**FLIGHT ENVELOPE**

(Example document for LSA applicants – v1 of 08.03.16)

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## Introduction

This document defines the flight envelope of the ABCD aircraft. The requirements are referenced in the compliance checklist of the certification programme ABCD-CP-00.

The boundaries of the flight envelope will be defined within this document. All speeds are calibrated airspeeds (CAS) (requirement 4.4 [1]) and given in knots if not stated otherwise.

All other units used are metric (SI units).

The weights are given in mass units (kg) but the formulas require force units as input, therefore these are calculated in place wherever they are used.

*Note: The speeds defined within this document should be used for the placards, speed markings, aeroplane flight manual (limitations), load calculations and need to be verified by flight test.*

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| **NOTICE**  This document is to provide an example of a flight envelope definition document for an aircraft type certificate application in accordance with CS-LSA. The document can be used even if the applicant does not own a DOA. It does not substitute, in any of its parts, the prescriptions of Part-21 and its amendments.  This document is intended to assist applicants in applying for an LSA RTC/TC and therefore demonstrating compliance of the design to the requirements.  The document should not be read as a template and it should not be used as a form to fill. The content shall be checked for appropriateness and changed accordingly by the applicant.  The required information can be presented entirely in this document, or in additional documents appropriately identified and referred to.  Comments and notes to the user are provided throughout the document *with “blue highlighted and italic text”.*  **IMPORTANT: All the statements and/or conclusions provided in this guideline can be considered realistic and have a reasonable technical basis but** **the designer is solely responsible of each of the statements that he/she will provide** |

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## References

|  |  |
| --- | --- |
| [1] | “ASTM F2245-12d,” ASTM. |
| [2] | “ABCD-FL-57-00 Wing Load Calculation,” EASA. |
| [3] | “ISO 2533:1975,” International Standardization Organization, 1975. |
| [4] | “CS-LSA Certification Specifications and Acceptable Means of Compliance, Amnd.1 29.Jul.2013,” EASA, 2013. |
| [5] | “ABCD-FTR-01-00 Flight Test Report,” EASA. |
| [6] | L. Smith, “NACA technical note 1945, ‘Aerodynamic characteristics of 15 NACA airfoil sections at seven Reynolds numbers from 0.7x10E6 to 9x10E6,” 1949. |
| [7] | “ABCD-WB-08-00 Weight and Balance Report,” EASA. |

## List of Abbreviations

FL100 flight level 100

CG centre of gravity

MSL mean sea level

a lift-curve slope of the aeroplane = [1/rad]

cL maximum lift coefficient taken from corresponding charts []  
cL\_max maximum lift coefficient of the clean wing []

cL\_flaps\_max maximum lift coefficient of the wing with flaps extended []  
cL\_flaps maximum lift coefficient of the flaps wing section with flaps extended []

g gravity acceleration equals 9.81 m/s2 [m/s2]

Re Reynolds number []

S wing area [m2]

SW wetted wing area (see [2]) [m2]

ρ air density at a certain altitude, see [3] []

ρ0 air density at sea level , see [3] []

VA design manoeuvring speed [kts]

VC design cruising speed [kts]

VD design dive speed [kts]

VF flaps maximum operating speed [kts]

VFE flaps maximum extension speed [kts]

VH maximum speed in level flight [kts]

VLO maximum landing gear operating speed [kts]

VNE never exceed speed [kts]

VS stall speed in landing configuration (flaps extended) [kts]

VS1 stall speed in clean configuration (flaps retracted) [kts]

aeroplane maximum take-off weight according to CS-LSA.5 [4] [kg]

aeroplane minimum flying weight [kg]

aeroplane minimum flying weight with full fuel [kg]

## Requirements

This document covers the following certification specifications requirements:

| **Requirement**  **CS-LSA**.15, 29th July 2013 amendment 1  (ASTM F2245-12d) | **Subject of requirement** | **Referenced chapter** |
| --- | --- | --- |
| 4.1.1 | Each of the following requirements shall be met at the most critical weight and CG configuration. Unless otherwise specified, the speed range from stall to VDF or the maximum allowable speed for the configuration being investigated shall be considered. | 4, 5, 6 |
| 4.1.1.2 | *VNE* must be less than or equal to 0.9*VDF* and greater than or equal to 1.1*VC*. In addition, *VNE* must be greater than or equal to *VH*. | 4.9 |
| 4.4 | *Performance, General –* All performance requirements apply in standard ICAO atmosphere in still air conditions and at sea level. Speeds shall be given in indicated (IAS) and calibrated (CAS) airspeeds. | 0 |
| 5.2.3 | *Flight Envelope* – Compliance shall be shown at any combination of airspeed and load factor on the boundaries of the flight envelope. The flight envelope represents the envelope of the flight loading conditions specified by the criteria of 5.2.4 and 5.2.5 (see Fig. 1). | Figure 1 |
| 5.2.3.2 | *Maneuvering Envelope* – Except where limited by maximum (static) lift coefficients, the airplane is assumed to be subjected to symmetrical maneuvers resulting in the following limit load factors:  (1) the positive maneuvering load factor specified in 5.2.5.1 at speeds up to VD; and  (2) the negative maneuvering load factor specified in 5.2.5.2 at speeds up to VD. | 6 |
| 5.2.3.3 | *Gust Envelope* – The airplane is assumed to be subjected to symmetrical vertical gusts in level flight. The resulting limit load factors must correspond to the conditions determined as follows:  (1) positive (up) and negative (down) gusts of 15 m/s (49.2 ft/s) at VC; and  (2) positive and negative gusts of 7.5 m/s (24.6 ft/s) at VD (see Fig. 1). | 6.1 |
| 5.2.4 | *Design Airspeeds:* | – |
| 5.2.4.1 | Design Maneuvering Speed, VA:  where:  VS = computed stalling speed at the design maximum weight with the flaps retracted, and  n1 = positive limit maneuvering load factor used in design. | 4.3 |
| 5.2.4.2 | *Design Flap Speed,* VF – For each landing setting, VF must not be less than the greater of:  (1) 1.4 VS, where VS is the computed stalling speed with the wing flaps retracted at the maximum weight; and  (2) 2.0 VSO, where VSO is the computed stalling speed with wing flaps fully extended at the maximum weight. | 4.4 |
| 5.2.4.3 | *Design Cruising Speed*, VC –  (1) VC in knots may not be less than 4.77 x √(W/S); and  (2) VC need not be greater than 0.9 VH at sea level. | 4.6 |
|  |  |  |
| 5.2.4.4 | Design Dive Speed, VD:  VD = 1.4 x VC min  where:  VC min = required minimum cruising speed. | 4.7 |
| 5.2.5 | *Limit Maneuvering Load Factors:* | – |
| 5.2.5.1 | The positive limit maneuvering load factor n1 may not be less than 4.0. | 6 |
| 5.2.5.2 | The negative limit manouevring load factor n2 may not be greater than −2.0. | 6 |
| 5.2.5.3 | Loads with wing flaps extended:  (1) if flaps or other similar high lift devices are used, the airplane must be designed for n1 = 2.0 with the flaps in any position up to VF; and  (2) n2 = 0. | 6 |
| 5.2.5.4 | Loads with speed control devices: | Not applicable |
| 5.2.6  5.2.6.1  5.2.6.2 | *Gust Load Factors* – The airplane must be designed for the loads resulting from:  The gust velocities specified in 5.2.3.3 with flaps retracted, and positive and negative gusts of 7.5 m/s (24.6 ft/s) nominal intensity at VF with the flaps fully extended.  NOTE 4 – In the absence of a more rational analysis, the gust load factors may be computed by the method of Appendix X3. | 6.1 |

Table 1 – Requirements

## Design Airspeeds

This chapter defines the operating and design airspeeds as required for certification [1].

## Maximum speed in level flight VH

According to flight tests [5] at maximum weight and maximum continuous power at sea level conditions, the maximum speed in level flight has been determined:

## Stall speeds VS, VS0, VS1

These speeds will be verified by flight test according to requirement 4.4.1 [1].

In order to calculate the stall speed, the maximum lift coefficient of the aeroplane as a whole is determined first.

The maximum lift coefficient of the aeroplane has been calculated starting from the polar curve of the wing profile taken form ref. [6] (p. 236, Re=2.9E6 flaps retracted and p.237, for the flaps in landing configuration, and in take-off configuration).

Considering the horizontal tail balancing force and the lower total wing lift due to wing lift distribution, the total aeroplane lift coefficient has been lowered by 15% with respect to the one of the profile.

Therefore aeroplane lift coefficient is estimated to

and for the landing configuration (since the span extension of the flaps is half of the span of the wing):

Stall speeds have been calculated based on these calculated lift coefficients.

The wetted wing area SW is used instead of total wing area S because of a lower lift within the fuselage section of the span.

Flaps retracted (take-off configuration):

Flaps extended (landing configuration):

Flaps extended (take-off configuration):

With .

The stall speed in landing configuration (flaps fully extended to 40 degrees) is 44 kts. Therefore it is In accordance with CS-LSA.5 [4].

In Take-Off configuration (flaps extended to 20 degrees) the stall speed is 47 kts.

*(Note: These speeds are estimates. The methods for the estimation can be various. It is important that these estimations are as precise as possible. Flight tests will be used to validate the stall speeds. In case the flight tests show different values, this might have an impact on the speeds used for design and ultimately might impair the compliance to the CS-LSA.5.)*

## Design manoeuvring speed VA

According to requirement 5.2.4.1 [1]

## Flaps maximum operating speed VF

According to requirement 5.2.4.2 [1], such speed shall be not less than the greater of

and

The speed has been selected as:

This is the maximum flap operating speed for the take-off (at 20 degrees) and landing flap settings at 40 degrees.

## Flaps maximum extension speed VFE

On this aeroplane the maximum flap extension speed is identical to the flap operating speed VF.

This speed is the maximum speed for flaps in take-off and landing configuration.

## Design cruising speed VC

According to requirement 5.2.4.3 [1]

may not be less than:

and need not be greater than:

The speed has been selected as:

*(Note: can be selected to be higher than .)*

*(Note: and VDF ,VD ,VNE correlate with each other. should be selected to allow for a minimum margin of 22% to VDF in order to be able to satisfy the requirements for the next subchapters.)*

## Design dive speed VD

According to requirement 5.2.4.4 [1]

For a higher value than the one above has been chosen:

*(Note: ASTM F2245-12d 5.2.4.4* [1] *requires an exact value for the dive speed. Indeed, such value should be understood as a minimum value. This will be clarified in the next amendment of the CS-LSA.)*

## Demonstrated dive speed VDF

According to requirement 4.1.1.1 [1] VDF must be less than or equal to VD.

In this case VDF is equal to VD:

*(Note: In case the demonstrated VDF is lower than VD then VNE needs to be limited accordingly which could have an impact on the selection of VC as well.)*

## Never exceed speed VNE

According to requirement 4.1.1.2 [1] the VNE

Shall be greater than or equal to:

and

must be less than or equal to:

The speed has been selected as:

*Note: If the aircraft is equipped with retractable landing gear then VLO must be determined as well (CS-LSA.15 6.12.2).*

## Altitude

The maximum permissible operational altitude is 13000ft. Despite the CS-LSA requirements do not require to accounts for the effects of altitude, such effects have been considered up to 10000 ft. In fact the gust load factor have been calculated at such altitude. This is considered acceptable since it covers the operational range within which the aeroplane will fly most of the time.

*(Note: the CS-LSA requirement does not require to account for the effects of altitude. Calculating the loads at sea level would be acceptable. In this case, the choice to consider such effect up to 10000 ft is a decision of a designer, which would be accepted by the team.)*

## Manoeuvring and Gust load factors n

Summary of limit load factors according to certification specifications and gust requirements.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Limit load factors** | | | **Valid for** | **Requirements** |
| Positive manoeuvring load factor |  | **4** | At all weights, CG positions, altitudes and speeds; Flaps retracted | 5.2.5.1 [1] |
| Negative manoeuvring load factor |  | **-2** | At all weights, CG positions, altitudes and speeds; Flaps retracted | 5.2.5.2 [1] |
| Positive manoeuvring load factor flaps extended |  | **2** | At all weights, CG positions, altitudes and speeds up to | 5.2.5.3 [1] |
| Negative manoeuvring load factor flaps extended |  | **0** |

Table 2 – Manoeuvring limit load factors

## Gust envelope

Gust load factors need to be considered because they can exceed the prescribed maximum load factors at different weights and altitudes.

Since gust loads depend on air density and aircraft mass they will be calculated for all twelve cases (sea level and 10000ft=FL100, maximum, minimum flying weight and minimum flying weight with full wing fuel tanks) according to requirement 5.2.3.3 [1] with flaps retracted (requirement 5.2.6.1 [1]) and fully extended (requirement 5.2.6.2 [1]) at .

The calculation is based on appendix X3 [1]. To calculate the gust loads at altitudes other than at sea level the formula X3.1 [1] is altered to include the density at sea level as well:

The corresponding weights are defined within [7].

Since the gust loads on the wing and tail have been chosen to be treated together, is the slope of the lift-curve of the aeroplane ().

*(Note: the applicant should provide the method for the calculation of the slope of the lift-curve of the aeroplane)*

| **speed** | **V [kts]** | **Aircraft load** | **Aircraft weight [N]** | **altitude** | **density [kg/m^3]** | **K\_g** | **u\_g** | **U\_de [m/s]** |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | 120 | WMTOW | 5886 | MSL | 1.225 | 0.570 | 9.72 | 15 | 4.84 | -2.84 |
| 120 | Wmin,fwd | 4679 | MSL | 1.225 | 0.522 | 7.73 | 15 | 5.54 | -3.54 |
| 120 | Wmin,aft | 4395 | MSL | 1.225 | 0.509 | 7.26 | 15 | 5.71 | -3.71 |
| 120 | WminFF | 5052 | MSL | 1.225 | 0.538 | 8.34 | 15 | 5.33 | -3.33 |
| 120 | WMTOW | 5886 | FL100 | 0.9 | 0.628 | 13.23 | 15 | 5.24 | -3.24 |
| 120 | Wmin,fwd | 4679 | FL100 | 0.9 | 0.585 | 10.52 | 15 | 6.11 | -4.11 |
| 120 | Wmin,aft | 4395 | FL100 | 0.9 | 0.573 | 9.88 | 15 | 6.33 | -4.33 |
| 120 | WminFF | 5052 | FL100 | 0.9 | 0.600 | 11.36 | 15 | 5.84 | -3.84 |
|  | 160 | WMTOW | 5886 | MSL | 1.225 | 0.570 | 9.72 | 7.5 | 3.56 | -1.56 |
| 160 | Wmin,fwd | 4679 | MSL | 1.225 | 0.522 | 7.73 | 7.5 | 4.03 | -2.03 |
| 160 | Wmin,aft | 4395 | MSL | 1.225 | 0.509 | 7.26 | 7.5 | 4.14 | -2.14 |
| 160 | WminFF | 5052 | MSL | 1.225 | 0.538 | 8.34 | 7.5 | 3.89 | -1.89 |
| 160 | WMTOW | 5886 | FL100 | 0.9 | 0.628 | 13.23 | 7.5 | 3.82 | -1.82 |
| 160 | Wmin,fwd | 4679 | FL100 | 0.9 | 0.585 | 10.52 | 7.5 | 4.41 | -2.41 |
| 160 | Wmin,aft | 4395 | FL100 | 0.9 | 0.573 | 9.88 | 7.5 | 4.55 | -2.55 |
| 160 | WminFF | 5052 | FL100 | 0.9 | 0.600 | 11.36 | 7.5 | 4.23 | -2.23 |
|  | 90 | WMTOW | 5886 | MSL | 1.225 | 0.570 | 9.72 | 7.5 | 2.44 | -0.44 |
| 90 | Wmin,fwd | 4679 | MSL | 1.225 | 0.522 | 7.73 | 7.5 | 2.70 | -0.70 |
| 90 | Wmin,aft | 4395 | MSL | 1.225 | 0.509 | 7.26 | 7.5 | 2.77 | -0.77 |
| 90 | WminFF | 5052 | MSL | 1.225 | 0.538 | 8.34 | 7.5 | 2.62 | -0.62 |
| 90 | WMTOW | 5886 | FL100 | 0.9 | 0.628 | 13.23 | 7.5 | 2.59 | -0.59 |
| 90 | Wmin,fwd | 4679 | FL100 | 0.9 | 0.585 | 10.52 | 7.5 | 2.92 | -0.92 |
| 90 | Wmin,aft | 4395 | FL100 | 0.9 | 0.573 | 9.88 | 7.5 | 3.00 | -1.00 |
| 90 | WminFF | 5052 | FL100 | 0.9 | 0.600 | 11.36 | 7.5 | 2.82 | -0.82 |

Table 3 – Gust load factors

## V-n Envelope

Below a typical flight envelope is shown. This specific one is corresponding to MTOW and FL100. For other design weights the shape of the envelope remains similar, with the difference that the gust lines will change (due to different load factors as per Table 3).

Figure 1 – Manoeuvring envelope at MSL and Gust envelope at FL100

## Compliance statements

Compliance statements are shown below:

|  |  |
| --- | --- |
| **Requirement reference** | **Subject** |
| CS-LSA F2245-12d  4.1.1 | 4.1.1 Each of the following requirements shall be met at the most critical weight and CG configuration. Unless otherwise specified, the speed range from stall to VDF or the maximum allowable speed for the configuration being investigated shall be considered. |
| **Statement of compliance** | The requirement has been met. This is shown in chapters 4, 5 and 6. |

|  |  |
| --- | --- |
| **Requirement reference** | **Subject** |
| CS-LSA F2245-12d  4.1.1.2 | 4.1.1.2 *VNE* must be less than or equal to 0.9*VDF* and greater than or equal to 1.1 *VC*. In addition, *VNE* must be greater than or equal to *VH*. |
| **Statement of compliance** | The requirement has been met. This is shown in chapter 4.9. |

|  |  |
| --- | --- |
| **Requirement reference** | **Subject** |
| CS-LSA F2245-12d  4.4 | 4.4 *Performance, General –* All performance requirements apply in standard ICAO atmosphere in still air conditions and at sea level. Speeds shall be given in indicated (IAS) and calibrated (CAS) airspeeds. |
| **Statement of compliance** | The requirement has been met. This is shown in chapter 0. |

|  |  |
| --- | --- |
| **Requirement reference** | **Subject** |
| CS-LSA F2245-12d  5.2.3 | 5.2.3 *Flight Envelope* – Compliance shall be shown at any combination of airspeed and load factor on the boundaries of the flight envelope. The flight envelope represents the envelope of the flight loading conditions specified by the criteria of 5.2.4 and 5.2.5 (see Fig. 1). |
| **Statement of compliance** | The requirement has been met. This is shown in Figure 1 |

|  |  |
| --- | --- |
| **Requirement reference** | **Subject** |
| CS-LSA F2245-12d  5.2.3.2 | *Maneuvering Envelope* – Except where limited by maximum (static) lift coefficients, the airplane is assumed to be subjected to symmetrical maneuvers resulting in the following limit load factors:  (1) the positive maneuvering load factor specified in 5.2.5.1 at speeds up to VD; and  (2) the negative maneuvering load factor specified in 5.2.5.2 at speeds up to VD. |
| **Statement of compliance** | The requirement has been met. This is shown in chapter 6. |

|  |  |
| --- | --- |
| **Requirement reference** | **Subject** |
| CS-LSA F2245-12d  5.2.3.3 | *Gust Envelope* – The airplane is assumed to be subjected to symmetrical vertical gusts in level flight. The resulting limit load factors must correspond to the conditions determined as follows:  (1) positive (up) and negative (down) gusts of 15 m/s (49.2 ft/s) at VC; and  (2) positive and negative gusts of 7.5 m/s (24.6 ft/s) at VD (see Fig. 1). |
| **Statement of compliance** | The requirement has been met. Gust loads have been determined for all critical weights. Also effects of altitudes up to FL100 have been considered. See chapter 6.1. |

|  |  |
| --- | --- |
| **Requirement reference** | **Subject** |
| CS-LSA F2245-12d  5.2.4.1 | 5.2.4.1 Design Maneuvering Speed, VA:  where: VS = computed stalling speed at the design maximum weight with the flaps retracted, and n1 = positive limit maneuvering load factor used in design. |
| **Statement of compliance** | The requirement has been met. This is shown in chapter 4.3. |

|  |  |
| --- | --- |
| **Requirement reference** | **Subject** |
| CS-LSA F2245-12d  5.2.4.2 | 5.2.4.2 *Design Flap Speed,* VF – For each landing setting, VF must not be less than the greater of:  (1) 1.4 VS, where VS is the computed stalling speed with the wing flaps retracted at the maximum weight; and  (2) 2.0 VSO, where VSO is the computed stalling speed with wing flaps fully extended at the maximum weight. |
| **Statement of compliance** | The requirement has been met. This is shown in chapter 4.4. |

|  |  |
| --- | --- |
| **Requirement reference** | **Subject** |
| CS-LSA F2245-12d  5.2.4.3 | 5.2.4.3 *Design Cruising Speed*, VC –  (1) VC in knots may not be less than 4.77 x √(W/S); and  (2) VC need not be greater than 0.9 VH at sea level. |
| **Statement of compliance** | The requirement has been met. This is shown in chapter 4.6. |

|  |  |
| --- | --- |
| **Requirement reference** | **Subject** |
| CS-LSA F2245-12d  5.2.4.4 | 5.2.4.4 Design Dive Speed, VD:  VD = 1.4 x VC min where: VC min = required minimum cruising speed. |
| **Statement of compliance** | The requirement has been met. This is shown in chapter 4.7. |

|  |  |
| --- | --- |
| **Requirement reference** | **Subject** |
| CS-LSA F2245-12d  5.2.5.1 | 5.2.5.1 The positive limit maneuvering load factor n1 may not be less than 4.0. |
| **Statement of compliance** | The requirement has been met. This is shown in chapter 6. |

|  |  |
| --- | --- |
| **Requirement reference** | **Subject** |
| CS-LSA F2245-12d  5.2.5.2 | 5.2.5.2 The negative limit maneuvering load factor n2 may not be greater than −2.0. |
| **Statement of compliance** | The requirement has been met. This is shown in chapter 6. |

|  |  |
| --- | --- |
| **Requirement reference** | **Subject** |
| CS-LSA F2245-12d  5.2.5.3 | 5.2.5.3 Loads with wing flaps extended:  (1) if flaps or other similar high lift devices are used, the airplane must be designed for n1 = 2.0 with the flaps in any position up to VF; and  (2) n2 = 0. |
| **Statement of compliance** | The requirement has been met. This is shown in chapter 6. |

|  |  |
| --- | --- |
| **Requirement reference** | **Subject** |
| CS-LSA F2245-12d  5.2.6  5.2.6.1  5.2.6.2 | *Gust Load Factors* – The airplane must be designed for the loads resulting from:  The gust velocities specified in 5.2.3.3 with flaps retracted, and  Positive and negative gusts of 7.5 m/s (24.6 ft/s) nominal intensity at VF with the flaps fully extended.  NOTE 4 – In the absence of a more rational analysis, the gust load factors may be computed by the method of Appendix X3. |
| **Statement of compliance** | The requirement has been met. This is shown in chapter 6.1. |