Battery-Electric Winch Embedded System Requirements

General

This document concerns the requirements for the embedded control system that will control a winch to launch sailplanes safely, effectively, and repeatably while providing good pilot and operator experiences. It will implement active cable tension control as the primary control mechanism during a launch and active tension control during cable retrieve. It will also provide for low speed cable manipulation during ground handling. It shall be a semi-automated distributed real-time embedded microprocessor based system. This document employs a partitioning much of which was explored in earlier simulation projects. The partitioning has been modified and refined based on those experiences. This partitioning is not cast in concrete and may be revised in response to reviews of this document.

A number of abbreviations are used in this document for brevity. A list is contained at the end of the document.

[In this document certain clarifying or justifying statements for why a particular requirement is being established are included in brackets.]

[The initial implementation will be for a proof of concepts prototype. It will begin with one drum, one motor, controller, and one battery system but may be extended with a second motor, controller, and battery system. There is no expectation for this prototype to be extended to multiple drums. The fundamental objectives of this prototype are to demonstrate the value of

Tension Control
Semi-Automation
Battery-Electric Drives

There will be a high value put on expedience and cost and not expending effort on enhancements that do not directly support these objectives. That said, the embedded controller design shall be readily extensible to practical winches employing multiple drums for operational purposes hereafter referred to as “club” winches.]

Real-time winch operation shall be orchestrated by a Master Controller (MC) that shall communicate with a number of microprocessor based controllers distributed throughout the winch, an integrated control panel (CP), and a Host Controller (HC). The Host Controller is a non-hard real-time entity whose primary operational function is to provide Launch Parameters (LPs) personalized to the glider, pilot capabilities and preferences, environmental conditions, parachute employed… for the immediately upcoming launch via the operator selecting pilots, gliders, airfields, parachutes... from a database and inputting environmental data when it is not provided by optional Environmental functions to be described. It is expected to be implemented on a PC or Pad computer. It may provide current launch displays, message logging, launch replays, sub-system status monitoring, calibration, and maintenance support but those are not crucial to the objectives of the initial prototype. Its design is not the subject of this document but some of its behaviors and the requirements it imbues are reflected in the descriptions that follow.

Prime Directive

The winch operator has ultimate authority for operation and control of a launch. This operator must actively initiate the beginning of any launch and he may abort the launch at any time. The system design/implementation shall provide for immediate means for removing power from the motor (s), firing the guillotine(s), and applying drum brake(s) even in the event that there is a total failure in the microprocessor based embedded control system.

Winch Scope Supported

Looking forward to a club winch, the system design shall be capable of supporting winches with up to 7 drum/cable systems. Commonly each drum/cable system will include a driven drum, a fairlead, a guillotine, a mechanical brake, and a means for measuring line tension and cable angle to the glider. [A single mechanical brake may affect only the active drum or there may be a brake for each drum. With multi-drum implementations there will be a requirement to independently back tension each cable for the recovery tow-out phase. This may be done with mechanical friction, i.e. analog brakes, or small auxiliary motors on each drum.] Commonly a single motor system will provide primary motive power during a launch with dog clutches being employed to connect the active cable system to the motor but the possibility of a motor per line system (e.g. Hydrowinch) is also possible and should be supported unless unduly difficult.

[An alternate drive system employs a capstan drive. A winch using this scheme may employ take up drums that actively provide the back tension to the capstan but could also employ simple pinch rollers providing the low side tension and dropping the cable into a storage box. A high value is placed on being able to support such a capstan winch as well but design modifications to do so are acceptable.]

The target winch systems employ a battery-electric drive system. This does not preclude alternative prime motive drive systems (e.g. diesel, gasoline, hydraulic) but the primary design shall be in support of such systems and design modifications to support alternative drive systems are acceptable. This also does not preclude alternative energy storage systems, e.g., ultracapacitors, but for simplicity the term battery will be used in this document for the energy storage element. The motive power may be provided by a single motor but multiple combined motors shall be supported. The motors and their controllers are not required to be identical and each could employ different speed reduction ratios to the driven drum or capstan. Each motor/controller may have its own battery system or one common battery system could support them all. As much as possible, the primary winch controller system design and implementation shall be as agnostic to the motor, controller, and battery system(s) makeup as practical. Similarly the battery system(s), which may also include contactors, dc-dc converters, chargers, BMS systems… may not be identical but the primary winch controller design shall be to the maximum extent possible agnostic to the battery system details. [The motor group controller functional definition that follows shortly is based on this goal.]

Primary Embedded System Functions

Overview

The distributed embedded system shall employ controllers implementing the following functions to effect the specified winch behaviors. Not all functions are required in every implementation and those are so noted in the sequel as optional. In some cases, e.g. multiple drum winches, there may be multiple instances of a function as identified in the descriptions below using the plural. Figure 1 illustrates the major elements of a single motor, single drum winch for purposes of the discussion below. Some lessor and optional functions described below are not included in the depiction for brevity.

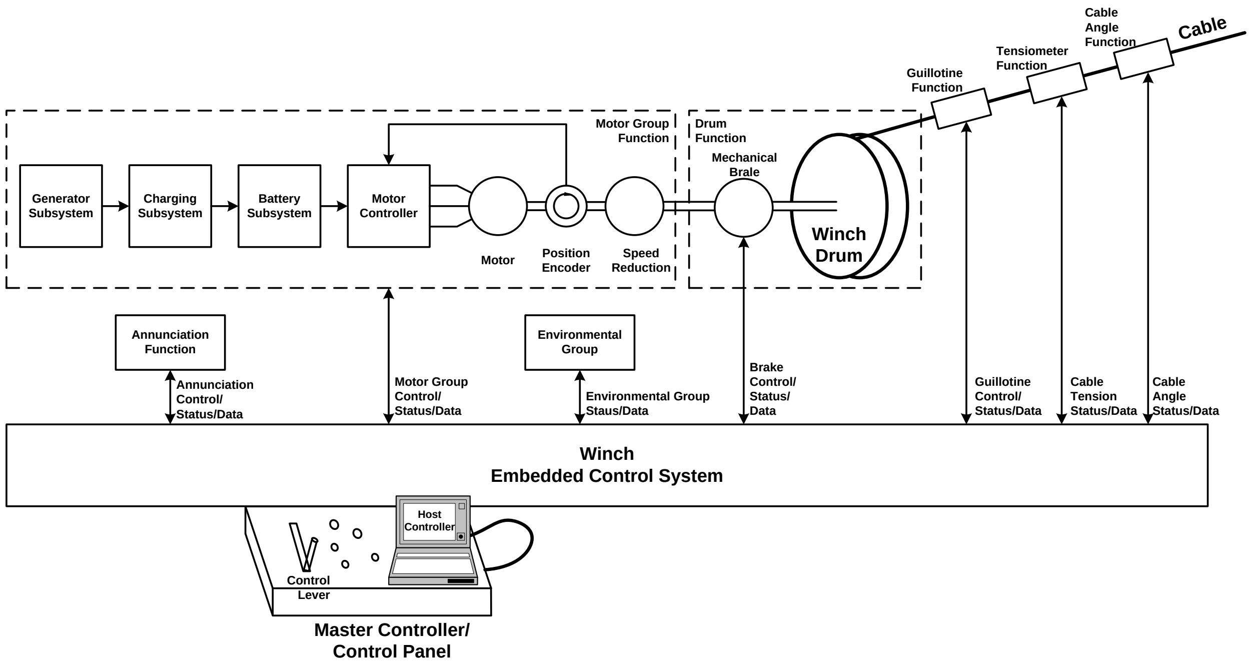


Figure 1. Winch Components and Function Partitioning

These functions shall communicate using an intercommunication means hereafter referred to as the primary network. Communications shall be via packetized messages hereafter referred to as messages. All messages shall be visible to all functions on the primary network. More than one function or function instance may reside on a single microcontroller connecting to the primary network. These functions will all have hard real-time requirements and appropriate operating systems or design methodologies consistent with hard real-time operation shall be employed.

Winch operation is primarily controlled through the Master Controller (MC) function described shortly. It receives inputs from an integrated Local Control Panel (LCP or just CP) and optionally a Remote Control Panel (RCP) when enabled by the primary winch operator, the distributed functions via status/data messages, and from the Host Controller (HC). The status/data messages may be initiated by the MC and/or HC or may be autonomously generated by a function when there is a substantive change in status or, optionally, if there has not been a report within a specified period of time.

To the greatest extent possible all function's quantitative message payloads shall employ SI units.

If the payload size for any function becomes too large for a single message these functions may require multiple response messages and/or the function command-response pairs may be further divided by payload.

Calibration and System Parameters for Embedded Systems Functions

In addition to Launch Parameters (LPs), functions may require System Parameters (SPs) and/or Calibration (Adjustment) Parameters (APs) to implement their purpose. The immediately following discussion applies to all the functions described below as needed.

System parameters are parameters that do not generally vary launch to launch (as opposed to LPs which do typically vary launch to launch) but may need to be changed periodically. They are associated with the function, not the realization. An example is the length of cable installed on an individual drum. System parameters must be able to be interrogated, modified, and validated (e.g. CRC) by the HC via command and status/data messages. This also does not preclude functions from employing alternative means (e.g. UARTs) to set these values if this capability is not supported by the HC particularly in early implementations.

Calibration parameters are generally parameters specific to a particular hardware realization of a function. There may be different realizations of the same functions, e.g. a running line tensiometer configuration for measuring cable tension versus one employing load pins on sheaves. Each realization may have a totally different set of calibration parameters. The HC may implement calibration/maintenance operations using messaging over the primary network. Other than reserving message addressing for such operations, the details of this are beyond this requirements definition. This also does not preclude functions from employing alternative means of connecting maintenance/calibration controllers, e.g. a UART to a PC running a calibration/maintenance program – particularly for early implementations.

Master Controller/Control Panel (MC/CP) Function

As its name implies, this function orchestrates the winch during operation. It initiates commands to other functions and employs status and measurements from them. It shall request and accept launch parameters (LPs) from the HC and statuses from the critical functions immediately prior to a launch. It shall periodically report the current operational state and active drum/cable system or immediately upon any change in this state or drum/cable system.

Integrated with the MC is a local control panel employed by the operator to interact with the embedded control system. It provides inputs; switches, buttons, Control Lever (CL), and outputs; LEDs, text displays, and aural outputs (e.g., beepers). The primary operator analog input shall be via spring loaded Control Lever (possibly mechanically damped) that returns to a rest position when released. It provides a value to the MC indicating its deflection from the rest position with 0 representing the rest position and 1 representing the full forward position. The MC can support a Remote Control Panel (RCP) but its inputs are a subset of the LCP and an operator must be present at the LCP and must enable the RCP and shall at any time be able to execute guillotine, brake, and abort actions or effect reversion of sole control to the LCP. This is unlikely to be present in the initial prototype implementation but is a future enhancement that shall be allowed for in the design.

Gateway Function

This function bi-directionally connects the primary network to the Host Controller (HC). It allows the HC to see any messages on the primary bus and to send messages to functions on the primary bus. Under command from the MC, the gateway function shall enable/disable non-critical messages (TBD) conveyance from the HC, i.e. disable non-essential messages from the HC during active launch operations.

Motor Group (MG) Function

This function accepts drum torque commands from the MC and causes such torque to be delivered to the active drum. It may control multiple motor controllers (possibly different motors and controllers in a motor group) and apportion the desired drum torque to the constituent motors but that action is transparent to the MC, i.e. the MC is agnostic to the number of motors and controllers, the motors/controllers (may be different motors and/or controllers) type, and the gearing (speed reduction) employed from each motor to the drum. It shall return status, active drum speed, and commandable torque in response to commands from the MC or HC or autonomously if there is a substantive change in status. (More on commandable torque in the section on abnormal launch situations.) For single drum systems it shall implement and report the cable deployed measurement normally provided by a Drum Function as commanded by the MC or HC.

It may also accept commands from the HC requesting status of it and the underlying functions it may control or monitor, e.g. battery systems, dc-dc converters, charging systems…. but thinking on this has not yet sufficiently gelled to state this as a requirement yet.

The Motor Group function also accepts commands to enable/disable the motor(s)/controller(s) – typically via the motor(s)/controller(s)’s contactor(s). Alternative robust means of activating/deactivating the contactor(s) by the operator through control panel inputs that do not involve any microprocessor shall be provided.

Tension Sensing Function(s)

This function or function instance measures the cable tension and reports it and the function's status in response to commands from the MC or HC. It shall autonomously report status and tension if a substantive status change occurs.

Cable Angle Sensing Function(s)

This optional function or function instance measures the cable angle and reports it and the function's status in response to a command from the MC or HC. It shall autonomously report status and cable angle if a substantive status change occurs.

Tension Calibration Sensing Function(s)

This optional function or function instance is employed during calibration of tensiometers and cable angle sensors. It employs an inline calibrated tension sensing element (e.g. load cell) to measure the cable tension during calibration operations. Its behavior is analogous to that of the Tension Sensing Function(s) but it shall have its own address and the only source of commands for it is from the HC.

Guillotine Function(s)

This function or set of function instances accepts commands from the MC to activate and reset (if supported) its associated guillotine(s) in response to commands from the MC. It provides the guillotine's status and current condition upon interrogation from the MC or HC. Any substantive change in status shall result in an autonomous status/data message. Alternative robust means of activating guillotine(s) by the operator through the control panel that do not involve any microprocessor shall be provided.

Drum (including brakes) Function(s)

This function or function instance is employed to engage or disengage designated drums from the motor group in the case of multiple drum winches in response to commands from the MC or HC during calibration operations. It also supports commands from the MC or HC to apply or release the designated drum's brake. Alternative robust means of activating/deactivating the brakes (binary) by the operator through the control panel that do not involve any microprocessor shall be provided.

It shall report the drum system status and its estimated working radius and the cable deployed using an algorithm described in [1] based on drum revolutions employing SPs characterizing the drum and cable. In the case of a single drum system with constantly engaged drive system this odometer/working radius is relegated to the Motor Group Function.

Particularly for multi-drum systems back tensioning, during cable retrieve operations may be effected via analog brakes or via per drum auxiliary motors. For single drum systems, the back tensioning may be implemented using the primary drive motor(s). For these reasons, the MC may need to perform some discovery operations to determine which capabilities a drum system instance supports (could conceivably be different between different drums but unusual) and employ commands and accept responses appropriate to the implementation. It shall provide the current status, cable deployed, and working radius of its associated drum in response to commands from the MC or HC.

Even-Wind Function(s)

This optional function or function instance is employed to activate or deactivate even-wind provisions by command from the MC (and possibly the HC during some calibration operations). It shall provide the current status of its associated even-wind system in response to commands from the MC or HC.

Remote Control Panel (RCP)

As described above, a subset of the CP inputs and outputs may reside in an optional RCP, e.g., at the glider end location. The primary operator at the winch location may give control to a secondary operator operating this RCP but the primary operator always retains ultimate control authority. [In the common case where this RCP is physically located near the glider end of the cable, telemetry or wireline signaling may be employed with a gateway like function connecting into the primary network.]

Environmental Group Functions

The following set of optional functions comprise functions that report the current environmental conditions shall be supported by the design.

Density Altitude Related Functions

This function provides measurements necessary to compute the current density altitude [which is employed in generating the tailored LPs for each launch]. These measured variables are

- Temperature
- Pressure
- Humidity (optional)

The function shall respond to commands from the HC with these measurements and may be enabled (via SP) to report these autonomously if a measurement report has not been commanded within an SP specified time.

Wind Function

This function provides measurements to estimate the headwind, crosswind, and gust components. The measured variables are

Wind Relative Direction (angle relative to longitudinal winch axis)
Wind Speed (average over previous SP defined seconds)
Wind Gusts (peak wind speed in previous SP defined seconds)

These are employed by the HC to produce the headwind component used in generating the LPs is. [Note the MC should never need to request any of this data.] The function shall respond to commands from the HC with these measurements and may be enabled (via SP) to report these autonomously if a measurement report has not been commanded within an SP specified time.

It is possible that this function is remotely telemetered in from the glider end location as noted previously.

Magnetic Heading

This function provides the current winch longitudinal axis magnetic orientation. The function shall respond to commands from the HC with these measurements and may be enabled (via SP) to report these autonomously if a measurement report has not been commanded within an SP specified time. [It may employ calibration parameters to correct for deviation.] It shall be able to be enabled via a SP to automatically report when the heading has changed by an SP defined value.

Tilt

This function provides the current tilt values of the winch longitudinal and roll axes from the horizontal plane and optionally the tilt rate along these axes. The function shall respond to commands from the HC with these measurements and may be enabled (via SP) to report these autonomously if a measurement report has not been commanded within an SP specified time. It shall be able to be enabled, via a SP, to automatically report when the tilt has exceeded a SP defined limit or when some combination (TBD) of tilt and tilt rate has been exceeded along some axis (not necessarily the principle axes) for the purpose of detecting imminent tip-overs. Further definition of this function is required.

GPS Lat/Long Function

This function provides the GPS estimate of winch position. The function shall respond to commands from the HC with these measurements and may be enabled (via SP) to report these autonomously if a measurement report has not been commanded within an SP specified time.

Time

This function provides a GPS estimate of current GPS Time and Leap Seconds. The function shall respond to commands from the HC with these measurements and may be enabled (via SP) to report these autonomously if a measurement report has not been commanded within an SP specified time for logging purposes. Such messages shall occur on the next available integral second epoch so that fractional seconds shall not be required or reported. It is possible that the HC will be the time messages source freewheeling off its internal timer which is synchronized to network time when connected.

Annunciation Function (optional)

This optional function, on command from the MC or HC, generates visual and/or aural indication that winch operations are in progress to warn nearby personnel. It shall return status on command from the MC or HC.

Logging Function

Logging of all messaging on the primary bus is expected be employed. This logging may be realized on an optional logging function monitoring the primary network or it may reside in the HC function. [In the case of a distinct gateway function this optional logging function may commonly be integrated together with that function.] There will likely be provisions for extracting data from the logger from the HC via the primary network but these requirements and details are TBD. This does not preclude extraction of data via alternative connections, e.g. UART to PC.

Operational Behaviors

The system shall support the operational behaviors now described using a set of modes/phases/states. The first 4 modes described below are not part of a launch proper. Following their description the modes associated with a normal launch are described. Then abnormal conditions and additional modes of operation that support these are described.

Safe/Neutral

In this mode of operation the motor(s) shall be disabled (contactor open) and if multiple drums are present they shall be disengaged. Drums/cable systems may only be changed while in this mode of operation.

Ground Handling

This mode is primarily employed for taking up cable slack after the cable is connected to the glider. The selected drum system shall be under speed control with the control lever controlling the commanded speed. The control scheme shall not creep at 0 commanded speed (within a SP defined vicinity of the control lever rest position). Maximum commandable speed shall be very low (SP; about a fast walking pace) when the cable end is in the vicinity of the winch and the cable tension limited to a SP specified value that is easily countered by ground handling personnel. A higher SP defined speed shall be allowed when the cable end is far from the winch end to support loading the cable on the drum at low tension at the end of operations.

Retrieve

This mode is employed during the cable retrieve back to the glider end following a launch, at the beginning of operations, or at the end of operations to relieve excess tension for storage. The system shall provide means for back tensioning the cable during retrieve to avoid overruns in the event of a sudden stop by the retrieve vehicle. Preferably this is by means of active tension control but simpler method, e.g. setting dragging brakes, may be acceptable. As discussed previously, there are several methods that this back tensioning may be effected and the MC may need to employ discovery to determine what commands and responses would be employed during this mode of operation.

In the event of a cable break or cable disconnect from the retrieve vehicle provisions shall be implemented to prevent the cable from accelerating to a speed that could cause damage to the winch or a hazard to ground personnel. This specified speed is a SP.

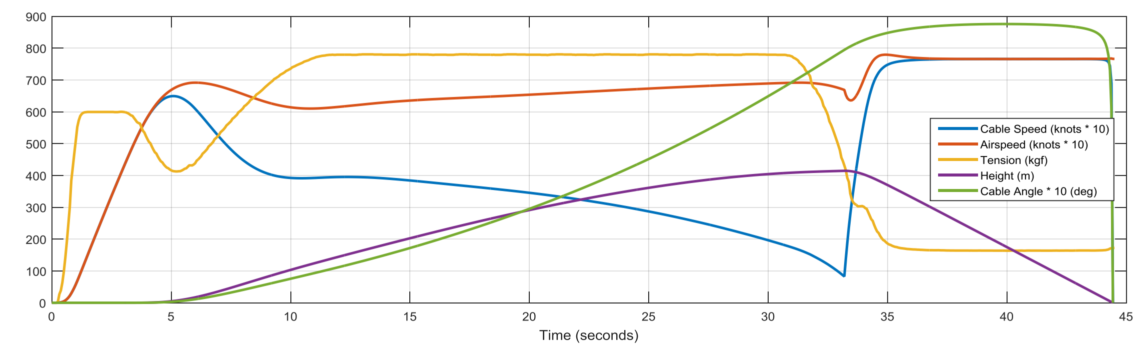
A special parameterization of this mode may be used for static calibration of tensiometers and cable angle sensors. Here the cable would be connected to a calibration load cell attached to the frame or a fixture. The only difference from normal operation may be a higher level of tension allowed. Details of switching between these allowed levels are TBD.

Armed

In this mode the selected drum system shall be held at 0 cable velocity by the motor(s) using the same control law employed for Ground Handling except that moving the control lever shall have no effect until the full forward position is reached. When this position is reached, a final status check of all active drum systems and functions required for a launch and a request for the Launch Parameters from the HC are initiated. Assuming the statuses are acceptable and the LPs are received, the launch proper begins.

Normal Launch Sequence

A normal launch shall sequence through the phases described below. A qualitative description of the behavior of the winch during normal launches is based on the proposal first described in reference [2]. This document provides mathematical formulae based on those descriptions but with refinements for smoothly varying the cable tension through the launch. Abnormal conditions and operational modes to address them are described following this exposition. Normally the CL will be held in its maximum forward position throughout the launch until the parachute is released. The tension equations below shall be scaled by the measured control lever position ranging from 0 to 1, s_{cl} in the equations below, to allow the operator to moderate the predetermined tension profiles as he deems necessary for any reason. The textural descriptions below assume the CL is held at the full forward position but the equations incorporate the behavior when the CL is not fully deflected.



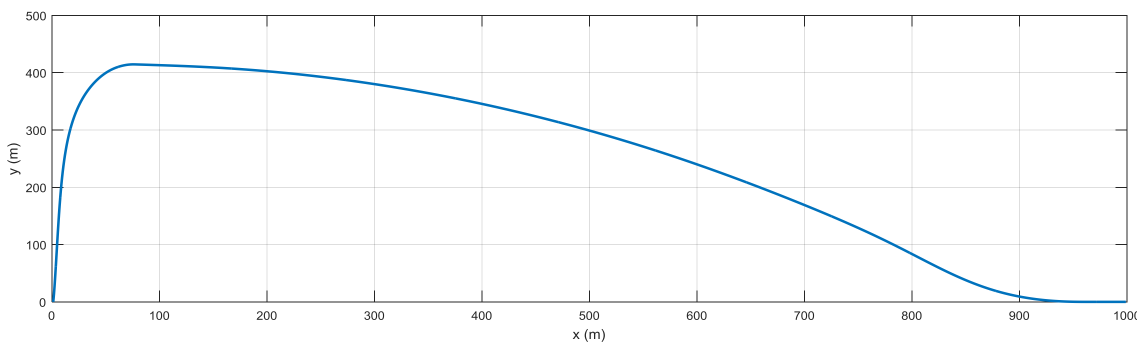


Figure 2 illustrates the key dynamical variables during a normal representative launch. The bottom plot is the xy launch trajectory – more precisely the glider cable end trajectory as it shows the parachute path during the recovery phase. The initial cable length depicted is 1,000 m. The top plot shows the cable and glider speeds (assumes no winds), the tension, the height, and the cable angle. This figure shall be referred to in the descriptions below.

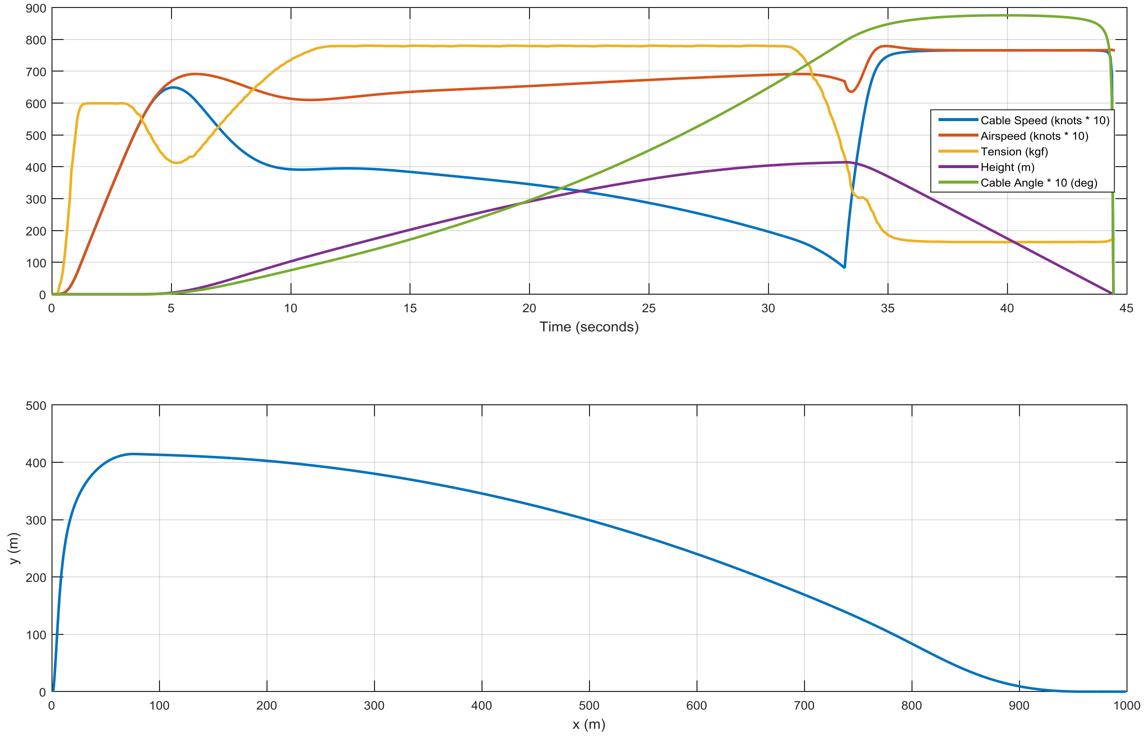


Figure 2. Key Dynamical Variables During Normal Launch.

Ground Tension Taper Up

The launch begins with the cable tension being tapered up over a LP specified number of seconds to a LP specified ground tension factor F_{gr}. The taper function employed shall be

$$f_{st} = s_{cl} \frac{F_{gr}}{2} \left(1 - \cos\left(\pi \frac{t}{T_{st}} \right) \right) \tag{1}$$

where f_{st} is the tension during this taper up period, t is the time since the launch sequence initiation, and T_{st} is the specified taper up period for this launch *st*art phase. This period is 1 second in the example with a ground run tension of 600 kgf. The example employed a 600 kg glider so this tension yields about a 1 g ground acceleration (~19 kts/sec) ignoring friction/drag.

[The purpose of such a raised cosine taper function is to avoid a sudden jerk of the glider at the start of the launch and to reduce non-linear (saturation) control law behaviors when presented with a step input.]

Ground Run

The commanded tension is held constant at the LP specified ground tension level F_{gr} while the glider/parachute/cable accelerates. The commanded tension during this ground run phase is given as

$$f_{gr} = \max\left[s_{cl}\, F_{gr},\, F_{mgr} \right] \tag{2}$$

The commanded tension is never less than F_{mgr}, a SP. [F_{mgr} is some small value intended to keep a positive tension on the cable at all times even with some slight tension measurement offset that might otherwise result in the cable going slack and an ensuing drum snarl.] This launch phase concludes when the cable speed reaches a LP specified trip value V_{tr}. [This value is around the headwind corrected glider stall speed.] This cable speed trip value was about 40 knots in the example and this speed was reached about 2.5 seconds into the launch.

Rotation Tension Taper

As the speed increases above the trip value the tension shall be quarter cosine tapered down with increasing cable speed as defined by the equation

$$f_{rt} = \begin{cases} \max\left[s_{cl}\, F_{gr} \cos\left(\dfrac{\pi}{2} \dfrac{v - V_{tr}}{V_{td} - V_t} \right),\, F_{mrt} \right] & v > V_t \\ \max\left[s_{cl}\, F_{gr},\, F_{mrt} \right] & v \le V_t \end{cases} \tag{3}$$

This function results in a tension equal to the constant ground tension value below the trip cable speed and above this speed would taper to 0 at V_{td}, a LP near the wind corrected maximum winching speed. Note that this equation applies equally well during the ground run phase. [Analysis and simulations have shown that excessive tension during the rotation can result in excessive overshoot in the glider airspeed particularly with high values of ground run tension necessitating this taper down. Also, should the pilot not rotate the glider drag will result in the cable speed stabilizing at slightly below V_t when this tapering behavior is employed.] When the pilot commits to the rotation, the cable speed will peak and then start to fall. Detection of this falling cable speed condition results in the transition to the launch Rotation Taper Up phase. This cable speed peak occurs at just over 5 seconds into the example launch.

Rotation Taper Up

During this period the tension tapers up from the tension value at the entry to this phase to the initial climb tension over an SP specified period of seconds according to the following equation

$$f_{tu} = s_{cl}\left[f_{rev} + \left(F_{clb} - f_r\right)\sin\left(\pi \frac{t - T_{rev}}{2T_{tu}}\right)\right] \quad (4)$$

where f_{rev} is the tension on entry to this phase, F_{clb} is the LP specified climb tension, T_{rev} is the time of entry into this phase, and T_{tu} is the LP specified rotation tension taper up period. This will result in a smooth increase in tension from the value at entry into this phase to the climb tension value using a quarter sine taper. The duration of this phase is T_{tu}. In the example the tension is ramped up over a 6 second period starting about 5.8 seconds until 11.8 seconds where it reaches the climb tension value or 900 kgf (tension factor 1.5). It started slightly after the cable speed peaks to insure the speed had peaked and had begun to fall.

[Close examination of the figure show a slight kink in the tension function. Ideally the transition would occur when the cable speed slope goes through 0 from negative to positive but it takes some time to robustly recognize the cable speed having reached a minimum value. Hence this taper function is actually started after the tension has begun to increase due to the falling cable speed and the speed dependent tension equation of Equation (3). The quarter sine rotation taper up Equation (4)'s slope does not match at the transition point in the observed kink. Future refinements may attempt to better spline the tension function at this transition.]

Climb Tension

During this period the tension shall be held constant at the F_{clb} value according to

$$f_{cb} = \max\left[s_{cl}\, F_{cb},\, F_{mcb}\right] \quad (5)$$

F_{mcb} is a minimum value that shall be commanded to insure positive tension on the cable at all time to avoid cable snarls. Future refinements may slowly taper this tension as the launch progress using a function of time or cable angle but that is not part of the initial system requirements definition. [The glider airspeed increases during the climb due to the simulation model holding a constant AoA and the increasing lift factor as the climb progresses requires higher airspeed to produce the required lift.]

Pre-Release Taper Down

When cable angle measurements are available the tension will be reduced smoothly over a few seconds once the cable angle reaches a LP specified value γ_{rl} according to the relation

$$f_{rl} = \begin{cases} s_{cl}\left[F_p + \dfrac{F_{clb} - F_p}{2}\left(1 + \cos\left(\pi \dfrac{t - T_{rl}}{T_p}\right)\right)\right] & t - T_{rl} < t \le t - T_{rl} + T_p \\ s_{cl}\, F_p & t > t - T_{rl} + T_p \end{cases} \tag{6}$$

where T_{rl} is the time the cable angle γ_{rl} was reached, T_p is the LP specified value that conceptually indicates when the tension would have been reduced to a minimum value F_p, an LP specified minimum tension value. The pilot releasing or the cable back releasing results in the cable speed increasing under the remaining tension, which must be greater than F_p. This increase in speed by an SP defined percent results in the transition to the Retrieve phase described next. This taper down begins about 31 seconds into the example launch and the release about 3 seconds later.

In the case that cable angle is not available the operator would decide when it is nearing time to release and reduce the tension manually by retarding the control lever.

Recovery

During the recovery phase the control mode shall be cable speed with a LP specified maximum cable speed and LP specified tension limits. [The reason these are launch parameters is the parachute employed may vary from launch to launch and these limits may be parachute dependent.]

A cable odometer function shall be implemented keeping track of the estimated amount of cable still deployed. During the recovery phase when the remaining cable reaches a SP specified distance from the winch this maximum commandable cable speed shall be tapered down such that the cable speed is limited to a very low SP specified value before the cable preamble reaches the winch.

Abnormal Conditions

It is crucial to make every effort to identify every abnormal condition that may develop during operation, including the operator's behavior and invalid inputs, and to effect an appropriate response for the embedded control system for each such. Some key abnormal conditions are described below but during the design process great attention shall be employed to identify and determine the safest and least stressful behavior that the winch system should exhibit in the case of these events and to identify additional abnormal condition that should be handled .

There are a number of launch critical functions and during every phase described above their current status and operational capabilities shall be examined by the MC and appropriate actions taken. Such condition checking processes shall be clearly identifiable in the software implementation. Whenever possible the system shall deal with a function failure in a fail-soft manner if this will potentially provide a safer outcome. The system shall signal [e.g. aurally with a beeper] the operator that an abnormal condition has occurred and provide some indication [e.g., text display] of the nature of this abnormal condition to aid him in his response.

The operator may activate switches, press buttons, or move the control lever at any time and what should be done in response to any of these in every operational phase shall be considered. This is not to say that certain actions, e.g. pressing the tension zero button in the middle of a launch, would not be rightly ignored.

Now the identification of some key abnormal conditions and discussion regarding them. Further additions and refinements are expected during the review and development process.

Cable Failure

This is a cable failure on the winch side of the parachute. This abnormal condition will manifest itself to the winch as an inability to establish meaningful tension in the cable with application of additional torque and a rapid increase in cable speed. With regard to the pilot/glider there is little that can be done and since the cable speed will be increasing the winch side of the broken cable will be rapidly departing the glider's vicinity. The system implementing a cable speed limit, which could be different for each phase, prevents the cable speed from increasing unduly. The operator shall be able to reduce this cable speed or cable speed limit by retarding the control lever such that 0 cable speed shall result at the rest position.

Weak Link Break or Early Pilot Release

Here the separation is such that the parachute can deploy and the main concern is the glider flying into it. Some tension can be established by the parachute drag but usually well below what would normally be commanded during the different phases above. This should result in the cable speed increasing and the parachute being pulled away from the glider. Again maximum cable speed limiting shall be incorporated into the design and this may vary depending on the launch phase. Mostly here the operator just needs to make sure the inflated parachute and cable preamble does not contact the glider or interfere with the pilot's vision while he deals with the release.

Operator Abort

Here the operator aborts the launch for some reason, e.g., wing drop or a conflicting of conflicting traffic sighted after the launch has begun. The operator will normally abort by rapidly retarding the control lever to the rest position. This should remove tension from the cable and commonly the glider will overrun (on the ground) or overfly the cable (in the air) with an automatic cable release. The initial thought would have the winch transition to a speed control mode similar to that employed for a normal cable recovery. The operator would leave the CL in the rest position until the glider stops, if still on the ground, or clears the falling away cable if in the air. If in the air the operator could then restart the cable by advancing the CL and proceed like for a normal cable recovery. If the abort was low and the glider is landing straight ahead letting the cable drop would probably be the best course of action.

Motor Failure

In the case of multiple motors, the motor group function shall implement a fail-soft behavior when one or more motors fails indicating this to the MC via status and a reduction in the commandable torque data value. The MC shall recognize this and adjust the tension profile in accordance with the available torque and signal the operator of the motor failure.

Slack Cable at Launch Initiation

This is a situation where all the slack was not removed from the cable or possibly the cable had snagged on a grass clump and suddenly pops free. This would generally manifest during the ground taper up period. Mostly this would result in the drum accelerating rapidly and then the cable going taut and jerking the glider. How to detect and deal with this situation needs further thought. Limiting the commandable drum torque such that it is only slightly greater than that needed to accelerate the combined drum effective mass, cable parachute mass, and glider mass is one idea. During this short period the tension would be monitored and if cable tension does not rise accordingly within some tolerance abort the launch. But a cable stuck on a clump of grass might initially tension up properly and then popping free result in a sudden drop in tension would occur. Usually the drum inertia would prevent a major increase in drum speed before the cable goes taut again and the cable elasticity would moderate the resulting jerk. In general it should not be difficult to do better than a human operator manually controlling a classic winch.

Unexpected Glider Mass Detected During Ground Run

Knowing the expected glider and cable/parachute mass and tension values being employed during the ground run allows the glider to be "weighed" during the ground run according to $f = M\,a$. In addition, a sloped run can add or subtract a bias to this value. The expected launch mass and slope bias will be launch parameters delivered by the HC. This could detect a mis-selection of the correct glider or major errors in the pilot and passenger weights. If the measured weight deviates by more than a SP specified amount abort the launch. Then the situation is back to the early operator abort scenario just described.

[It is more important when the measured glider mass is much less than expected as then the glider could easily over accelerate and excessively overspeed during the rotation and/or might not have the elevator authority to control the speed in the climb. The tolerance could be somewhat greater for a measured glider mass that is larger than expected as this would only result in a lower acceleration and climb angle.]

Tension Sensor Failure During Launch

Here the tension sensor has signaled that its measurements are no longer reliable. If this occurs before flying speed is attained the system can abort. But if the glider has already left the ground it may be preferable to continue the launch in a degraded condition as described next. The operator would be signaled (e.g. CP beeper triple beep) and could determine whether to continue the launch in the degraded condition or abort the launch. The winch operation could be degraded to torque control with a reduced tension profile level. This would require some confidence that the motor controller can control the motor torque with some accuracy. Further definition is required.

Cable Angle Sensor Failure

Here the cable angle sensor has failed and the sensor function's status indicates unreliable cable angle measurements. The cable angle is only employed to initiate the tension taper down behavior at the climb end. If the operator is notified of this he can manually effect this taper down. So the principle requirement here is to notify the operator of the situation. [A launch could be allowed to be initiated with this sensor down as long as the operator acknowledges the sensor loss before the launch begins, e.g., on arming the system he is signaled of the issue and has to performing the arming action again to continue. Or the HC could take this optional function out of the system and the operator knows the taper down must be effected manually.]

Per-Drum Speed Sensor Failure

This should only be relevant for multi-drum winches with per drum position/speed sensors for use in active per-drum back tensioning during a retrieve. There should be no issue with launching with an already extended cable as cable speed during a launch comes from the Motor Group using the known speed reduction and estimated working radius. [For internal combustion driven winches employing a fluid coupling or torque converter there need to be a position/speed sensor on the output shaft or the drum proper but this is not considered here assuming battery-electric drives.]

Missing Sensor/Status Messages

Several of the above abnormal conditions that are associated with sensor data have assumed the function so indicated this condition with a bad status. It is also possible for there to be a communications failure where one or more messages from a function was lost - either not sent or received erroneously. This could be the result of a failure in all or a part of the communications network, e.g. broken wire, or noise and interference. The system design shall consider the effect of missing messages and effect robust means of dealing with same. This could include provisions for freewheeling through a limited number of missing messages before declaring a function AWOL and then reacting appropriately – most likely using the same provisions for the sensor failure scenarios described above. Combinations must be considered here.

Abbreviations

The following abbreviations are used in this document.

CL – Control Lever

AP – Calibration (Adjustment) Parameter

(L)CP – (Local) Control Panel

HC – Host Controller

MC – Master Controller

LP – Launch Parameters

RCP – Remote Control Panel

SP – System Parameter

References

[1] George Moore, Working Radius Variation, Stresses, and Odometer Functionality for Glider Winch Drums, Revision 2.4 (or later), March, 2014.

[2] George Moore, Tension Controlled Automation Proposal, February, 2008.