# BASIC CRITERIA FOR AIRWORTHINESS REQUIREMENTS

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**SUMMARY**

OSTIV President, Professor Loek M.M. Boermans, has asked the OSTIV Sailplane Development Panel to extend the application range of OSTIV Airworthiness Standards (OSTIV AS) to slightly higher but mainly lower take-off weights (TOW), than sailplanes and powered sailplanes currently covered by OSTIV AS. In order to adapt the data and numbers given in OSTIV AS for other TOW in a suitable and clever way, basic criteria for airworthiness requirements must be established, or, when already available, they must be revised and implemented into the coming SDP efforts. The author tries to summarize, what he already knows about the subject and asks for more input on the subject in order to complete the basic requirements.

**PREFACE**

An airworthiness requirements is not a schoolbook on how to build an aircraft, but a collection of minimum requirements, the fulfillment of which is officially accepted as condition under which a new design may become airborne in a responsible way.

A good requirement should restrict the designers freedom as little as necessary, but also give them enough room for new or even unusual solutions. Presenting final solutions to design problems cuts creativity and stops evolution. But with the development of aircraft to more extreme sizes and speeds, airworthiness requirements have to be extended. To do this in a clever way, an understanding of the basic ideas behind the requirements is necessary. This paper wants to discuss some of these ideas and invite those persons who participated in the development of airworthiness requirements in the past to also make inputs.

**EVOLUTION OF BASIC CRITERIA**

For humans, flying is inherently dangerous, more than ground and sea traffic, however a bit easier than traveling in space.

That an acceptable level of safety in aviation has been achieved in a result of elevated levels of care and responsibility in aircraft design and operation. These levels are usually higher than those for land vehicles and boats.

In his article about "The Nature of Flight Limitation" [Lit. 1], H.A. Tarode summarizes the background of current airworthiness requirements. The article is a key to the problem addressed in the title, but not all information necessary to invert the task, how to make a good requirement, is given there.

In LBA-Note M531-423/2001, see [Lit. 2], Uwe Irmer reports about VD in different requirements.

Richard Eppler read a paper about $V_D$ – calculation and simplifications of requirements recently, see [Lit. 3].

**1st criterion: Protection of persons (and environment)**

Protecting

- the public,
- passengers
- and the pilot

is a major concern of airworthiness requirements. I would like to add to also regard the environmental impact like consumption of resources or noise and other emissions. Those should be regarded and appropriate requirements that must be weighed against the use of an aircraft in its lifetime.

Examples:

This means that light weight and low speed aircraft having low impact energy should have less stringent requirements than heavier and faster ones.

Also when only a little or no fuel is on board, more relief is possible.

Noise and exhaust emission must be weighed against the expected engine operation time during the whole lifetime of an aircraft. As an example noise and exhaust emissions of a touring motorglider, with the engine almost permanently running, must be treated more restrictively than a sailplane with a foldable power-plant where a few percent engine time compared to the total operating time are usual.

**2nd criterion: Safe load factor and speed combinations**

Another great subject regarded by airworthiness requirements is the so called "design envelope" which describes the combination of load factors and speeds within which the aircraft can safely be operated, and also which maneuvers can safely be done. Inside the "design envelope" there are areas inside which natural laws guarantee inherent safety against overload in any operation. This range is usually marked green on the air speed indicator. There are yellow marked ranges at elevated speeds as well as a non marked narrow speed range near stall, where some load and speed combinations are restricted. In these speed ranges, care and responsibility are needed for safe operation. The maximum speed, usually marked by a red radial on the ASI, is usually much lower than speeds at which the aircraft becomes uncontrollable. Very efficient aircraft must have airbrakes to control speed. The operational part of the design envelope, the so called maneuvering envelope, can be influenced b the pilot directly. Here training and experience of the operating crew may be compensated by relief in static strength.

**3rd criterion: Environmental impact on the aircraft**

There is another design envelope which results from the fact that the aircraft is operated in the natural air mass. They so called gust envelope is concerned with the impact of atmospheric turbulence.

Also in that aspect speed and load factor combinations are given, within which operations are inherently safe, but also a low-speed range as well as a high-speed range is only open for (restricted) operation, when the turbulence of the air mass is foreseeable low and/or high energy turbulence air mass can be avoided by operational means.

In the case of small aircraft, including big sailplanes that must land on suitable but unprepared ground, OSTIV SDP has done some work. It has been determined that the ground loads must not only be connected with take-off or landing mass, but also be strongly dependent on landing speed, emergency landing conditions included.

Some aircraft must be towed to altitude in order to get into soaring conditions of the atmosphere and able to handle these conditions.

Environmental conditions can only partially or even not at all be controlled by the pilot. Here a speed range must be defined, inside which operation is inherently safe and, in case of ground contact, minimum emergency conditions must be covered.

**4th criterion: Structural strength and stiffness of the airframe**

A major subject of any airworthiness requirements is the structural strength of an airframe required by the load factor and speed combination as has been discussed.

These must regard inprecision in airframe design, construction materials and process and environmental impact on the structure. A rather low but adequate safety factor (usually only 1.5) must give a reserve in strength for unforeseeable risks.

Also stiffness and mass distributions of the airframe itself must be limited by tolerances in order to avoid overload or aerodynamic and aeroelastic instabilities (flutter).

**5th criterion: Input from operational experience**

Associated with the subject above is the experience gathered in accident investigation, which result in appropriate requirements as far as improvement that can be expected by design rules.

By doing this changing factors are regarded, which may result from new operational procedures or missions.

Human abilities must be regarded in such a way to not exclude too many persons from aviation — because of being too small and lightweight, or too tall, too heavy or too strong (in a panic).

**6th criterion: Flying qualities and flight training procedures**

This criterion leads to requirements for which minimum flying qualities must be demonstrated. Also a minimum standardization must be regarded, so that a pilot has only minor problems in familiarization when changing from one aircraft to another.

Flying qualities have an obvious impact on flight safety. Also, accident examinations contribute heavily to the requirements and transferring current requirements to other categories of aircraft requires very professional judgment.

**Sub-Criteria:**

After the major subjects are specified, criteria that are more precise must be given. Many of them are interconnected.

**Masses**

Aircraft categories are usually limited by their maximum masses (MTOW) in operation. The simple idea behind this fact is:

A heavy aircraft is usually large, carries many passengers, much fuel, and is also relatively fast. This leads to high kinetic energy at impact in a crash, endangering the public, passengers and pilots.

**Speeds**

The speed also contributes highly to the second power, to the kinetic energy. Thus, besides the mass, the potential speed levels must be considered.

**Mass and speed combination**

So for large mass and/or high speed aircraft, the highest precautions must be applied resulting in quite detailed requirements. Also, highly qualified persons are registered to operate these planes.

**Mass and load distribution**

Associated with mass and load is its distribution to the components. This has an important impact on strength and flying qualities and must therefore be limited within reasonable boundaries.

**Maximum design speed VD and maximum speed in operation $V_{NE}$**

For speeds, the maximum speed is most significant.

$V_D$, the dive speed, cannot be arbitrarily chosen. In case of JAR 22 a minimum sinking speed must be shown at that speed in aerodynamically clean configuration. The idea behind this may be that altitude can be controlled even in big areas of lift — even in the magnitude of 7.5 m/s vertical component, it is possible to dive away from a cumulonimbus without getting sucked inside. The formula given for sailplanes in JAR 22 is very special compared to other requirements. In operation, $V_{NE}$ is marked by a red radial line on the ASI. The never-exceed speed, $V_{NE}$ has to be close, but below $V_D$.

AIR 20 54:

$$V_C = 54\sqrt{\frac{m/s}{100 \cdot c_{xE=7}}} \quad \text{[km/h]}$$

$$V_D = 1{,}05 \cdot V_C + 40 \quad \text{[km/h]}$$

$$c_{xE=7} = c_D \quad \text{with} \quad L/D = 7 \text{ (clean configuration)}$$

BCAR D: $V_D > V_C!$ $V_C = 70$ mph

semi aerobatic: $1{,}6 V_C$
full aerobatic: $1{,}8 V_C$

BCAR E: $V_D = 3{,}0\ V_S$ normal
$= 4{,}5\ V_S$ semi acro
$= 5{,}5\ V_S$ full acro

where Vg is the stall speed.

RLD: $V_D > K\sqrt{S}$

| | normal | | acro | |
|---|---|---|---|---|
| K: | 46 | - | 52 | very good aircraft |
| | 42 | - | 48 | |
| | 38 | - | 44 | |

FAR 23: $V_D = 6{,}34\sqrt{\frac{n_1}{W/S}}$ [m/s] W/S in [kg/m$^2$]

$V_D = 27{,}3\sqrt{\frac{n_1}{W/S}}$ [knots] W/S in [lbs./sq. ft]

$n_1$ = safe positive load factor
$n_1$ = 4,4 for Utility, $n_1$ = 3,8 for Normal, $n_1$ = 6,0 for Acrobatic

FAR 25: $V_D = V_C / M_C \cdot 0{,}8$

$V_D$ / $M_C$ is determined by a 7.2° pitch down manoeuvre for 20 seconds followed by a mild 1.5 g round out and reduction of throttle setting.

$V_A = V_{S1}\sqrt{n}$

All requirements agree in that $V_D$ is greater than the max speed $V_C$, which is the highest speed used in operation. So when something goes wrong in operation near or at VC, careful corrections with controls must still be possible.

**Maneuvering speed $V_M$ or $V_A$**

The maneuvering speed $V_M$ or $V_A$ is always given as a multiple of the stall speed in clean configuration and maximum weight, with the factor $\sqrt{n_1}$ Here $n_1$ is the load factor for stall at $V_A$ (see AIR 2054, FAR 25, FAR 23, BCAR D, BCAR E, JAR 22, OSTIVAS).

The load factor $n_1$ goes up with aerodynamic quality and operational strain (aerobatic). Thus, the background for the maneuvering speed is well set with these two criteria. A high aerodynamic quality results in a high speed ratio, $V_A/V_{S1}$. For sailplanes n1 varies between 4 9BCAR E) and 5.3 in category u (Utility), and up to 6.5 (BCAR E) and 7 (JAR 22/OSTIVAS) in category A (Aerobatics). Whereas the load factor 7 has something to do with human factors (tolerance of short time g-loads in a seated position), $n_1$ = 5,3 results from the good aerodynamics of sailplanes, which in turn result in a wide usable speed ratio $V_A/V_{S1}$.

As aerodynamic quality will constantly be improved, fixed values for $n_1$ are not adequate. Their consequences together with modern design parameters (weight, size, stiffness) have to be constantly monitored and adjusted in regard to whether they reach the goal they were set for. Circumstances change and a sentence like e.g. "goed gevormde Zweefliegteugen met vrejdragened vleugels" (well shaped gliders with cantilever wings) as used by RLD in 1965, do not seem appropriate today.

$V_C$ or $V_{NE} > V_A$ is always agreed with a safe speed margin to carefully correct conditions that may show up when things have gone wrong exceeding $V_A$.

**Rough air speed VB and other gust speeds**

Gust loads according to criterion 3 above are loads an aircraft (and its occupants) experiences without pilot involvement. They originate in the atmosphere due to turbulence. Generally only one type of gust, either sharp like a step or of the (1-cos) type is given. All requirements agree in that the gust speed $V_B$ must be equal or greater than the maneuvering speed. Gust strength may vary from 15m/s vertical up or down speed for a sharp edged gust to 20 m/s for the maximum of a (1-cos) shaped gust.

For gust speeds above $V_B$ the maximum gust loads decreases to 7.5m/s vertical up or down speed at $V_D$. For powered sailplanes, a value in between is given for $V_C$.

For sideways gust appropriate conditions apply, assuming that the turbulence is isotropic (i.e. horizontal and vertical gusts are the same). Only JAR 22 requires stronger horizontal gusts. OSTIV-SDP has checked this problem and agreed that horizontal gusts are stronger than vertical ones, at least at lower flight levels where sailplanes(and other light aircraft) are frequently operated.

**Other operational speeds**

For other operational speeds sometimes fixed values are given. This may be correct within several weight classes of aircraft, however when the weight limits are disregarded, the operational speeds should be a constant factor of the stall speed. When external operational conditions are given, provisions must be made so that these components are compatible (e.g. a slow lightweight sailplane must not be towed by too fast a tow plane, or too weak winches must not try to tow heavy two seat sailplanes).

This is an area which, to my knowledge, is not covered by appropriate regulations yet and created a lot of headache in the past, see towing sailplanes with (over-) powered sailplanes and UL-aircraft.

**Pilot information**

As discussed above, most speed limits are given together with appropriate load factors n. The so called V-n-diagram is the boundary of the design envelope inside which the operation of the aircraft is safe.

Having shown the criteria for speeds and their appropriate load factors, we can better understand the color codes on the ASI.

There is a green range, starting with safety margin above stall, ending at $V_B$, within which the aircraft is remarkably safe as gust and abrupt maneuvers will stall the aircraft but not break it.

Approaching $V_C$ or even $V_{NE}$, only reduced maneuvers are allowed, as well as the turbulence level must be limited. This range is indicated by a yellow arc at the ASI and the famous red radial at VNE that shows the absolute speed limit.

Lights on instruments are showing an equivalent level of safety or its degradiation:

| | |
|---|---|
| Steady green light | normal operation |
| Steady yellow light | caution range |
| Steady red light | a limit is reach or exceeded |

Together with this philosophy of lights goes the classification of unusual condition in the manual:

| | |
|---|---|
| • | Notes |
| ! | Caution |
| □ | Warning |

A note draws attention but is not related to safety. When a caution is disregarded this leads to a minor or long term degradiation of flight safety. When a warning is disregarded an immediate or important degradiatin of flight safety has to be expected.

**Control systems**

Control surfaces and systems must be designed such that small pilots having both small forces and small stroke can correctly command the aircraft. On the other hand tall and strong pilots must not overstress controls in a panic. This is perhaps why minimum mass and minimum age are required to pilot an aircraft, apart form minimum mental and medical requirements.

**Ground loads including emergency conditions**

Operational requirements result in ground loads. It is a difference whether an aircraft is designed to operate from unprepared ground, like sailplanes must do in an outlanding, or on prepared (hard) surface air fields.

Landing gear requirements will have a strong impact here and landing gear loads and emergency landing requirements will be closely associated, whereas in a big transport aircraft both cases seem to have no connection.

**Launching loads**

For both towing aircraft and sailplanes, launching loads are to be regarded, where a wing launch may be a determining load case. This shows why this subject has to be carefully regarded in design and operational requirements.

A lot of operational experience is laid down in the appropriate requirements and the operational rules.

**Design and construction**

In design and construction requirements, the feedback from manufacturing and operational requirements is obvious.

In most requirements the historic background is no longer apparent. In such cases it would be very helpful to have the historical background in order to correctly apply the experience to an extended application range of OSTIVAS.

Standards for handles, motions and color codes have been developed and should be further encouraged.

Flight monitoring instruments and other pilot information

Minimum flight monitoring instruments, placards and flight manuals may depend on the complexity of the airplane and may differ even inside a group of similar airplanes. Also, design and operational circumstances can interfere strongly with each other.

Requirements for engines and propellers are so special that they must not be regulated here, however, adopted following the guidelines given in by the criteria 1 through 5 above.

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**Literature**

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