Cable loads in aero-tow

By Dr. Ing. Edgardo Ciani

Presented at the 10th OSTIV Congress, South Cerney, England, June 1965

1) The use of tow-planes is very common, as it offers the advantage of greater radius and greater height, permitting an easy contact with thermals also in a flat country.

The maximum loads on the cable are not easy to calculate or to measure, and for this reason it is generally assumed that the maximum load can reach the breaking strength of the cable (or of a predetermined breaking point). So it can be interesting to analyse the possible cable loads.

2) It has to be observed that there are already few accidents in aero-tow, even less than the low number of accidents to sailplanes. Also the deficiencies due to the age of the hooks and the structural parts, are negligible. All this signifies that generally, the structures supporting the cable loads are sufficient, although their calculation is made on other hypotheses.

Occasional cable breaks do not signify that the breaking strength of a new cable is sometimes attained (say 1500 or 3000 kg); in all cases, breaking occurs on worn cables. Measurements on a worn cable (Nylon, diameter 14 mm, breaking strength 1600/1900 kg) showed a breaking load of 100/150 kg — and the cable was still in service!

Of course for attaining a normal service life, it is necessary to select cables with an initial breaking strength far higher than the bare minimum. But for calculation of structures (hooks and cables being dimensioned by experience so far), we must know the cable load. Sometimes the problem is solved by assuming that the cable will attain the breaking strength of a new one, i. e. a very high strength. We also suppose the use of predetermined breaking points; this adds another uncertain element and can cause a shorter service life.

It will certainly be better to know, although with a limited exactness, these loads. This paper is an attempt to calculate them.

3) Flight measurements will be the best solution, but it was not possible for the writer to find data. Ground measurements were made (AVM, Bresso, 1954) measuring, with a deformation device, the load in the cable due to sudden nearly-stopping an L-5 tow-plane (900 kg, 165 HP) after 50 m run at full throttle. For this purpose, the cable was hooked to a Canguro sailplane (500 kg) and laid on the ground as to be in tension after a 50 m run of the tow-plane. The test pilot reported "a shock never experienced in flight". Loads of 100/150 kg were found.

4) Symbols.

aa = Sailplane acceleration
at = Tow-plane acceleration
Ar = Percentage stretch at the breaking load of the cable
dV = Speed difference between tow-plane and sailplane
dVi = Same as above, at the beginning of cable stretching
Dlc = Elastic variation of cable length
DT = Variation of cable load
DV = Variation of speed
E = Sailplane glide ratio
g = Gravity acceleration
l = Length of cable
k = Elastic coefficient of cable
Ma = Weight of sailplane divided by g
Mt = Weight of tow-plane divided by g
Qa = Weight of sailplane
Qt = Weight of tow-plane
t = Time
T = Load on the cable
Tn = Normal load = Qa/E
Tr = Breaking load of the cable
Va = Speed of sailplane
Vt = Speed of tow-plane
Vas = Stalling speed of sailplane
z = Height

5) Scheme of the phenomenon.
For the analysis the phenomenon was simplified as follows:

a) Normal aero-tow:
Horizontal flight; cable load is Tn, both aircraft at the same V and z.

b) Cable slackening:
The sailplane is nearer to the tow-plane; the distance between the aircraft is diminished by S m. The cable is slackened. Both aircraft at same V and z.

c) Return to "a":
The tow-plane maintains horizontal flight, V and z. As cable load is zero, the sailplane diminishes its V and maintains z, thus increasing its distance from the tow-plane. At the end of this phase both aircraft have the same z, but the tow-plane maintains its V, while the sailplane has a lower V. Cable is just in tension.

d) Stretching:
As Va is lower than Vt, the cable must stretch; this increases the cable tension: acceleration of the sailplane and a deceleration of the tow-plane begins. After some time both will have the same speed, and at this moment the cable tension will be maximum.

e) Damping:
At this moment we suppose that the pilot of the sailplane will damp the phenomenon.

6) Analysis of 5 b.
If the sailplane is S m too near to the tow-plane, the time for returning to its normal position is (neglecting the acceleration of the tow-plane):

$$t = \sqrt{\frac{S}{aa}}$$

and as the drag creating the acceleration is equal to Tn:

$$aa = \frac{Tn}{Ma}$$

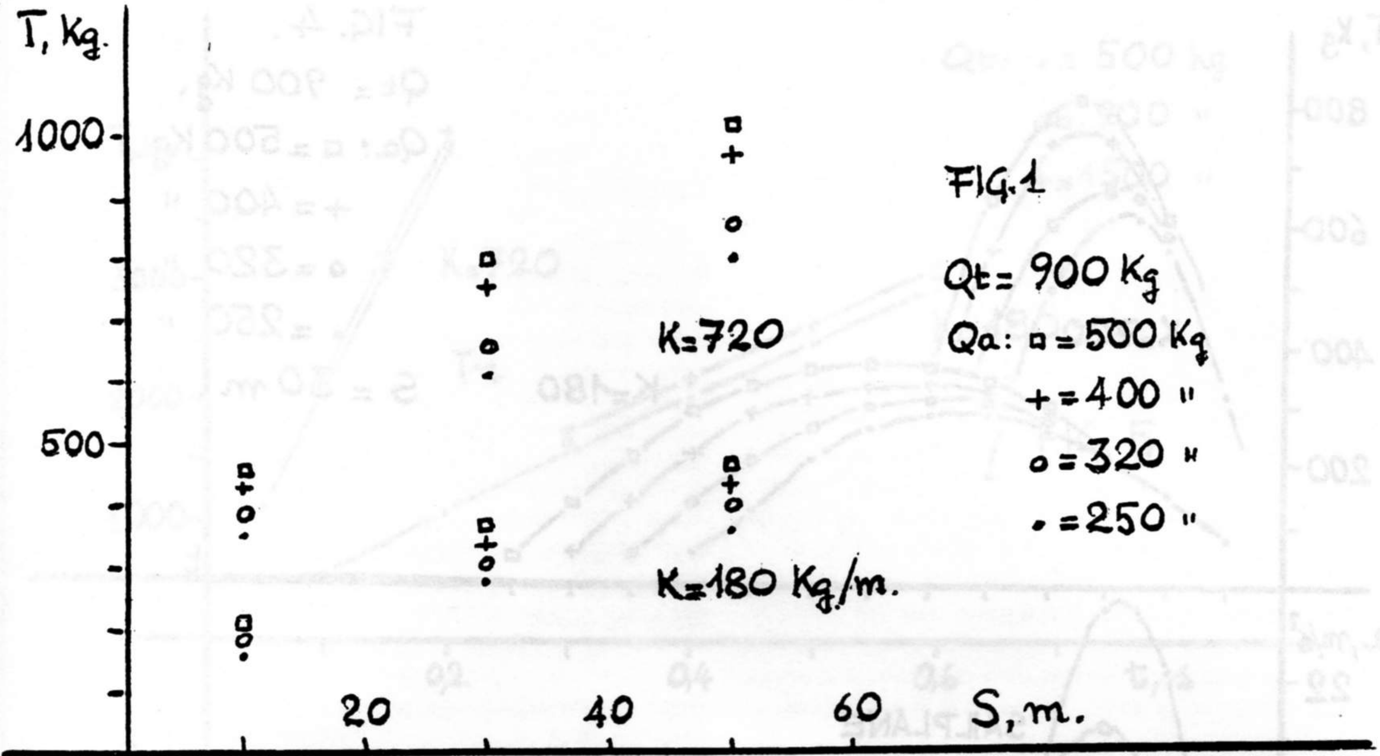


FIG.1

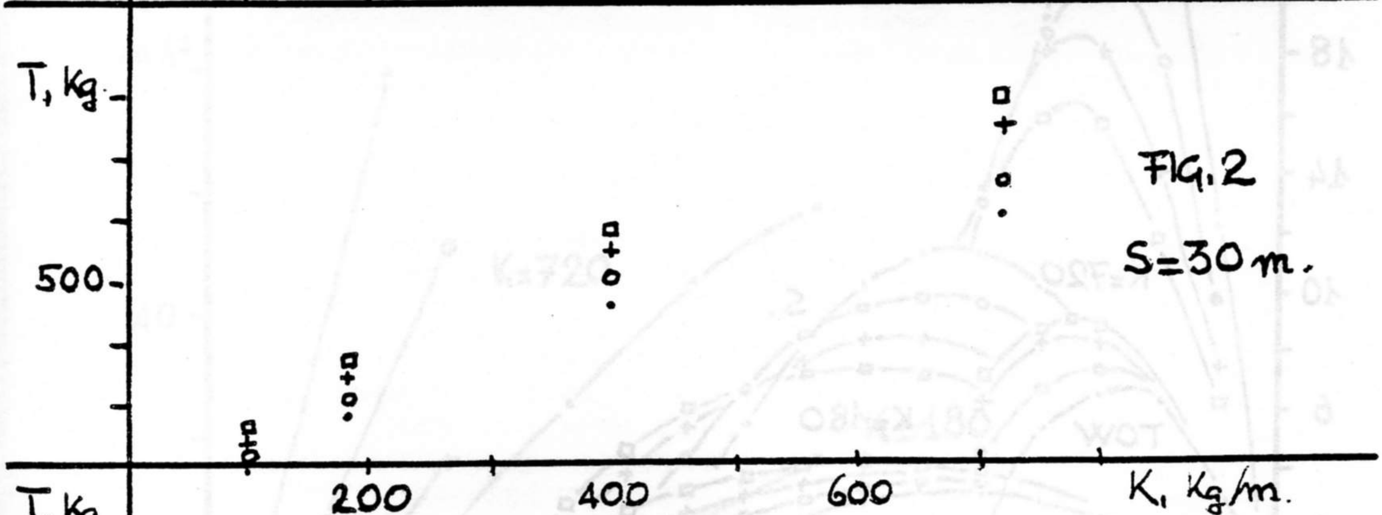


FIG.2

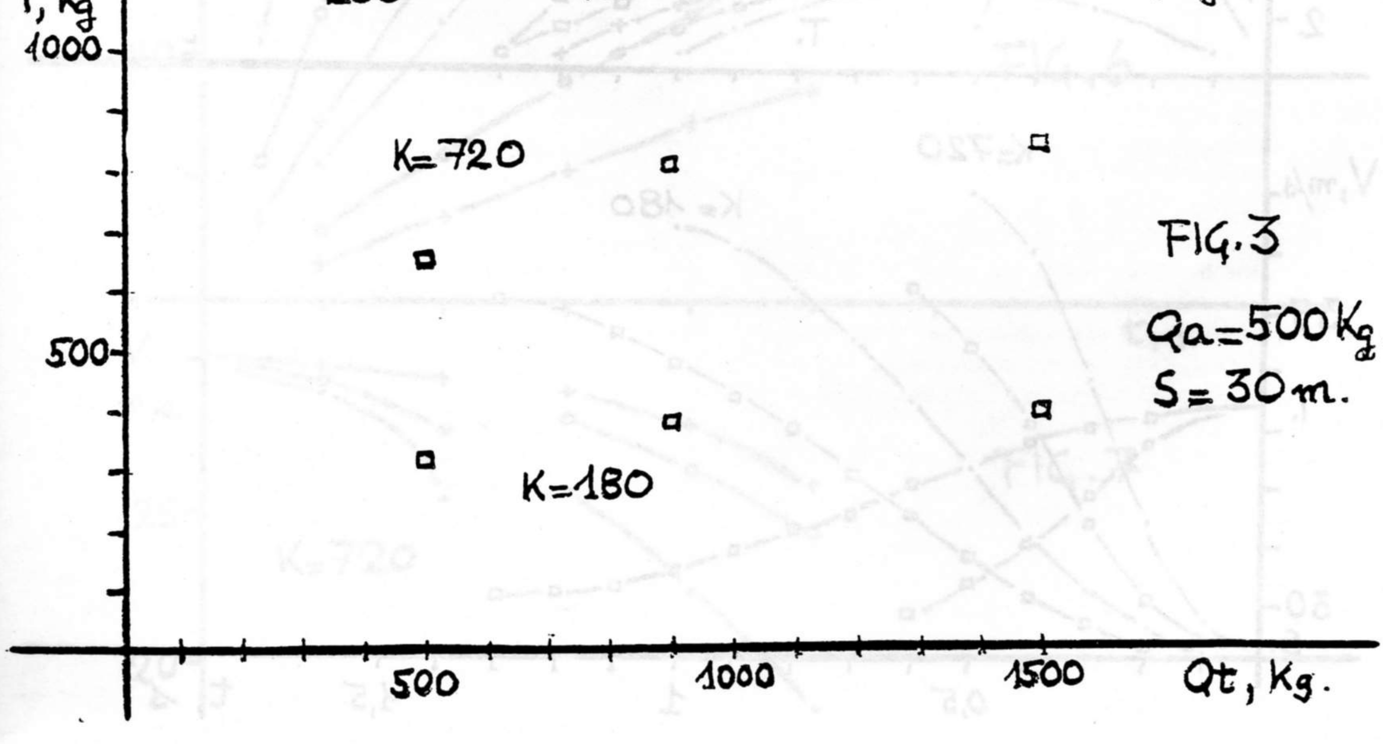
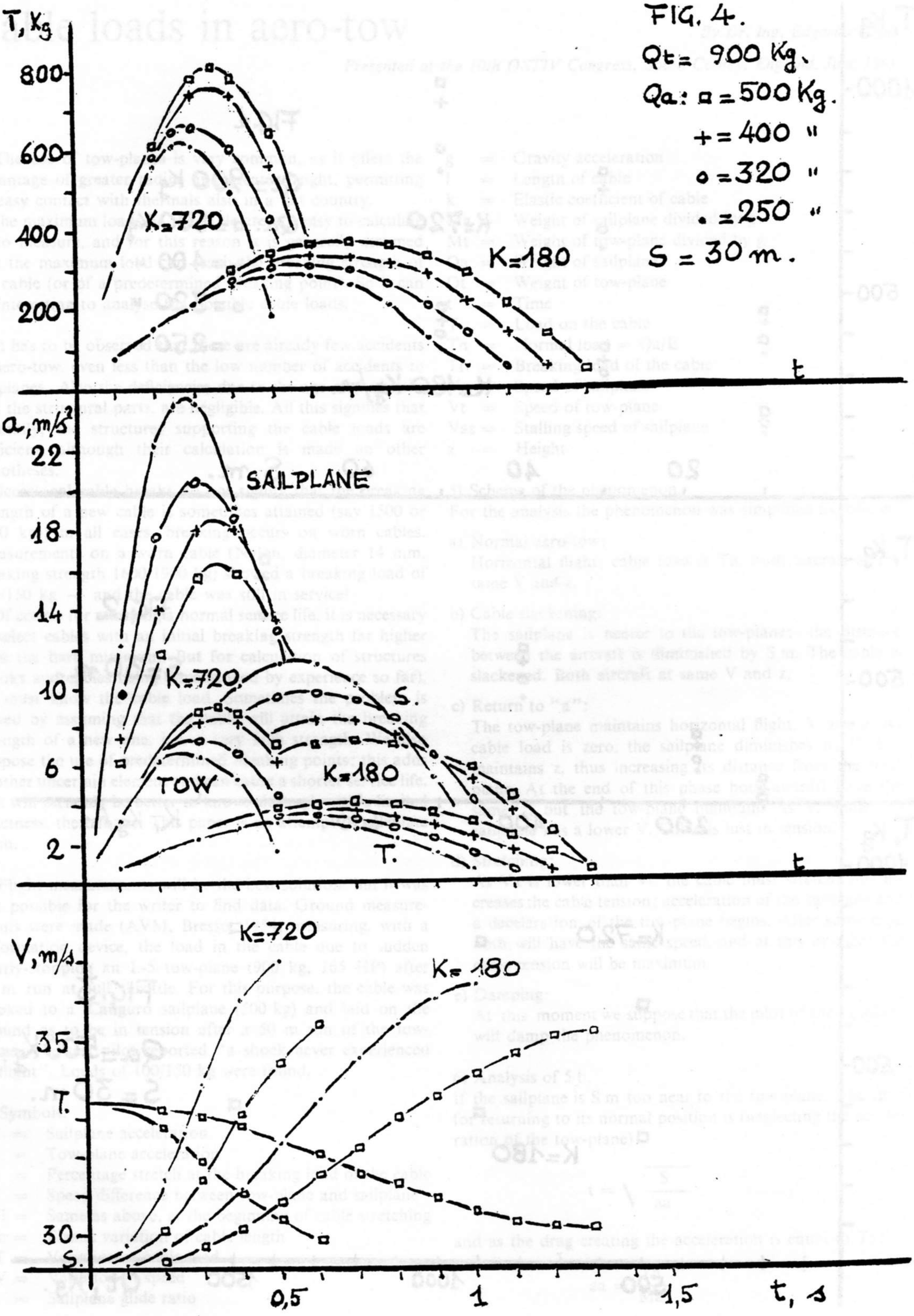


FIG.3

FIG. 4.



Qt = 900 Kg.
Qa: □ = 500 Kg.
+ = 400 "
o = 320 "
• = 250 "
S = 30 m.
T, Kg
800
600
400
200
K=720
K=180
t
a, m/s²
22
18
14
10
6
2
SAILPLANE
K=720
S
K=180
TOW
T.
t
V, m/s
K=720
K= 180
35
30
T.
S.
0,5
1
1,5
t, s

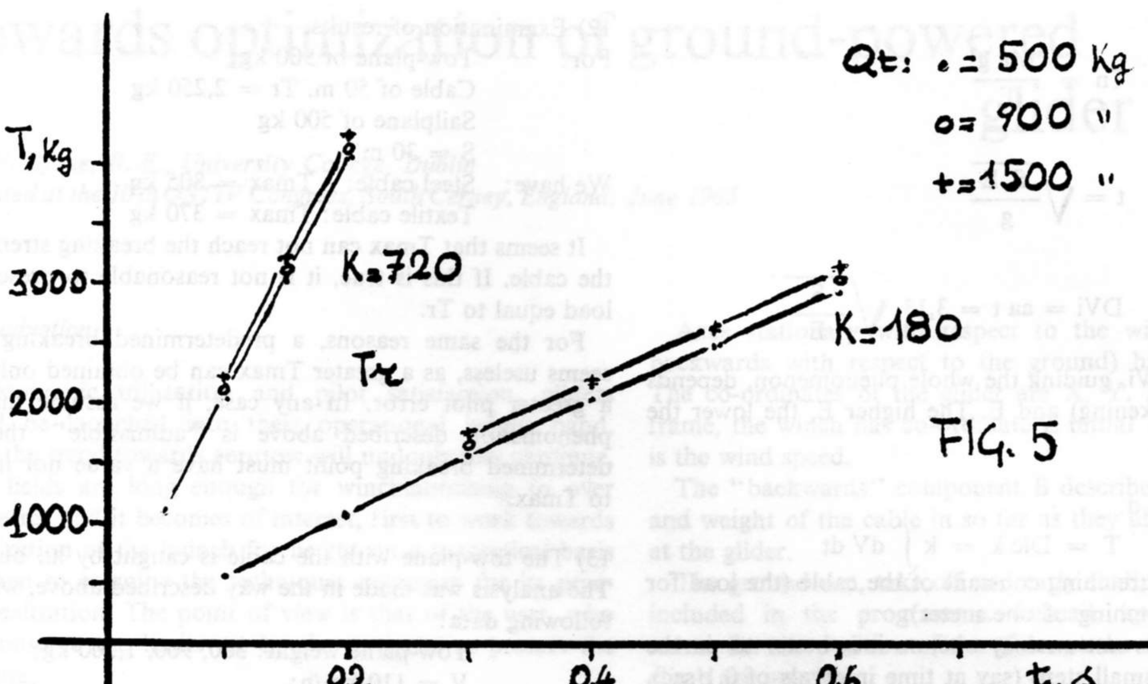


FIG. 5

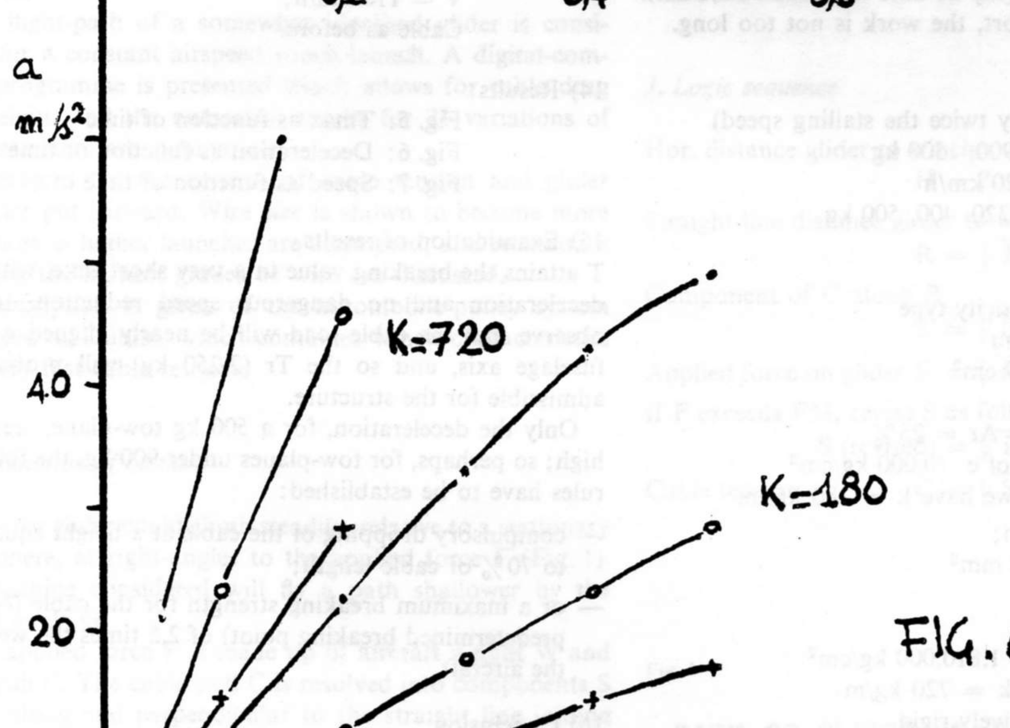


FIG. 6

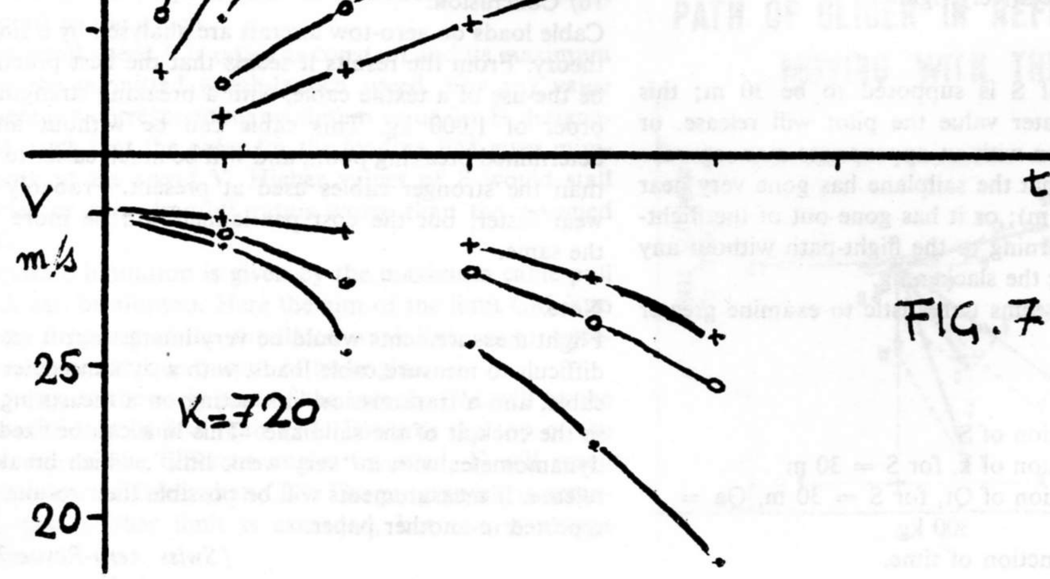


FIG. 7

where

$$Tn = \frac{Ma\, g}{E}$$

we obtain

$$t = \sqrt{\frac{S\, E}{g}}$$

and

$$DVi = aa\, t = 3{,}13 \sqrt{\frac{S}{E}}$$

Observe that DVi, guiding the whole phenomenon, depends only on S (slackening) and E. The higher E, the lower the maximum load.

7) Analysis of 5 d.

$$T = Dlc\, k = k \int dV\, dt$$

where k is the stretching constant of the cable (the load for obtaining a stretching of one meter).

The integral is not an easy one, so it is better to do the calculations in small steps (say at time intervals of 0,1 sec). The phenomenon being short, the work is not too long.

8) Data.
V (5a): 120 km/h (nearly twice the stalling speed)
Tow-plane weight: 500, 900, 1500 kg
Sailplane: E = 16 at 120 km/h
Weight: 250, 320, 400, 500 kg

9) Tow cables.
a) Textile: Perlon, low elasticity type
Diameter 12 mm
Virtual area 0,9 cm^2
Tr 2250 kg
Stretch at Tr = Ar = 25%
Virtual module of e 10,000 kg/cm^2
With a length of 50 m, we have k = 180 kg/m.
b) Steel: Diameter 5 mm;
Virtual area 20 mm^2
Tr 2,250 kg
Ar 6,25%
Virtual module 1,810,000 kg/cm^2
With a length of 50 m, k = 720 kg/m
Note. Both cables are relatively rigid.

10) Values of S.
The maximum value of S is supposed to be 30 m; this signifies that for a greater value the pilot will release, or bring the cable in tension with an appropriate manoeuvre.

S = 30 m signifies that the sailplane has gone very near to the tow-plane (at 20 m); or it has gone out of the flight-path by nearly 75°, returning to the flight-path without any manoeuvre for reducing the slackening.

For these reasons it seems unrealistic to examine greater values.

11) Results.
Fig. 1: Tmax as a function of S
Fig. 2: Tmax as a function of k, for S = 30 m
Fig. 3: Tmax as a function of Qt, for S = 30 m, Qa = 500 kg
Fig. 4: T, a, V, as a function of time.

12) Examination of results.
For: Tow-plane of 900 kg
Cable of 50 m, Tr = 2,250 kg
Sailplane of 500 kg
S = 30 m
We have: Steel cable: Tmax = 805 kg
Textile cable: Tmax = 370 kg

It seems that Tmax can not reach the breaking strength of the cable. If this is true, it is not reasonable to prescribe a load equal to Tr.

For the same reasons, a predetermined breaking point seems useless, as a greater Tmax can be obtained only with a greater pilot error. In any case, if we assume that the phenomenon described above is "admissible", the predetermined breaking point must have a value not inferior to Tmax.

13) The tow-plane with the cable is caught by an obstacle. The analysis was made in the way described above, with the following data:
Tow-plane weight: 500, 900, 1,500 kg;
V = 110 km/h;
Cable as before.

14) Results:
Fig. 5: Tmax as function of time
Fig. 6: Deceleration as function of time
Fig. 7: Speed as function of time

15) Examination of results.
T attains the breaking value in a very short time, with great deceleration and no dangerous speed reduction. It is to observe that the cable load will be nearly aligned with the fuselage axis, and so the Tr (2,250 kg) will probably be admissible for the structure.

Only the deceleration, for a 500 kg tow-plane, seems too high; so perhaps, for tow-planes under 900 kg, the following rules have to be established:

- compulsory dropping of the cable at a height equal (say) to 70% of cable length;
- or a maximum breaking strength for the cable (or for a predetermined breaking point) of 2,5 times the weight of the aircraft.

16) Conclusion.
Cable loads on aero-tow aircraft are analysed by a simplified theory. From the results it seems that the best practice will be the use of a textile cable, with a breaking strength of the order of 1,000 kg. This cable can be without any predetermined breaking point, and will be much easier to handle than the stronger cables used at present. Probably it will wear faster, but the cost per launch will be more or less the same.

Note.
Flight measurements would be very interesting; it seems not difficult to measure cable loads, with a dynamometer on the cable, and a transmission link acting on a measuring device in the cockpit of the sailplane. This link can be fixed to the dynamometer with a "very weak link", which breaks after release. If measurements will be possible their results will be reported in another paper.

(Swiss Aero-Revue 7/1966)