AC NO. - 23-9

U.S. Department of Transportation
Federal Aviation Administration

Advisory Circular

Date: 1/27/88
AC No: 23-9
Initiated by: ACE-100
Change:

SUBJECT: EVALUATION OF FLIGHT LOADS ON SMALL AIRPLANES WITH T, V, +, OR Y EMPENNAGE CONFIRGURATIONS

1. PURPOSE. This advisory circular (AC) provides information and guidance for an acceptable means, but not the only means, of demonstrating compliance with the requirements of Part 23 of the Federal Aviation Regulations (FAR) regarding evaluation of design flight loads for small airplanes with T, V, +, or Y empennage configurations. Accordingly, this material is neither mandatory nor regulatory in nature and does not constitute a regulation.

2. RELATED REGULATIONS. Sections 23.301, 23.331, 23.333, 23.351, 23.367, 23.395, 23.397, 23.399, 23.421, 23.423, 23.425, 23.427, 23.441, 23.443, 23.445, and 23.455.

3. BACKGROUND. Section 23.427(c) requires that configurations where the horizontal tail surfaces are supported by the vertical tail, or have appreciable dihedral, must be designed for the combined vertical and horizontal loads resulting from each flight condition (taken separately) prescribed by Part 23 of the FAR. Guidance for the development and verification of acceptable analysis methods is contained in this AC.

It should also be noted that the simplified design load criteria of appendix A of Part 23 of the FAR are only applicable to airplanes with conventional empennage configurations.

Many different empennage configurations have been certificated or are in an advanced stage of design, covering at least one example of all the major types defined in paragraph 4 below. The following acceptable means of compliance is based on a review of methods used for the development and verification of design loads for past certification programs.

4. DEFINITIONS.

a. Conventional Tail. An empennage with a horizontal stabilizer having little or no dihedral or anhedral mounted low on the vertical stabilizer or on the aft fuselage.

b. T-tail. An empennage with a horizontal stabilizer having little or no dihedral or anhedral and mounted at or near the top of the vertical stabilizer.

c. V-tail. An empennage consisting of two panels set at a vee angle, upright or inverted, performing the functions of longitudinal and directional stabilizer. Control surfaces perform the dual functions of elevator and rudder.

d. + Tail. An empennage with a horizontal stabilizer having little or no dihedral or anhedral mounted on the vertical stabilizer considerably above the body, but not at the tip of the vertical stabilizer.

e. Y-tail. An empennage consisting of two panels set at a vee angle, and a vertical stabilizer. The vee surfaces may be mounted at the top of the vertical surface or all surfaces may be fuselage mounted. Control surface functions are separated.

5. ACCEPTABLE MEANS OF COMPLIANCE. Actual design loads are normally calculated, even if the basis for these loads is wind tunnel or flight test measurement. Design loads are calculated at conservative combinations of parameters which would be virtually impossible to obtain simultaneously in flight. The development of these design loads generally use one of the following procedures:

FINAL LOADS	ANALYSIS	WIND TUNNEL TEST	FLIGHT TEST
Based on conservative analysis only.	Review previous certifications, literature, etc. Use conservative criteria.	None, except possible verification of airplane stability derivatives.	None
Based on wind tunnel measured component loads.	Use technique that accepts inputs from wind tunnel test.	Use strain gauges or pressures to develop load versus airplane parameters on empennage components, including rolling moments at intersecting surfaces.	None
Based on flight test measured component loads.	Use technique that accepts inputs from flight test.	None, except possible verification of airplane stability derivatives.	Use strain gauges or pressures to develop load versus airplane parameters on empennage components including rolling moments at intersecting surfaces.

a. Analysis Methods. Where reliance is placed mostly on analysis, a conservative approach should be used. The level of conservatism is dependent on the background of information available. Analysis methods used on previously type certificated airplanes of very similar design and performance are the most readily acceptable. The degree of conservatism in any approval based on analysis only (including data from technical literature) should be acceptable to the Federal Aviation Administration (FAA).

The most reliable analytical methods use some form of lifting surface theory to adequately evaluate the mutual influence of the aerodynamic surfaces. The ability to analytically simulate yaw, pitch, and control surface deflection effects is desirable.

Modeling of the entire airplane is important when using lifting surface analytical methods to account for sidewash and downwash flow field effects which can vary considerably, depending upon the configuration.

Less complex methods may be used providing conservative assumptions are made.

Methods for estimating the rolling moment added to the vertical stabilizer by the horizontal stabilizer of T and + empennage configurations are detailed in many reports. Appendix 1 contains a partial list of relevant reports.

The aerodynamic complexity of an unconventional tail configuration is such that a rational analysis is strongly recommended. An acceptable degree of accuracy can now be obtained using the computing resources of a personal computer.

In lieu of a rational analysis, the limit design rolling moment induced by sideslip, rudder deflection, or lateral gust on a T-tail configuration may be estimated as follows:

$$M = 0.3\ q\ SH\ bH\ \beta$$

where Mr = induced rolling moment at horizontal tail intersection with vertical tail (lb-ft)

q = dynamic pressure (lb/ft2)

SH = area of horizontal tail (ft2)

bH = span of horizontal tail (ft)

β = effective vertical tail side-slip angle (radians)

The effective vertical tail side-slip angle due to rudder deflection is dependent on rudder geometry. The effective vertical tail side-slip angle due to lateral gust may be assumed to be equal to $\frac{1.2U}{V}$ (radians)

where U = equivalent gust velocity (ft/sec)

V = equivalent airspeed (ft/sec)

The resulting rolling moment shall be combined, as required by § 23.427(c), with the vertical tail surface loads specified in §§ 23.441 and 23.443. This method does not include the effects of compressibility or dihedral. One study shows that 60 dihedral can increase the stabilizer rolling moment by 50%. Also, this method of estimating rolling moment is intended to be used for a static strength analysis only. Aerodynamic rolling moments estimated by this method and used for input to a flutter analysis could lead to unpredictable inaccuracies.

For airplanes with V-tails and Y-tails, loads should be validated by wind tunnel or flight tests until an adequate data base has been established for these tail configurations.

b. Wind Tunnel Test. Where reliance is placed mostly on wind tunnel test, the model should be sufficiently large to minimize any scale effects and allow for installation of strain gauges, and/or adequate pressure taps. If a large scale model of the empennage alon is used to maximize physical size of the surfaces, an evaluation should be made to determine that wing, body, power effects, wind tunnel wall corrections, etc., would not invalidate the partial model results.

Strain gauges installed at the roots of the aerodynamic surfaces to measure surface loading and rolling moment is the preferred method for measuring loads. However, pressure taps may be used if a sufficient number is installed to accurately predict the spanwise and chordwise surface loadings.

Test conditions should include pitch and yaw cases, and conditions with deflected control surfaces.

c. Flight Test. Some flight test loads may be required to determine if the full-scale airplane aerodynamic and aeroelastic characteristics have been adequately accounted for in the airloads analysis.

If flight testing is to be used as the primary source of loads data, rather than a validation, an extensive survey should be conducted. Instrumentation should be installed to monitor basic airplane parameters including speed, altitude, normal and lateral load factors, angle of attack, sideslip, pitch and yaw rates and accelerations, and control surface positions.

A flight strain survey with gauges installed at the roots of the aerodynamic surfaces to measure surface loading and rolling moment is the preferred method for verifying structural loads; however, inflight pressure measurements may be used if sufficient pressure taps are provided to assure verification of the spanwise and chordwise pressure distributions on the aerodynamic surfaces. The airplane should be flown through maneuvers which are adequate to verify the analytical techniques used for the determination of design loads.

Flight test verification using a strain gauge balance to directly measure the rolling moment at the top of the fin has the added advantage of being able to check the level of rolling moment developed in stalls, rolling maneuvers, and buffet due to spoiler deflection in flight and during ground roll.

d. Design Conditions. For all of the empennage configurations listed, any flight condition which generates a lateral aerodynamic load on the vertical stabilizer also generates an aerodynamic influence load on the horizontal stabilizer. With the exception of a + tail mounted lower than approximately midway up the vertical stabilizer, these effects are additive, and should be included in the design loads.

The symmetric loading conditions of §§ 23.331, 23.421, 23.423, and 23.425 do not generate a net lateral aerodynamic load on the vertical stabilizer.

The unsymmetric loading conditions of §§ 23.351, 23.367, 23.441, and 23.443 generate a net lateral aerodynamic load on the vertical stabilizer and induce a rolling moment on the horizontal stabilizer. The loads resulting from each of these conditions which produce design lateral loads on the vertical stabilizer are combined with the appropriate horizontal stabilizer balancing load for one-g level flight. The rolling velocities from the conditions specified in §23.455 also cause unsymmetrical loads on the empennage.

The key loading component for T-tail and + tail empennages where the horizontal stabilizer is mounted high on the vertical stabilizer is the rolling moment that is induced at the intersection of the horizontal and vertical stabilizers in all conditions that generate lateral aerodynamic load on the vertical stabilizer. An acceptable method for developing this rolling moment is presented in paragraph 5a.

In general, for a T-tail configuration, the rolling moment is in the range of 4 to 6 times the value produced by a 100-80 percent distribution of the conventional stabilizer design load, as discussed in § 23.427. Since atmospheric gusts may occur in any direction, it is advisable to evaluate loads on the empennage when the design gust velocities of §23.333(c) are applied in the most critical combinations of vertical and horizontal gusts which vectorially produce the most critical loads. For a V-tail, the most critical loads are accounted for by evaluating gusts horizontally, vertically, and normal to the tail surface.

When the aerodynamic influence of the side load on the vertical surface of a T-tail or + tail is carried over onto the horizontal stabilizer surfaces, and combined with the applicable level flight balancing load, a critical condition may be developed on one side of the horizontal stabilizer.

Propeller slipstream or inflow effects should be evaluated where the empennage surfaces are immersed in the slipstream, or the propeller is located in close proximity to the empennage, and these effects are expected to have a significant effect on loads. This recommendation is based on § 23.301(a) which defines limit loads as the maximum loads to be expected in service and §23.301(b) which requires air loads to be distributed to conservatively approximate or closely represent actual conditions.

Figure 1 shows typical loadings on a conventional low horizontal tail and on a T-tail in steady roll and sideslip maneuvers. For steady roll, the loads on the horizontal and the vertical surface of the T-tail are much greater than for the conventional low tail, and both produce a moment in the same direction. For sideslip, the moment due to the conventional horizontal tail load counters the moment due to the vertical tail load. For the T-tail, the moment due to the horizontal surface adds to the moment due to the vertical tail load. At some point, with the horizontal surface located about halfway up on the vertical surface, the moment due to the load on the horizontal surface is zero, for the sideslip maneuver.

Figure 1 - EMPENNAGE MANEUVERING FLIGHT LOADS

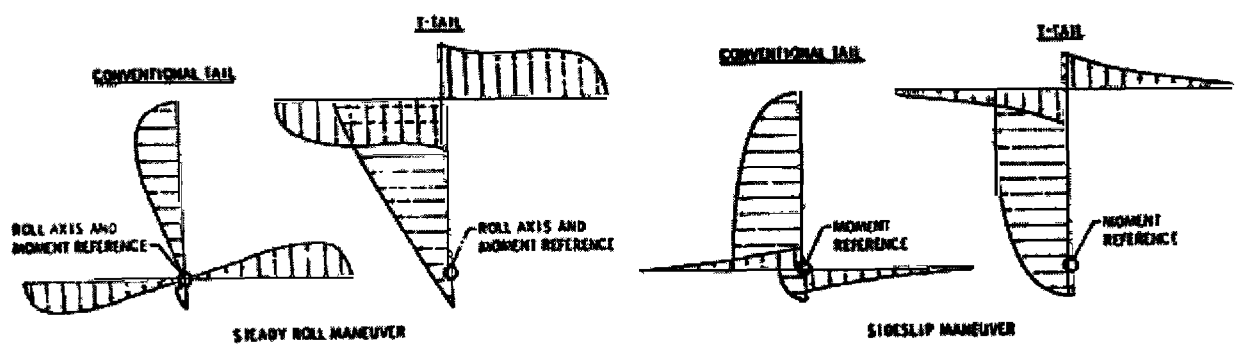

Figure 1 - EMPENNAGE MANEUVERING FLIGHT LOADS

For V and Y empennage configurations, it is necessary to increase the unit loads on each side of the tail surface to account for the tail surface dihedral, since the significant air loads act normal to the surface. Thus the unit loads, based on the projected area, on each side of the tail surface due to vertical loads on the tail assembly should be increased by a factor equal to 1/cos theta, while the unit horizontal loads on the tail assembly should be increased by a factor equal to 1/sin theta. Theta is the dihedral angle, or the angle between each side of the tail surface and the horizontal.

The following supplementary condition should also be investigated:

A ± 50 f.p.s. gust, acting normal to the chord plane of one side of the tail surface at V_C, should be combined with a one-g balancing tail load. Reduction for downwash is acceptable. It is evident that this condition is unsymmetrical, since one side of the V-tail is not as highly loaded by the gust.

e. Acrobatic Category Airplanes. The flight loading conditions prescribed in Part23 of the FAR are the same regardless of airplane category. Only the maneuvering load factor differs, i.e., the positive limit maneuver load factor required for normal category is 3.8g maximum, 4.4 for utility category and 6.0 for acrobatic category.

For acrobatic category airplanes with unconventional empennage configurations, the maneuvers and their safe entry speeds for which certification is requested should be carefully considered as to the possibility of causing higher combined loads on the empennage and aft fuselage, than would be determined from the conditions required by Part 23 of the FAR. if higher loads appear likely, further investigation should be done.

f. Control Surface and System Loads. Where a control surface receives simultaneous inputs from more than one pilot control force (i.e., from two different control axes, being actuated by either one or two pilots), the forces defined in § 23.397 remain applicable unless proven otherwise by test. Previous policy, CAM 3.211-1 in Civil Aeronautics Manual 3, permitted a one-third reduction of the pilot control forces for a specific tail configuration which utilized combined control inputs. Recent tests have shown this policy to be invalid and it should not be applied, unless it can be substantiated.

Previous policy in CAM 3.211-1 also recommended a combined control surface maneuvering load condition for airplanes with control surfaces that receive simultaneous inputs from more than one control axis. This policy is valid and the following supplementary condition should be investigated:

Empennage and aft body loads should be evaluated at maneuvering speed (VA) conditions with maximum pilot control forces applied simultaneously on each applicable axis to give the greatest deflection of the control surface relative to the fixed surface. Control system flexibilities, as they affect control surface travel, may be taken into account if substantiated by test.* These incremental loads should be combined with the appropriate one-g balancing tail loads.

***Note:** Advisory Circular 23.683-1 dated September 25, 1984, provides guidance on control system operation tests.

JEROLD M. CHAVKIN
Acting Director, Central Region

APPENDIX 1

1. NACA TR 1171 NACA TN 2907	Effect of horizontal tail span and vertical location on the aerodynamic characteristics of an unswept tail assembly in sideslip. D. R. Riley, 1954
2. NACA TN 3245	Calculated subsonic span loads and resulting stability derivatives of unswept and 45° swept-back tail surfaces in sideslip and steady roll. M. J. Queijo; D. R. Riley, 1954
3. NASA Memo, 4-1-59L	Effect of horizontal tail chord on the calculated subsonic span loads and stability derivatives of isolated unswept tail assemblies in sideslip and steady roll. K. W. Booth, 1959
4. AIAA Paper No. 74-1038	Determination of stability derivatives of isolated rigid tail assemblies in sideslip and steady roll. D. R. Riley, 1974
5. Engineering Sciences Data Unit Memorandum No 49	Contribution to rolling moment derivative due to sideslip resulting from interference effects of fin or tailplane. R. W. Gilbey, Engineering Sciences Data Unit, 1984
6. NACA RM L54108	Investigation at high subsonic speeds of the pressure distributions on a 45 degree swept back vertical tail in sideslip with a 45 degree swept-back horizontal tail mounted at 50 percent and 100 percent vertical tail span. Harleth G. Wiley; William C. Moseley, Jr., November 1954
7. NACA RM L55E04	An investigation at high subsonic speeds of the effects of horizontal tail height on the aerodynamic and loading characteristics in sideslip on a 45 degree swept-back untapered tail assembly as determined from force tests and integrated vertical tail span loading. Harleth G. Wiley, William C. Moseley, Jr., June 1955

8. NASA TM X-3149	Low Speed aerodynamic characteristics of a transport configuration having a 42 degree swept supercritical airfoil wing in 3 tail height positions. Paul G. Fournier; William C. Sleeman, Jr., December 1978
9. NACA Rep. 1269	Theoretical span load distributions and rolling moments for sideslipping wings of arbitrary planform in incompressible flow. M. J. Queijo, 1956
10. NACA TM 856	The lift distributions of wings with end plates. W. Mangler, 1937
11. NASA TR-R48	A systematic kernel function procedure for determining aerodynamic forces on oscillating or steady finite wings at subsonic speeds. Charles E. Watkins; Donald S. Wooliston; and Herbert J. Cunningham, 1959
12. NACA RM 2992 RAE Report No. 2158	Theoretical load distribution on fin-body-tailplane arrangements in a sidewind. J. Webber; A. J. Hawk, 1954