Some Thoughts on Airworthiness Requirements

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Summary

The basic principles and some particulars of the requirements are reviewed with an eye to the extension of the OSTIV AS to lower weight classes. In the new domain the character of the structure, primary controls and undercarriage might cause special problems. The extension presents an opportunity to convert to chaotic interpretation of some natural laws in the theoretical concept of the standards. A few remarks on service loads and stress are made and a short summary of handling criteria is given.

Notation

f	eigenfrequency	1/s
g	acceleration of gravity	9.80665 m/s^2
$\bar{i}$	number of load peaks exceeding the level	1/landing
k_e	elevator stick displacement	mm
n	normal load factor	
D	damping ratio	
F_e	elevator stick force	N
L_g	length of ground run	m
M	sailplane mass	kg
M_T	tow plane mass	kg
P	probability	
S	design wing area	m^2
T_1	time constant of first order mode	s
V	flight speed	m/s, km/h
α	angular eigenfrequency	rad/s
μ	mass ratio	

Subscripts

a	short period mode
D	Dutch roll
p	phygoid mode
T	aerotowing
t	for the tow plane
W	winch launching
x	rolling mode
0	without damping
y	yawing mode

Introduction

In view of a planned extension of the application range of OSTIV AS it seems appropriate to review and – if and where necessary – supplement some of its principles and requirements. Gerhard Waibel, in his opening paper (1), has given a clever summary of guiding principles to be observed in the discussion concerning the planned extension of the application range of OSTIV AS, at the same time listing some formulae for operational speed limits, too, for showing the differences in various national standards. Following the invitation for joining the work, may I add a few remarks to it.

Practical applications of airworthiness standards is based on a balanced sharing of rights and responsibility between the authority, the designer/manufacturer and the user. In its present form the OSTIV AS is reflecting the technical level and financial capacity of these parties in the line of gliding. Extending the domain of competence to lower weights and to different classes may include manufacturers and users having substantially dissimilar levels in technology and finances. Can this problem be left to the national authorities, or should some parts of the standards be adapted to it? Is it advisable to amplify the standards with some acceptable means for compliance, or should we keep an eye on publishing monographs like e.g. the handbook of Stender and Kieseling (2)?

Scope and Extent of the Extension

The purpose and the planned new boundaries of the extension are not quite explicit in the paper of Waibel (1). Taking it literally, only the upper and lower limits of the maximum allowed take-off mass should be extended leaving the competency of the standards limited to conventional sailplanes. But quite a number of new concepts materialized in the last decades, mostly without a full and common legal standardization. Will our extension cover some of them, too, or not? In this respect, the upper range extension doesn't give major problems: beyond the future limits JAR respective FAR standards can and will be used.

In case of a wider extension, involving also new classes, the lower range presents a much more difficult task. In order not to overregulate but nevertheless to pay the necessary attention to each of the respective new classes the following characteristics may be considered:

a) type of the primary structure: is the wing profile holding its form or is the wing stretched out only by the pressure distribution;
b) type of primary controls: are the control moments produced by aerodynamic means (control surfaces) or control by CM transfer;
c) undercarriage: has the aircraft a mechanical undercarriage (wheel(s) resp. skid(s)) or take-off and landing on foot.

If the aircraft to be licensed is out of bound in one of these specifications either a proper Airworthiness Standard or a supplementary class in OSTIV AS may be recommended.

Theoretical Basis

Waibel (1) has set down that "An airworthiness requirement is not a schoolbook how to build an aircraft," but nevertheless a good Airworthiness Standard reflects the modern scientific way of thinking, thus encouraging new developments. Theory and practice have always been well balanced in gliding, being many times in the forefront of the former while keeping to the current requirements of the latter. Particulars of the requirements are mostly drawn up to cover the practical problems, but only a sound theoretical basis can assure a harmonic and balanced set of the specifications.

In the beginning, aeronautical engineering was based on the concept of traditional deterministic natural laws. Flow turbulence and fatigue problems necessitated the introduction of stochastic data analysis methods and probability concepts.

This change was made possible by expanding the domain of probability theory to include continuous functions as well, opening the way to correlation functions and spectral analysis. Strictly speaking, the autocovariance function and the spectral density function derived from it constitute trespassing the boundaries of the traditional probability theory based on the sequences of statistically independent discrete variables. But this broader application did not cause calculation errors because the laws regulating this domain are more strict than those of the probability series.

The theory of turbulence was going unobtrusively farther, using the differential equations and adopting such – at that time seemingly special – concepts as the integral scale and Taylor's scale. Some five decades ago, following the early perception of Poincaré, a new province of mathematics, named for short chaotics, came into being. Radically new conceptions and methods were introduced and turned out to be suitable to the analysis of nonlinear differential equations. Turbulence is one of the favorite matters in chaotics.

At first sight it seems strange that on our part there is no sign of following this line, except taking notice of the strange attractor for turbulence. What might be the causes of this? The basic concept is, and most of the methods of chaotics are, of a deductive character postulating the knowledge of the system of the determinant differential equations. In our case this is true only for turbulence, and even in this case going through the whole set of deductive procedures would be mostly uneconomic or even impossible. Therefore, we are developing another, inductively formulated set of chaotic numerical procedures using only the records of the movements, forms, etc. for the analysis.

In retrospect it seems that this started actually with the Kovásznay theorem (3). Based on it, Gedeon (4, 5) initiated the use of turbulence-type spectrum formulae for road/terrain or railway track modeling and input/output calculations. Further publications reported on the substitution of complex eigenspectrum vectors for spectrum matrices in multiple input-output calculations, on modeling of stochastic surfaces, on regular-instationary stochastic functions, etc. Finally the need and the possibility for a full conversion vas indicated by the unexpected character of the spectra of four atmospheric turbulence records measured at the Institut für Physik der Atmosphäre, Oberpfaffenhofen (Gedeon (6,7)).

Of course, this planned conversion – or unification – cannot be done in a few months or even years but it will need the professional and devoted work of many man-years. Our first impressions are as follows.

It seems useful and necessary to begin with the reconciliation of the elementary concepts and record assessment procedures. To our surprise, the first attempt for a very simple and universal new procedure for the classification of the records and rating of the sampling frequency, moreover a deficiency in the standard definition of the geometric similarity has been found (Dóra and Gedeon (8)). On the other hand, the strange and unique turbulence spectrum structure found for the aforementioned Oberpfaffenhofen records is still not accepted by us to be sure and exact. We are aware of the limitations of the measuring process and of the Fourier calculus. As indicated at the end of our last OSTIV paper (8), we try to check on them by way of the phase portrait. The second variant of the planned calculation procedure seems to work well and we will try to get a more detailed and realistic model of the fine structure of turbulence.

For short, we have now the opportunity to establish major general improvements in theory and in the calculation procedures. How much of this will be directly applicable to the OSTIV AS is not yet clear; however, it will have its use. Anybody intending to join this work will be welcomed by the present two-man task force.

After this general introduction, more specific remarks follow.

Service Loads and Stress

Launching and Ground Loads

Aerotowing

Waibel (1) called our attention to the unpleasant possibility of underpowered tow planes, especially in the lower weight classes. A possible way of solution – perhaps useful in general terms, too – may be the introduction of a minimal towing speed V_{Tmin}. Requirements for licensing a tow plane type for a sailplane type can include then the following.

1. A parameter to be considered might be the tow plane – sailplane mass ratio:

$$\mu = \frac{M_t}{M} \qquad (1)$$

   The license of the tow plane should restrict the types of sailplanes to the mass ratio range of e.g. $1.2 \leq \mu \leq 5$.
2. Sustained tow while holding height or in climb should be demonstrated in the speed range $V_{Tmin} \leq V_T \leq V_{Tmax}$.
3. A steady climb of at least 1.5 m/s is to be demonstrated at a speed in this range.
4. The length of the ground run at take off L_{gmax} must not exceed e.g. 60 m.

For convenience requirements 3-4 might be covered by choosing an appropriate upper limit of the weight ratio.

Winch Launching

Winch loads can be calculated fairly correctly and easily, as documented by flight measurements of Dezső Györgyfalvy (Gedeon (9)). A short control of the present requirements using data of recent new designs would be a most welcomed addition to it, the more if enlarged with some flight measurements on recent designs.

The true break strength of winch cables can imply real hazards for light sailplanes if not paid properly attention to it. Weak links are not used in some countries and cables used for the normal weight classes might be too strong for the new classes. And what about cables conducing to frequent cable breaks because of wear and fatigue? Can we do something about them?

Landing

Sailplanes and similar light sport aircrafts are to be stressed for landing regularly on unprepared (fairly soft) grounds. Load statistics measured on old types (Fig. 1, Gedeon (10)) gave approximately regular load statistics and showed the benefits of a soft and damped undercarriage. Analysis and publication of newer designs would be welcomed for fatigue load collectives and because at that time the greatest load peaks were registered not at the moment of landing but later in the landing run. If this tendency has not changed then our requirements give good maximum load ranges but using an incorrect calculation procedure. The author suspects that the procedure is right for the modern undercarriages but a check would be reassuring.

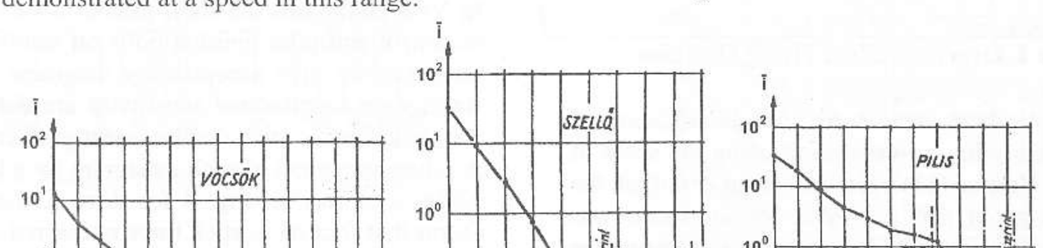

Figure. 1. Landing Load Statistics for Three Types (Gedeon (10))

Flying Qualities

The problem of finding the optimal size, specifications and formulation for the requirements is increased for the part on handling because the design and testing for satisfactory flying qualities is a problem of moving in six degrees of freedom unaccustomed to mankind. Type classification to good or to dangerous requires much more than some numerical checks on a number of single measurable parameters. A well-balanced, agile and at the same time docile sailplane is a distinguished card of the designer as well as of the flight test pilot.

OSTIV AS Section 2

Flight imposes a substantial number of safe and useful detail requirements but without presenting the objectives, domain of competence and a classification of the handling requirements and there is no complete logical summary of the domain. Fig. 2 tries to propose a possible classification design intended for starting the discussion.

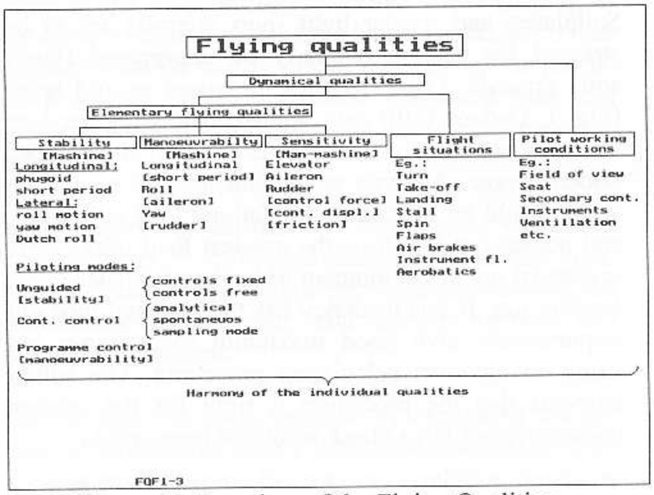

Figure 2. Overview of the Flying Qualities

Up to now the best method for the classification of handling is the pilot opinion rating using the scale of Cooper and Harper (11). The statistical proof of the method was given and a variant for sailplanes was composed by Gedeon (12,13). In design and testing the recommended relevance and chronological order is the following: *elementary qualities* $\rightarrow$ *flight situations* while the problem of pilot working conditions remains the responsibility of detail design. A short sketch of the basic methods of flying qualities design philosophy are given e.g. by Gedeon (14).

The motion of the glider is described by the equations of motion according to the six degree of freedom of the movements. These differential equations can be linearized and separated in longitudinal and lateral parts.

For the longitudinal motion the characteristic equation of the linearized differential equations reads in factorized form:

$$\left(\lambda^2 + 2D_a\alpha_{0a}\lambda + \alpha_{0a}^2\right)\left(\lambda^2 + 2D_p\alpha_{0p}\lambda + \alpha_{0p}^2\right) = 0 \quad (2)$$

For the lateral motion it is:

$$\left(\lambda + \frac{1}{T_{1x}}\right)\left(\lambda + \frac{1}{T_{1y}}\right)\left(\lambda^2 + 2D_D\alpha_{0D}\lambda + \alpha_{0D}^2\right) = 0 \quad (3)$$

As regards the longitudinal motion we have therefore for the short period mode:

$$f_{0a} = \frac{\alpha_{0a}}{2\pi} \qquad f_a = f_{0a}\sqrt{1 - D_a^2} = \frac{\alpha_{0a}\sqrt{1 - D_a^2}}{2\pi} \quad (4)$$

For the phygoid mode it reads:

$$f_{0p} = \frac{\alpha_{0p}}{2\pi} \qquad f_p = f_{0p}\sqrt{1 - D_p^2} = \frac{\alpha_{0p}\sqrt{1 - D_p^2}}{2\pi} \quad (5)$$

In VFR conditions the short period mode seems to be dominant and pilot opinion polls on stability and manoeuvrability give acceptability diagrams like Fig. 3. Ratings on longitudinal sensitivity are determined by the stick force – stick displacement gradients (Q feel). A schematic graph of such a diagram for a hypothetical glider is shown on Fig. 4 for three CM positions. It seems that friction to stick force ratios, not shown here, also strongly influence the ratings.

By the way, caution or even warning must be expressed against trimming by use of a spring. It diminishes or even terminates the Q feel essential for intelligent flying!

The phygoid mode is dominant in case of IFR flights because of the longer brain delays when flying on instruments. We have as yet less data than for the short period case.

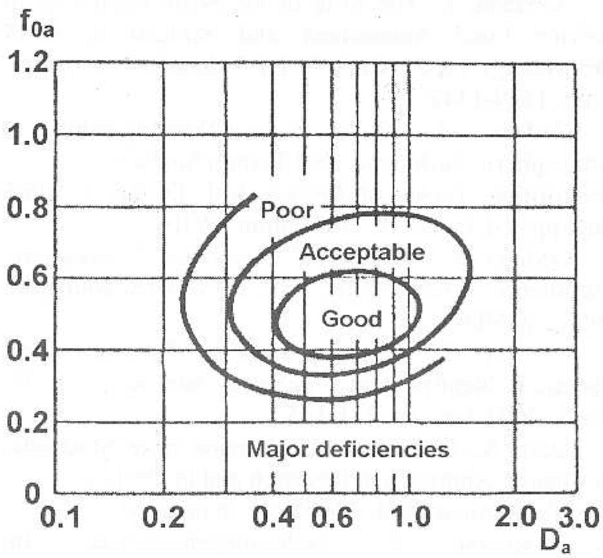

Figure 3. Pilot Opinions on Short Period Frequency (after Shomber & Gertshen(15) resp. O'Hara (16))

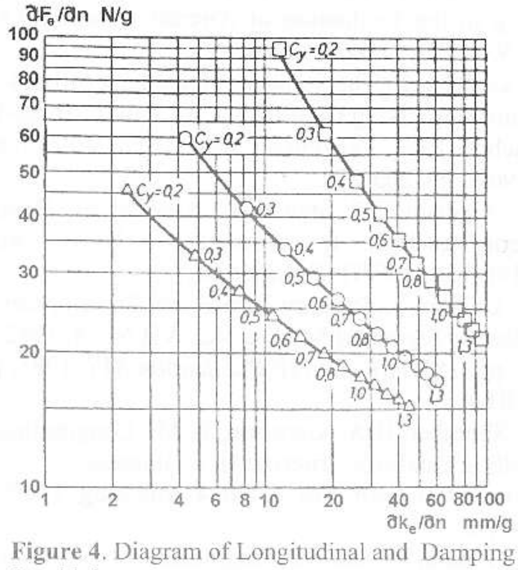

Figure 4. Diagram of Longitudinal and Damping Sensitivity

In the lateral modes the Dutch roll is a full three degree of freedom oscillation having the frequency

$$f_{0D} = \frac{\alpha_{0D}}{2\pi} \qquad f_D = f_{0D}\sqrt{1 - D_D^2} = \frac{\alpha_{0D}\sqrt{1 - D_D^2}}{2\pi} \tag{6}$$

This oscillation mode can cause problems primarily in aero tow. Of course, in tow the eigenfrequency and damping is different from that given by (6). Water ballast in the wings increases the moment of inertia lowering thus the Dutch roll frequency and damping ratio. With water tanks full, the sailplane feels to be quite different, so to say a different type from the handling point of view.

The second mode in lateral movements separates usually into two first degree modes in roll and in yaw respectively. Pilot induced oscillations are therefore practically excluded in these modes. A general summary of the pilot opinions on the rolling mode after O'Hara (17) is shown on Fig. 5. It was collected on simulator and it seems to be valid for different classes of aircraft. For sailplanes it can be summed up to recommend as much aileron power as possible without fear of PIO problems.

In the yaw mode stability in holding the course is desirable but otherwise there are few if any problems in construction for ease in piloting.

Sensitivity in the lateral modes does not make a serious problem. If the elevator forces are right then the ratio of the control force limits in Section 2.13 gives an acceptable control stiffness ratio, albeit compliance with the aileron forces limit may pose real problems.

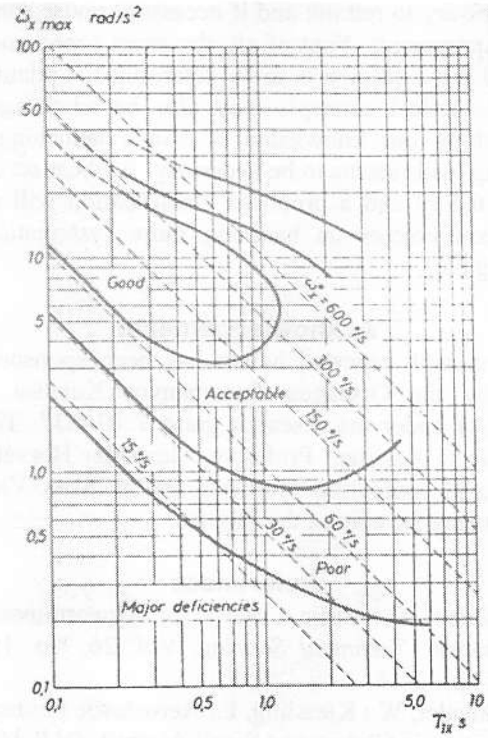

Figure 5. Pilot Opinions on Rolling Mode (after O'Hara(17))

Discussion of the various flight situations will require too much place and time so the author ask to be exempted from it in the present paper. When required, it can be supplemented in another study.

Concerning seemingly secondary handling problems nevertheless directly connected with safety the following may be mentioned.

Section 2.32: Use of Air Brakes

The opening of the air brakes may have two unwanted secondary effects: the decrease of the lift coefficient and a change of the longitudinal moments. The decrease of the lift is a minor inconvenience increasing slightly the landing speed. A sudden or inadvertent opening when flying near the ground can cause serious accident in this case. In cloud flying the change of the longitudinal moments can be dangerous when air brake opening is necessitated because of problems with speed control.

A more detailed formulation of this section is proposed giving single requirements to the lift coefficient decrease and to the change of the moments respectively. The former can be expressed perhaps in terms of the percentile increase of the stall speed, the latter as the elevator displacement necessary for re-trimming.

Conclusions

Because of the planned extension of the OSTIV AS it is necessary to rethink and if necessary revise some of the requirements. First of all, the exact scope and extent of the extension is to be determined. Updating of the theoretical concepts may also be advantageous. Refreshing our knowledge of winch launching and landing loads seems to be necessary. Publication of the basic theory and a proposed classification will make the requirements on handling more systematic and intelligible.

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