UPSETS IN PITCH: A GUIDE TO DESIGN DIVING SPEED?

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Summary

This paper investigates a proposal (1) by Dipl. Ing. Marcel Gaille of the Swiss Bundesamt fur Zivilluftfahrt that the minimum Design Diving Speed in OSTIV Airworthiness Requirements might be defined by considering the maximum speed attained in a reasonable time in a pitching manoeuvre.

It is concluded that this suggestion, with a little modification, leads to a formula of the form:

$$Vdmin \quad k.Vo + DV \qquad (1)$$

where k and DV are to be chosen to give generally acceptable results.

1. Introduction

In the first post-war issue of British Civil Airworthiness Requirements, Section E (2), the lowest value of the Design Diving Speed was simply a multiple of the stalling speed, with different factors for Normal, Semi-Acrobatic and Acrobatic Categories. Experience showed that this system was somewhat unsatisfactory, mainly owing to the difficulty of predicting the stalling speed to a suitable degree of accuracy. In the 1960 issue of BCAR Section E (3), an expression was introduced of the form

$$Vdmin = 9w + 50 \text{ (non-cloud-flying)} \qquad (2)$$

$$\text{or } Vdmin = 9w + 78 \text{ (cloud-flying)} \qquad (3)$$

These expressions, which were mainly due to Cedric Vernon, had the advantage that they involved only the wing loading at Design Maximum Weight, a quantity which was precisely defined.

A similar expression, in metric units, was adopted in the 1964 issue of OSTIV Airworthiness Requirements (4) and was retained in the 1966 issue (5).

In the 1971 issue (6), the German formula was adopted, of the form

$$Vdmin \text{ in km/h} = 18\,(w/Cdmin)^{1/3} \qquad (4)$$

where w was in kgf/sq.m and Cdmin was the minimum drag coefficient of the sailplane in the clean configuration.

This expression is based on the arbitrary assumption of a sinking speed of 7.8 m/s and some other simplifying assumptions. It has the advantage that it introduces the aerodynamic properties of the sailplane.

The same formula continued in use in the 1976 OSTIVAR (7) and in JAR-22 (8) for Category U sailplanes, although JAR-22 reverted to the previous wing-loading formula for Category A sailplanes. The relevant drag coefficient for Category U was stated to be "the lowest possible drag coefficient of the sailplane."

The provisional OSTIVAR of October 1986 retains the formula of JAR-22, but the drag coefficient is now defined as "the drag coefficient in a steady dive at speed Vd at Design Maximum Mass, with the wing flaps in whichever en-route position yields the greatest value of Vd." This was agreed at the 1985 meeting of the OSTIV Sailplane Development Panel meeting at Rieti. It was proposed by Dipl. Ing. Wolf Lemke and was adopted on the grounds that it represented a more rational interpretation of the existing formula.

This discussion followed an observation by Dipl. Ing. Gerhard Waibel at the previous meeting in Prague in October 1984 that the values of Design Diving Speed for some modern sailplanes were becoming unnecessarily high in relation to operating speeds. Various suggestions were made, including one by Marcel Gaille to the effect that the Design Diving Speed might be defined by considering the maximum speed reached in a reasonable time in a pitching manoeuvre, rather analogous to the definition in JAR-25, Large Aeroplanes (10). This proposal was considered at the Rieti meeting of the OSTIV SDP. It was agreed that it had obvious technical merits but needed further calculation and consideration. Wolf Lemke's proposal was therefore adopted as representing a reasonably satisfactory interim solution.

The object of the present paper is to examine Marcel Gaille's proposal and to show that it can lead to a very simple formula.

2. The Original Proposal

Mr. Gaille proposed that a requirement could be based on the following assumption:

"From an initial condition of stabilized flight (e.g., V for the best glide angle), the sailplane is assumed to be upset, flown for. . .sec (e.g., 10 sec) along a flight path 30 degrees below the initial path, and then pulled-up with a load factor of 2.0 (1.0 g acceleration increment). The resulting computed speed at pull-up, at which point airbrakes may be used, is to be considered as the minimum Design Diving Speed."

3. Calculations and Considerations

All of the figures quoted below, and those in Tables 1 and 2, are based on calculations which assume that the drag of the sailplane is of the form

$$D = a.v^2 + b.n^2/v^2 \qquad (5)$$

Table 1.
Speeds attained in dives by a training sailplane.

Maximum lift/drag ratio = 25
Equivalent airspeed for minimum drag = 68 km/h
Initial equibalent airspeed = 68 km/h
Initial height = 0 m
(a) Increase in flight path slope = −30 deg
Total flight path slope = −32.29 deg

TIME OF DIVE sec	FINAL EAS km/h	CHANGE OF ENERGY HT m	FINAL TRUE HT m
1.0	85.6	−0.7	−11.3
2.0	102.8	−1.8	−25.2
3.0	119.6	−3.6	−41.7
4.0	135.8	−6.3	−60.6
5.0	151.4	−10.0	−81.9
6.0	166.3	−14.9	−105.5
7.0	180.5	−21.2	−131.2
8.0	193.9	−29.2	−159.0
9.0	206.6	−39.0	−188.7
10.0	218.5	−50.6	−220.2

(b) Increase in flight path slope = −20 deg
Total flight path slope = −22.29 deg

TIME OF DIVE sec	FINAL EAS km/h	CHANGE OF ENERGY HT m	FINAL TRUE HT m
2.0	91.9	− 1.7	− 16.8
4.0	114.9	− 4.8	− 38.6
6.0	136.5	− 10.0	− 65.0
8.0	156.4	− 17.8	− 95.9
10.0	174.6	− 29.0	− 130.8
12.0	191.0	− 44.0	− 169.3
14.0	205.6	− 63.0	− 211.2
16.0	218.5	− 86.2	− 255.9
18.0	229.8	− 113.5	− 303.1
20.0	239.7	− 144.8	− 352.6

If airbrakes were not used in the manoeuvre suggested above, the speed in the pull-up would continue to increase until the component of weight along the flight path had diminished so far as to equal the drag, taking account of the load factor. This would lead to some very high speeds. For example, a heavily-laden Standard Class sailplane could attain about 302 km/h at the end of the dive and a maximum of about 334 km/h in the pull-up.

Both in JAR-25 and in the above proposal, the "pilot-controlled drag devices" are used when the pull-up is initiated. In this case, the maximum speed attained will generally be that at the end of the straight dive, assuming that the airbrakes comply with JAR 22.73 and 22.75. This statement is not always exactly true but a reasonably accurate calculation would require a detailed knowledge of the airbrake characteristics and, in particular, their influence on both the profile and induced drags.

Table 2.
Speeds attained in dives by an Open Class sailplane.

Maximum lift/drag ratio = 60
Equivalent airspeed for minimum drag = 120 km/h
Initial equivalent airspeed = 120 km/h
Initial height = 0 m
(a) Increase in flight path slope = −30 deg
Total flight path slope = −30.95 deg

TIME OF DIVE sec	FINAL EAS km/h	CHANGE OF ENERGY HT m	FINAL TRUE HT m
1.0	137.6	− 0.3	− 18.2
2.0	155.2	− 1.0	− 39.1
3.0	172.7	− 1.8	− 62.5
4.0	190.1	− 2.9	− 88.4
5.0	207.4	− 4.3	− 116.8
6.0	224.5	− 6.0	− 147.6
7.0	241.5	− 8.1	− 180.9
8.0	258.3	− 10.7	− 216.6
9.0	275.0	− 13.8	− 254.6
10.0	291.5	− 17.5	− 295.1

(b) Increase in flight path slope = −20 deg
Total flight path slope = −20.95 deg

TIME OF DIVE sec	FINAL EAS km/h	CHANGE OF ENERGY HT m	FINAL TRUE HT m
2.0	144.1	− 1.0	− 26.1
4.0	168.1	− 2.6	− 57.1
6.0	191.8	− 4.8	− 92.8
8.0	215.1	− 7.8	− 133.2
10.0	238.1	− 11.8	− 178.2
12.0	260.7	− 17.0	− 227.8
14.0	282.9	− 23.6	− 281.8
16.0	304.5	− 32.0	− 340.1
18.0	325.6	− 42.2	− 402.7
20.0	346.2	− 54.6	− 469.4

There will be a great simplification, with little error, if only the conditions at the end of the straight dive are considered.

Tables 1 and 2 show the results of step-by-step calculations of straight dives for two sailplanes. One has approximately the characteristics of the K-8 (Max L/D = 25 at 68 km/h) and the other those of a modern Open Class sailplane (Max L/D = 60 at 120 km/h).

In the latter case, the effect of drag on the speeds attained is very small. After a 30-degree dive for 10 sec, the speed increment is 97% of that which would have occurred had the drag been zero. For a 20-degree dive for 15 sec, the figure becomes 96%. Even for the "K-8" the corresponding figures are 85% and 79%.

Such figures immediately suggest that, in framing a Requirement, it might be reasonable to neglect the drag. The steeper the dive, the more realistic is this approximation, so only the 30-degree dive will be considered henceforth. If the dive were maintained for 10 sec, the speed increment would be 177 km/h, regardless of the sailplane's performance. An expression for the minimum Design Diving Speed then becomes

$$Vdmin = Vo + 177 \text{ (km/h)} \qquad (5)$$

In this case of the chosen examples, this leads to the following values:

Vo = 68 km/h, Vdmin = 245 km/h (132 knots);
Vo = 120 km/h, Vdmin = 297 km/h (160 knots).

These values of Vdmin might be thought a little high for the "K-8" and a little low for the Open Class sailplane. However, this approach suggests a further possibility, that equation (5) be replaced by

$$Vdmin = k.Vo + DV, \qquad (6)$$

where k is a factor (>1) and DV is the speed increment in a 30-degree dive, neglecting the drag, over some period less than 10 sec. Physically, this seems to be a more realistic scenario since in practice the initial speed for an upset will usually exceed Vo.

For example, if we take k = 1.5 and assume that the dive is maintained for 7.5 sec., equation (6) becomes

$$Vdmin = 1.5Vo + 132 \text{ km/h}. \qquad (7)$$

This leads to the following values:

Vo = 68 km/h, Vdmin = 234 km/h (126 knots);
Vo = 120 km/h, Vdmin = 312 km/h (168 knots).

These figures might be thought more reasonable and I would propose that serious consideration be given to an expression of the form of equation (6) with k and DV adjusted so as to give generally acceptable results.

It is noteworthy that (6) is similar in form to the expression proposed in 1966 by Mr. B. Schneider (11) although the numerical values and the considerations involved are different.

If the usual substitutions are made, then equation (6) is of the form

$$Vdmin = (\text{const.}/Cdo^{1/4}) + DV, \qquad (8)$$

whereas the present OSTIV/JAR-22 Requirement is of the form

$$Vdmin = \text{const.}/Cdmin^{1/3}, \qquad (9)$$

other things being equal in both cases. Assuming that Cdo and Cdmin are much the same, this suggests that (6) is likely to be somewhat less sensitive to errors in estimating Cdo than (9). For example, a 5% error in Cdo would result in an error of between 0.5% and 0.7% in Vdmin if equation (7) were used and about 1.6% if the present OSTIV/JAR-22 formula were used.

All of the above is based on calculations which assume a simple theoretical expression for the sailplane drag. At both high and low lift coefficients, this expression is unlikely to be strictly correct, but it seems probable that a suitable choice of constants in an expression such as (7) would allow for such discrepancies.

4. Conclusion

A formula for the minimum value of the Design Diving Speed for use in OSTIV Airworthiness Requirements is proposed, based on the following assumption:

"From an initial condition of stabilized flight at some speed greater than that for best glide angle, the sailplane is assumed to be upset and flown for a stated period of time along a flight path inclined at 30 degrees below the horizontal. Recovery is then initiated, at which instant the pilot deploys the airbrakes. The speed attained at the initiation of recovery is to be considered as the minimum Design Diving Speed. In calculating this speed, no account is to be taken of the drag of the sailplane."

This assumption leads to a very simple formula as shown in equation (6) above. The quantities k and DV are open to discussion, but if the initial speed is 1.5 times the speed for best glide angle and if the 30-degree dive is maintained for 7.5 sec., then equation (7) is obtained, which seems to lead to reasonable results.

This method of defining the minimum Design Diving Speed has a rational basis, is broadly similar to that used elsewhere (e.g., in JAR-25) and the numerical values can easily be modified if desired.

These considerations are only intended to apply to Category U sailplanes.

5. References

1. Gaille, Marcel. "OSTIV Sailplane Development Panel Meeting 1985 and Minutes of the 1984 Meeting in Prague." (Letter dated 9 May 1985 to Professor Piero Morelli, Chairman of OSTIV SDP).
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4. OSTIV Airworthiness Requirements for Sailplanes, July 1964.
5. OSTIVAR, December 1966.
6. OSTIVAR, September 1971.
7. OSTIVAR, September 1976.
8. Joint Airworthiness Requirements: JAR-22, Sailplanes and Powered Sailplanes. Airworthiness Authorities Steering Committee. First issued on 1st April 1980.
9. OSTIVAR, October 1986 (Provisional).
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11. Schneider, B. "Commentaire sur deux propositions originales du reglement francais AIR 2054." Aero-Revue, 1966, No. 2.

6. Symbols

a, b	Coefficients in the expression for the drag, equn. (5).
Cdmin	Minimum drag coefficient.
Cdo	Zero-lift drag coefficient.
D	Drag.
k	A constant.
n	Load factor.
V	Airspeed.
DV	Increment in airspeed.
Vd	Design Diving Speed.
Vdmin	Minimum Design Diving speed.
Vo	Airspeed for best glide angle.
w	Wing loading.
	Airspeeds are "equivalent."