The Design and Development of Glider Launching Winches

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ABSTRACT

The use of winches for launching sailplanes has increased in recent years as the cost of fossil fuel has risen. Although the height that a sailplane achieves in the winch launch is limited by geographical and other considerations, the reduction in cost of flying training operations is of considerable benefit.

The Royal Air Force Air Cadet organization has used winches extensively in their primary glider pilot training. The author has assisted the Ministry of Defence in the reduction of cost and the improvement in reliability for their winch launch system.

The mechanical engineering features of winches for launching gliders are discussed in detail. The opportunity has been taken to bring together in one place the design formulae and charts for winch equipment.

No attempt has been made to define the cost of launching a sailplane by winch in current terms as this will depend upon the circumstances of the location. Sufficient information is given for costs to be predicted by the users.

INTRODUCTION

The use of gliders by National Government organizations as a means of low cost introduction to flying training is now well established throughout the World. Germany was the first to see the value of gliders in the 1930's, while in England an organization called the Air League of the British Empire established the Air Defence Cadet Corps. It was this Corps that sent boys for training at Civilian Clubs up and down the country.

In 1941 this organization was taken over by the R.A.F. and renamed the Air Training Corps, now the Air Cadets. This new organization quickly founded its own training organization and now operates 27 gliding schools. The adult staff of these schools now numbers 6,000 adults, mostly part time, and some 35,400 cadet members. Gliding instruction to solo standard is given to Cadets in the course of their membership, and overall supervision of the flying training is vested in the Air Cadet Central Gliding School based near Nottingham.

In 1974, I was asked by the Ministry of Defence to undertake a review of the winching equipment in use to suggest ways in which the cost of operations might be reduced and the serviceability improved. This report is a brief record of the significant results of the work.

THE CASE FOR THE WINCH

The winch is the quickest method of launching a glider to the height of about 1,000' (300 meters). The additional weight of the launching equipment attached permanently to the glider is small, unlike the case of the aerotow where the aeroplane weighs more than the glider but has to be lifted up to release height. As the winch machine stays on the ground, the launch cost is perhaps half that of the aerotow.

The height gained in a winch launch is about one third of the horizontal distance between the glider and the winch at the commencement of the launch. This height is strongly influenced by the competence of the pilot, and some people find it disturbing to be climbing at what appears to be a steep angle.

In training operations the winch provides a speedy and cheap method of getting pilots into the air. With a two drum configuration on a winch a frequency of launch of one every five minutes can be attained. It has been noted that winch operations establish a close relationship between those in the group, whereas this camaraderie is not found to the same extent in aerotow operations. Normally six or seven people are necessary for winching operations, although it can be carried out by three.

The maintenance and operation of the winch are often not carried out to the same standard as the towing aircraft. Winch drivers are not always given enough training in this task, nor are defects in the mechanism of the winch rectified as speedily as the importance of the equipment would require. It is thereforeimportant to build into the design of the winch the robust porportions necessary to achieve reliability over a period of years. The designer is helped in this in that the period of time when the engine is delivering power is about 35 seconds per launch. Engine wear is not significant if operating temperatures are maintained and the engine does not run cold.

WINCH OPERATING COSTS

An analysis of spare parts usage was carried out on the Air Cadet winches from information supplied by the procurement office of the Ministry of Defence. The number of a part used in a year was multiplied by the part cost and the usage value established. These costs were arranged in descending order value and plotted on Graph 1. The classic Pareto distribution was shown where 80% of the cost of the inventory was taken up by 20% of the items. The most significant was launching cable, as shown below:

Launching Cable	65.0%
Lead on Rollers	8.7%
Cable Spreader Gear	4.2%
Weak Link Device	2.7%

These individual parts were then related to the assemblies from which they came and a further distribution was shown:

Launching Cable	54.9%
Cable Serving Unit	22.4%
Guide Roller Assy.	8.54%
Weak Link Assy.	3.8%
Miscellaneous Parts	10.4%
	100.0%

The cost of replacing these assemblies reflected the use they received and the quality of the design. Fuel costs were not recorded in this investigation. Experience in Civilian Clubs suggests that it requires about ½ Imperial gallon of petrol to launch a glider to 1,000'; for diesel engines, the figure is halved.

SERVICE EXPERIENCE OF LAUNCHING CABLE

In British Operations two types of cable are used: solid drawn 10 swg piano wire and 4 mm diameter preformed steel wire cable to British Standard BSS 3530/1968. There is little to choose between them in the cost per launch, and the solid drawn wire breaks more often and is marginally more expensive when the winch is well designed. The Air Cadets have standardised on the following after exhaustive tests:

Designation	7/19
No. of Skeins	7
No. of Wires/Skein	19
Diameter of Wire	0.011" (0.3 mm)
Cable Breaking Load	1.02 tons (1038 kg)
Material	100 ton sq " steel
Weight	4.5 lbs/100 foot

Cable balance is of the utmost importance in a steel cable. If the load is not carried equally between the core strands and the six outer skeins, the core strands can be stretched beyond their yield point. When the load is relaxed, the stretched inner core will push itself out between the outer skeins.

The cable is no longer capable of further service and should be scrapped.

A simple test exists to check the balance of the cable before it is fitted to the winch. A length of six feet or so should be uncoiled from the drum on the upper side. The free end is then looped back to lie beside the cable at the point where it leaves the drum. The loop so formed should hold itself in a vertical position. If it does not do this, there is too much twist in the lay length of the cable and it should be rejected.

A balance cable should be able to carry out more than 2,000 launches before it needs replacement. It should be appreciated that glider launching is one of the most strenuous duties that a cable can perform, and that the actual lift of a cable will depend upon the operating surface.

Cable wear occurs mostly from abrasion with the ground in the course of taking it out from the winch behind the towing vehicle. Grass is much better in this respect than metalled runways, but the soil and grit particles picked up become embedded between the strands of the wire and cause abrasion and stress rises in the wire threads.

The most significant evidence of abrasion is seen when the ends of the wire threads bend up at 90° to the surface of the cable. They extend about 1/16th inch from it. These short ends pick up grass and can carry it into the winch. Their frequency in a length of cable is a good guide to the condition of the cable.

Fatigue is not induced by the act of the launch itself but can be brought about by the action of the cables on the lead on rollers. However, a drag parachute is necessary to prevent the cable coiling up when the tension is released at the end of the launch. It is also there to prevent a wave pattern forming in the cable on drawing in to the drum and thus causing the cable to loop over itself.

LEAD ON PULLEYS

Investigation of used cable under the microscope shows the shiny surface of the steel crystals indicating the formation of Martensite. This comes about through work hardening of the steel when in contact with the hardened steel rollers.

In the "Box" design, wear occurs on the surface of the rollers by the action of the cable. The cable is free to move across the surface of the rollers and from roller to roller. The fast moving wire can only accelerate the smooth and stationary roller by friction and heat is generated by the sliding motion. The surface of the roller is thereby softened and in due course creep occurs in the steel and ridges and furrows are formed on the roller surface.

The diameter of a steel roller will cause the cable to follow a tight radius and thus induce high bending stresses in the wires of the cable. It is this high though momentary additional loading that brings about the fatigue in the cable.

Wire cable has been used in the Mining Industry for many years and it is helpful to examine their recommendations on pulley size contained in the British Standard Specification 329/1957.

The formulae for the maximum bending stress in a wire wound rope is:

$$\text{Stress} = \frac{Ed}{D} \times K$$

where $E = 30 \times 10^6$ (Youngs Modulus)
d = diameter of the wire
D = diameter of the rope
$K = 0.44$

and the diameter of the pulley in inches is established from the relation:

$$D = d(0.015S + 37)$$

where S = cable speed in feet per min.

Graph No. 7 shows this relation.

RECOMMENDED PULLEY DESIGN

To overcome the twin difficulties of induced stress by pulleys and overheating through friction, a revised form of swing pulley has been designed in line with Graph No. 7. Cable speed on a launch is not constant, for it rises quickly to its maximum value at the start of the launch and then declines as the glider climbs. The variation of cable speed over the launch period is shown in Graph 3.

Pulley inertia and cost are also

inputs into the design decision and larger diameters that thus require lower rotational speed were favored. A diameter of 16.5" was chosen for the pulley. The wire groove was drawn to suit 4 mm diameter wire rope precisely.

To overcome the friction caused by the wire rope moving from one pulley to another, the main pulley was mounted on side plates that rotated about the axis of the wire as it left the guide pulley for the cable drum. No matter what direction the cable approached the winch, the cable was always directed to the drum along the same path, and thus remained in contact with the pulley at all times. Wear is therefore minimal.

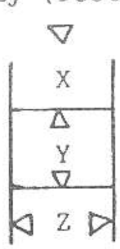
This design criteria has been used widely in the past, but the small sized pulley often used suggests that the effect upon the wire rope of such a small pulley has not been appreciated. The swivel mount is sufficiently large to allow weak lines and chock absorber ropes to pass onto the drum should the winch operator fail to brake in time.

CABLE DRUM DESIGN

Cable drum capacity in feet is calculated from the following formulae. It is usual to design to carry between 3,000 to 4,500' (1000-1500 meters)

where X = depth of flange in inches
Y = diameter of barrell " "
Z = width of reel between flanges in inches
D = Rope diameter in inches
$C = \frac{\pi}{12D^2}$ Constant

Capacity (feet) = (X+Y)XZC



To fix the drum size, two other decisions have to be made:

1. The distance of the lead on pulley to the point of contact of the wire with the cable drum.
2. The maximum speed of the wire in the course of the launch. This decides the drum diameter when the overall drive ratio of the engine is known.

Self-laying cable is achieved on the drum when the included angle subtended by the width of the drum from the point where the cable leaves the lead on pulley is not more than 4^{o}. In these circumstances serving gear is not necessary and should be avoided. The cable will wind itself evenly on the drum and can be unwound without snags. Experience over many years has shown that drum widths of 4" are satisfactory, if made from ¼" mild steel plate (6 mm). Lesser guage material tends to buckle in use.

Drum diameter depends on the engine and transmission used. The Air Cadet winch used a 330 cubic inch petrol engine driving through a dry plate clutch, and a final drive ratio of 2.5:1 to a drum barrel of 14.625" diameter. The power output of the engine is 105 BHP at 2600 r.p.m.

Current practice in civilian gliding clubs is now to use diesel engines of up to 200 h.p. driving a 4" wide drum of 3.5 feet barrel diameter through a fluid coupling. Such an arrangement is commonly found fitted to a redundant bus chassis.

However, there is the danger that too much horsepower in the cable will induce cable breaks and overspeed the sailplane in the launch. A diesel engine of 150 hp is therefore thought to be the most suitable for it allows a good launch to be given and the increased transmission losses to be absorbed without loss of performance. There are several engines of this power output currently available.

The hydraulic coupling will give smooth acceleration at the start of the launch from rest, but to overcome the slippage on load it is recommended that a power lock be fitted. Such an arrangement will give a 1.1 drive ratio under power.

It is then a matter of arithmetic to get the right amount of torque to the cable drum to produce the necessary wire tension and cable speed of 5,500 fpm (55 kts). The engine manufacturer is usually willing to supply engine performance curves.

In gusting winds, the loads induced in a sailplane in the course of the launch, and also the cable, can be severe. It is therefore mandatory for a weak link to be fitted to the cable to break at loads between 1,000 lbs and 1,100 lbs (500 - 550 kg). It follows that the winch should not be capable of imposing a tension in the cable of a greater amount in still air conditions. With an engine of 150 hp and correctly chosen ratios, a single speed drive is sufficient.

SAFETY PRECAUTIONS - WEAK LINKS

The Air Cadets use the Three Hole Plate as their weak link device. Made from 16 swg plate it provides a consistent breaking load on the tensile testing machine. It is familiar, reliable, but is expensive to use.

The failing load falls in service as creep takes place in the metal loaded frequently too close by the yield point of the material. Tests carried out by the Air Cadets themselves on a series of weak links where the breaking load was found after a known number of launches had taken place, indicated that breaking load diminished in the following relation:

$$Y = 1000 - x^{-0.0313}$$

where Y is the breaking load
x is the number of load applications (launches).

Refer to Graph 8.

Certain other designs of weak links have been tried where steel is placed in shear to give a precise shear value. One of the best tested was a swinging latch design that placed the 7/32" diameter steel wire in double shear. It too showed a slight reduction in breaking load over some 2,000 launches. The three hold plate appears to have a mean average service life of 82 launches.

CABLE GUILLOTINES

Cable guillotines are a mandatory requirement to enable the cables to be cut in an emergency. The Air Cadets have a hardened steel blade which falls onto a steel anvil to sever the cable. This guillotine works under the action of balance weights and springs. It is released from the winch driver's position.

The steel of the guillotine blade has a demanding duty, for the cable is made from wire of 100 tons breaking stress (1544 MN/m^2). Blade material is easily blunted or chipped. Steel to specification En 28 has been found to be most suitable for this purpose. It has the composition:

Carbon	0.45%	Chromium	1.0%
Silicon	1.0%	Molybdenum	0.4%
Nickel	3.0%	Vanadium	0.6%

Harden to 48 on the Rockwell C scale.

Steel to the En40B specification hardened by the Nitrided process may also be used where one shot emergency use is expected. The nitrided surface will not corrode and will therefore remain in condition for a long period. After one or two impacts the cutting edge may begin to flake away from the body of the blade. The 40B material can not be ground for further use unlike the En 28 material.

DRUM BRAKES

Internally expanding brakes have not been found to be entirely satisfactory for they require frequent adjustment. Caliper disk brakes are now preferred.

CONCLUSIONS

This paper records the present state of development of the glider launching winch. By careful design, such a machine can be reliable and an effective method of launching sailplanes. The winch is of particular value in flying training organizations where the need is for quick rate of repetition launches.

No attempt has been made here to define the cost of a winch launch for that will depend on local circumstances, the initial cost of the winch, and the quality of the design. A well designed winch should last for well over 100,000 launches. A recently constructed winch in the U.K. cost 13,000 Pounds.

The design of the Cab has not been discussed for it is here that the designer is free to express himself. It should be remembered that the cab should have good visibility, be quiet, comfortable and with the controls falling easily to the hand of the winch driver. Safety controls must be conspicuous and easy to actuate.

A well designed winch can be the focal point of a gliding operation for it brings the members together in common endeavour and encourages a sense of comradeship that aerotowing can not do. It is false economy to put up with poor winch performance or lack of reliability when with a little thought good performance and reliability can easily be achieved.

I should like to thank the Ministry of Defence for their permission to publish this paper, and those manufacturers who have given freely of their advice and experience in the course of this work.

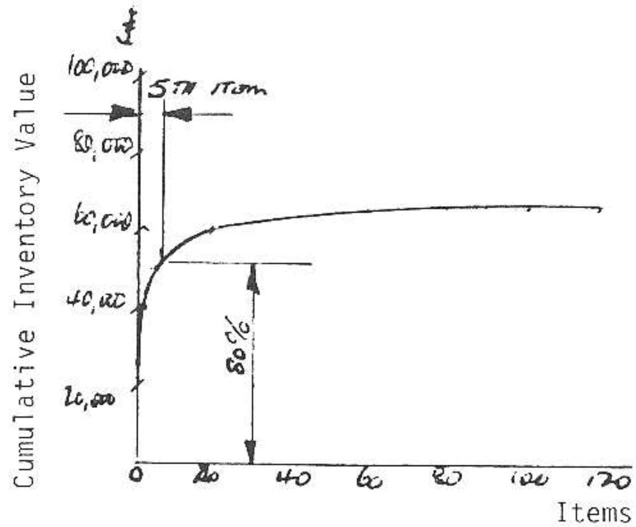


Fig. 1. Inventory Usage Value

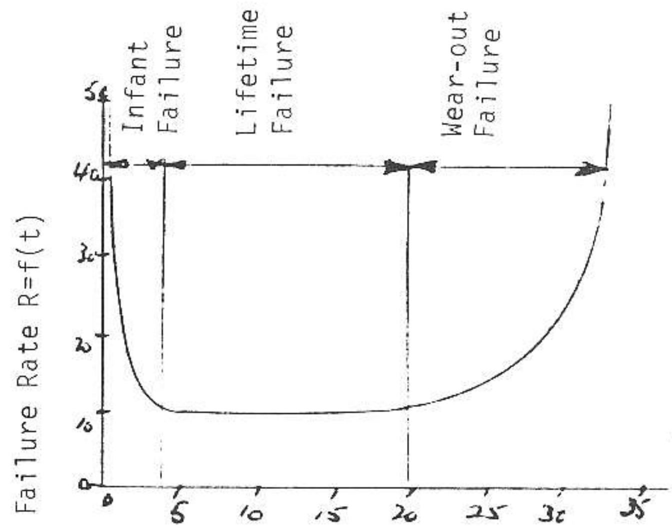


Fig. 2. Time-Years

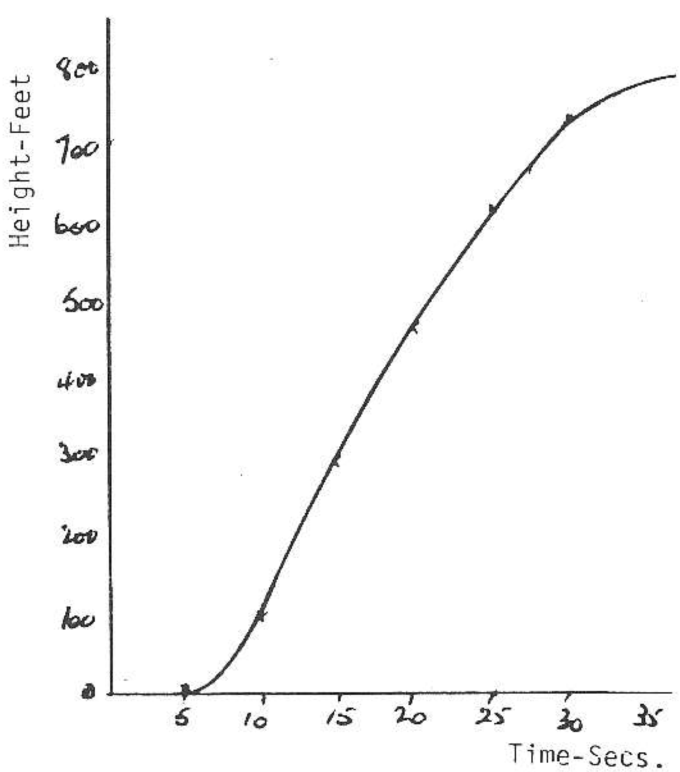


Fig. 3. Height/Time For Winch Launch

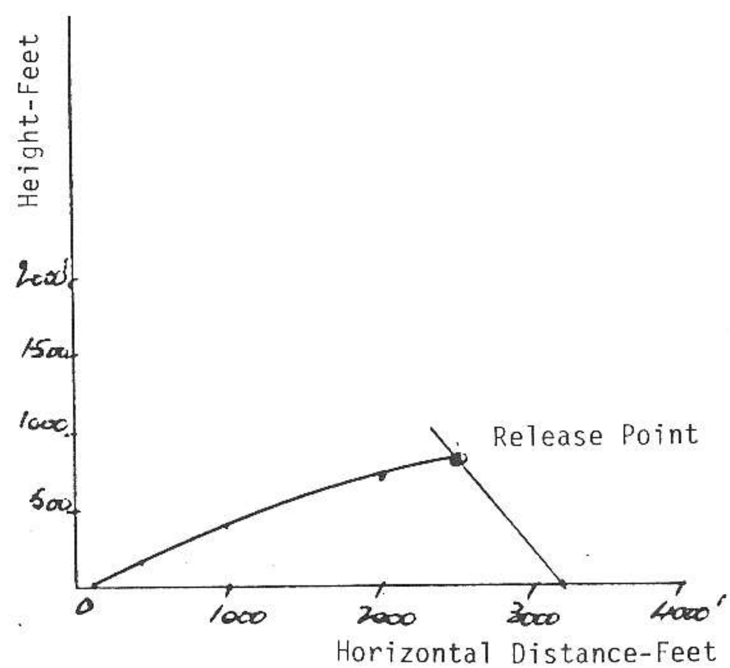


Fig. 4. Vertical & Horizontal Height Relation

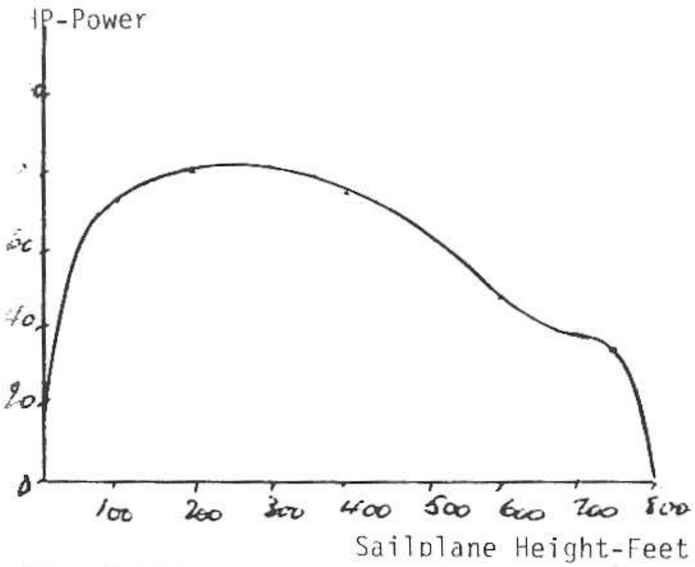


Fig. 5. BHP & Height
Sailplane AOW AOW = 526 lbs;
826 lbs

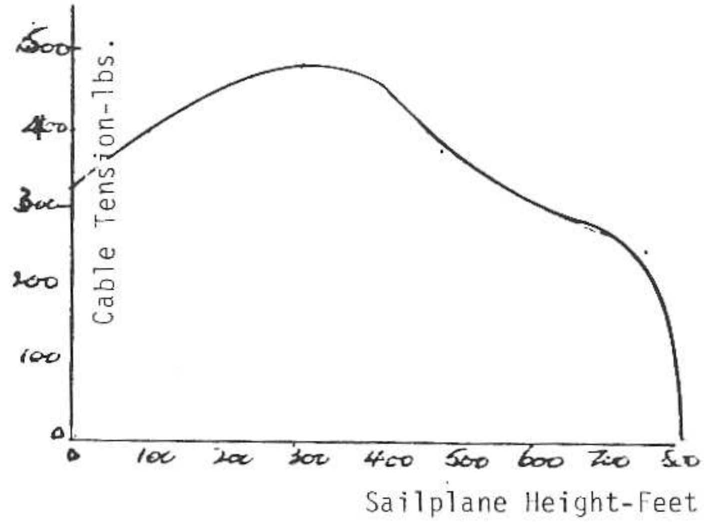


Fig. 6. Cable Tension & Height

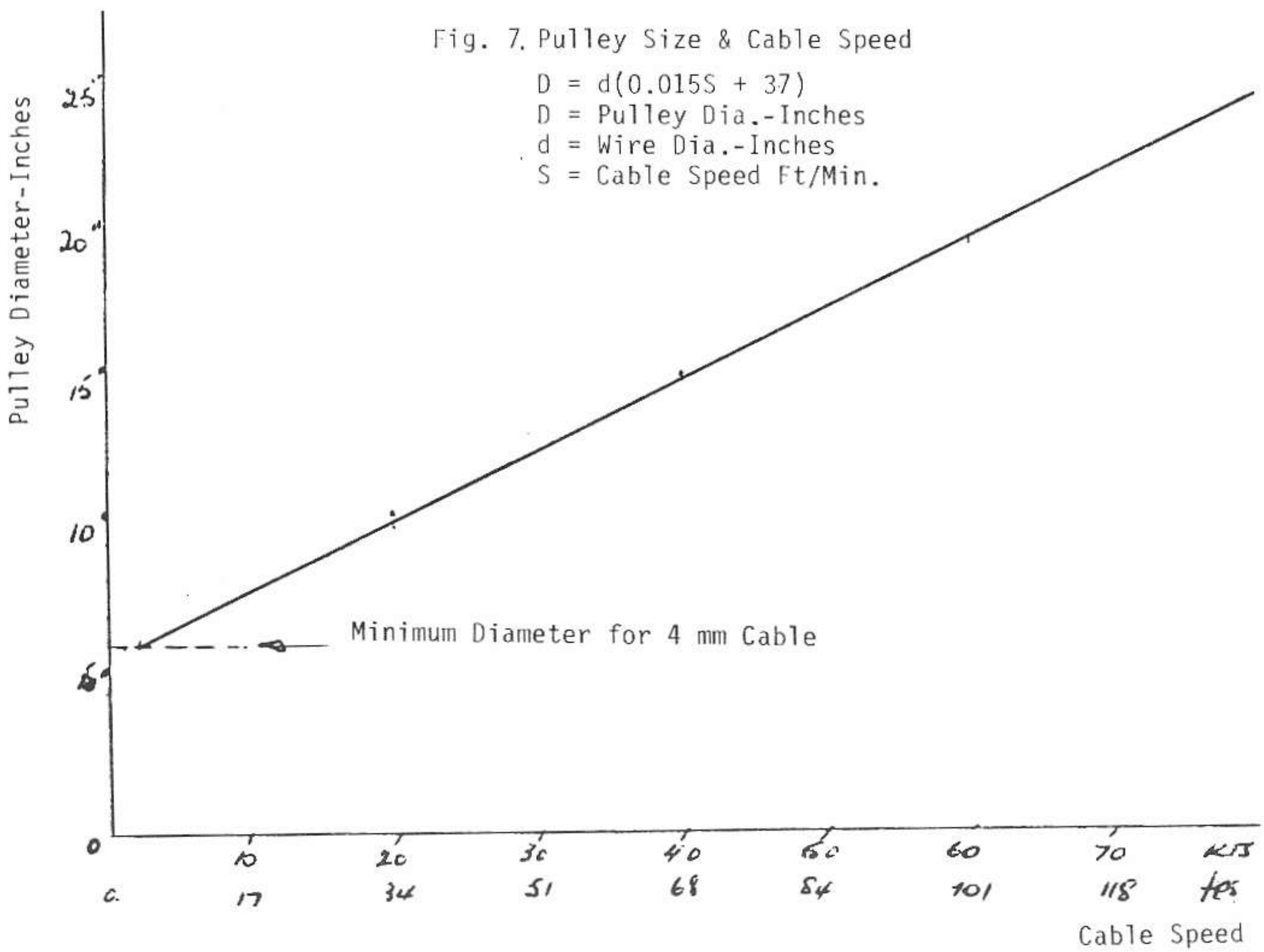


Fig. 7. Pulley Size & Cable Speed

$D = d(0.015S + 37)$
D = Pulley Dia.-Inches
d = Wire Dia.-Inches
S = Cable Speed Ft/Min.

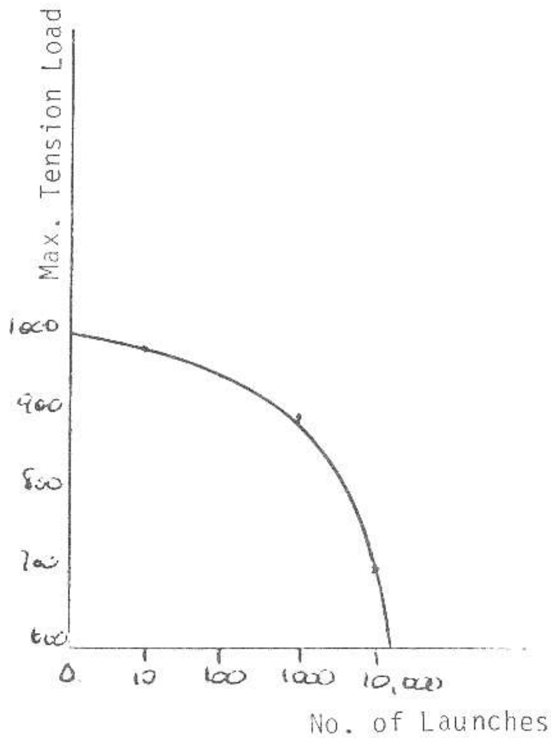


Fig. 8. 3-Hole Plate. Variation of Break Hold With Usage.

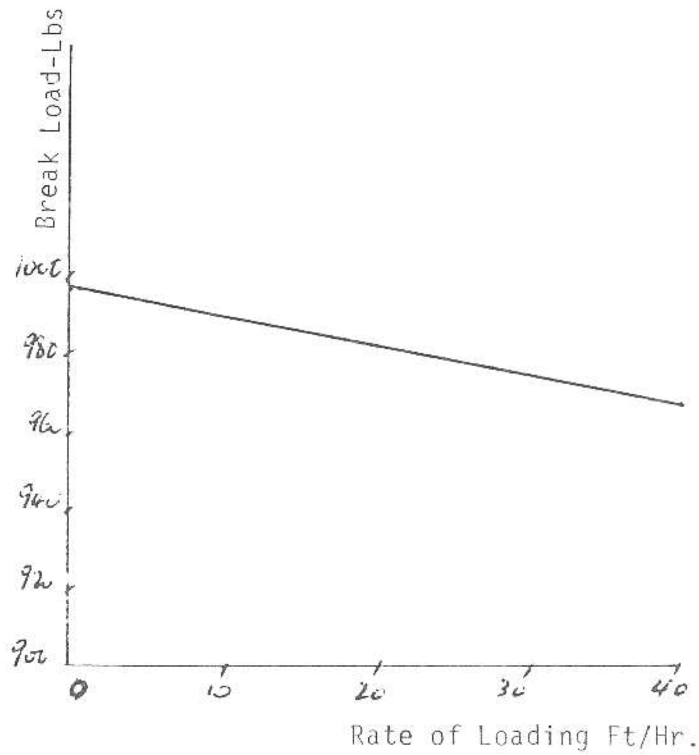


Fig. 9. Break Load. Variation with Rate of Loading. 3-Hole Plate Weak Link.