The Estimation of Tow Times for Aerotow Launching of Gliders

I.A. Cohn, Department of Transport, Melbourne, Australia

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Schleppzeiten

Es wird eine Methode abgeleitet zur Berechnung der Schleppzeiten eines Schleppflugzeuges mit Segelflugzeug wobei die Schleppzeit definiert wird als die Gesamtzeit für den Start, die Beschleunigung bis zur Steiggeschwindigkeit, Steigen bis zur Ausklinkhöhe, Absteigen und Landen. Die meisten Parameter können von Flugversuchsdaten bestimmt werden und der Rest kann mit genügender Genauigkeit geschätzt werden.

Die Methode wird angewandt auf Pawnee, Callair und Super Cub, die die Segelflugzeuge Libelle und Blanik schleppen. Die Schleppzeiten werden in den Tabellen 1, 2 und 3 sowie in Figur 1, 2, 3, und 7 dargestellt, Steiggeschwindigkeiten und Startstrecken werden in Tabelle 4, 5 und 6 gezeichnet. Die Pawnee gibt bessere Zeiten als die Callair, die beide die gleiche Motorentype haben. Das rührt daher, dass die Pawnee leichter ist und geringeren Widerstand hat. Die Super-Cub-Zeiten sind etwas länger, aber es scheint, dass die Startkosten niedriger werden wegen der beträchtlich niedrigeren Motorenleistung.

Durée du remorquage

Une méthode de calcul de la durée du remorquage est établie, la durée du remorquage étant définie comme la somme des temps nécessaires au décollage, à l'accélération pour atteindre la vitesse de montée, à la montée proprement dite, à la descente et à l'atterrissage de l'avion remorqueur. La plupart des paramètres peuvent être déterminés à partir de mesures en vol, les autres pouvant être appréciés avec suffisamment de précision.

La méthode est appliquée au Pawnee, au Callair et au Super Cub remorquant des Libelle et des Blanik. Les temps de remorquage sont présentés dans les tableaux 1, 2 et 3 et sur les figures 1, 2, 3 et 7. Les taux de montée et les distances de décollage sont donnés dans les tableaux 4, 5 et 6 et les taux de montée sont tracés sur les figures. Le Pawnee est plus rapide que le Callair qui possède le même moteur parce qu'il est plus léger et plus fin. Les temps du Super Cub sont un peu plus longs mais il est intéressant de remarquer que le prix de revient du remorquage doit être plus bas compte tenu du fait que cet avion a un moteur beaucoup moins puissant.

Introduction

Aerotowing is a glider launching method extensively used throughout the world. An important operational feature of light aeroplanes used for glider towing is the capability to tow the glider to an adequate launch height within a reasonable time, since, firstly, the operating cost of an aeroplane is usually almost directly proportional to the flight time, and, secondly, the tow time determines the launch rate available. It is the purpose of this note to give a method for estimating the glider towing times for light aeroplanes, and in particular to give the estimated towing times for three light aeroplanes commonly used for glider launching in Australia, namely the Piper PA-25-235 Pawnee, the IMCO Callair A9, and Piper PA-18-150 Super Cub aircraft.

List of symbols

B – constant in linearised climb rate equation.
B_f – biplane interference factor.
b_T – towing aircraft wing span.
b_G – glider wing span.
$\overline{D}_G$ – mean glider drag.
D – drag.
e_G – glider span efficiency factor.
h – standard altitude.
K_1 – $\frac{1}{\pi l_G \lambda}$
l – tow rope length.
S – take-off distance
S_{Tg} – towing aircraft take-off ground roll distance.
s – wing area.
t – time.
V_C – climb speed CAS.
V_G – glider lift-off speed TAS
V_T – towing aircraft lift-off speed TAS
$V\eta$ – glider best L/D speed TAS.
ν_{CO} – climb rate sea level ISA.
ν_C – combination climb rate.
ν_{CT} – towing aircraft climb rate.
W_T – towing aircraft weight.
W_G – glider weight
χ – altitude index for take-off distance.
η – glider best L/D ratio.
η^* – glider L/D at speed V_C.
λ – aspect ratio.
ρ – atmospheric density.
σ – relative density.
Φ – tow rope incidence.

The calculation of Tow Times

For the towing aeroplane, the glider towing cycle consists of a take-off ground run and subsequent acceleration to climbing speed, a climb from airfield height to relase height, followed by a descent and landing.

(a) Take-off

The time required to complete the take-off ground run and acceleration to climb speed, t_{tO}, can be estimated, assuming a constant acceleration, to be

$$t_{tO} = \frac{2\,S\,\nu\sigma}{V_C} \tag{1}$$

where S is the take-off distance including the ground run and the acceleration to climb speed.
V_C is the climb speed (CAS)
σ is the relative density.

The take-off ground run distance plus the distance for acceleration to the climb speed at ground level, will approximate the normally quoted take-off distance to 50 ft. Any errors introduced by these approximations are not significant in relation to the total tow time as the take-off time is a small proportion of the total tow time for normal release heights.

(b) Time to climb to Release Height

The climb rate of the glider and towing aeroplane combination, $\frac{dh}{dt}$, can be expressed as

$$\frac{dh}{dt} = V_{CO} - B \cdot h \tag{2}$$

where V_{CO} is the climb rate at sea level density height.
h is the density height.
B is a constant.

The time to climb to release height, t_c, can be calculated by integrating between the height limits of the airfield height, h_O, and the release height $h_O + \Delta h$, where Δh is the tow height above the airfield.

.e.
$$t_C = \int_{h_O}^{h_O+\Delta h} \frac{dh}{\nu_{CO} - B \cdot h} \tag{3}$$

or
$$t_C = \frac{1}{B} \ln \left[\frac{\nu_{CO} - B \cdot h_O}{\nu_{CO} - B\,(h_O + \Delta h)} \right]$$

(c) Time to Descent and Land

The descent technique may vary widely from pilot to pilot and from tow to tow. For the purposes of this study it is assumed that the average rate of descent is 1000 ft. per minute to 500 ft. above the airfield and that the approach from 500 ft. together with the landing takes one minute. The time for descent and landing, t_{dl}, then becomes.

$$t_{dl} = \left(\frac{\Delta h - 500}{1000} \right) + 1.0 \text{ minute} \tag{4}$$

The total estimated tow time, t, can thus be expressed as (5)

$$t = \frac{2S\sqrt{\sigma}}{V_C} + \frac{I}{B}\ln\left[\frac{\nu_{CO}-B\cdot h_O}{\nu_{CO}-B(h_O+\Delta h)}\right] + \left[\frac{\Delta h-500}{1000}\right] + 1.0 \text{ minutes}$$

The Calculation of Take-off Distance and Climb

Performance data for combinations of towing aeroplanes and gliders are not normally available. However, it is possible to calculate this performance from separate data for the towing aeroplane and the glider. One method for doing this is given by J. C. Fincher (Reference 1) and will be used here. Mr. Fincher derives the following relations:

The combination climb rate, ν_C, is given by

$$\nu_C = \frac{V_C}{(W_T+W_G)}\left[C_1-C_2-C_3-C_4\right] \quad (6)$$

where $C_1 = \dfrac{W_T\cdot\nu_{CT}}{V_C}$ (Towing aeroplane excess thrust)

$C_2 = \dfrac{W_G}{\eta^*}$ (Glider drag)

$C_3 = 3{\cdot}5{*}10^{-6}\cdot V_C{}^2\cdot\cos^3\Phi.I.\sigma$ (Rope drag)

$C_4 = \dfrac{4\,B_f\cdot W_T\cdot W_G}{\pi\,\rho\,V_C{}^2\,b_T b_G}$ (Biplane Interference Drag)

The combination take-off distance to 50 ft., S_{50}, is given by

$$S_{50} = \frac{V_C{}^2}{2g}\cdot\frac{(W_T+W_G)}{\left(\dfrac{W_T\cdot V_C{}^2}{2g.S_{Tg}}-\overline{D}_G\right)} + \frac{50\,(W_T+W_G)}{(C_1-C_2-C_3-C_4)} + I\cdot\cos\gamma \quad (7)$$

where the mean glider ground roll drag is given by

$$\overline{D}_G = \frac{W_G}{2}\cdot\left[\frac{I}{2\eta}\cdot\frac{V_T{}^2}{V\eta^2} + \frac{2K_1\cdot W_G}{\rho\cdot s}\left(\frac{I}{V_G{}^2}+\frac{I}{V_T{}^2}-\frac{V_G{}^2}{V_T{}^4}\right) + \frac{V_G{}^2}{V_T{}^4}\right]$$

The majority of the parameters in the above equations can be obtained from flight test results, and the remainder estimated to the degree of accuracy required. It must be noted that conditions of zero wind and runway slope have been assumed for the purpose of these calculations.

One of the main influences on both the combination take-off distance and climb rate is the towing aeroplane weight. Before any of these calculations are carried out the accurate towing configuration weight should be established, empty weights being obtained from the weight and balance section of the aircraft Flight Manual, or if such a document has not been issued, the aircraft load data sheet.

Towing Aeroplane Altitude Performance

Where the towing aeroplane altitude performance is available from flight tests the constants ν_{CO} and B of equation (2) can be determined from climb rates at two or more heights. The take-off distance, S_T, can be approximated, where data are available for two heights, say sea level and h_1, by

$$S_T = S_{T\,(\mathrm{SeaLevel})}\,\sigma^{\chi}$$

where $\chi = \ln\sigma_1/\ln\left(S_{T1}/S_{T\,(\mathrm{SeaLevel})}\right)$

It only sea level ISA performance for the towing aeroplane is available, then the altitude performance can be estimated as follows;

For a normally aspirated piston engined aircraft, the climb rate, $\nu_{CT}(h)$, at a density height, h, can be estimated as

$$\nu_{CT}(h) = \left(\nu_{CTO} + V_C\cdot\frac{D}{W}\right)\cdot\left(\frac{\sigma(h)^{1.117}-0{\cdot}065}{0{\cdot}935}\right) - \frac{V_C}{\sqrt{\sigma(h)}}\cdot\frac{D}{W} \quad (9)$$

where $\dfrac{D}{W}$ is the drag to weight ratio at the climb speed.

This relation is developed in the Appendix.

If more precise information is not available the take-off distance of the towing aeroplane, S_T, can be conservatively estimated at altitude, given the sea level ISA distance, by assuming the value of the index χ in equation (8) to be –2.7.

Table A
Towing aircraft details*

Towing Aircraft Type	Piper PA-25-235 Pawnee	IMCO Callair A9A	Piper PA-18-150 Super Cub
Wing Span (ft.)	36.2	34.8	35.3
Wing Efficiency Factor 'e'	0.84	0.9	0.78
Towing Speed 'Vc' – kt. CAS	60	60	55
Lift/Drag Ratio α Vc	9.5	8.3	9.4
Propulsive Efficiency α Vc	0.49	0.51	0.57
Estimated Lift-off Speed V_{LO}	50	50	45
Test Weight (lb.)	2000	2100	1500
Typical Towing Weight (lb.)	1790	1940	1380
Test Climb Rate at Sea Level (FPM)	1296	1091	1088
Test Climb Rate at 5000 ft. (FPM)	Not available	Not available	Not available
SL. Test Take-off Distance to 50 ft. (ft.)	670	670	530
5000 ft. Test Take-off Distance to 50 ft. (ft.)	Not available	Not available	Not available
Typical Empty Weight (lb.)	1460	1610	1060
Oil (lb.)	20	20	15
Fuel (lb.)	140	140	135
Pilot (lb.)	170	170	170
Towing Weight (lb.)	1790	1940	1380
Rated Engine Power (BHP)	235	235	150

* These data have been derived from the following sources:
(a) References 2, 3 and 4.
(b) Owners Manuals (For dimensions, fuel capacities, etc.).
(c) Typical empty weights for Australian aircraft used in Glider Towing Operations.

The Estimated Tow Times for Three Light Aeroplanes

Basic performance data for the Piper PA-25-235, the IMCO Callair A9, and the Piper PA-18-150 aeroplanes are available from References 2, 3 and 4 respectively, and are summarised in Table A. All three types are used in Australia for glider towing duties.

In order to provide a common basis for comparison, the glider towing performance of these aeroplanes has been calculated for two glider types; the single seat Glasflügel H-201 Standard Libelle and the two seat L-13 Blanik. Glide performance data at maximum weight for these gliders are given at Table B and are derived from References 5 and 6 respectively.

Typical towing weights for the towing aeroplanes have been based on average empty weights of examples of these types used for glider towing in Australia. For consistency it has been assumed that the typical towing weight comprises the empty weight, plus oil, plus 5/8 full fuel capacity plus a pilot weight of 170 lb.

Reference 4 gives data for the 135 HP version of the Piper PA-18 only, so these have been corrected for an engine power of 150 HP by assuming that the propulsive efficiency, given in Reference 4, remains constant at 0.57.

Because of the extensive nature of these calculations they were made using a FORTRAN computer program.

Estimated tow times for the three aeroplanes are given in tables 1, 2 and 3 and plotted in figures 1, 2, 3 and 7, and the climb rates and take-off distances in tables 4, 5 and 6; climb rates are also plotted in figures 4, 5 and 6.

It is important to note that the calculations are for calm air conditions and standard altitudes only. Further the «Low Tow» towing position, standard in Australia, and a tow rope length of 100 ft., are both assumed.

Table B
Glider details*

Glider Type		Glasflügel H-201 Standard Libelle	L-13 Blanik
Maximum take-off weight (lb.)		638	1102
Wing Span (ft.)		49.2	53.2
Speed for max. L/D (kt.)		50	50
Max. L/D**		33.5	27.6
Aspect Ratio		23.6	13.7
Wing Area (ft.^{2})		102.3	206.0
L/D**at	35 kt.	23.0	19.0
	40 kt.	25.6	23.8
	45 kt.	29.2	25.5
	50 kt.	32.5	26.6
	55 kt.	30.6	25.0
	60 kt.	28.7	22.9
	65 kt.	26.5	21.0
	70 kt.	24.1	19.2
	75 kt.	22.1	17.3
	80 kt.	20.1	15.9

* Details taken from References 5 and 6.

** It is assumed that during the tow the glider landing gear is extended. The L/D values given are reduced from the clean L/D values, derived from references 5 and 6, by 2 to account for the extended landing gear. Bickle (Reference 7) establishes that landing gear extension has an effect of this order on the drag of modern high performance sailplanes.

Discussion of Results

Comparison of the three aeroplanes shows reasonably similar towing times for airfield heights of between sea level and approximately 2000 ft. standard altitude. This is illustrated in Figure 7. The somewhat better performance of the PA-25-235 Pawnee, as compared with the Callair A9, considering that both use the same engine type, can be attributed to the lower typical towing weight of the Pawnee and the higher drag of the Callair. In view of the relatively high installed engine power of both the Callair and the Pawnee, it seems probable that the launch costs incurred when using these aeroplanes would be slightly higher than those for the PA-18-150 Super Cub, which aeroplane gives only marginally longer tow times using a rated engine power of 150 BHP.

Concluding Remarks

There appears to be considerable scope for optimising the design of specialised glider-towing aeroplanes with similar performance but having less installed engine power and lower empty weights than the types investigated here. It is obvious that descent times constitute a major part of the overall tow time. The descent times could be reduced considerably for an aeroplane fitted with effective dive brakes or flaps usable at high speeds, and these would seem to be desirable design features for a towing aircraft. The calculation method given above could be refined with further work. For example, the descent rates were assumed to have certain fixed values, and if greater accuracy is desired, additional information would need to be obtained, possibly by timing descents and landings.

Table 1
Combination Tow Time – Piper PA-25-235

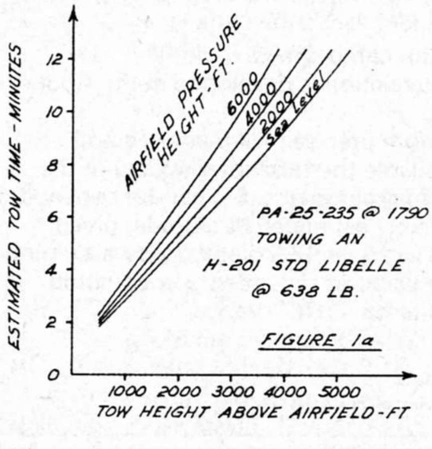
Tow Height	Tow Time, minutes Towing Libelle				Towing Blanik			
ft.	Airfield	Density	Height	ft.	Airfield	Density	Height	ft.
	0	2000	4000	6000	0	2000	4000	6000
1000	2.8	3.0	3.2	3.5	3.2	3.5	3.8	4.4
2000	4.9	5.2	5.7	6.3	5.6	6.1	6.8	7.9
3000	7.0	7.6	8.3	9.3	8.1	8.9	10.1	11.8
4000	9.3	10.0	11.1	12.6	10.8	11.9	13.6	16.2
5000	11.6	12.6	14.1	16.2	13.6	15.1	17.5	21.3

Table 2
Combination Tow Time – Callair A9A

Tow Height	Tow Time, minutes Towing Libelle				Towing Blanik			
ft.	Airfield	Density	Height	ft.	Airfield	Density	Height	ft.
	0	2000	4000	6000	0	2000	4000	6000
1000	3.0	3.3	3.6	4.2	3.5	3.9	4.4	5.3
2000	5.4	5.9	6.6	7.7	6.2	7.0	8.2	10.1
3000	7.8	8.6	9.8	11.7	9.2	10.4	12.4	15.8
4000	10.4	11.6	13.3	16.3	12.3	14.2	17.2	23.0
5000	13.1	14.8	17.3	21.9	15.7	18.3	23.9	33.1

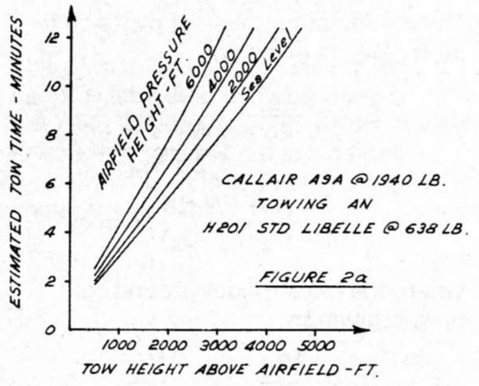
Table 3
Combination Tow Time – Piper PA-18-150

Tow Height	Tow Time, minutes Towing Libelle				Towing Blanik			
ft.	Airfield	Density	Height	ft.	Airfield	Density	Height	ft.
	0	2000	4000	6000	0	2000	4000	6000
1000	3.2	3.4	3.8	4.3	3.8	4.3	4.9	5.9
2000	5.6	6.2	6.9	7.9	6.9	7.8	9.0	11.1
3000	8.2	9.1	10.2	11.9	10.1	11.5	13.6	17.1
4000	11.0	12.2	13.8	16.4	13.6	15.7	18.8	24.4
5000	13.9	15.5	17.8	21.7	17.4	20.2	24.8	33.9



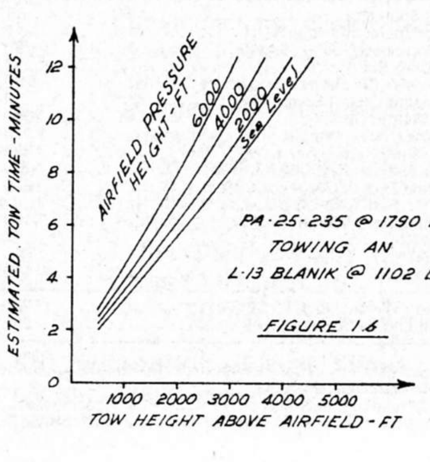
PA-25-235 @ 1790 LB TOWING AN H-201 STD LIBELLE @ 638 LB.

FIGURE 1a



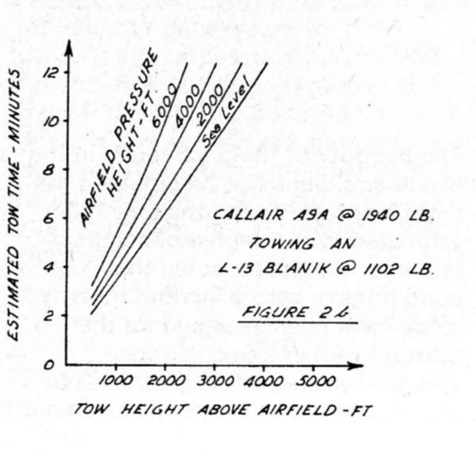
CALLAIR A9A @ 1940 LB. TOWING AN H201 STD LIBELLE @ 638 LB.

FIGURE 2a



PA-25-235 @ 1790 LB. TOWING AN L-13 BLANIK @ 1102 LB.

FIGURE 1b



CALLAIR A9A @ 1940 LB. TOWING AN L-13 BLANIK @ 1102 LB.

FIGURE 2b

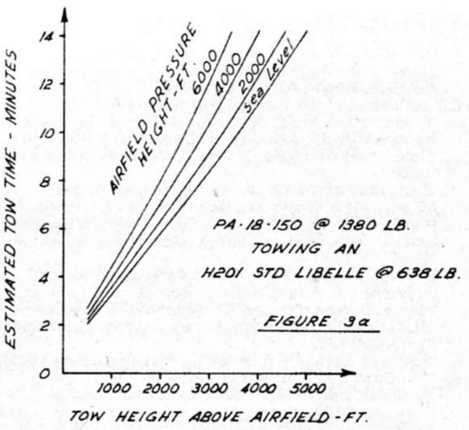


FIGURE 3a

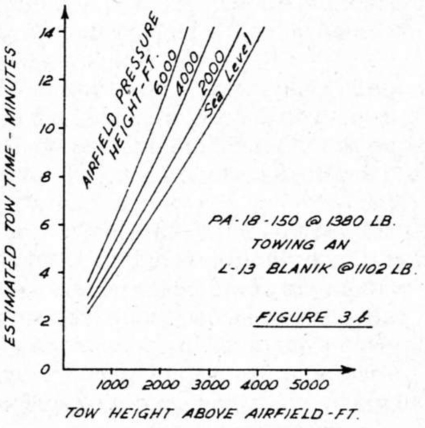


FIGURE 3.b

Table 4
Climb Rate and Take-off Distance – Piper PA-25-235

Density	Climb Rate ft./min.			Take-off Distance ft.		
Height ft.	Pawnee alone	Towing Libelle	Towing Blanik	Pawnee alone	Towing Libelle	Towing Blanik
0	1493	1014	786	537	803	1072
1000	1412	954	734	581	884	1196
2000	1332	894	683	629	974	1340
3000	1252	833	631	682	1074	1507
4000	1172	773	579	739	1188	1705
5000	1092	712	527	802	1317	1940

Table 5
Climb Rate and Take-off Distance – Callair A9A

Density	Climb Rate ft./min.			Take-off Distance ft.		
Height ft.	Callair alone	Towing Libelle	Towing Blanik	Callair alone	Towing Libelle	Towing Blanik
0	1221	836	645	572	836	1098
1000	1145	777	594	619	920	1223
2000	1068	719	543	670	1014	1367
3000	992	660	493	727	1119	1533
4000	916	601	442	788	1238	1728
5000	840	542	391	855	1372	1958

Table 6
Climb Rate and Take-off Distance – Piper PA-18-150

Density	Climb Rate ft./min.			Take-off Distance ft.		
Height ft.	Super-Cub alone	Towing Libelle	Towing Blanik	Super-Cub alone	Towing Libelle	Towing Blanik
0	1218	745	542	449	255	1084
1000	1149	697	502	486	836	1228
2000	1080	649	462	526	923	1399
3000	1012	600	422	570	1033	1608
4000	943	552	381	618	1153	1863
5000	874	503	341	671	1291	2183

Appendix

The Derivation of Climb Rate at Altitude from Sea Level Data

For any propeller driven aircraft the climb rate, ν_{CT}, is given by

$$\nu_{CT} = \frac{\eta P}{\rho W} - \frac{D}{W} \cdot \frac{V_C}{\sqrt{\sigma}} \qquad (1)$$

where $\frac{P}{W}$ is the aircraft engine power/weight ratio

$\frac{\eta}{\rho}$ is the propulsive efficiency

$\frac{D}{W}$ is the aircraft drag/weight ratio

V_C is the aircraft forward speed (CAS)

σ is the relative density

Now for a normally aspirated piston engine in the standard atmosphere the power is a function of relative density. A function for normally aspirated engine power is given by Von Mises (Reference 1) as

$$P(\sigma) = P_{\text{Sea Level}} \left(\frac{\sigma^{1.117} - 0{\cdot}065}{0{\cdot}935} \right) \qquad (2)$$

Substituting (2) in (1) we have

$$\nu_{CT} = \frac{\eta}{\rho} \cdot \frac{P_{\text{Sea Level}}}{W} \left(\frac{\sigma^{1.117} - 0{\cdot}065}{0{\cdot}935} \right) - \frac{D}{W} \cdot \frac{V_C}{\sqrt{\sigma}} \qquad (3)$$

Where the value of $\frac{\eta}{\rho}$ P Sea Level is not known, but the sea level climb rate, ν_{CTO}, and the value of $\frac{D}{W}$ at the climb speed, V_C, are known, we have,

$$\nu_{CT} = \left[\nu_{CTO} + \frac{D}{W} \cdot V_C \right] \cdot \left[\frac{\sigma^{1.117} - 0{\cdot}065}{0{\cdot}935} \right] - \frac{D}{W} \cdot \frac{V_C}{\sqrt{\sigma}} \qquad (4)$$

The value of $\frac{D}{W}$ at the speed V_C can

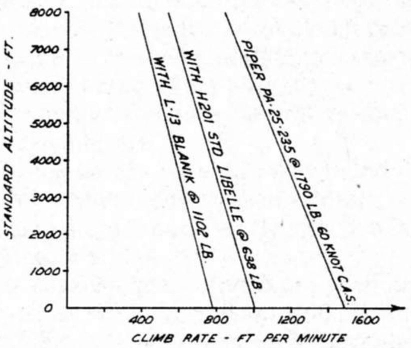


FIGURE 4 ESTIMATED GLIDER TOWING CLIMB RATE FOR THE PIPER PA·25·235 @ 1790 LB.

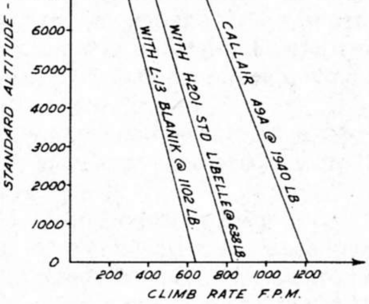


FIGURE 5 ESTIMATED GLIDER TOWING CLIMB RATE FOR THE IMCO CALLAIR A9A @ 1940 LB.

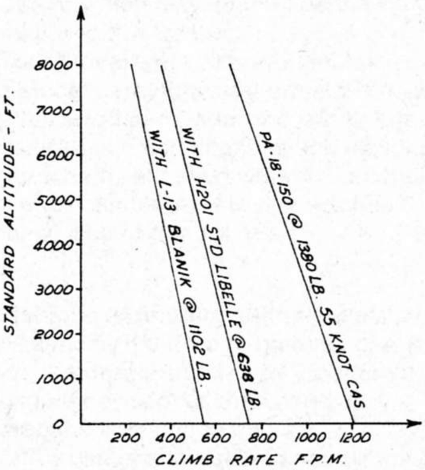


FIGURE 6 ESTIMATED GLIDER TOWING CLIMB RATE FOR THE PIPER PA·18·150 @ 1380 LB.

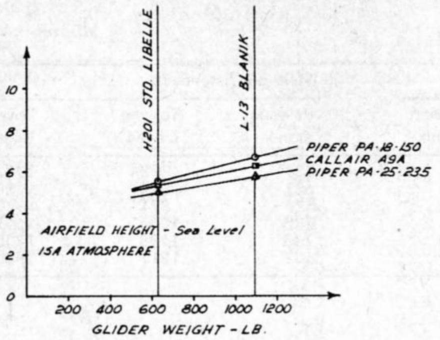


FIGURE 7 COMPARISON OF TOW TIMES FOR THE PA·25-235, CALLAIR A9A AND PA·18·150 GLIDER TOWING AIRCRAFT.

normally be estimated reasonably accurately should test data not be available. The analysis assumes that the propulsive efficiency, $\frac{\eta}{\rho}$, remains constant. This assumption can be considered valid for the small altitude ranges considered in this paper. Where V_C is given in terms of knots CAS and the climb rate ν_{CT} is in feet per minute, equation (4) becomes

$$\nu_{CT} = \left[\nu_{CTO} + 101{\cdot}3 . \frac{D}{W} . V_C\right] \cdot \qquad (5)$$

$$\cdot \left[\frac{\sigma^{1.117} - 0{\cdot}065}{0{\cdot}935}\right] - 101{\cdot}3 . \frac{D}{W} \cdot \frac{V_C}{\sqrt{\sigma}}$$

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