Considerations on Dive Brakes

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I. INTRODUCTION

Wing-mounted dive brakes[1] have become almost universally employed on present day sailplanes and contribute greatly to the safety and ease of flight. Present trends seem to be toward increased effectiveness of these devices as exemplified by the Standard Class requirement for terminal velocity limiting capability as well as increased use of supplemental devices such as flaps and tail parachutes. Most of these devices serve a multiple function of terminal velocity limiting, rapid descent from altitude and landing glide-path control.

In spite of the wide use and acknowledged value of these drag regulators the spread of their use to other types of aircraft has been slow and research and development efforts have been proportionately small.

The purpose of this paper is to present some considerations on dive brakes with the hope that they may focus thought and lead to research which may result in improvements in future sailplanes.

II. ANALYSIS

A. Isolated Brakes

1. Brake Alone

Brakes are not generally considered separately as component parts of the aircraft because the interference effects are so large as to make the application of component data questionable. Nonetheless from an academic standpoint, consideration of an isolated brake may provide some insight into dive brake characteristics.

The tests of Reference 1 by Randall have been chosen to represent an isolated brake. These tests were of a doubly symmetric airfoil over a 90° angle-of-attack range. At the higher angles the double wedge airfoil is taken to be representative of an isolated two-dimensional brake when tested with tip plates attached. Data are based on pressure measurements taken at a Reynolds number of 490,000 based on the model chord and at a Mach number of 0.2. The data have been replotted from those of the referenced report to represent the brake angle of attack at zero when the model angle was 90° and are shown on figure 1.

It is seen that the brake represented in this figure has a drag coefficient of about 1.2, which decreases with increasing angle of attack. The lift curve slope is negative at about

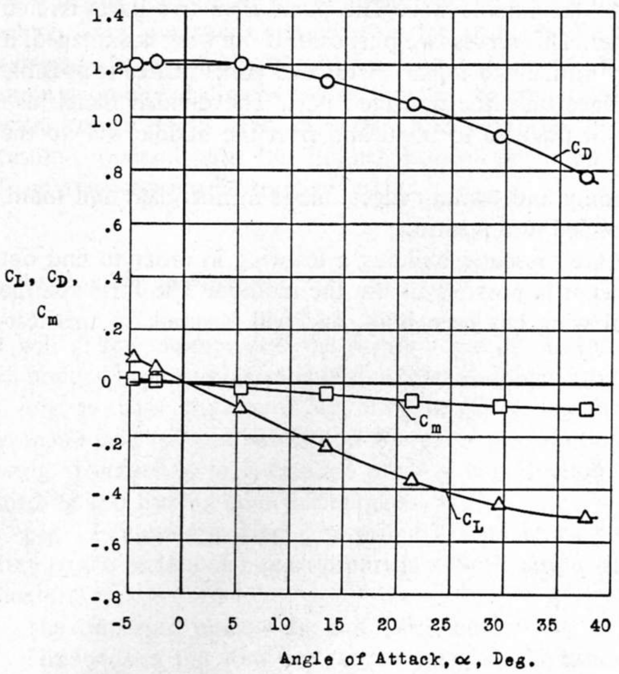

Figure 1. - Representative characteristics of a two-dimensional brake.

[1] For the purposes of definition, the term 'dive brake' refers to all drag regulating devices and the term 'spoiler' refers to wing-mounted brakes designed to spoil the airflow over the wing.

−.019 per degree. This is about a fifth of the value associated with ordinary airfoils and, of course, of apposite sign. The brake exhibits a negative moment curve slope about the centroid of the section, which indicates it to be mildly stable.

The negative lift curve slope may be visualized in the manner of figure 2, which compares a wing and brake section. The downward deflection of the flow from the airfoil results in an upward force whereas for the brake the increase in angle causes the flow be deflected upward resulting in a downward force. These general characteristics are considered representative of shapes having high drag normally selected for brakes.

2. Effect of Brake Location

Let us next assume that a brake is mounted on a sailplane as shown in figure 3. The effect of adding the brake alone on the pitching moment can be approximated by

$$\Delta M = M_b + D_b\,(\,h_b - l_b \sin\alpha\,) - L_b\,(\,l_b \cos\alpha\,).$$

The effect on the static stability can be obtained by differentiation and simplification considering small angles

$$\frac{dM}{d\alpha} = \frac{dM_b}{d\alpha} - D_b\, l_b - \frac{dL_b}{d\alpha}\, l_b\,.$$

From this equation it is apparent that for a brake situated behind the center of gravity the drag term will be stabilizing but the lift term, due to the negative lift curve slope, will be destabilizing. The opposite holds for such a brake located ahead of the center of gravity. It is quite possible for a brake mounted behind the center of gravity to be destabilizing even if the interference effects on the tail are not considered.

Not only can the static stability become reduced due to the dive brake, but the pitch damping is also reduced. Considering the damping due to pitching velocity, it can be shown to be related directly to the stability. For an isolated brake at some distance, 1b, from the center of gravity,

$$\Delta C_{m_q} = \frac{2\Delta C_{m_\alpha} l_b}{c}$$

Similarly, a brake exhibiting a negative lift curve slope, if placed laterally from the center of gravity, will, by itself, show negative damping in roll. This may lead to an autorotative condition similar to an aircraft spinning.

On the basis of consideration of an isolated brake it might be concluded that locating the brake far from the center of gravity may result in undesirable changes in trim, stability and damping particularly if the brake exhibits a negative lift curve slope or causes a reduction in local lift curve slope. The increase in drag, however, may be expected to result in increases in stability and damping about any of the axes except for some cases where the brake is located ahead of the center of gravity.

B. Brakes and Bodies in Combination

Much of the research work on spoilers and brakes dates from the period of the initial development prior to the second World War (Reference 2). While this work has served the designer well, it is not complete, is becoming increasingly difficult to obtain and may not be generally applicable to modern designs. Therefore only general observations on the effects of combinations can be made.

Fuselage mounted brakes often seen on powered aircraft are seldom seen on sailplanes. This is because the interference drag of the brake mounted on the fuselage is much smaller than if the same size brake were mounted on the wing. Since lift forces on fuselages are small it may be expected that lift interference will also be small for fuselage mounted brakes unless they are in the proximity of the wing.

In the case of wing mounted brakes the interference effects are more complex. The size and location of the brakes on the wing has an important effect on interference. In Reference 2 it was pointed out that the change in zero lift angle increases for a single surface spoiler as the chordwise

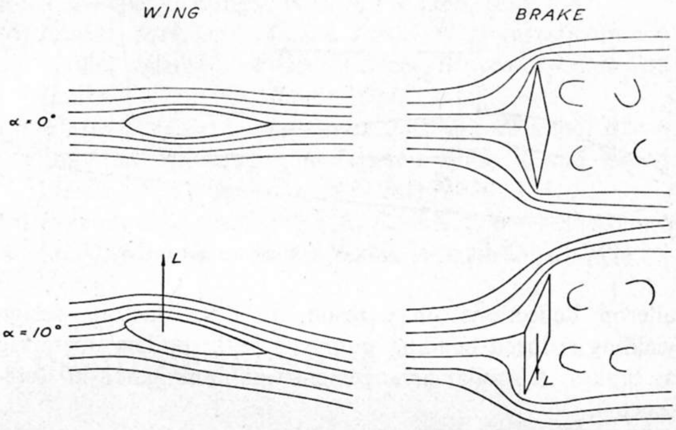

FIGURE 2 - FLOW COMPARISON

location moves aft. At the trailing edge it would approach a highly deflected flap in form. Many tests have been conducted by NASA in the USA on spoiler ailerons usually located in the vicinity of the ¾ chord on the outer wing. In Reference 3 it is seen that such a device produces a change in lift without changing the lift curve slope. Thus the interference effects might be said to have changed the character of the lift forces of an isolated brake completely. From figure 4, which is reproduced from Reference 2, we see that as the brake location moves forward the effect on zero lift angle (indicated by brake lift coefficient at $C_L = 0$) decreases but the effect on lift curve slope (indicated by the difference between brake lift coefficients at $C_L = 0$ and $C_L = .5$) generally increases until at the leading edge the change in trim is zero and the effect on lift curve slope is large. The same applies for a brake composed of elements on both upper and lower surfaces. Thus the farther forward on the chord a brake is located the more it behaves like an isolated brake in regards to lift. If a brake is moved aft it behaves progressively more like a control on the wing.

In Reference 2 it was shown that the drag of a brake in combination may be double that of the isolated brake if it is located near the wing maximum thickness position but tends toward that of the isolated brake where the wing is thin (leading and trailing edges). The nature of drag and lift interference is thus seen to be quite different.

C. Other Considerations

Spoilers are most commonly seen located at about mid chord and inboard of the ailerons. This arrangement can be expected to result in higher wing root bending moments with brakes out than retracted. This is quite evident in observing some of the newer glass fiber sailplanes whose wings deflect upward when the spoilers are operated in the landing approach.

(On many sailplanes the brakes cause the wings to bend downwards at high speeds — Editor.) Limiting root bending stresses may cause a reduction, in the normal load direction, in the flight operating envelope especially at high speeds with spoilers out over that for spoilers retracted. It is felt that more consideration of this problem is needed than has been given in the past especially with high performance type sailplanes. By placing spoilers in the outboard wing panels this effect can be reversed. Using outer panel spoilers both for drag regulation and to augment roll control (with large aileron deflections) may result in a satisfactory design yielding reduced bending moments with spoilers operating as brakes. A similar arrangement was investigated in Reference 4.

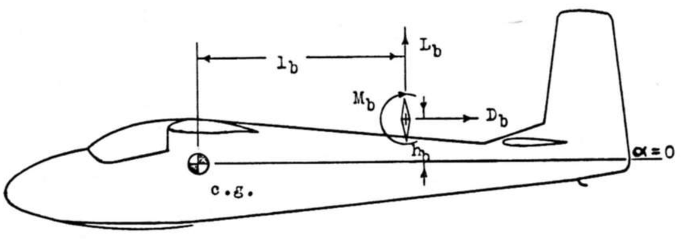

Figure 3. - Positive moment and force notation

Very little information is available to the designer on the effect of variations in brake design and location on the maximum lift coefficients of wings. Such information would not be difficult to obtain in tests in small wind tunnels and it would seem suited to research projects in the universities and technical schools.

Examination of the effect of chordwise location of spoilers on lift provides information which may be of value in preventing gliders from being lifted in high winds. A removable spoiler can be located on the wing just behind the leading edge when the aircraft is tied down. In Reference 5 small spoilers of five percent chord in height located at the 10 percent chord line reduced the lift from $C_L = 1.4$ to 0.33. The optimum chordwise location was found to be 12 percent chord behind the leading edge. Use of a fixed spoiler is not new for this purpose, however sailplanes continue to be blown from their moorings so that the idea perhaps is not well enough known.

D. Operational Requirements

The spoiler is particularly suited to landing because it permits a rapid and proportional control of glide path angle and allows steep descents over obstacles. If the glide is at a constant velocity the glide path angle is equal to the ratio of lift to drag and the horizontal distance required to clear the obstacle is simply a function of this ratio. In reality the sailplane will generally be decelerating between clearing an obstacle and touchdown in which case the distance, though still a direct function of L/D, will increase as the kinetic energy change in deceleration increases. If it is assumed that a sailplane with a wing loading of five pounds per square foot decelerates from 1.3 times the stalling speed at 50 feet to 1.15 times the stall speed at touchdown we may plot the ratio of distance along the ground divided by mean L/D for varying values of C_{Lmax}. This is shown in figure 5. This result is based on the development in Reference 6, page 198. It is apparent that, although it is advantageous to employ a high maximum lift such as can be obtained with flaps, the predominate factor in controlling the flight portion of the landing distance is the drag.

The rate of change with velocity of flight path angle due to the drag device will depend on the nature of the device. In the case of the parachute the change in flight path angle will vary practically inversely as the velocity squared because the drag is entirely parasitic. Such a device is least effective at low speeds as during landing.

Wing mounted brakes and flaps derive their drag through increasing both the profile and induced drag and thus show less variation with flight velocity.

For the ground stopping distance part of the landing distance the aerodynamic drag plays a secondary role, the primary factor being the effectiveness of the wheel brake. The velocity at touchdown determines the energy level to be absorbed hence stall speed is most important. Other things being equal, the ground roll will vary inversely as the maximum lift coefficient.

It would appear then, that wing flaps exhibiting high drag and lift have advantages over other devices for improving short field landing capability over that af a basic spoiler equipped sailplane. Wing mounted brakes offer advantages over fuselage mounted brakes.

Flaps for short field landings in sailplanes and those for use on high-speed aircraft landing on long runways may differ considerably. Whereas the airplane needs a very high maximum lift coefficient in order to minimize ground roll, the sailplane requires a steep approach angle to permit landing. Therefore landing flaps for sailplanes should have high drag. Split and plain flaps highly deflected would be preferable to slotted or Fowler types.

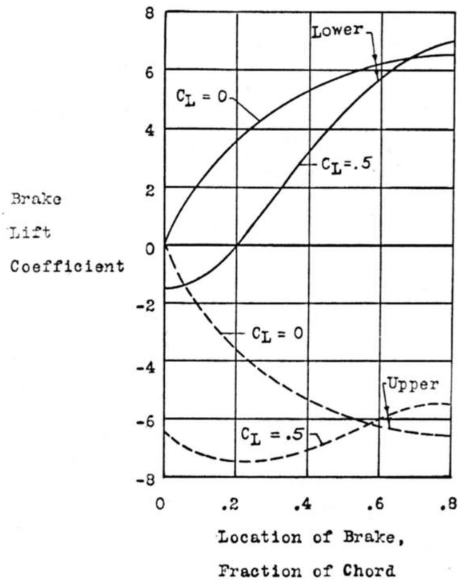

Figure 4.- Variation of brake flap lift coefficient with chordwise position on wing

Turning to the problem of emergency descent from high altitude where loss of altitude rapidly is the requirement, other factors must be considered. The most rapid descent occurs when the sailplane descends vertically. If the drag device allows such a descent without exceeding the limiting structural speed a safe rapid descent will be possible. It should also be desirable to have the brake device remain effective without undue effort from the pilot or without causing high loads in the structure.

Because of the rapid variation of drag with speed on devices acting to cause parasitic or profile drag changes, their use would be favored. Parachutes or rotor type brakes would

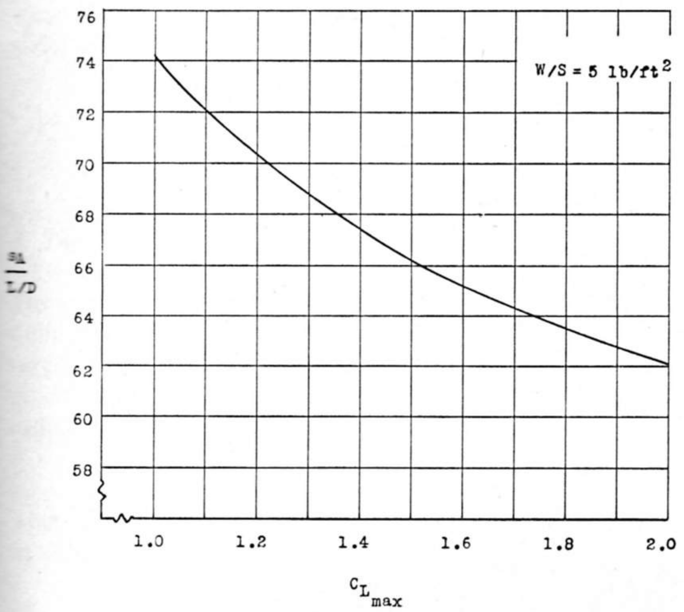

Figure 5.- Flight portion of landing distance to L/D ratio versus $C_{L_{max}}$.

appear suitable because of this and because they require no effort from the pilot to maintain the deployed condition. Velocity limiting wing brakes may also be suitable if they do not result in reduction in the allowable load factor envelope or require large actuation forces at high speeds. Wing flaps normally will produce large wing torsional moments in the wing structure and result in large nose down attitudes when used for rapid descents hence are less suitable for this function.

III. Symbols

c	Reference chord length
C_D	Drag coefficient
c. g.	Center of gravity
C_L	Lift coefficient
C_{Lmax}	Maximum lift coefficient
Cm	Pitching moment coefficient
$C_{m\alpha}$	Pitching moment curve slope, $dC_m/d\alpha$
C_{mq}	Pitching velocity damping, $dC_m/d\left(\frac{qc}{2V}\right)$
D_b	Drag force of brake
h_b	Height of brake above c. g.
L_b	Lift force of brake
l_b	Distance of brake aft of c. g.
M	Pitching moment
M_b	Pitching moment of brake about its moment center
q	Pitching velocity
S	Wing area
s_A	Horizontal distance from 50 foot obstacle to ground contact
V	Flight velocity
W	Weight
α	Angle of attack
Δ	Increment

IV. REFERENCES

(1) *Randall, Greenfield A.*, «Aerodynamic Characteristics of Two 20 percent Thick, Rectangular Wings up to 90° Angle of Attack at Subsonic, Transonic and Supersonic Speeds», NASA Company Report 73 097, 1967.

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(3) *Fischel, Jack, and Tamburello, Vito*, «Investigation of Effect of Span, Spanwise Location and Chordwise Location of Spoilers on Lateral Control Characteristics of a Tapered Wing», NACA TN 1294, May 1947.

(4) *Fischel, Jack, and Watson, James M.*, «Investigation of Spoiler Ailerons for Use as Speed Brakes or Glide Path Controls», NACA Report 1034, 1951.

(5) *Wenzinger, Carl J., and Bowen, John D.*, «Tests of Round and Flat Spoilers on a Tapered Wing in the 19-foot Pressure Wind Tunnel», NACA TN 801, 1941.

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Zusammenfassung

Während Sturzflugbremsen an Segelflugzeugen stark verbreitet sind, sind sie an Motorflugzeugen eher selten. Aus diesem Grund ist die Forschung und Entwicklung auf diesem Gebiet zurückgeblieben Es ist zu hoffen, dass die Gedanken dieses Artikels zu weiteren Untersuchungen führen werden, speziell zur Verbesserung zukünftiger Segelflugzeuge. Die Daten der in Figur 2 dargestellten Bremsklappe sind in Figur 1 aufgezeichnet. Sie zeigen eine etwas negativ verlaufende Auftriebskurve. Ist diese Bremsklappe hinter dem Schwerpunkt angebracht, so kann dies zu einem Verlust der Stabilität führen, ebenfalls kann der Dämpfungseffekt bei Längsneigungsänderungen beeinträchtigt werden.

Bei Sturzflugbremsen, die an den Flügeln montiert sind, konnte man verschiedene Nebenerscheinungen feststellen. Die Auftriebsveränderungen können wesentlich grösser sein, als die Untersuchungen an isolierten Bremsklappen gezeigt haben, während der Widerstand sich sogar verdoppeln kann. Die Belastungsverteilung an den Flügeln kann durch die Bremsklappen ebenfalls verändert werden, z. B. können die Flügelspitzen auf- oder abwärts gebogen werden, wenn die Klappen im Fluge betätigt werden. Dieser Effekt kann umgekehrt auftreten, wenn die Bremsklappen weiter zur Flügelspitze hin angebracht werden und für beides zur Widerstandserhöhung und Längsachsensteuerung verwendet werden. Bremsklappen, die nur den Widerstand vergrössern, ohne zusätzlichen Auftrieb zu geben, kürzen den Anflug, haben aber wenig Effekt in der Verkürzung der Lande-Rollstrecke. Klappen, die sowohl Auftrieb als auch Widerstand erzeugen, verbessern daher die Möglichkeit, auf kurzen Feldern zu landen, d. h. dass Bremsklappen für Segelflugzeuge mehr Widerstand erzeugen müssen, als solche für Motorflugzeuge, damit der gewünschte steile Anflugwinkel erreicht wird. Auftriebserhöhende Klappen sind ungünstiger für die Haltung der Endgeschwindigkeit im Sturzflug, besonders, da sie normalerweise hohe Torsionskräfte am Flügel verursachen. H. S.