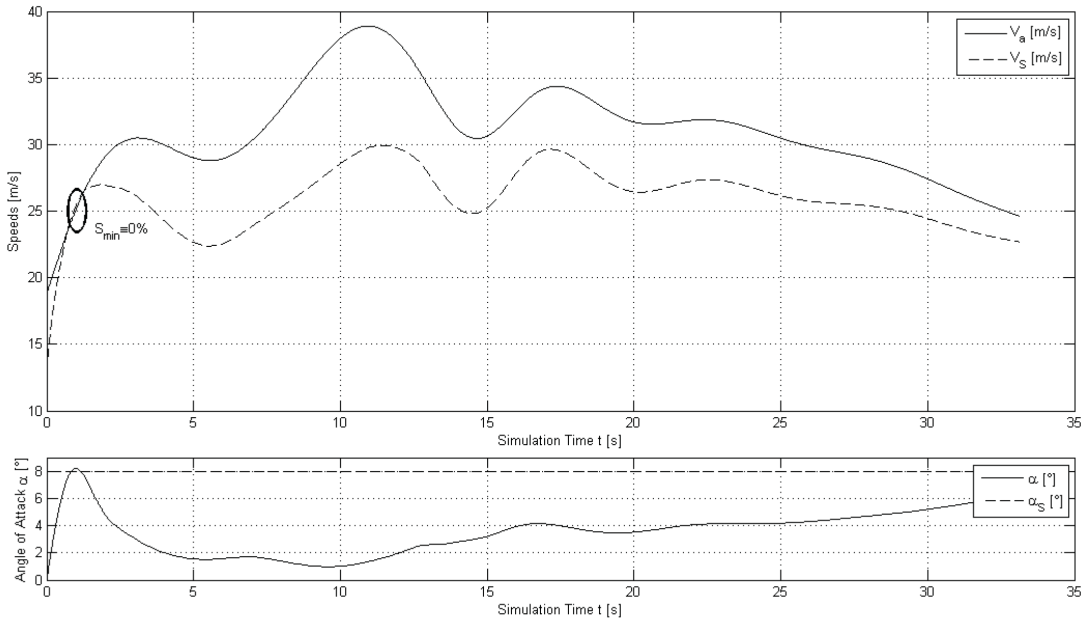

FIG. 8: Safety-relevant Parameters during an Aggressive Winch Launch

Section 3.4: Influence of Varying Cable Models

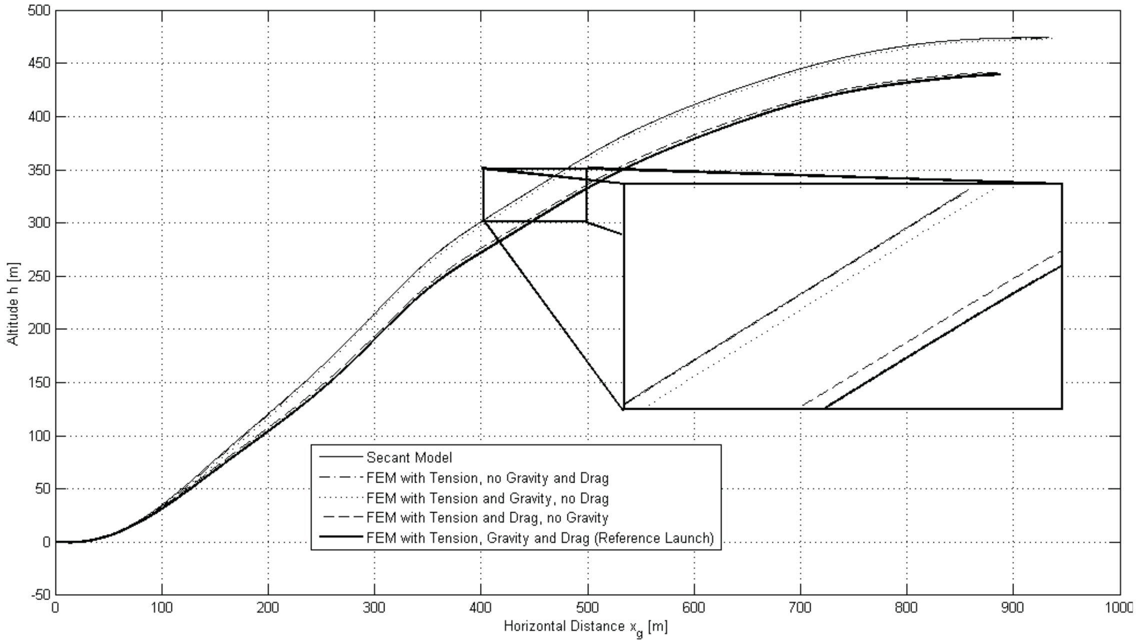

FIG. 9: Influence of Different Physical Cable Models on Flight Path