Module – 5

FLYING QUALITIES

Syllabus:

MIL and FAR regulations. Cooper-Harper scale. Pilot Rating. Flight test procedures. Hazardous flight testing: Stall and spin- regulations, test and recovery techniques. Test techniques for flutter, vibration and buffeting.

5.1 Flying Qualities

Aircraft stability and control is often referred to as flying qualities or handling qualities. However, when we discuss flying qualities we want to make sure that we are talking about the airplane with the pilot "in the loop." We do this because having the pilot in the loop may very well affect many of the stability and control parameters. For instance, if the longitudinal short period frequency is near the pilot's response frequency, then the pilot may "feed" the longitudinal motion and produce pilot-induced oscillations.

One of the easier ways to evaluate the airplane handling qualities with the pilot in the loop is to use pilot opinion. However, the problem with pilot opinion is that a pilot's opinion of an airplane's handling qualities will be biased based upon past experience and numerous other factors. Therefore, nearly every pilot would have a different opinion, or would stress different factors in their evaluation making consistent evaluation difficult if not impossible.

5.1.1 Federal Aviation Administration Regulations

Since the FAA regulations are considered minimum standards by the FAA, little effort has been made by the FAA to develop, or use, a flying qualities criteria other than the basic open loop stability and control criteria listed in other chapters of this book. This is especially true for small airplanes, since fly-by-wire and fly-by-light control systems have not reached this category of airplanes due to costs and maintainability issues. Since such systems are now seeing use in transport category aircraft, the FAA has attempted to establish minimum standards for flying qualities criteria[1] for these aircraft.

5.1.2 Cooper-Harper Pilot Rating Scale

The above problems with pilot opinion as a method to evaluate handling qualities led to several attempts to overcome some of the shortcomings and find some method to standardize and quantify it. This was of particular interest to the military who were developing aircraft with modern control systems and relaxed static stability. The most successful of these methods is the Cooper-Harper pilot rating scale developed by researchers at NASA and the Cornell Aeronautical Labs.[2] This method of quantifying pilot opinion was developed in the mid-1960s and has been revised and refined in succeeding years. The scale, along with the meanings of each rating is shown in Fig. 32.1.

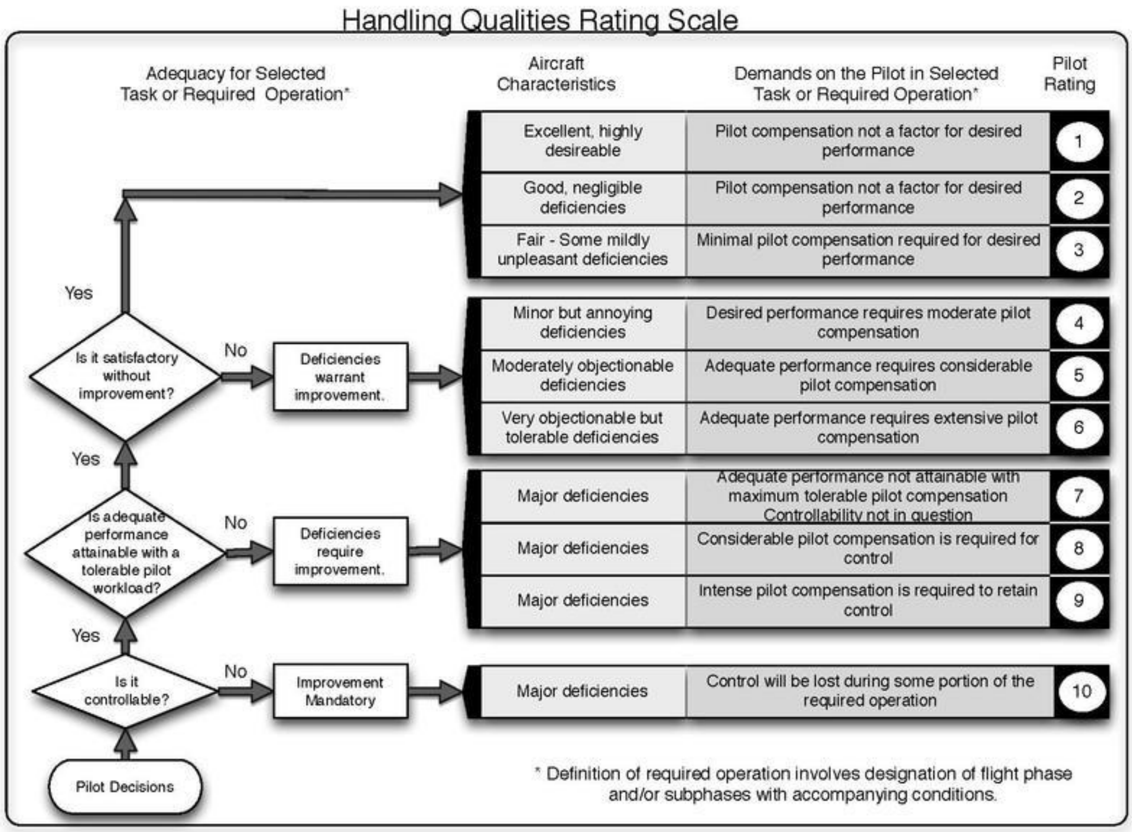


Fig. 32.1 Cooper-Harper handling qualities rating scale.[2]

The Cooper-Harper pilot rating scale works very well. Once a pilot is briefed on how to apply the ratings, his evaluation will generally agree within one number of any other pilot who evaluates the same aircraft. The method becomes much more accurate if a number of pilots of varying backgrounds and experience levels are used to evaluate a given airplane. The resultant average Cooper-Harper pilot rating will give an accurate evaluation of the aircraft or handling qualities item involved.

5.1.3 Levels of Flying Qualities

The background information for MIL-F-8785B (Ref. 3) simplifies the flying qualities ratings of the Cooper-Harper rating scale into three levels of acceptable flying qualities. These levels of acceptability and their respective definitions are:

Level 1: Flying qualities clearly adequate for the mission flight phase.
Level 2: Flying qualities adequate to accomplish the mission flight phase, but some increase in pilot workload or degradation in mission effectiveness, or both, exists.
Level 3: Flying qualities such that the airplane can be controlled safely, but pilot workload is excessive or mission effectiveness is inadequate, or both.

The above levels would correspond to Cooper-Harper rating scale as follows:

Level 1: 1–3.5 on Cooper-Harper scale
Level 2: 3.5–6.5 on Cooper-Harper scale
Level 3: 6.5–9+ on Cooper-Harper scale

It might also be noted that the handling qualities levels mention pilot workload. Pilot workload is a function of a large number of variables in addition to those related to stability and control. As a result, handling qualities may take on a much larger meaning, which may include:

1) human factors items such as cockpit design
2) airplane performance
3) meteorological conditions during the mission
4) other factors that may affect pilot workload

Therefore, when we conduct handling qualities investigations we need to be sure that the items and the conditions under which we want them evaluated are properly defined.

5.1.4 Flight Test Procedures

Although the FAA regulations for small airplanes do not address the use of flying qualities rating scales, the use of these scales is an excellent way of evaluating many flying tasks that the pilot may experience. For instance, the regulations do not address the level of difficulty that the pilot may experience in flying an ILS precision approach in a specific airplane. For such an evaluation use of the Cooper-Harper rating scale is a good way to perform the evaluation since it evaluates the flying qualities, in total, required to perform this task in addition to other related factors such as design of the instrument panel and specific instruments.

5.1.4.1 Designing the Test

The test should be designed so as to not cover too large of an area for evaluation. If possible, keep the evaluation to a specific task. Involve a large enough sample of pilots to identify the pilot population whose gains may match the airplane responses when they are in the loop. Five to ten pilots would provide a reasonable sample; one or two pilots does not.

5.1.4.2 Pretest Briefing

You should be sure to conduct a very complete preflight briefing, which should include the use of the rating scale. The pilots should be cautioned about deviating from the planned test as this may change the results.

5.1.4.3 Conducting the Test

The pilot should assign the rating immediately after completing the task. Allowing time to pass prior to assigning the rating may allow the pilot to rationalize and change the rating. Especially avoid having the pilot discuss the rating with other pilots prior to assigning the rating.

5.1.4.4 Post-Flight Debriefing

This debriefing should also be conducted as quickly as possible after the flight and without any discussions with other evaluation pilots. During this debriefing questions may be asked as to why the pilot assigned the rating, plus any other questions pertinent to the task.

5.1.4.5 Evaluating the Results

In evaluating the results, one will find that the majority of evaluation pilots assign ratings that are within one number of each other. However, if one pilot does not agree with the majority, particular attention should be paid as to why the rating was assigned. This may be the individual in the pilot population whose response frequencies and gains more nearly match those of the aircraft with the potential for problems. If such an individual exists in the evaluation pilot sample, efforts should be made to change the aircraft to eliminate the problem or provide notes in the Pilot's Operating Handbook to call attention to the potential for a problem.

5.2 Stall Characteristics

In addition to determining the stalling speed, a knowledge of the aircraft's characteristics as the airplane stalls is important, since if an inadvertent stall should occur we want the airplane to be well behaved without a tendency to enter uncontrolled flight. Therefore, an investigation of the stall characteristics of the airplane is an important part of any airplane certification.

As stated in Chapter 4, defining when the stall occurs is important since several different definitions of that event exist. In fact, there are several different definitions in the Federal Air Regulations. CAR 3 (Ref. 1) and FAR 23 (Ref. 2) define the stall as the airspeed when the nose pitches uncontrollably or the elevator control reaches the up stop. The current FAR 23 further says that for determining stall characteristics the elevator must be held against the up stop for two seconds before recovery can be initiated. However, FAR 25 (Ref. 3) defines the stall as the minimum airspeed seen during the maneuver. In this text we will use the CAR 3/FAR 23 definition.

5.2.1 Safety Consideration

Depending upon aircraft design, stall characteristics testing can be hazardous so it should be approached with caution. A number of safety items should be evaluated before beginning this testing.

5.2.1.1 Aircraft Egress

The ease with which the crew can egress should be evaluated. This is particularly true for aircraft that have aft cabin doors. For all aircraft, one should consider quick release doors or escape hatches that are easily reached by the crew during post stall gyrations or inadvertent spins. If an aft cabin door is the only option, then methods to get to that door in advent of an unrecoverable deep stall should be devised.

5.2.1.2 Considerations for Recovery Parachute

If the aircraft has swept wings and a T-tail, or an unswept wing with swept center section and a T-tail, then one should consider a recovery parachute system as these design features have been known to cause unrecoverably deep stalls. Recovery chute design should follow the same guidelines as that required for spin recovery parachutes which is provided in the following

5.2.1.3 Personal Equipment

Personal equipment for the crew during stall characteristics testing should include flying suit, helmet, jump boots, and a personal parachute. The more modern personal parachutes with deployment bag, to reduce opening shock, and a steerable canopy are preferred.

5.2.1.4 Minimum Test Altitude

A minimum test altitude should be established depending on the type of aircraft. For light single, or multiengine aircraft, this altitude should be at least 5000 ft above ground level (AGL). For heavier aircraft, this altitude AGL should be increased accordingly. These altitudes should be the recovery altitudes and not the altitude where the stall is initiated.

For multiengine aircraft with turbine, or normally aspirated reciprocating engines, care should be taken to ensure that the altitude selected is not the altitude where the minimum control speed and the stalling speed are the same or nearly the same. Selecting such an altitude will result in a rapid spin entry or out of control condition from which there may be no recovery!

5.2.1.5 Chase Aircraft

During initial, and any critical, stall characteristics testing a chase aircraft is a good idea. The chase aircraft crew should be prebriefed on minimum altitudes and the stalls to be performed so as to be in position to observe, clear the area, and provide assistance for the test aircraft without being in its way.

5.2.2 Fight Test Method

5.2.2.1 Aircraft Test Configurations

Good test planning dictates investigation of clean configuration power-off stalls first, followed by the power on clean configuration to regain altitude lost from the power-off tests. These are then followed by turning and accelerated stalls, which will normally result in more altitude gain. For the completion sequence, a power-off gear and flap down stall should be followed by a power-on stall in the same configuration. This approach to mixing the test configurations will result in less time spent climbing to regain altitude lost during a power-off stall sequence and will result in minimum flight time.

5.2.2.2 Trim Airspeed

Both CAR 3 and FAR Part 23 call for a trim speed of 1.5 times the stalling speed in the test configuration. For initial stalls where the stalling speed is not known, this can be the calculated stalling speed. Once test numbers are obtained the trim should be readjusted to 1.5 times the actual stalling speed. In trimming the aircraft for these speeds, one should insure that the power is in the power setting required for the given stall.

5.2.2.3 Power Setting

Regarding power settings for evaluating stall characteristics, for power on stalls, CAR 3 requires a power setting of 90% MCP while FAR Part 23 requires a power setting of 75% MCP. Generally, 75% MCP can be obtained to altitudes of 7000 ft MSL or above which does not present a problem from the safety point of view. However, 90% MCP may not be obtained above safe altitudes for many engines while conducting initial stall characteristics investigations. For airplanes that are approved under CAR 3, these initial investigations should be conducted at maximum available power at a safe altitude prior to retesting at a lower altitude where 90% MCP can be obtained. If the test location will not allow achieving 90% of sea level MCP then the maximum power available at the lowest safe altitude should be used.

Power-off stalls for stall characteristics should be performed with the propeller in the high rpm setting (low pitch) and the throttle reduced to the idle setting.

Power may be reapplied during recovery after the aircraft has achieved an airspeed of 1.2 times the stalling speed.

5.2.2.4 Deceleration Rate

CAR 3 calls for a deceleration rate prior to the stall of 1 mph/s while FAR Part 23 calls for a rate of 1 kn/s. Fig. 4.1 in this text shows a method of determining deceleration rate and stall speed if an automatic recording device that records airspeed vs time is available. Such instrumentation may be available for a commuter category certification or for a heavy twin, however, on most light aircraft programs such instrumentation is not available. Therefore the most common method is to pick up a count "thousand one, thousand two..." and attempt to make the deceleration rate match the count in knots or miles per hour prior to the airplane reaching 10% in excess of the stall speed and then maintaining that rate until the airplane stalls.

5.2.2.5 Control Usage

The regulations require maintaining wings level flight up until the stall break and no more than 15 deg of roll or yaw after the nose pitches downward uncontrollably. In order to do this there is nothing in the regulation that prohibits use of full control travel as long as that usage of the controls is unreversed and coordinated. Many pilots are hesitant to use full control travel during the stall for fear of an inadvertent spin entry. However, if the pilot is alert and ready to rapidly remove the full travel should the airplane roll in the direction of control deflection an inadvertent spin is unlikely. In any case, the pilot should be ready to rapidly reduce the angle of attack by applying nose down elevator. During stall characteristics testing the test pilot must be somewhat like the boxer in the ring ready to shuffle and jab the controls in response to the airplane's reactions.

The later amendments to FAR Part 23 require that the elevator control be held in the full up position for 2 s after the nose pitches downward uncontrollably. However, if a rapid uncontrollable departure from wings level flight occurs during this time the pilot should consider the characteristics for that stall unsatisfactory and recover immediately.

5.2.2.6 Stall Warning

The airspeed at which the stall warning device activates should be recorded for each stall. If the warning occurs at too high or too low an airspeed then the device should be adjusted and the stall repeated. Care should be taken during stall characteristics testing to insure that the deceleration rate is obtained prior to the activation of the device as higher or lower deceleration rates may affect when the device activates. However, with any deceleration rate the device should give adequate warning for the stall, but not come on so high an airspeed as to be a nuisance or to be ignored.

5.2.2.7 Defining Stall

On airplanes that do not require a stick pusher or stall barrier device, the stall is usually defined as when the elevator control reaches the up stop, as most light aircraft have sufficient elevator power to prevent the nose from pitching downward uncontrollably until the up stop is reached.

For aircraft with stick pushers or stall barrier devices, the stall is defined when that device activates. Again, Fig. 4.1 provides a graphical depiction of stall definition.

5.2.2.8 Recovery Technique

Normally, recovery from the stall can be effected by relaxing the back pressure on the elevator control. In cases where the airplane does not recover immediately from this action, use of down elevator, including full down elevator, is warranted. If rolling and yawing are occurring during the recovery these should be opposed by rudder and aileron in the direction opposite the roll or yaw, up to and including full rudder and aileron.

5.2.3 Data Requirements

The following data should be collected during the stall event:

1) warning airspeed
2) stalling airspeed
3) altitude loss during the stall
4) maximum roll, pitch, and yaw during the stall, including direction
5) normal acceleration during recovery

These data may be recorded by a data system or by hand from calibrated panel instruments. If hand recording is used a crew of two is useful since the test pilot needs to be paying attention to the aircraft rather than trying to gather numbers. However, if only a test pilot is used as a crew and a data system is not available then practice in flying the airplane while collecting data in an aircraft with benign stall characteristics may be worthwhile. Also, if hand recording is used a sensitive airspeed indicator graduated in 1 kn increments should be installed. For roll, pitch, and yaw angles, panel mounted attitude indicators have been found acceptable for collecting these data.

5.3 Airplane Spin Testing

In the nearly 100 years that airplanes have existed, the spin has remained a persistent problem. The investigation of the airplane's spin characteristics are among the most hazardous of flight tests. One of the reasons for this is that the dynamics of the spin are not well understood and a good deal of misinformation exists regarding spins. The spin is a disorienting maneuver that may cause even the experienced pilot to make the wrong control inputs to effect recovery. Additionally, modern aircraft designs contain design features that are adverse to good spin and recovery characteristics.

Although much effort has been made to make airplanes unspinnable, nearly all airplanes will spin under some condition. Early attempts at unspinnable airplanes limited c.g. travel and up elevator in an attempt to prevent the airplane from stalling and, therefore, spinning. However, this could be overcome by a zoom climb with resulting stall and spin when the airplane ran out of energy at the top of the climb.

From the flight test standpoint, the spin test is only performed on single-engine airplanes. Multiengine airplanes are exempt from spin testing by the FAA. There are two reasons for this: First, the single-engine airplane is more likely to be inadvertently spun due to the less experienced pilots that generally fly those airplanes. Second, multiengine airplanes are more likely to have unrecoverable spin modes than are single-engine airplanes due to their higher inertia in a spin.

5.3.1 Spin Definition

Before we discuss the spin further, we should first define it. A spin is an out-of-control maneuver at angles of attack beyond the stall during which the airplane rotates about its c.g. and an axis perpendicular to the Earth while descending vertically at high rates of descent.

Another term that is often used in spin literature and discussions is the incipient spin. The incipient spin is a transition maneuver between the stall and the fully developed spin where the airplane begins its autorotation. The incipient phase of the spin may also be accompanied by large changes in pitch as the airplane rotates.

5.3.2 Spin Types

There are two types of spins. The most common type, and in most cases the most difficult type for recovery, is the upright or erect spin. In this spin the rolling and yawing motion are in the same direction. This type can occur from normal flying maneuvers and is the most likely cause of spin accidents. If this spin occurs at traffic pattern altitudes, a safe recovery is unlikely. The second type of spin is the inverted spin. In this spin the yawing and rolling motion are in opposite directions and although both types of spins are disorienting to the pilot, this opposition of rolling and yawing makes the inverted spin the most disorienting.

5.3.3 Federal Aviation Administration Regulations

The FAA Regulations for spin certification apply only to single-engine airplanes and have not changed significantly for a number of years. However, in recent years the FAA has adopted some regulations on spin resistance as a result of NASA research. This spin resistant regulation is discussed in a later paragraph. Multiengine airplanes are not required to be certified for spins. There are at least two reasons why these airplanes are not required to demonstrate spins. First, these aircraft are not as likely to be involved in inadvertent spins as the pilots of such aircraft are likely to be more experienced than are pilots of single-engine airplanes. Second, these airplanes have higher wing loadings and larger inertias and are much more difficult to recover from a spin.

5.3.4 Flight Test Method

5.3.4.1 Preflight Briefing

The preflight briefing should include all members of the test team and a free exchange of ideas should be allowed during the briefing. The briefing should include:

1) Spins to be performed during the flight
2) Buildup technique to be used
3) Actions of the chase crew

4) Geographic location of the test and positioning of the ground crew
5) Communications discipline
6) Procedures in case of a mishap

5.3.4.2 Normal Category Spin Matrix

Figure 34.1 shows the normal category matrix of spins that must be accomplished for certification in the FAA normal category as recommended by AC 23-8A (Ref. 3). In this case, the regulation requires one turn spinning and no more than one turn during the recovery. As can be seen from this figure, the matrix for an all-up spin certification program requires a large number of spins. In recent years industry complaints have led to the issuance of AC 23-15 (Ref. 4) which provides some relief from this large matrix.

Fig. 34.2 provides the reduced spin matrix given in AC 23-15. As can be seen, the number of one-turn spins required by this matrix is considerably reduced from that recommended by AC 23-8A.

5.3.4.3 Aerobatic Category Spin Matrix

Fig. 34.1 also provides the recommended spins for an acrobatic category certification. This matrix is essentially the same as the normal category matrix except that the gear and flaps up spins are carried out to at least six turns spinning and one and one-half recovering. Since a buildup to six turns will be required for the purposes of safety, this matrix could well exceed 1000 spins. No relief, such as AC 23-15, is given for this matrix.

5.3.4.4 Test Conduct

Since the spin matrices shown above are quite large, the testing should be divided into manageable portions. Due to the high-stress nature of this testing, the pilot should not be subjected to more than a dozen spins per flight and no more than two flights per day. Once the decision is made on the type and number of spins to be performed on a given flight, the test crew should construct test cards.

34.5.4.1 Stone spin shorthand. One efficient way to construct the test card is with the use of Stone Spin Shorthand.[24] This shorthand method was developed by the late Robert R. Stone, a friend of the author's, during the spin program on the Beechcraft T-34C U.S. Navy Trainer. The shorthand box was adopted from a box used by the NASA Langley Spin Tunnel to note model control positions and modified to make sense in the cockpit. Fig. 34.14 (Ref. 24) shows the shorthand box and several representative spins and recoveries. Figure 34.15 (Ref. 24) is a sample test card. With this system, the complete control positions for various spins can be described without notes. It can also be used to assist the pilot in both planning the spin flight test and conducting the actual tests.

34.5.4.2 Buildup technique. A buildup technique should be used to reach the maximum number of turns for a given type of spin. The first turn should be approached by starting first with a one-half turn spin, followed by a three-quarter-turn spin and then a one-turn spin. The number of turns to recover from each of these spins should be evaluated before progressing to the subsequent spin. If the program is for acrobatic spins then spins beyond one turn should be approached in one-quarter- or one-half-turn increments depending upon recovery turns from the preceding spin.

The testing should begin with the aircraft loaded to forward c.g. at maximum takeoff weight and after the matrix at that loading is complete the loading should be changed in small increments of c.g. until aft c.g. is reached. During this aft movement of the c.g. it is not necessary to do the complete spin matrix, but only those spins that took the greatest number of turns to recover at the forward c.g. At aft c.g. the complete matrix should be completed.

Although this technique is quite flight time intensive, it reduces the possibility of encountering an unrecoverable spin and the use of the spin recovery parachute.

34.5.4.3 Control trim positions. The FARs state that the aircraft should be trimmed to $1.5V_{S1}$ as in stall characteristics. AC 23-3A states that if the airplane has a trimable stabilizer the extremes of trim deflection should be investigated. Again, a buildup technique might be advised as, at full deflection of a trimable stabilizer, the control forces during recovery might be quite high and the possibility for over stressing the aircraft might exist.

34.5.4.4 Recovery technique. The recovery technique used for recoveries should be rudder opposite the direction of spin, followed immediately by full down elevator. This is known as the NACA recovery. However, other recovery techniques should be evaluated. Advisory Circulars 23-8A and 23-15 both require the investigation of other recoveries such as neutralizing controls, elevator first recoveries, rudder only recoveries, and so forth, to see if such recoveries will produce an unrecoverable spin. In the case of spins that enter the flat mode, it has been found that sometimes aileron into the spin will effect a recovery. It should be noted that the FAA will not accept such recovery techniques for certificated airplanes.

34.5.4.5 Power-on spins. Advisory Circulars 23-8A and 23-15 both recommend the investigation of power on the spin characteristics. Both ACs ask for takeoff power to be used on some entries and to be held for one complete turn on some spins (see Figs. 34.1 and 34.2). Both permit the power to be reduced to idle for recovery. It has been the author's experience that leaving the power at takeoff power until the rotation stops will hasten recovery on many airplanes. However, it is then wise to reduce it to idle to prevent a large speed buildup in the ensuing dive.

34.5.4.6 Uncontrollable spin. Ailerons placed opposite the spin direction, such as might occur in an inadvertent spin entry, have been known to produce unrecoverable, or flat, spins. Also, in multiturn spins removing this opposite aileron at some point in the spin has produced unrecoverable spins. On some aircraft, power application has also had a similar effect.

If an unrecoverable, or flat, spin is encountered the chase aircraft crew should be briefed to count turns for the test pilot and to call out various recovery controls including landing gear and flap deployment. The emergency recovery controls should be briefed in the preflight briefing along with the number of spin turns these controls will be held before trying another combination. When none of the prebriefed control combinations work, then the spin recovery device should be employed. If this device fails, the test pilot should immediately egress the aircraft at the urging of the chase aircraft crew.

34.5.4.7 Data acquisition. The type of data acquisition system used will depend upon the financial resources of the flight test organization involved. However, the better the system and the more related parameters that it can collect, the more likely spin problems are to be solved rapidly. Also, should an accident occur, data may be available to clear the test pilot from wrongdoing or vice versa.

Chase video. As a minimum, the spin test should be recorded on video from the chase aircraft. A video camera with a 12 × 1 zoom capability is necessary in order to usefully track the aircraft during the departure and ensuing spin. It is worthwhile to let the chase crew practice tracking an aircraft during practice spins in an aircraft with known spin characteristics.

Cockpit video. It is also extremely worthwhile to have video from the cockpit of the test aircraft. This can assist in counting turns spinning and recovering along with recording other required data. It can be quite helpful in offloading many of the test pilot's data collection duties. If this video can be telemetered to the ground, the test crew can play a much larger role in the overall safety of the test.

Long lens ground tracking camera. If the aircraft can be tracked by long lens tracking camera from the ground this will also provide much useful data.

Onboard data collection package. If funds are available, a data collection system capable of collecting angle of attack and angle of sideslip at both wingtips, roll, pitch, and yaw rates and X, Y, and Z accelerations at the aircraft c.g., along with airspeed, altitude, control positions, and control forces will make spin testing and data analysis much more productive. Such available data will allow analysis of spin problems and improve recovery procedures.

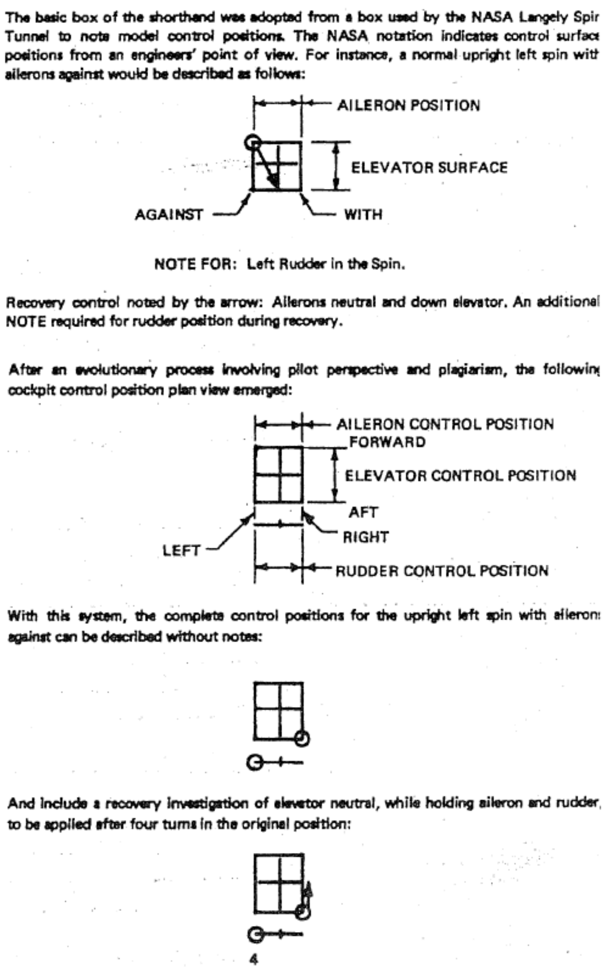
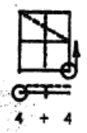
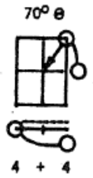


Fig. 34.14 Spin Shorthand developed by Robert R. Stone.[24]

Recovery control action can also be included to cover the possibility that the recovery nvestigation does not bring about recovery. In this case, stick full forward, ailerons-with nd rudder against to be applied after an additional four turns.



To illustrate the versatility of the system, consider the following: An inertia couplin entry from a 70° nose high attitude to an inverted left spin with ailerons against. Attemp recovery investigation after four turns by neutralizing ailerons and elevator. If the recover investigation does not bring about recovery in an additional four turns, reverse the rudder t effect recovery:



With this basic system, the majority of out-of-control flight investigations can be describe in a form facilitating glance reference in the cockpit and can be used to condense data fo permanent record or communication.

Fig. 34.14 Spin Shorthand developed by Robert R. Stone[24] (continued).

SPIN DATA SHEET

FLIGHT NO. ________ S/N ________ DATE ________ LAND: ____________

T.O. GROSS WT.: __________ LB CG: _______ % MAC T.O. ____________

CONFIG.: ____________________ IYMP: ________ TOTAL: ____________

SPIN NO.								
T.O.D.								
FUEL QTY.								
Hp START/REC.	/	/	/	/	/	/	/	/
KIAS START/REC.	/	/	/	/	/	/	/	/
THRUST								
ENTRY								
TRIMS: E = R = A = SPIN CONTROLS								
TURNS PLAN/REC.	/	/	/	/	/	/	/	/
INSTR. R/N								

SPIN NO.	INSTRUMENTATION: PRE-FLT R/N: POST-FLT R/N:
	/ / / / / / / / /
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Fig. 34.15 Spin data card.[24]

5.3 Dive Testing for Flutter, Vibration and Buffeting

5.3.1 Introduction

Determining that the aircraft is free from flutter, vibration, and buffeting for airspeeds from stall speed up to and including the design dive speed V_D is the most hazardous testing in aircraft certification and should be approached with utmost caution. It usually comes at or near the end of the aircraft development program for at least two reasons. First, is that the analysis of structural dynamic phenomena is difficult and time consuming even with modern computers and only begins in earnest after the aircraft is completed and a ground vibration survey has been conducted. Second, it obeys the test pilot's longevity rule, which says that if you put the really hazardous tests off until last you live longer!

5.3.2 Federal Aviation Administration Regulations

CAR 3 (Ref. 1) has requirements for flutter and vibration while FAR Part 23 (Ref. 2) has requirements for vibration and buffeting and has separated flutter into a stand-alone regulation. There have been numerous changes between CAR 3 and FAR Part 23, and FAR Part 23 has seen several changes on these items since its issuance.

5.3.3 Theory

The phenomena discussed in this chapter comes under what is called aeroelastic effects. Such effects include control reversal, divergence, and flutter. All are normally caused by a lack of structural stiffness in one or more of the airplanes components when these components are under aerodynamic load. The author is not an expert on these subjects; therefore, the following should be seen as a test pilot's understanding of the subject and a more thorough knowledge should be obtained from structural dynamic references.

5.3.3.1 Control Reversal

Control reversal occurs when the deflection of a control surface in flight causes the aircraft component to which it is attached to deflect to a point where its deflection overpowers the movement of the control surface and causes a reaction in the opposite direction to what the pilot intended. This is discussed for aileron controls in Chapter 30, and the structural mechanics discussed in this chapter apply for other control surfaces as well.

5.3.3.2 Divergence

Structural divergence is like aileron reversal in that it is an aeroelastic effect. However, structural divergence nearly always leads to an immediate failure of the structure. Since the lift of an airfoil acts at the 1/4 chord of an aerodynamic surface and the elastic axis of the structure normally occurs near mid-chord a twisting moment is introduced by the production of lift. However, the lift is increased as a function of velocity squared while the structural stiffness in torsion is near linear. Since the twisting of the surface increases its angle of attack, there will be an airspeed where the lift created will overcome the structural stiffness and the surface will diverge and fail. Therefore, this speed should be well above the airspeed range of the airplane.

5.3.3.3 Flutter

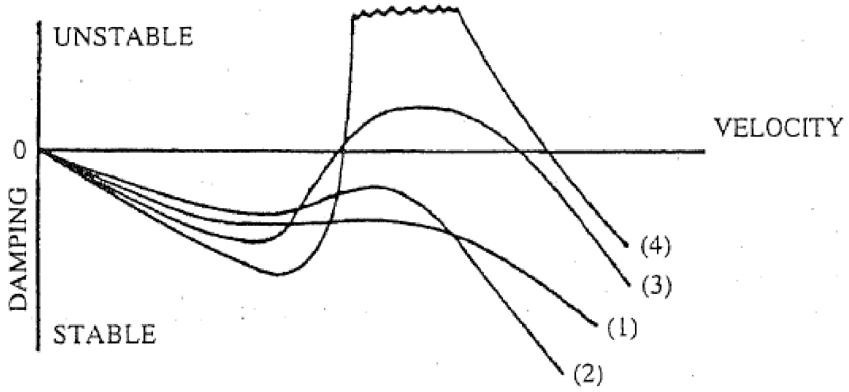
Aerodynamic flutter is a resonance of the airplane's structure when influenced by the atmosphere or control inputs. It is a function of the structural stiffness, inertia properties, and aerodynamic forces. For flutter to occur at subsonic speeds the part, or parts, in question need at least two degrees of freedom and there has to be a coupling between them. This will depend upon the natural frequencies of the part or parts. Depending upon the type of flutter, it can occur at any airspeed. It also can be destructive in a very short period. During the author's experience with flutter in the prototype Aero Commander 112, the complete horizontal tail, upper vertical tail, and rudder departed the aircraft in 0.3 s which was followed by a very wild ride! This occurred when five flutter modes all came together at the dive airspeed.

35.3.3.1 Natural frequencies. Every structure has a natural frequency. This is particularly true of metal structures. In general, it can be said that the stiffer the structure, the higher the frequency. Since most of the frequencies associated with the atmosphere and aviation occur below 50 Hz it is desirable to have the structural frequencies of the aircraft above that range. However, in most cases this is not possible to achieve. It then behooves the airplane designer to keep the natural frequencies of the various components separated by sufficient margin that they will not come together under load. In addition, most structures have several harmonics of the resonant frequency. The in-flight frequencies are a function of the air loads on the airplane which are functions of airspeed.

35.3.3.2 Flutter modes. The flutter modes refer to the degrees of freedom of the structure. Some examples are wing bending, wing torsion, aileron rotation, elevator rotation, horizontal tail bending, horizontal tail torsion, fuselage bending, and so on. The coupling of the resonant frequencies of these modes will create flutter and it can generally be said that the more modes that couple the greater, and quicker, the destruction with the torsional modes being among the more destructive.

35.3.3.3 Nodal lines. A nodal line in the discussion of flutter is a line on the structure that does not deflect during the flutter oscillation. If one considers the elevator rotation mode by itself, one can see that this line would coincide with the hinge line. However, if we combine the elevator rotation mode with the stabilizer bending mode, we can see that this nodal line will have a location other than along the hinge line. It is important in the ground vibration survey to identify the modes, their frequencies, and the location of the nodal lines. The reason for this is that if instrumentation, such as accelerometers or strain gauges, are placed upon a nodal line there will not be any indication that you are approaching a flutter speed. In the author's accident with flutter, the nodal lines had been misidentified and the accelerometers placed on the actual ones. It is worthwhile for the test crew to ask the flutter engineers to show the sketch of the nodal lines on the airplane and ensure that the instrumentation accelerometers are placed as far away from these lines as possible to insure they see the maximum accelerations from the excitation.

35.3.3.4 Coupling. For flutter to occur there must be coupling. In the simple modes (control surface rotation) the coupling frequency must come from the atmosphere. However, if control surfaces are not properly balanced this may occur. For the more complex modes, the coupling will come from other modes such as aileron rotation and wing bending, or other combinations. After the ground vibration survey and the flutter analysis, the flutter engineers should be able to tell which modes are most likely to couple and the airspeed at which that may occur. Fig. 35.1 (Ref. 4) shows a plot of damping vs airspeed for a representative coupling. From this plot one can see that there is an airspeed where the damping becomes unstable and the modes couple causing flutter. That airspeed should be above the dive speed of the airplane.



Curves 1 and 2 show slight trends towards instability, but do not approach actual instability.

Fig. 35.1 Structural damping vs airspeed.[4]

35.3.3.5 Aerodynamic damping and excitation. In-flight the atmosphere provides damping for the motion of the airplane and its parts. However, at the same time the atmosphere imparts energy to the airframe. As speed increases the aerodynamic forces may excite the natural frequencies of the structure and cause the structural damping to go unstable resulting in flutter. As the energy imparted is a function of airspeed squared, the faster the flight, the higher this forcing energy.

35.3.3.6 Mass distribution. The location of large masses such as fuel or engines will affect the structural frequencies. For instance, fuel in tip tanks, or located in the outboard portion of the wing, will lower the structural frequency of wing bending. Unbalanced control surfaces generally have their center of mass behind the hinge line which will cause rotation when subjected to a gust. This rotation provides excitation to the airframe and can induce flutter. As a result, having control surfaces balanced to near 100% is an effective measure to reduce the possibility of flutter. However, having this balance concentrated at the end of the surface may not be the best approach since it is likely to lower the bending and torsional frequencies. Having the balance weight distributed along the surface or located in the center of the surface is the best approach from the flutter standpoint. It may, however, result in a heavier airplane.

5.3.4 Flight Test Method

Prior to commencing the test the airspeed indicator should have a fresh calibration and the pitot-static system should be leak checked. This assumes that the position correction calibration is recent and linear at high airspeed. If this is not the case then a calibrated chase aircraft with a calibrated speed range greater than that of the test aircraft should be used to determine the speed of the test.

Control surfaces should be balanced to the most under balanced (tail heavy) condition and the trim tabs set to the maximum allowable free play. The control system damping should be minimized to simulate wear. These values should be obtained from the flutter analysis and become part of the type design if the tests are successful.[4]

Since the airplane mass locations may affect the flutter modes, consideration should be given to the fuel loading. If the fuel quantity affects the flutter modes then at least a maximum and minimum fuel load should be tested.[4] The c.g. should be at the aft c.g. location to reduce the down load on the horizontal tail to help prevent overstressing should tail flutter be encountered. The most critical condition of weight should be tested.

Prior to beginning the dives, make sure that the pilot restraint system is secure and so tight that it is uncomfortable.

5.3.4.1 Buildup Technique

Like any critical or hazardous flight test a buildup technique should be used in reaching the dive airspeed.

35.6.1.1 Altitude. For the test altitude, the technique is to build down as was discussed briefly earlier. In other words, the high-altitude airspeeds should be obtained before the low-altitude airspeeds are obtained.

35.6.1.2 Airspeed. The buildup in airspeed should begin at the initial flutter clearance airspeed (usually 130 kn, or 150 mph for light aircraft) and progress in 10-kn increments until the flutter analysis shows signs of reduced damping. At that point speed increments should be reduced to 5-kn increments. The number of airspeed increments per flight is a function of the instrumentation system (telemetry or on-board recording) and the confidence in the flutter analysis. If telemetry is available and the actual results are as expected from the flutter analysis, then a large number of airspeeds can be obtained per flight. However, if only on-board recording is available, then two to three airspeed increments may be all that should be obtained per flight with that number decreasing as speed increases. During the airspeed increments near the dive speed it is best to be cautious.

5.3.4.2 In case of Problem

Should flutter be encountered or an unusual vibration be felt in the airframe, reduce power to idle and recover from the dive as rapidly as possible without overloading the airplane or introducing large control movements. If no damage to the airframe is observed, *do not* repeat the test point until the cause has been determined, a fix installed, and the airframe inspected thoroughly. If the flutter is destructive before the above action can be taken, hang on, pray, and wait for the thrashing to subside before trying to exit the aircraft. This will require considerable altitude, so be ready to deploy your personal parachute as soon as you are free of the aircraft and expect the ground to appear very rapidly.

5.3.5 Data Analysis

Since the test aircrews lives are at stake, they should be involved in the data analysis. The degree to which they participate is a function of their knowledge of the subject and the experience and capability of the individual, or individuals, doing the flutter analysis. This becomes more difficult if telemetry is used for data collection. Therefore, if telemetry is used, the aircrew should stop the buildup at a point of their choosing and review the data with the flutter engineer(s). Particular attention should be paid to how the actual data compares with the analysis.

At least two potential data presentations are worth examining as the test progresses. One is how rapid the oscillations from the excitation damp. If this changes significantly as the test progresses and does not agree with the analysis then the test should be suspended until an explanation can be found. The second presentation is a plot of acceleration of the various structural modes vs the frequency of the oscillations. This second presentation is more valuable than the first in evaluating changes in the modes as the airspeed increases. If the modes show a significant change in frequency or acceleration between airspeeds, and this is not shown by the analysis, then again testing should be suspended and explanations found and if necessary fixes applied. Flutter is a very mathematically complex subject that requires considerable experience to master. Therefore, aircrew members should retain a healthy scepticism toward the flutter engineers and their analysis.

Previous exam questions:

1. (10AE831 – June/July 2018)

a. Write a brief notes on: (6M)

i) Handling qualities and HQ levels ii) Flight phase categories iii) Flight envelopes

b. Explain the Cooper-Harper pilot rating scale for handling qualities with the help of a neat flow chart. (14M)

c. What is a spin shorthand? Describe the stone shorthand with neat sketches. (6M)

d. Explain spin build-up and recovery techniques, keeping the phases of spin in view. (8M)

e. Define the terms: (6M)

i) Flutter ii) Vibration iii) Buffeting in dive testing

2. (10AE831 – June/July 2017)

a. Explain the Cooper-Harper pilot rating scale for handling qualities of aeroplanes.(20M)

b. Explain the flight test method for stall testing and data requirement. (10M)

c. Explain flutter, Vibration and buffet in a drive testing. (10M)

3. (06AE831 – June/July 2011)

a. Explain the Cooper-Harper pilot rating scale for handling qualities of aeroplanes.(20M)

b. Explain the effect of various airframe components on spin. (20M)

4. (06AE831 – May/June 2010)

a. Describe Cooper-Harper handling and qualities scale. (12M)

b. Write levels of flying qualities on Cooper-Harper scale. (8M)

c. Explain the flight test method for stall testing and data requirement. (8M)

d. What is spin short hand? (5M)

e. Explain spin build up and spin recovery techniques. (7M)