SOME LIMITING FACTORS IN DIVE BOMBING

(With special reference to human aspects)

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Dive bombing received greatest notoriety during the early phases of World War II with the much publicised successes of the JU87's (Stukas) which paved the way for the advance of German Panzer Divisions across Europe and enabled an Air Army to occupy the well defended island of Crete.

In these days of Jet aircraft, dive bombing still has some place in both strategic and tactical planning. With the increased speeds of modern aircraft an examination of some of the limiting factors of this method of carrying the war to the enemy is not out of place, especially as a number of lives and valuable aircraft are lost during the process of dive-bombing training and tactics evolution.

Accuracy of Dive Bombing.

The accuracy of dive-bombing depends amongst other factors on:—

1. The angle of dive (to the horizon). The greater the angle the greater is the accuracy attained.
2. The height of bomb release. The lower the height the greater is the accuracy.
3. Indirectly on the speed as this factor would affect amount of wind drift whilst determining the effectiveness of small arms or anti-aircraft fire from the ground.

Technique.

The technique of dive-bombing usually consists of flying up-sun of the target, *winging over* from a given altitude, *diving* in a rectilinear flight path towards the target, *releasing the bombs* at a given altitude and then *pull out* from the dive. These various phases of technique are illustrated diagrammatically in Fig. 1.

During the rectilinear dive from A to B at angle θ. with the horizon, the aircraft will gain speed at a rate of acceleration which is related to the angle θ and expressed by sign where g is the acceleration due to gravity. Knowing the speed on entry into the dive at A, the angle of dive and the altitude of A and B, (the moment of bomb release and the commencement of the pull-out) it should theoretically be possible to determine the "terminal" velocity at B taking meterological and air resistance factors into consideration.

Similarly the aircraft will gain speed at a diminishing rate of acceleration from B to C (the lowest level of the pull out or safety height) and its maximum speed will be at C.

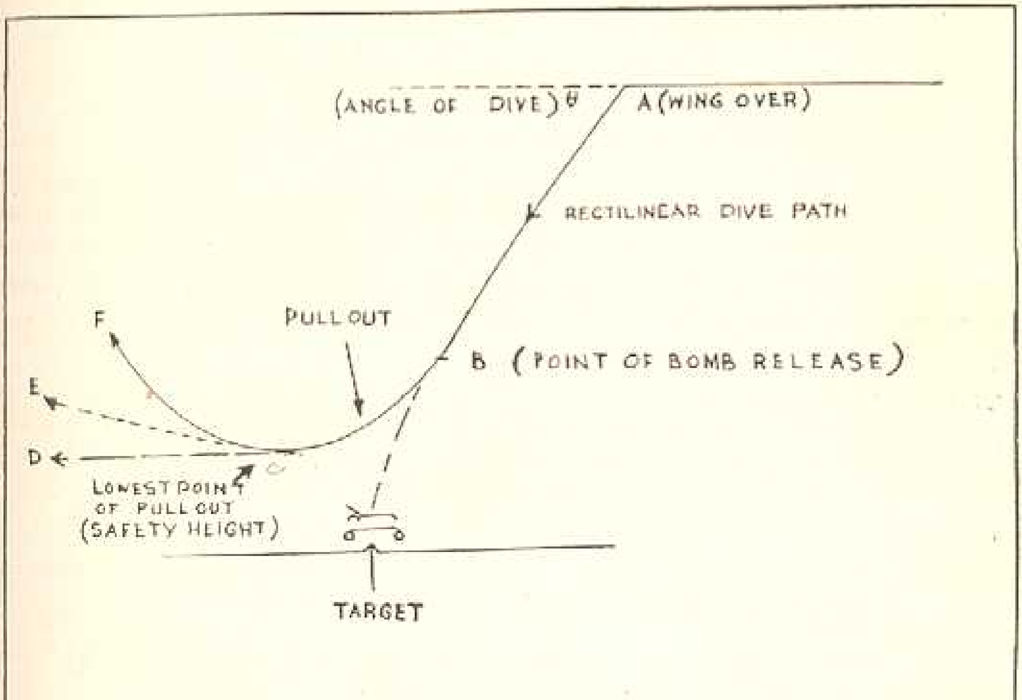


FIGURE-1.

Centripetal Forces developed during Pull Out

It is obvious from the foregoing that certain centripetal forces are put into action during the pull out and these will give rise to Centrifugal accelerations which affect the human body. For the sake of simplicity of calculation it is assumed that the curvilinear aircraft path B—C is the arc of a circle and that the pilot after pull out will follow a more or less rectilinear climbing path CD or CE and not continue the pull out along CF.

The maximum centrifugal force developed at C under the above conditions is given by the equation:

$$G \text{ max. in multiples of gravity (g)} = \frac{V^2(1-\cos\theta)}{15h} + 1.$$

where V — Speed of aircraft in m.p.h.
θ — angle of dive in degrees.
h = difference in altitude between points B and C in feet.

Immediately after the commencement of the pull out at point B, this force will be less than at C.

In further calculations, V is taken as the maximum velocity developed during dive-bombing.

Human Tolerances to Centrifugal Forces in Conventional Seated Position.

In considering the effects of centrifugal forces on the human body, it is necessary to take into consideration not only G maximum $\left(\frac{V^2(1-\cos\theta)}{15h}+1\right)$ but the period during which it acts. Assuming V to be constant from B to C in Fig. 1 for the sake of simplicity the duration of G acting from point B to C is given by the expression:

$$\underset{\text{in seconds}}{t} = \frac{h\theta}{84(1-\cos\theta)V}$$

Charts 1 and 2 have been constructed for angles of dive (θ) of 45° & 60° & 75 respectively for varying speeds V & heights of pull out 'h', using formulae above.

CHART 1

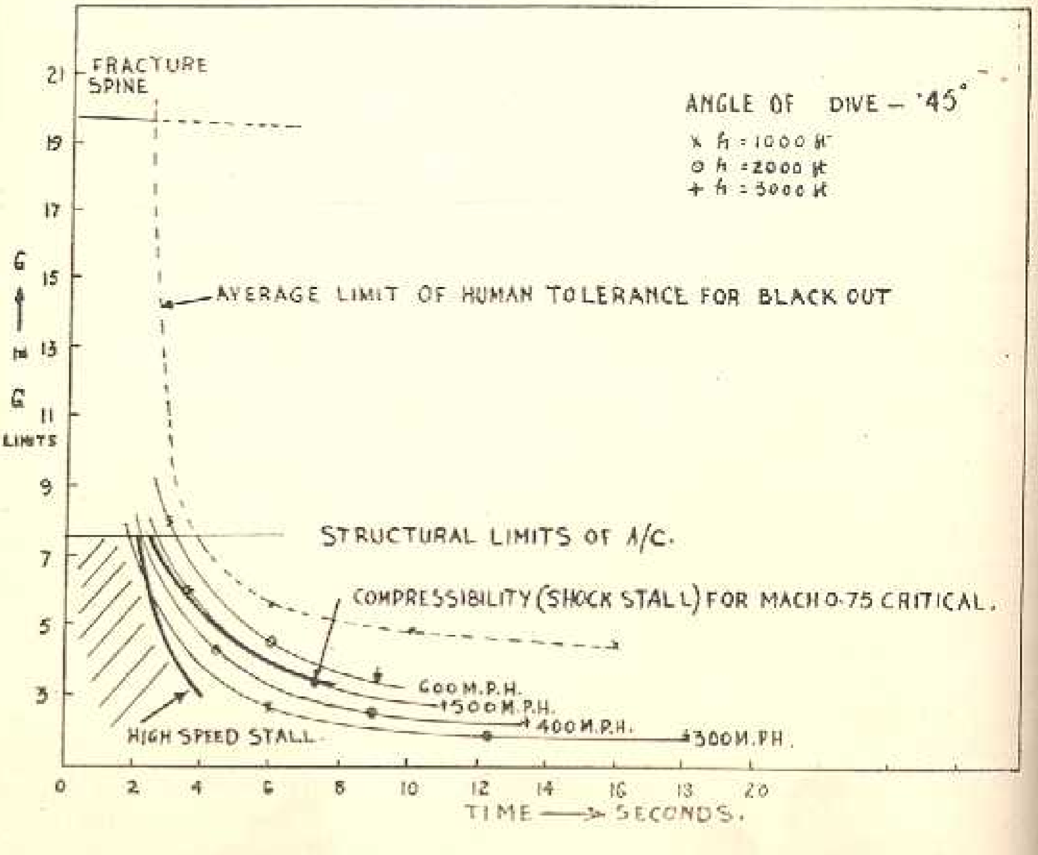
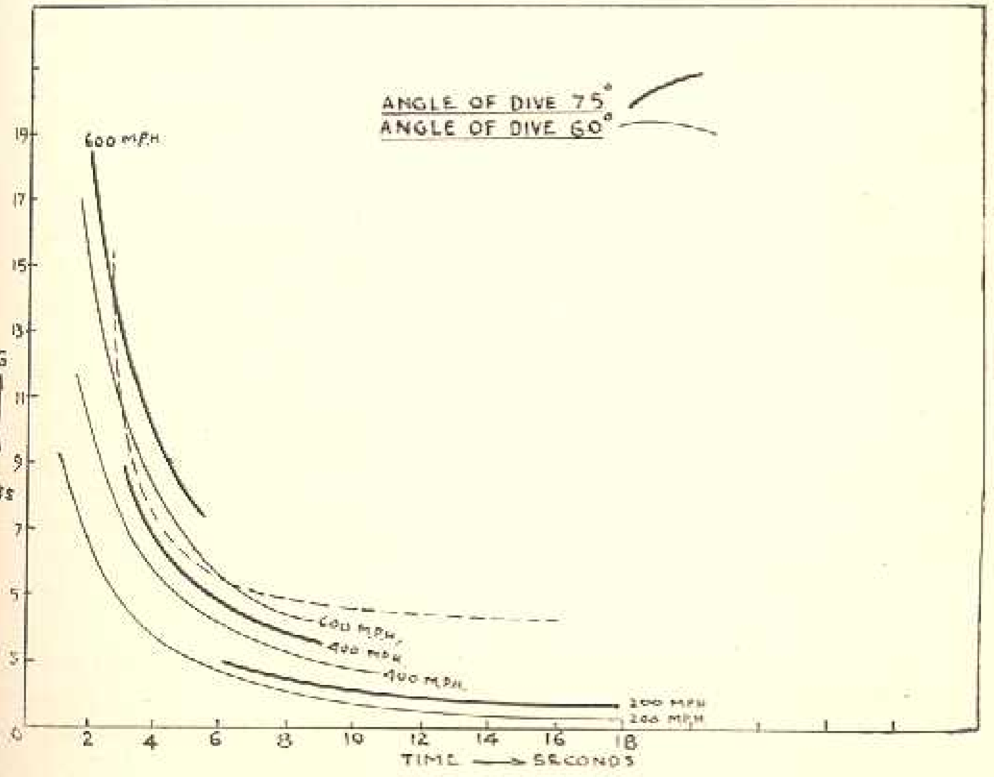


Chart 1 shows that up to 600 m.p.h. at 45° angles of dive, pull outs may be effected within any "heights" h, without black out or loss of consciousness for the *average* human subject, provided of course that the pull out is not continued much beyond the lowest point of the pull out (point 'C' in Figure 1).

Chart 2 shows a some what different picture with a shift of the G-time curves up & to the right with increasing angle of dive - so that speeds are reached when the curves first touch & then cross and recross the "human tolerance line" - vide 600 m.p.h. at 60° angle of dive line, which shows that for slow pull out lasting longer than 7 seconds, the limits of human tolerance for black out are not reached and the same situation arises for sharp pull out of durations shorter than 3 seconds. Between these two intervals of time "medium" pull out will result in black out.

CHART 2



The black out threshold is, however, not the only human aspect for consideration. Chart I shows that high G forces (19G and above) if sustained for even short intervals of time result in skeletal failure. However, this particular limitation is well above the structural limits of the aircraft which have been assumed to be in the neighbourhood of 7.5 G (Chart 1).

Indicated in Chart 1 are two other curves whose position is peculiar to the 45° angle curves of G-time. The first of these demarcates the area of high speed stalling of the aircraft and has been charted on the equation.

Stalling speed at a particular G level — Stalling speed at 1G x $\sqrt{G}$.

It will be seen that the danger of a high speed stall arises(in the case of the 45° angle of dive) paradoxically only at speeds of 300 m.p.h. and below. (e.g. at 300 m.p.h. if 6G is pulled for about $2\frac{1}{2}$ seconds).

Chart 1. indicates also (in order to produce a composite picture of the limitations of dive-bombing) the line representing the onset of compressibility effects for an aircraft with a critical Mach No. of 0.75. It will be seen that pull-outs from dives of 45° will hit compressibility effects slightly above or below 500 m.p.h. depending on the height of pull out as already defined. With increasing G loading, compressibility will be encounterd at lower speeds.

Limitations.

It can now be stated that the various limitations of dive bombing are:—

1. Compressibility (Shock Stalls)
2. High Speed Stalls.
3. Structural Limits of Aircraft.
4. Human Tolerance to Black-Out and Unconsciousness.
5. Human Tolerance to Skeletal Failure.

On theoretical grounds these various limitations have been charted in order to bring out their inter-relationships. Such a procedure appears to show that

1. Some what narrow safety zone extends upwards, decreasing heights of pull out up to the structural limits of the aircraft.

2. That the greatest danger appears to exist from fairly sharp pull-outs at *lower speed* levels resulting paradoxically enough in the so-called HIGH SPEED STALL.

3. That danger of blacking out or loss of consciousness are non-existent provided the pull-out is not continued much beyond point C of Figure 1, because of the intervention of COMPRESSIBILITY and provided the pilot is of average G tolerance.

4. It is possible at certain speeds & pull out heights to over stress the aircraft without stalling, blacking out or losing consciousness.

Points to be Noted in above Exposition.

1. The curved line representing the limits for human tolerances (Charts 1 & 2)

is for *average* individuals only. In this respect there is considerable variation from one individual to another (but see below).

2. The Charts have been worked out on purely theoretical considerations and need to be checked by aerodynamic experts and possibly by practical experiment.

3. Points B & C of Fig. 1 probably vary greatly depending on the pilots judgement of height. This introduces the human factors of height judgement which is beyond the present scope of this paper.

4. The angle of dive, θ, may be difficult to judge whilst flying and even the dive screen used for checking purposes is liable to be in serious error.

5. The curve B-C has been assumed to be the arc of a circle for the purposes of deriving the quantity $\frac{V^2(1-\cos\theta)}{15h}$. In actual practice this is merely the ideal condition. Any variation from this ideal (other factors being constant) will result in a larger G force being pulled some where between B and C for a shorter time. The effect of this on the G-time curves of Chart 1 & 2 needs to be investigated.

6. V has been taken as the maximum permissible speed which is presumed to develop at point C. The speeds preceding this point up to B will be some what less and the G developed of a lower magnitude. On the other hand this will result in time 't' as calculated being on the low side. It is possible that after experience a pilot pulls out more sharply at point B and then eases out the pull out as the speed increases up to G, thus continuously changing the radius of the pull out.

7. Visual factors have not been taken into consideration.

8. The point of bomb release, B, is assumed to be the same instant that the pilot commences his pull out. There may be a lag in this in individual cases.

9. The G-time curves of Charts 1 & 2 have been calculated for the period from B to C only and no allowances have been made for subsequent aircraft flight paths on their effect on these curves.

10. An interesting point is that of the wing over into the dive at 'A'. If this is fairly steep, it will have the effect of increasing the pilot's G tolerance for the pull out. If the dive was commenced with a push over, the negative G would have the effect of reducing pilot's G tolerance.

Human Variations in G-Tolerance

CHART 3

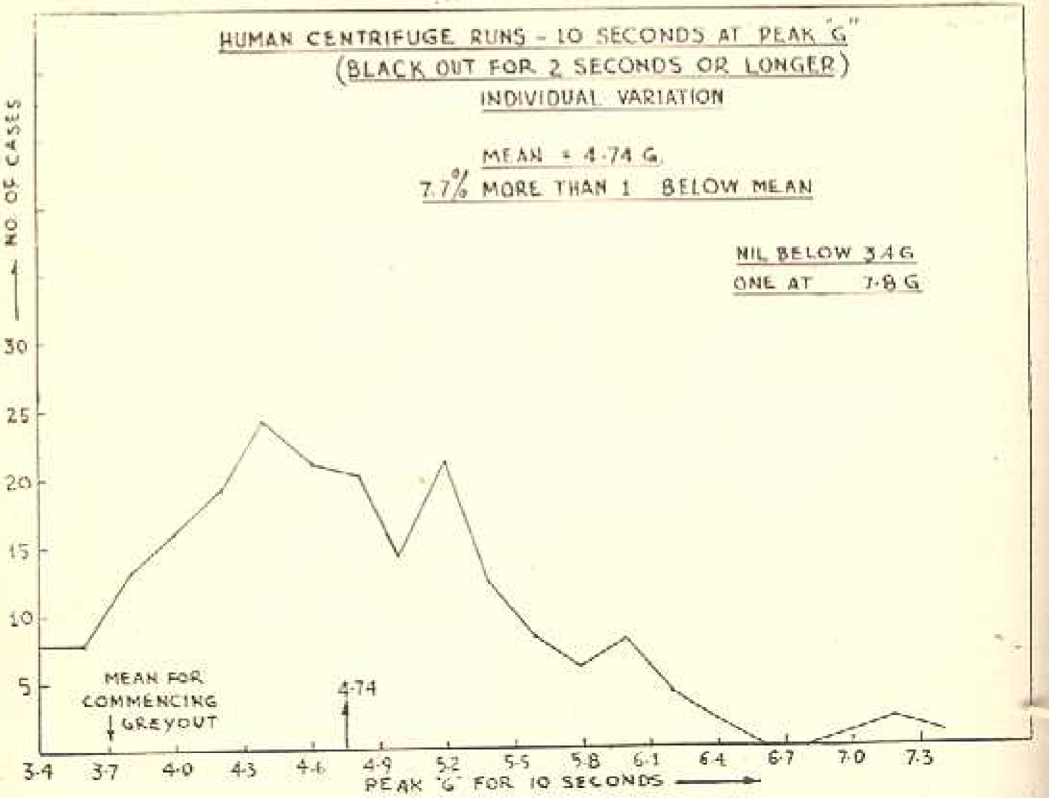


Chart 3 gives some idea of the variation (as determined on the Human Centrifuge) in tolerance to black-out amongst a series of 208 individuals, (1). 7.7% of the 208 individuals who were Service personnel show a black-out threshold of more than 1G below the mean of 4.74 G. It looks as though some even lower threshold individuals have been naturally eliminated from the group.

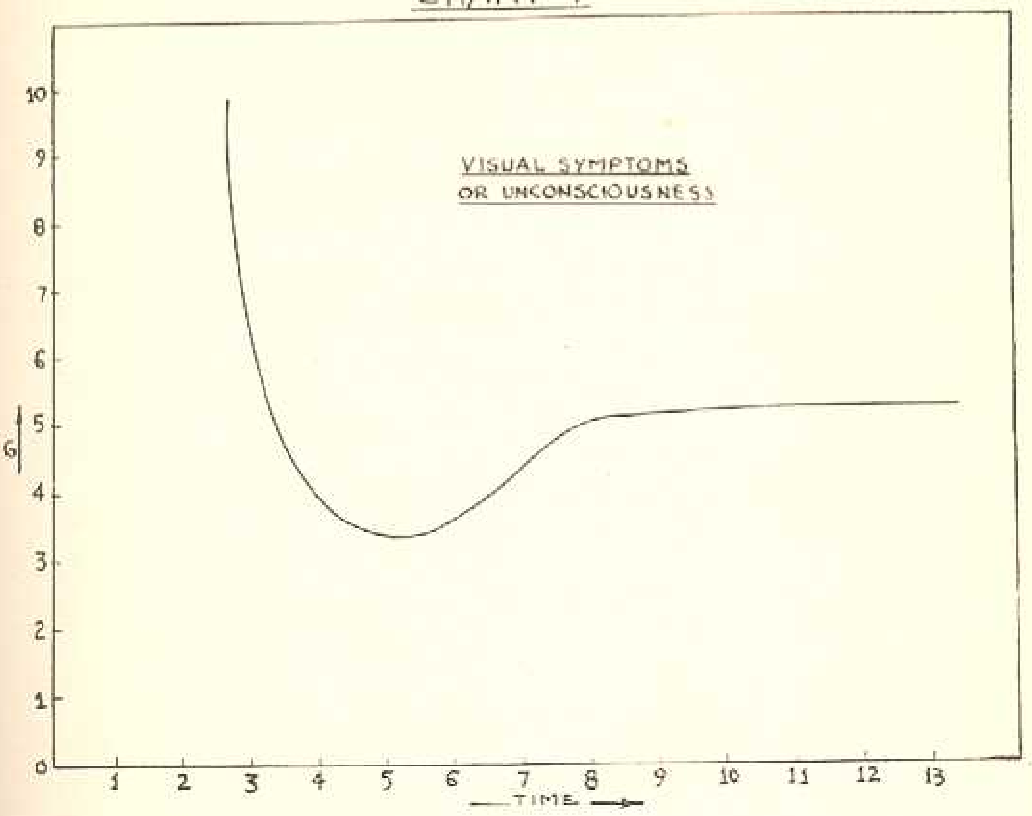
In addition, a single individual's threshold may vary periodically.

Carotid Sinus.

There is one other variation which it is interesting to consider. This is the effect of the Carotid Sinus which helps increase tolerance as indicated when discussing the wing-over.

Perhaps the curve of average human tolerance given in Charts 1 & 2 and which is a reproduction from Gagge (2) is too simple a representation. If we take the Carotid Sinus effect into consideration the curve may look more like that reproduced from Martin and Henry (3) see Chart 4.

CHART 4



When human variations are taken into consideration it will be seen that personnel with a low threshold or those suffering from a lowering of their normal threshold come very much into the picture and may suffer from visual symptoms or loss of consciousness in dive bombing manoeuvres.

Recommendations.

Pilot before commencing dive-bombing training or exercises should:—

1. Be suitably briefed regarding the various limitations involved.

2. Have some idea of their individual threshold & variations to centrifugal accelerations. This may be gained by previous set exercises involving sustained sharp turns or descending spirals provided accelerometers are fitted in the aircraft, or on the Human centrifuge.

3. Should be throughly conversant with certain self protective menoeuvres.

If accurate information is to be provided to the aircrew, an airborne Acceleration laboratory or a Human Centrifuge is an urgent I.A.F. requirement. Work with these will help save lives and aircraft.

References:

1. Normal Variation in Tolerance to Positive Radial Acceleration - by Lt. Comdr. Floyd. R. Stauffer - Journal of Aviation Medicine - June, 1953.

2. Aero Medical Problems of Space Travel - Lt. Col. A. P. Gagge - Journal of aviation Medicine. Dec. 1949.

3. The Effects of Time and Temperature upon Tolerance to Positive Acceleration-by Ernest. E. Martin & James. P. Henry. - Journal of Aviation Medicine Oct, 1951.