

Flight Test of Gliders and Powered Gliders

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Type Certification of Gliders and Powered Gliders

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Abstract

For the certification of an aircraft, it has to be shown, that it complies with all parts of the airworthiness code (e.g. CS 22 or JAR-22 in the case of gliders and powered gliders). The subparts 'Flight', 'Design and Construction', 'Operating Limitations and Information' as well as the Flight Manual have to be assessed by pilots, to allow a statement about the compliance with the relevant paragraphs. For the subpart 'Flight', test flights have to be carried out to show the compliance and to verify the relevant parameters of the pilot operating handbook. Example of necessary flight test procedures and instruments will be presented and samples of retrieved data and sources of error will be shown.

Symbols

EASA	European Aviation Safety Association	LBA	Luftfahrt-Bundesamt
CS	Certification Standard	V_D	Design speed
JAA	Joint Aviation Authorities	V_{NE}	Never exceed speed
JAR	Joint Aviation Requirements	V_S	Stall speed
$C_{D\min}$	Minimum drag coefficient	CG	Centre of gravity
n	Manoeuvring load factor	W	Weight
S	Design wing area		
IEM	Interpretative / Explanatory Material		

Introduction

In order to operate an aircraft legally, it has to be certified. To certify an aircraft means to show that it complies with the airworthiness requirements and that its flight characteristics meet the airworthiness requirements. For the certification of a newly designed aircraft, the designer has to apply for the certification to the organisation in charge, normally the national aviation authority. The designer will receive a confirmation letter stating the airworthiness code with which compliance is to be shown. During the following development of the aircraft, the designer will prepare substantiation reports for each individual paragraph of the airworthiness code. Some of the reports include results of flight tests carried out by test pilots. The reports will be presented to the certifying organisation which carries out either complete or spot checks depending on the amount of change to earlier existing designs and the qualification of the design organisation. Some of these checks may be flight tests conducted by pilots on behalf of the certifying organisation. In the scope of these test flights, the pilots have to measure parameters and make subjective statements about the flight characteristics of the aircraft. To

generate objective and reproducible values, the pilot needs to be well trained to his task. He also needs to be experienced in flying a large variety of different aircraft to have a solid basis of knowledge for his statements.

Development of standards for flight

In the beginning of aviation, no airworthiness codes were available. All the design was based on trial and error. During this time, the flying community gathered experiences and came to notice that each aircraft designer approaches similar difficulties when starting his development. Many pilots/designers were injured or killed by mistakes which other designers had already solved. For this reason it was decided to write the experiences down. The first design guidelines, later called Airworthiness Requirements, were created. Examples of the early steps are the Airworthiness Standards for the design of gliders and sailplanes of the Technical Commission of the Rhön contest, a famous gliding competition in Germany at that time. They demanded a proof of stability according to Prof. Lippisch of the Rhön-Rossitten-Gesellschaft in 1927.

The first requirements for the flight characteristics were written down by the British Air Registration Board in 1948 and contained in the British Civil Airworthiness Requirements,

Section E - Gliders. These Requirements were also adopted in Germany in 1951. Up to now, the standards have developed in several steps to the actual CS 22, which has been published by the EASA. Today we can see the Airworthiness Requirements as the sum of the experiences made so far.

For the time being, there are several points demanded by the CS 22, which have to be fulfilled:

CS 22 Subpart B – Paragraphs for Flight

General

- 21 - Proof of compliance
- 23 - Load distribution limits
- 25 - Weight limits
- 29 - Empty weight and corresponding c.g.
- 31 - Ballast

Performance

- 45 - General
- 49 - Stalling speed
- 51 - Take-off
- 65 – Climb
- 71 - Rate of descent
- 73 - Descent, high speed
- 75 - Descent, approach

Controllability and Manoeuvrability

- 143 - General
- 145 - Longitudinal control
- 147 - Lateral and directional control
- 151 - Aerotowing
- 152 - Winch-launching and auto-tow launching
- 153 - Approach and landing
- 155 - Elevator control force In manoeuvres

Trim

- 161 - Trim

Stability

- 171 - General
- 173 - Static longitudinal stability
- 175 - Demonstration of static longitudinal stability
- 177 - Lateral and directional stability
- 181 - Dynamic stability

Stalls

- 201 - Wings level stall
- 203 - Turning flight stalls
- 207 - Stall warning

Spinning

- 221 - General
- 223 - Spiral dive characteristics

Ground Handling Characteristics

233 - Directional stability and control

Miscellaneous Flight Requirements

- 251 - Vibration and buffeting
- 255 - Aerobatic manoeuvres

The airworthiness code says, that:

a) Each requirement of this Subpart must be met at each appropriate combination of weight and CG within the range of loading conditions for which certification is requested.

(...)

b) Compliance must be established for all configurations (such as position of air brakes, wing-flaps, landing gear etc.) at which the sailplane will be operated except as otherwise stated. In demonstrating compliance, the power plant or propeller, if retractable, must be retracted, except as otherwise stated.

(...)

(CS 22.21 - Proof of Compliance)

The envelope for flight test

The Airworthiness Code knows two categories of gliders and powered gliders: the Utility and the Aerobatic category. For both categories Limit Manoeuvring Load Factors are prescribed. Table 1 shows the corresponding values.

Figure 1 shows the flight envelope characterising the boundaries for the flight tests. The operation of the aircraft as well as the official certification flights by the authority will later on be carried out up to V_{NE} , which is calculated as 0.9 times V_D .

The test program

Flight testing consists of three steps: planning, flying, and interpretation of the data received. Test flights have to be planned precisely. The basis of the tests is given by the airworthiness code. There are requirements, which deal with e.g. speeds and glide path angles of the aircraft (stall speed, minimum and maximum sink speed), pilot forces, respond times on control inputs that have to be proved.

In principle it has to be verified that the aircraft meets all the paragraphs at every loading condition, CG position and flap and gear setting. Because of the effort, to fly all this cases in detail, normally the most critical cases are selected for flight test. These are the rear CG positions with maximum mass for stall, minimum control force and stability tests and the front CG positions e.g. for spiral dive and landing.

This implies that the CG range has to be defined before the relevant flight test, at least roughly. Also the structural layout and the limit loads have to be known to commence flight test to give the pilot information about the boundaries of the flight envelope.

The flight test itself normally starts with ground handling and taxiing tests. Thereafter, the first flights will be carried out in a very conservative manner, e.g. without retracting the gear and the engine and by keeping the aircraft in a safe speed range with a certain distance to the stall speed and the maximum

speed. Primarily, the response to control input and the handling characteristics will be examined. When the basic tests have been conducted, the flight regime will be enlarged towards stall speed. As one can imagine, these tests will be carried out at a safe height over unpopulated terrain.

At an early stage of the flight tests, the static pressure pickups for altimeter and air speed indicator will be calibrated for example by a deployable static probe (shown in Figure 2) and a precise reference indicator.

With this information about the stall speed, several reference speeds, e.g. for take-off, approach, roll rate and stability can be calculated, thus the corresponding flights can be performed. To shift the boundary of the flight envelope to higher speeds, the aero-elastic behaviour of the aircraft must be the focal point. It is state of the art that knowledge from ground vibration tests and flutter calculations is used to prove the qualification for higher speeds up to V_D . With an aero-elastic expert opinion about the uncritical flutter behaviour the upper speed range will be opened for the in-flight flutter test.

Having shown the suitability for high speeds, the investigations of spin, spiral dive and possible aerobatic manoeuvres are the next items on the list of the test pilots. For spin tests a deployable drag chute (Figures 3, 4, 5) is strongly recommended. For tests beyond the rear limit of CG, additionally deployable tail ballast is used in some cases (Figure 4).

Results of flight tests for spin and stall may lead to a shift of the CG limits which has an influence on the pilot control forces. For this reason, the flights for measuring the stability parameters are carried out rather late in the investigations. Furthermore the possible trim speeds have to be recorded when the maximum control surface deflections of the controls are defined for serial production.

For powered gliders, there are special tests to be carried out for take-off performance. Information is needed about the distance horizontal from rest until reaching a height of 15 m (not more than 500 m) and the time between lift off and reaching a height of 360 m (not more than 4 minutes). For powered gliders, cooling test flights are required to show that the maximum temperature will not be exceeded using the allowable engine power setting.

For each intended take-off method the flight characteristics have to be shown in detail. Here, the manoeuvrability in the complete take-off phase and the absence of tendencies to ground loop or for uncontrolled pitch oscillation is of basic interest.

Besides all the data that can be measured the test pilot has to provide information to the designers about several points that are not measurable. According to the airworthiness requirements it must be possible for example to perform safe transitions from one flight condition to another, including slip and stall and each manoeuvre without "requiring exceptional piloting skill". A spin must be controllable by using "the standard procedure".

Development of airworthiness requirements

Airworthiness requirements are not fixed for all times. As mentioned, the requirements develop with the achievable performance of aircraft as well as with new materials. Pursuant to the Airworthiness Standards for sailplanes (BVS No. 1-3) of 1939, sailplanes had to be capable of performing a vertical dive with speed brakes extended without exceeding the maximum speed V_{NE} . Compliance with this requirement could be shown as the wings still were short and thick caused by the old wooden design. After introducing fiber reinforced plastics in glider manufacturing, this requirement was changed into a 45° flight path without exceeding V_{NE} (JAR-22.73). Later, with regard to the progress in glider construction using laminar airfoils and having in mind the need to reduce drag to increase performance, the 45° path angle was reduced to 30° for non-aerobatic gliders and finally as a second way to show compliance to "less than 30° when a rate of descent of more than 30 m/s can be achieved" (CS 22.73).

Also the stall speed for the landing configuration (V_{S0}) and maximum weight (V_{S1}) changed during the development of the airworthiness requirements. The first issue of the JAR-22 in 1980 demanded 75 km/h for V_{S0} and 85 km/h for V_{S1} . Later in 1982 it increased to 80 km/h for V_{S0} and 85 km/h for V_{S1} . In 1987 in JAR-22 Amendment 4 it changed to 80 km/h for V_{S0} and 80 km/h for V_{S1} . Finally in 1995 it changed to 80 km/h for V_{S0} and 90 km/h for V_{S1} which is still applicable today.

Flight test examples

CS 22.73 requires a high speed descent

It must be shown that the sailplane with the airbrakes extended, will not exceed V_{NE} in a dive at an angle to the horizon of:

- (a) 45° when the sailplane is approved for cloud flying and/or aerobatics when certificated in the Aerobatic or Utility Category;
- (b) in other cases
 - (i) 30°
 - (ii) less than 30° when a rate of descent of more than 30 m/s can be achieved.

To test the high speed descent characteristics, the pilot has to accelerate at a safe height up to a speed beyond V_A , extend the airbrakes carefully and accelerate further to V_{NE} . Then, flying straight at V_{NE} , he has to record the altitude versus time over a sufficient period of time. To keep the hands at the controls, this should be done by a video camera or by a dictating machine. Thereafter, the glider or powered glider has to be recovered from the descent, the airbrakes are to be retracted and the flight continues with the remaining height.

If we take for example the DG-1000S, a double seated glider, certified for aerobatics with a V_{NE} of 270 km/h this test means a minimum descent rate of about 53 m/s! Thus the pilot has to accelerate to about 200-220 km/h, extend the airbrakes and push the nose down to reach the maximum speed. To make a reproducible steady measurement it is recommended to maintain this state for a period of about 20 seconds, which

means a loss of altitude of at least 1060 m, plus acceleration and deceleration time. It is also recommended to have a reserve of altitude left after the test, just in case anything unforeseen happens. Because of the high speed, these tests have to be flown in calm conditions that means preferably early in the morning with an aero tow up to 3000 m.

CS 22.75 requires a descent, approach

The second test example should be a flight according to CS 22.75 Descent, approach. It must be shown that the sailplane has a glide slope not flatter than one in seven at a speed of $1.3 V_{S0}$ with air brakes extended at maximum weight.

According to the code, the aircraft has to be loaded to maximum weight for this test. In this case the maximum mass with water ballast tanks empty is relevant according to CS 22.49. This means take the empty weight of the aircraft, the actual weight of the pilot(s) and add the rest of the required weight in form of ballast. Because an overload would bear the risk to fail the test and a lack of mass would not provide the required evidence, the mass should be met within an accuracy of at least +/- 1kg. After take-off first the stall speed V_{S0} with this mass should be determined if not done already. V_{S0} means:

(...) the minimum steady speed at which the sailplane is controllable with:

- (1) landing gear extended;
- (2) wing-flaps in the landing position;
- (3) air brakes retracted or extended whichever position results in the lowest value of V_{S0} ;
- (4) maximum weight; and
- (5) CG in the most unfavorable position within the allowable range.
- (6) For a powered sailplane:
 - (i) the engine idling (throttle closed);
 - (ii) propeller in the take-off position;
 - (iii) cowl flaps closed position;

With this speed multiplied by 1.3 and the airbrakes extended, the glide slope angle has to be measured. That means the speed is to be maintained and the descent rate or the height versus time is to be recorded over a certain period. If we take V_{S0} as 78 km/h the test has to be carried out at 101 km/h. This means a descent rate of at least 4.0 m/s and a loss of 120 m in 30 seconds. Because of the better accuracy it is recommended to use the difference in altitude and time for the test.

CS 22.51 requires powered gliders take-off performance

For powered gliders, the take-off distance has to be measured according to CS 22.51 Take-off:

- (a) For a powered sailplane the take-off distance at maximum weight and in zero wind, from rest to attaining a height of 15 m must be determined and must not exceed 500 m when taking off from a dry, level, hard surface. In demonstration of the take-off distance, the powered sailplane must be allowed to reach the selected speed promptly after lifting

off and this speed must be maintained throughout the climb.

- (b) The selected speed must not be less than;
 - (1) $1.3 V_{S1}$, or
 - (2) any lesser speed, not less than $1.15 V_{S1}$, that is shown to be safe under all reasonably expected operating conditions, including turbulence and complete engine failure.

For this test the maximum weight including water ballast has to be established. This can mean that up to 200 litres of water are to be added for the latest powered gliders designed. Again, the take-off mass should be met with sufficient accuracy. The take-off should be recorded extensively to obtain the relevant data. This means the flight path is to be recorded from the ground by photos or video, the actual wind is to be recorded because of the requirement of zero wind and the actual speed and climb rate of the aircraft is to be recorded by video or GPS. Additionally the geometry of the airfield should be available, to calculate the achieved distances from the photos or the video. Because of this amount of different data, the measurement of take-off performance bears the most intensive work following the flight test. The take-off tests are also relevant for the judgment of the behaviour of touring motor gliders as tow planes.

Finally, it must be said that the conduct of a test contained in Subpart D – Design & Construction in advance of his test flights in his own interest. Paragraph 807, Emergency Exit states, that

- (a) The cockpit must be so designed that unimpeded and rapid escape in emergency situations during flight and on the ground is possible with the occupant wearing a parachute.
(...)

In performing a simulated emergency exit on the ground, the pilot will gain valuable experience for leaving the aircraft rapidly in case of emergency. An average escape time to bail out should be about 4 to 5 seconds, when the canopy is opened in advance. To open the canopy in advance will save it from damage and implies, that the procedure to open the canopy will be trained when removing it.

Additional tasks for test pilots

As is clearly visible, the main tasks for test pilots concern Subpart C – Flight. In addition to the above mentioned working points, the test pilots will be asked for statements about points of the airworthiness requirements, Subpart D - Design and Construction. For example, CS 22 states that:

- The cockpit and its equipment must allow each pilot to perform his duties without unreasonable concentration or fatigue. (771 – General)
- Each cockpit must be free from glare and reflections that could interfere with the pilot's vision, and designed so that the pilot's vision is sufficiently extensive, clear and undistorted for safe operation. (773 - Cockpit View)
- Each cockpit control must be located to provide convenient operation, and to prevent confusion and inadvertent operation. (777 - Cockpit Controls)

- The cockpit must be so designed that unimpeded and rapid escape in emergency situations during flight and on the ground is possible with the occupant wearing a parachute. (807 - Emergency Exit)

- The cockpit must be designed so as to afford suitable ventilation under normal flying conditions. (831 – Ventilation)

For certification purposes, official pilots often have to provide statements about Subpart G —Operating Limitations and Information. Here, the markings on the airspeed indicator and the engine instruments and placards in the cockpit are the items to look for.

Preparation and equipment for flight test

To achieve expressive results of flight tests, some important tools are required. In the early days of glider flying just a watch, a pencil and paper in addition to the memory of the pilot were used. With technical progress several other items have been added to the standard equipment of a test pilot. The airworthiness requirements demand in the Interpretative / Explanatory Material (IEM) 22.21:

(1) Instrumentation for flight test

(a) For test purposes the sailplane should be equipped with suitable instruments for conducting the required measurements and observations in a simple manner. If reliable results cannot be obtained otherwise, the Authorities may request the installation of special test equipment.

(b) At an early stage in the programme the accuracy of the instruments and their correction curves should be determined, and particular attention should be paid to the position error of the air-speed indication system; the influence of the configuration of the sailplane should also be accounted for.

The most common tools for test flying are:

- (a) The standard instruments or cockpit instruments of better accuracy,
- (b) Parachute,
- (c) a written test flight program,
- (d) dictating machine,
- (e) camera / video camera with corresponding mountings for the camera that can withstand the planned g-loads,
- (f) dynamometers,
- (g) ruler for angles (pitch, roll, yaw) ,
- (h) tape measure,
- (i) pencil and paper,
- (j) recording GPS, e.g. logger,
- (k) accelerometer,
- (l) stop watch,
- (m) ground equipment for take-off test,
- (n) electrical sensors in combination with a recording computer.

Although most of the measurements needed for the certification of a glider or powered glider may be performed with these instruments there may be the need for further instrumentation. Especially the use of computer systems and

electrical sensors that can collect a large amount of data simultaneously without requiring input from the pilot may facilitate the workload significantly. A large step into the direction of helping the pilot is a video camera recording the instrument indications and the horizon. Attached to a solid mounting that can withstand loads up to about 10 g, the camera in connection with a remote control and a cable microphone fulfils the function of recording values and times. It even provides information about the accuracy with which the pilot is flying.

A GPS based logger system can also provide additional information but has the disadvantage that the data rate is 1 Hz at best and that the filters in the receiver smooth out abrupt manoeuvres.

The above mentioned tools and their variants are only examples of suitable equipment. After many flight tests, it has turned out, that it is much more useful to be experienced with less complicated tools than to have the most expensive, highly sophisticated tools available. Especially the training of the procedures needed to carry out precise flight manoeuvres will bring the best advantage for flight tests and assure that the flight tests are reproducible and not a matter of pure chance.

Interpretation of measured data

It is not possible to take the recorded results of a flight test directly as a proof of compliance. Paragraph CS 22.45 – General states, that “compliance with performance requirements (...) must be shown for still-air in standard atmosphere and at sea-level. “

For a solid flight substantiation report, several important items are of interest. The conditions have to be documented precisely that at least the following data will be stored with the files:

1. wind direction and speed, temperature, degree of turbulence, altitude of test,
2. serial number of aircraft, loading conditions, state of design, condition of aircraft,
3. name of the pilot, experience on comparable aircraft,
4. sensors and tools used, last calibration, description of measurement,
5. description of flight test technique.

Especially the atmospheric conditions are very important because of the influence on the speeds of the aircraft. One should keep in mind that a speed measurement by GPS or a ground based observer is the speed in relation to the surface of the earth; which is in contrast with the airspeed indicator reading available to the pilot or barometric sensor that indicates a speed in relation to the surrounding air as shown in Figure 10.

To use speed information measured in different coordinate systems, the actual wind has to be used to calculate vectors in the same coordinate system. For example, it is not possible to prove the descent angle of 1:7 by a ground based camera and measurement in the pictures without information about the wind and the height.

Another point to consider is the correction of the available engine power for the actual density altitude. Using engine power at altitudes other than sea level will provide less climb rate and acceleration. The results of flight tests have to be corrected in accordance with the well known procedures.

Concluding remarks

Flight tests are very interesting in the opinion of many people. Test pilots have even been dare devils or heroes for a long time and young boys wanted to become pilot. Looking closer onto the task of pilots performing flight tests, one can see that a lot of preparation, training and experience is required to judge an aircraft, nobody or only a very few people have flown before. A good test pilot can save a lot of money to the aircraft designer but also the opposite is possible. Anyway, pilots are only human and though they can make mistakes.

There have been aircraft that could be flown by test pilots but not by pilots with very little experience because of their critical flight characteristics. Thanks to the work of these pilots, designers obtain the relevant information to improve or modify the flight characteristics of their aircraft and make them suitable for a larger range of pilots. In the most of the present glider design organisations the designers are also the test pilots, which is even better.

Even the certification of aircraft can be seen as a kind of quality control to reduce the risk for an average pilot using a newly designed aircraft. After certification of a glider the pilot can be sure that within the green arc of the airspeed indicator he can fly without overloading the aircraft and that the stall speed without water ballast is less than or equal to 80 km/h. It also has been verified that he can make an approach to a narrow field with a glide slope of at least 1:7 and that the relevant data and procedures in the flight manual are correct.

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Table 1
 Limit manoeuvring load factors (CS 22.337)

Category	Utility	Aerobatic	at Speed
n1	+5.3	+7.0	$V_A = V_S \sqrt{n}$
n2	+4.0	+7.0	
n3	-1.5	-5.0	$V_D = 18 \cdot \sqrt{\frac{W}{SC_{D_{min}}}}$ for sailplane of Category U
n4	-2.65	-5.0	$V_D = 3,5 W / S + 200$ (km/h) Category A

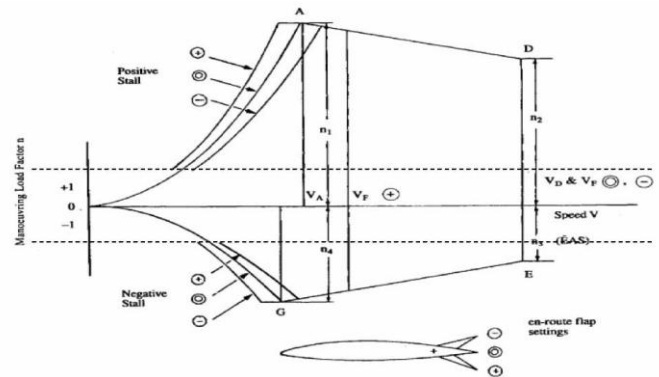


Figure 1 V-n Diagram, the flight envelope



Figure 2 Deployable static probe used for calibration of the static system



Figure 3 Drag chute for spin tests



Figure 6 Simulated emergency exit



Figure 4 Jettisonable ballast for spin tests



Figure 7 Flight test equipment



Figure 5 Drag chute for spin tests after use, partly released to reduce drag

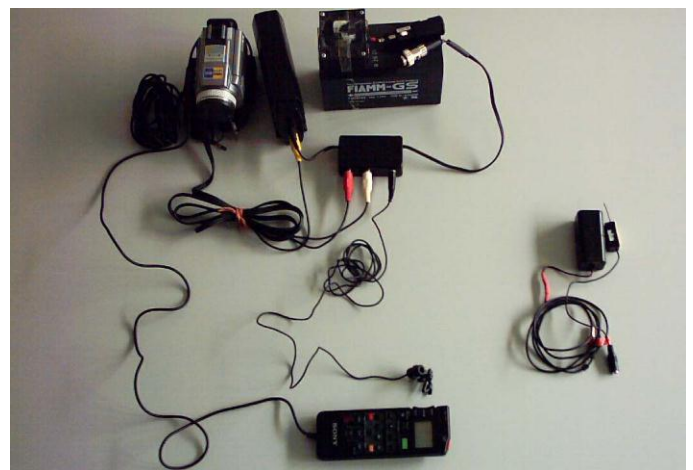


Figure 8: Possible camera system with second remote camera and radio transmission.



Figure 9 Example of a ground equipment for take-off and landing test. A camera is looking through a transparent grid. It requires a very precise setup.

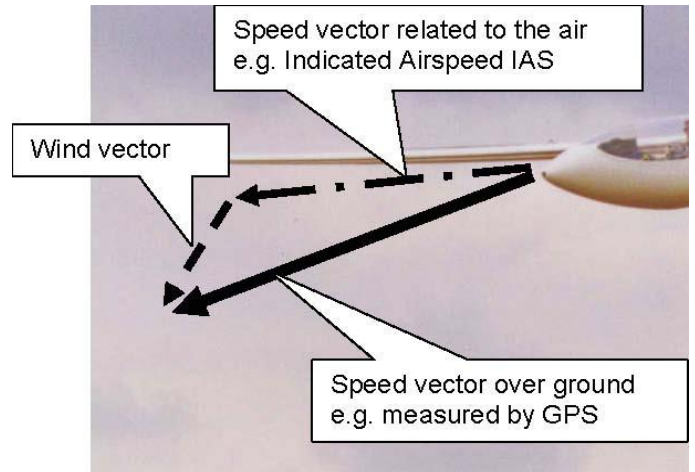


Figure 10: Relation of different speed vectors