THE EFFECT OF INERTIA IN THE WINCH LAUNCH

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1. Introduction.

Inertia of mechanical components is present in all transmission systems. When a winch used for launching sailplanes the inertia effect of the cable drum inertia is significant. The inertia of the engine, gearboxes all play a part and should be taken into account in the design of the detail of the winch system.

Rotating masses, whatever their Inertia value, take up energy as they accelerate, and give out energy as they decelerate. Energy in the winch launch is the product of cable tension and cable speed. The presence of large inertia's in the rotating masses can increase cable tensions significantly in the course of the launch thus making management of the system difficult.

The purpose of this paper is to show how inertia of the rotating parts influence the launch. A example is used that employs numbers for mass, speed and power that are typical of winch launch operations. The energy flows are defined throughout the launch. A better understanding of the winch launch system can be achieved.

2. The Nature of Inertia.

Newton's First Law of Motion states that bodies continue in a state of uniform motion in a straight line until some force is applied to change that state of motion. As the applied force must move with the body while its situation is changed, so energy is expended. The amount of energy used up is the product of the value of the force and the distance that it travels.

The concept of weight is well known. Weight is a product of mass of the body and acceleration due to gravity. As the value of this acceleration is taken to be a constant on the earth's surface, variations in weight are the result of gravity operating on different values of mass. A heavy body therefore has a large mass.

The inertia a rotating body is a product of the value of mass, its diskibution in the body and is given the description:

Moment of inertia.

The energy of motion, kinetic energy, is again a product, that of half the moment of inertia and the square of the angular velocity in radians. This energy is described as foot lb. on Meager Joules per second. In this numerical example, the sailplane's speed is considered to accelerate smoothly to 60 kts (88 fps)

and to remain constant at this value in the climb. However after the initial acceleration phase, the cable, and drum reduce in velocity as the climb proceeds. They therefore give up energy to the system.

3. The Inertia Values of the Winch System

The launching system has many inertia values but most are small. For convenience the following are considered the most significant:

1. The Cable Drum
2. The Sailplane
3. The Cable

The Cable Drum

The cable drum consists of two flanges of 36 inches diameter disks 1/4 thick steel mounted on a shaft. The flanges are held apart by a

$$E = 0.5 \times MI\omega^2 \tag{1}$$

where

MI is moment of Inertia
ω is rotational velocity.

The cable drum values will be:

1. Weight about 72 lbs
2. The mass is 2.2365 lbs
3. The Moment of Inertia (MI) is 18.3 lbs ft.

The Sailplane

In this example the weight of the sailplane is taken as 1,000 lbs which gives a value for its mass of 31.06 lbs.

The Energy Value of the sailplane is the sum of the Kinetic Energy and the Potential energy.

On the ground the sailplane has only kinetic energy due to it motion. In the climb it gains potential energy as it gains height.

The sailplane's Energy value becomes:

$$E = \frac{M \times V2}{2} + M \times g \times H \tag{2}$$

where

M is mass
V is the velocity in fps,
H is the height if feet
g is gravity acceleration

The Cable

The common practice is to used steel cable to launch the sailplane. Some years ago the use of 4 mm diameter preformed stranded cable of 7x19 construction was universal.

Increased powers have brought about the use of 5 mm cable. The weight per unit length has therefore risen from 4 lbs to 6.25 lbs per 100 feet. A similar increase of 56% has taken place in the break out load of the cable.

The Cable Speed Range

The cable speed will rise to a maximum of about 60 kts (88 fps) and then diminish progressively to zero at the top of the launch. The cable speed and the sailplane speed are equal for only the period on which both are on the ground.

As the sailplane rotates into the climb, the flight path starts to have a component of rotation about the winch. The speed of the cable and sailplane therefore diverge.

The cable tension does not increase to compensate for the loss speed for the power is not constant. This is just as well for, were it to do so, the sailplane's structure would have to withstand very large loads indeed

These factors place a restraint upon the height to which a sailplane can be launched by the space available. In this example, the cable length is 5,000 ft.

The power that can be used realistically is limited by the weight of the sailplane. That limit would seem to be 200 horsepower (150 kW).

The profile of a winch launch was described by J.C. Riddell. The energy requirement and the cable speed for the idealized winch launch are given.

Disregarding the inertia of the engine and transmission, the energy required for the launch on a time basis can be derived. It is shown below and in Figure 1.

4. Energy Levels in the Winch Launch

The rate at which energy is being fed to the launching system at any one time is the sum of the rates of the energy taken up by the components of the system. As each unit has a different value of inertia and different speed values, the rate at which each takes up energy is not the same.

The amount of energy in a system at any one moment is:

$$E = \frac{MI\omega 2}{2} + \frac{MsVa2}{2} + MsgH + \frac{McVc2}{2} \tag{3}$$

-where

MI is the moment of inertia of the cable drum
Ms is the mass of the sailplane
Mc is the mass of the cable.
Va is the velocity of the sailplane
Vc is the velocity of the cable
H is the height of the sailplane above the launch point
g is the acceleration due to gravity
ω is the rotational velocity of the cable drum in radians per second.

5. Flywheel Effect

In section 3, equation (1) the energy of the rotating drum was shown as

$$Ed = 0.5 \times MI \times \omega^2 \tag{1}$$

and the rate of change of energy in time dt is:

$$dE/dt = MI\omega d\omega \tag{4}$$

These two small equations tell us that the energy stored in a rotating drum is dependent upon the inertia value of the drum and the square of the rotational velocity. So slow reving drums of large size can have more storage capacity than high reving drum of smaller diameter in lighter material. For the same time periods, the rate of change of

Table1.

Time-secs	Cable Speed f.p.s.	Cable Energy B.H.P.	Drum Energy B.H.P.	Sailplane Energy B.H.P.	Engine Power B.H.P.
0	0	0	0	0	0
0.62	20	5.69	10.73	18.22	34.64
1.242	40	8.52	21.43	36.34	66.32
1.863	60	9.47	25	54.55	89
2.48	80	10.28	18.78	72.86	102
3.11	100	9.95	19.26	90.79	120
10.54	64	-4.95	-9.38	158.34	142
8.76	63	-0.10	-.11	144.1	143.89
7.3	54	-1.32	-2.51	139	137.17
6.25	46	-1.12	-2.1	135	131.4
5.3	38	-1.09	-2.05	123	120
4.65	21	-1.01	-1.90	103	100
4.46	13	-0.45	-1.06	83	81

power decreases as the rotational speed slows for it is influenced by the value of the rotational speed..

Figure 1 shows that there is an abrupt transfer of power

Table 2.- Energy Transfer Rate

Time - seconds	2	4	6	8	10	12	14
Horsepower - BHP	75	37	25	19	15	12.5	10.7
Tension Increment-lbs	470	235	156	117	94	78	67
Tension Rise - %	47	23.5	15.6	11.7	9.4	7.8	6.7

to the system from the cable and drum as the sailplane rotates into the climb.. This can only be absorbed by a rise in cable tension or a reduction of power from the engine. Such a transfer of power is very difficult to judge manually and winch driver adjustments almost always too slow.

In the example the energy increment to the system is 82,754 ft lb. If this power is fed slowly into the system, its effect would be slight. At this stage of the launch it is transferred in a short time and its effect on the launch may be judged from Table 2.

The Additional Power Effect

It can be seen that when the T/W ratio changes from 1 to 1.5 the cable tension increases and therefore the load on the sailplane structure is increased. Table 3 below shows how the load factor changes.

While an increase in load factor from 1.41 to 1.8 can be well within the capability of the structure to withstand it, it will be seen that a similar power surge to a lightly loaded sailplane can cause a much greater rise in load factor, and may in cases of a powerful winch and a heavy drum bring about a risk of structural failure.

6. Rotation into the Climb and the Danger of Apparent Power.

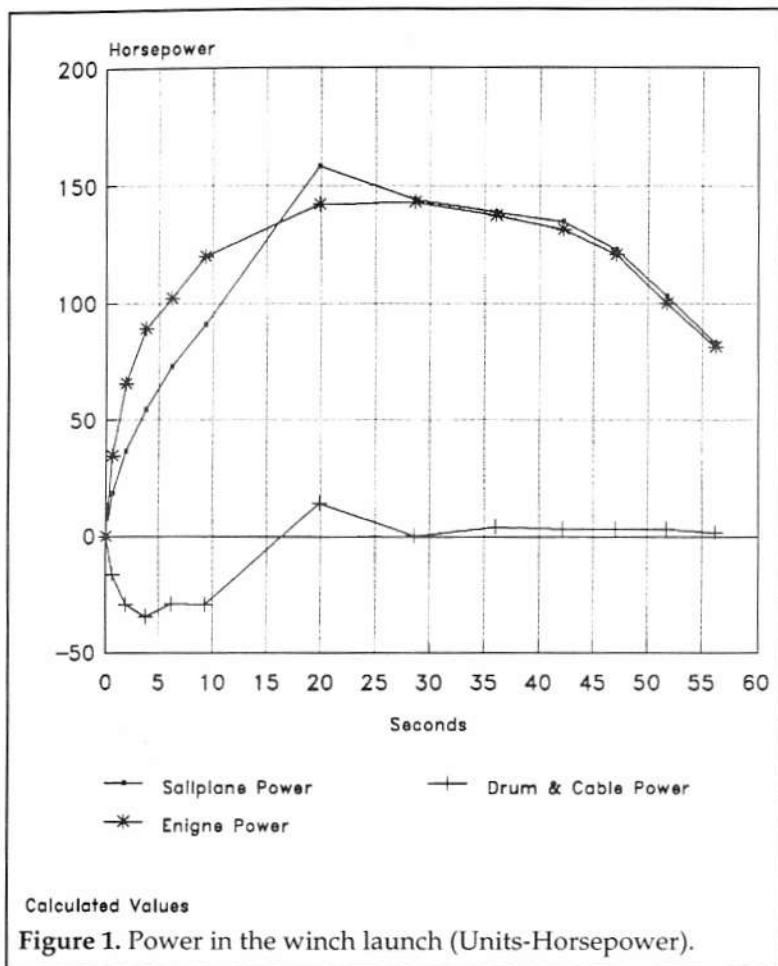To those on the ground, both at the launch point and at the winch, the early stages of the launch appear, and are satisfactory. The rotation will be normal, but if the winch driver is slow to respond and he does not maintain sufficient power, the sailplane may loose airspeed at a low height - below 200 ft - and a stall will result.

TABLE 3: T/W Ratio, Climb Angle & Load Factor.

T/W Ratio	0.5	N	1.0	N	1.5	N
Cable Ang	Climb Ang	Load F.	Climb	Load F	Climb	Load F
0 deg	26.6	1.12	45	1.41	56.3	1.8
10 "	24.4	1.19	40	1.53	49.5	1.94
20 "	21.9	1.26	35	1.64	43	2.07
30 "	19.1	1.32	30	1.73	36.6	2.18
40 "	16.2	1.38	25	1.81	30.3	2.28
50 "	13.1	1.42	20	1.87	24.2	2.36
60 "	10	1.48	15	1.93	18.1	2.42
70 "	6.6	1.48	10	1.97	12	2.46
80 "	3.3	1.49	5	1.99	6	2.48

Horsepower

Calculated Values

Figure 1. Power in the winch launch (Units-Horsepower).

Legend: —•— Sailplane Power   —+— Drum & Cable Power   —*— Enigne Power

If a ground impact occurs, then the accident is described as "Pilot Error" and dismissed as such. Although this analysis shows that the winch system did not provide the necessary power to sustain the launch, the launch appeared to those on the ground to be quite normal.

7. The Weak Link - Tension Limitation.

The weak link was inserted in the launching cable many years ago as a protection for light slow flying gliders. The intention was to reduce the effect on the structure of the difference in the load that the structure could withstand and the breaking load of the cable. In the British Gliding movement the weak link load was laid down at 1050 lbs, later increased to 1100 lbs on a 4 mm cable of breaking load 2200 lbs.

The increase in all up weight of glassfibre two seaters to 1600 lbs and more required higher powered launches and heavier launching cables with break out loads of 3,500 and 5,000 lbs. To meet these higher launching loads, as range of weak links were introduced in the UK operations. Five values were given and they ranged from 1100 lbs to 2000 lbs. Each type of sailplane or glider had its allowable weak link value defined by the B.G.A.

This was a necessary step at the time but it did not address the problem of power limitation on the wire. The consequence was that some gliders when launched on their correct link value suffered a high incidence of cable failure. To overcome this, the practice has grown up of launching on a higher value of the weak link.

8. Conclusion.

Safe winch launching will only take place when the winch power is matched to the all up weight of the sailplane being launched and takes into account the inertia of the ground launching equipment.

The power must be continuously adjusted to suit the phases of the climb as the sailplane passes through them. This requires that engine output torque, cable speed, are measured continuously and adjusted to conform to the profile of the launch laid down.

The technical challenge is not great with the transducers and the computer resources are available to us. I hope that the ideas that I have expressed here will encourage others to take up the challenge of improving the safety of our launching operations by improved technology.

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