U.S. Department of Transportation
Federal Aviation Administration

Policy Statement

Subject: Rotorcraft Advanced Flight Controls (AdFC) Handbook

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Summary

This policy statement recognizes the *Rotorcraft Advanced Flight Controls (AdFC) Handbook* for use as guidance for certification of parts 27 and 29 rotorcraft AdFC systems, such as fly-by-wire and fly-by-light systems, by FAA certification personnel.

Current Regulatory and Advisory Material

Current policy documents do not adequately define a robust certification process for the new and novel aspects of an AdFC design for rotorcraft.

Policy

The attached Rotorcraft AdFC Handbook provides guidance for AdFC certification projects.

Effect of Policy

Whenever a proposed method of compliance deviates from the guidance in this policy statement, the project aircraft certification office (ACO) coordinates with the policy issuing office, the Rotorcraft Directorate Standards Staff (ASW-110), using an issue paper. Similarly, if the project ACO becomes aware of reasons to disagree with an applicant's proposal that meets this policy, the ACO coordinates their response with the ASW-110 office. Applicants should expect that certificating officials would consider this policy when making findings of compliance.

Implementation

The Rotorcraft AdFC Handbook lists compliance finding methods that may apply to type certificate, amended type certificate, supplemental type certificate, and amended supplemental type certification programs. Compliance finding methods in this document apply to all rotorcraft AdFC programs as of the date of issuance of this policy. When reviewing a proposed certification basis for an AdFC program, the project ACO should ensure that the means of compliance proposed by the applicant would allow at least for a compliance finding in accordance with the requirements of this policy statement.

Conclusion

The FAA has concluded that it is appropriate to utilize the Rotorcraft AdFC Handbook to make compliance determinations for AdFC systems.

Lance T. Gant
Acting Manager, Rotorcraft Directorate
Aircraft Certification Service

Attachment

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Rotorcraft Advanced Flight Controls (AdFC) Handbook

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Acronyms

Acronyms	Description
14 CFR	Title 14 Code of Federal Regulations
AdFC	Advanced Flight Controls
BIT	Built-In Test
ED	EUROCAE Document
EUROCAE	European Organization for Civil Aviation Equipment
FEP	Flight Envelope Protection
FHA	Functional Hazard Assessment
HQRM	Handling Qualities Rating Method
PIO	Pilot Induced Oscillations
RTCA	Radio Technical Commission for Aeronautics
SA	Safety Assessment
SAE	Society of Automotive Engineers
SAS	Stability Augmentation System
SC	Special Conditions
SSA	System Safety Assessment

Chapter 1 - Introduction.

1.1 **Background.** The term “Advanced Flight Controls” (AdFC) describes systems that differ from conventional flight control systems with respect to the applied signal processing and signal transmission technology. Conventional flight control systems typically use mechanical elements (rods, bell cranks) for transmitting command inputs from the pilot’s controls to the rotor blades for primary control. Conventional systems may include superimposing electronic stability augmentation systems and autopilots with some level of control on a mechanical primary flight control system. AdFC systems, on the other hand, typically feature electronic signal processing and signal transmission using electrical wires, such as fly-by-wire, optical fibers (fly-by-light), or potentially even non- mechanical media (radio frequency control). Novel forms of these types of flight controls systems include unique hardware like inceptors (e.g., side stick controllers). Since AdFC systems typically employ a high level of integration and increased functionality relative to conventional systems, a greater possibility exists for development errors that are not as obvious or testable as those for conventional flight control systems. Therefore, this guidance was developed and includes a list of potential special conditions (SC) that may be required to account for these novel characteristics.

1.2 **Scope.**

1.2.1 The guidance contained in this document addresses areas that need special attention in the development and certification of AdFC systems installed and used on rotorcraft.

1.2.2 AdFC systems generally consist of a control system that interfaces with some type of actuator that in turn interfaces with some inherent device providing aerodynamic controls (e.g., swash plate and associated linkages) and a type of monitor system. The required analysis should include the complete aircraft flight control system.

1.2.3 This guidance material makes no distinction between normal and transport category rotorcraft employing AdFC systems. This guidance primarily concentrates on part 29 applications; however, it is also appropriate for part 27 AdFC applications.

1.3 **Applicable Reference Documents.** The following document standards are applicable for use in determining compliance for AdFC systems.

1.3.1 Radio Technical Commission for Aeronautics (RTCA) Document DO-160/European Organization for Civil Aviation Equipment (EUROCAE) EUROCAE Document (ED) 14, *Environmental Conditions and Test Procedures for Airborne Equipment*. New AdFC equipment should use the RTCA Document DO-160G/EUROCAE ED 14G or later approved revision.

1.3.2 RTCA Document DO-178/EUROCAE ED 12, *Software Considerations in Airborne Systems and Equipment Certification*. Software for new AdFC equipment should use the RTCA document DO-178B/ EUROCAE ED 12B or later approved revision.

1.3.3 RTCA Document DO-254/EUROCAE ED 80, *Design Assurance Guidance for Airborne Electronic Hardware*. This document is an accepted standard for complex hardware.

1.3.4 Society of Automotive Engineers International (SAE) Aerospace Recommended Practice (ARP) - ARP4754A/EUROCAE ED-79A, *Guidelines for Development of Civil Aircraft and Systems*. This document is the accepted standard for the concept of the Safety Assessment (SA) and system development assurance processes.

1.3.5 SAE ARP - ARP4761, *Guidelines and Methods for Conducting the Safety Assessment Process on Civil Airborne Systems and Equipment*. This document is the accepted standard to apply the SA process.

1.4 **Procedures.** The Handbook consists of two primary chapters. Chapter 2, Safety Assessment (SA) Processes, addresses the safety assessment methods that are unique to AdFC systems. Chapter 3, Special Conditions, lists candidate novel or unusual design features for SC and provides a methodology to show compliance for each when applied to AdFC systems.

Chapter 2 - Safety Assessment (SA) Processes.

2.1 Introduction.

2.1.1 Compliance with §§ 27.1309 and 29.1309 for AdFC systems should follow the safety assessment and systems development processes defined in ARP4754A and ARP4761. This section of the guidebook lists considerations and examples relevant to AdFC systems.

2.1.2 Definition of Terms.

2.1.2.1 Degraded operation – deviation of the output(s) below nominal performance, while still providing at least minimal operational performance.

2.1.2.2 Active Receptor or Inceptor - the pilot's control implementation device, sometimes called a controller, side stick, or collective controller, with tactile response.

2.1.2.3 Rate Limiting – a non-linear reaction where a lag occurs between the command and the actuator due to a maximum velocity in the system.

2.1.2.4 Control Power – the power (pilot and system) available to move the control surfaces and blade angles.

2.1.2.5 Flight Mode Changes – in an AdFC system, mode changes occur when transitioning from one flight mode (ex Alt Hold) to another mode (ex Spd Hold).

2.1.2.6 Translational Rate Command System – a system that allows both stable and maneuverable control systems to be active simultaneously.

2.2 14 CFR 27.1309 and 29.1309, Compliance Considerations.

2.2.1 Advisory Circular (AC) 20-174 identifies ARP4754A as an acceptable means for showing compliance with §§ 27.1309 and 29.1309. Of the assessment processes listed in ARP4754A, the functional hazard assessment (FHA), preliminary system safety assessment (PSSA), common cause analysis (CCA), and the system safety assessment (SSA) should be utilized, at a minimum. The current versions of ACs 27-1 and 29-2 provide additional information about the use of the SA process.

2.2.2 AdFC systems are typically part of complex integrated systems that provide more than one category of functionality. Evaluations of AdFC systems, which are a part of complex integrated systems, have unique concerns that are independent of integration issues of other systems. The following are examples of potential AdFC failure conditions. This is not an exhaustive list.

- System availability.
- Excessive Flight Control induced loads.
- Control of mistrim.
- Degraded modes.
- Hydraulic system failure effects.
- Electrical power system failure effects.
- Engine failures, including total loss of power.
- Improper mechanical installation.
- AdFC failures resulting in:
    - Reduced stability.
    - Reduced control margins.
    - Reduced maneuvering capability.
    - Significant flight path discontinuities.
    - Requiring pilot manual reconfiguration of the AdFC system.
    - Automatic mode change failures.
    - Changes to inceptor characteristics.
    - Static and Dynamic Rollover.
    - Ground Resonance.
    - Loss of Tail Rotor Effectiveness.

Additional potential AdFC failure conditions include:

2.2.2.1 Aliasing Effects are caused by analog-to-digital conversion of sensor signals, which contain significant signal noise at frequencies above the sample frequency. This is the conversion of the high frequency noise into a low frequency signal, superimposed on the original sensor signal. The effect is a distortion (e.g., D.C. offset) of the measured signal.

2.2.2.2 False Alerts, such as warnings or cautions, are triggered by monitors that are too sensitive because the monitor thresholds or failure confirmation times are too small.

2.2.2.3 Limit Cycles are typically caused by nonlinearities in combination with high control gains, which should be minimized and reduced to an acceptable level. Typical nonlinearities in flight control systems are poor resolution of digital signals, control signal limitation (e.g., actuator rate saturation), and hysteresis (e.g., backlash of bearings). Limit cycles may affect controllability and make the system prone to pilot induced oscillations (PIO).

2.2.2.4 Oscillatory is a type of failure caused by one of a number of effects: system instability due to a corrupted sensor signal (e.g., angular rate), excitation from a corrupted hardware component (e.g., operational amplifier), or excitation of resonance frequencies (e.g., air resonance, structural resonance of tail rotor shaft).

2.2.2.5 Spurious Data are caused by signal perturbation from external sources (e.g., sensor noise, electromagnetic interference) or defects of equipment (e.g., loose electrical contact).

2.2.3 Proving the validity of the assumptions should use a means of assessment that is appropriate to the consequences of the failure. The more severe the consequence of the failure or assumed increased pilot action, the greater the rigor required for the validation of the assumption. Techniques may include analysis, simulation, modeling, ground, or flight test, as appropriate.

Example: Evaluate status, warning, and caution systems with a clear understanding of the functioning and failure effects of the AdFC. Evaluations should include ground and flight assessments with normal and emergency use in representative operational situations. Other failures (e.g., electrical system failures) that can affect the AdFC should also be evaluated as supporting systems.

Example: Assess the flight manual instructions associated with normal and emergency operation of the AdFC in flight and on the ground in representative operational situations. The ability of the crew, particularly for single pilot operations, to follow the flight manual procedures should be determined given that the flight characteristics could be degraded and should not require excessive workload or skill.

The following are examples of assumptions.

2.2.3.1 The pilot’s ability to identify the correct nature of failures and the correct procedures.

2.2.3.2 The adequate intervention time for the pilot to deal with the failure condition and any associated aircraft response.

2.2.3.3 The type of flight phase, environmental, or emergency procedures the system can operate.

2.3 Additional Considerations

2.3.1 With a redundant (i.e., multiple channel) AdFC system, consider the following cases when a failure is detected:

2.3.1.1 Where all control channels are operating in parallel and their output signals are consolidated, the affected control channel should be deactivated or isolated while the remaining channels provide the required functionality.

2.3.1.2 Where one channel is active while the other channels are on standby, the affected control channel should be deactivated and replaced with one of the standby channels, which then provides the required functionality.

2.3.2 For faults that are not continuously detectable by the monitoring system, use the period of latency to derive the probability of failure occurrence.

2.3.3 Continuous monitoring schemes, such as voltage comparators, input data monitoring (validity, parity, update, and range), memory checks, and watchdog timer should be performed to detect potential equipment failures and system malfunctions, such as signal runaways and oscillatory failures.

2.3.4 Consider the use of dissimilar hardware and software, combined with cross monitoring between dissimilar channels, to detect potential generic faults.

2.3.5 Display warning and caution indications in the cockpit should be used to alert the crew and inform the pilot about the state of system degradation or failures. The information displayed tells the pilot which actions must be taken (e.g., to fly hands-on or to stay within a reduced flight envelope). This will likely be an ongoing effort as the system design matures.

2.3.6 AdFC systems typically employ reset features to reengage compromised parts of the AdFC system after failures (i.e., to reengage one or more of several control paths that have been disengaged following a monitor trip) for situations where the condition that caused the monitor trip remains invalid. These reset features may be automatic or manual, but both types have specific safety concerns associated with them. Some of the concerns associated with the automatic features include determination of all appropriate conditions for reset, and determination of all appropriate conditions to inhibit reset. Some of the concerns associated with manual reset include crew workload and the ability of the crew to determine appropriate conditions for reset actuation. Detailed procedures to use this feature should be established and approved and should incorporate protection mechanisms to avoid flight hazards, if incorrectly engaged.

2.3.7 Consider pilot training for flight with degraded handling qualities, if the level of degradation results in diminished control characteristic.

2.3.8 In some cases, maintenance requirements may be appropriate to address the detection and correction of latent failure.

Chapter 3 - Special Conditions.

The following novel or unusual design features are candidates for special conditions:

3.1 Interaction of Systems and Structures.
3.2 Pilot and Co-Pilot Dual Controls.
3.3 Lateral-Directional and Longitudinal Stability.
3.4 Control Authority Awareness (both saturation and limited authority).
3.5 Flight Characteristics Compliance via the Handling Qualities Rating Method (HQRM).
3.6 Flight Crew Alerting.
3.7 Command Signal Integrity.
3.8 Flight Envelope Protection (FEP) (if installed).

3.1 Interaction of Systems and Structures.

3.1.1 There is a possibility that an operation of an AdFC system, either directly or because of a failure, could affect the rotorcraft’s structural capabilities or aeroelastic stability, both in the normal and in the failed state. Examples include active load alleviation functions, such as stability augmentation or vibration suppression systems. In order to determine the applicability of SC, a review with a structures engineer is necessary.

3.1.2 Areas for Consideration:

3.1.2.1 Active Load Alleviation.

3.1.2.1.1 Load limits should be derived from the limit loads from the conditions specified in 14 CFR parts 27 and 29 subpart C, taking into account the behavior of the active load alleviation functions for the specified limit maneuver or gust condition. Design limit loads may be defined by assuming the active load alleviation functions are operable.

3.1.2.1.2 Consider the failure detection, crew alerting, and operating procedures to minimize the probability of exceeding limit loads with inoperable active load alleviation. Also consider the severity of the structural load response to gusts and limit maneuvers, with the load alleviation function inoperable. The intent of these criteria is to establish a means to ensure that the probability of exceeding a design limit load condition is no greater than for rotorcraft with similar flight characteristics that do not include active control functions.

3.1.2.1.3 It should be demonstrated by analysis, simulation, or testing that static structural strength satisfies limit load criteria for symmetrical and asymmetrical structural maneuvers specified in subpart C, using the final configuration and control laws of the active load alleviation functions.

3.1.2.2 Failure Transients.

3.1.2.2.1 The guidance material for stability augmentation system (SAS) failures (AC 29-2C, Appendix B, b.(6)) may be helpful in defining appropriate pilot actions and time delays. Flight simulation may be used to evaluate control responses associated with pilot corrective action. Analysis or testing should show that the rotorcraft could withstand these loads multiplied by an appropriate safety factor. The certificating authority should approve the appropriate safety factor that may relate to the probability of the failure occurrence.

3.1.2.2.2 It should be demonstrated that the failure transient does not lead to divergence, control reversal, or other hazardous aircraft effects.

3.1.2.3 Continued Flight in a Failure State.

3.1.2.3.1 Evaluate failures of the system that result in sustained structural vibrations to ensure that the vibrations do not produce loads that could result in catastrophic failure, divergent dynamic effects, detrimental deformation of primary structure, or hazardous effects on the flight crew or passengers.

3.1.2.3.2 If prescribing a restricted flight envelope in a failure state, it should be demonstrated that the restricted flight envelope provides for normal flight maneuvers and excursions resulting from normal atmospheric disturbances without exceeding structural limits.

3.1.2.4 Pilot Induced Oscillation (PIO). PIO is a sustained oscillation or a series of uncontrollable aircraft oscillations resulting from the pilot's attempt to control the aircraft. Unique aspects of AdFC systems demand special consideration of the following three main classifications of PIO:

3.1.2.4.1 Category I - Linear Aircraft-Pilot Interactions. Category I PIO is a dynamic instability within the normal (linear) operating region of pilot-aircraft interactions. For digital fly-by-wire control systems, a phase delay parameter includes latencies resulting from computer frame rates, asynchronous processing, sensor transport delays, data-busses, and actuators. A rotorcraft free of PIO tendencies will avoid high frequency phase roll-off, which is achievable by maximizing the attitude response frequency and minimizing the gain at the 180-degree attitude phase lag frequency.

3.1.2.4.2 Category II – Quasi-Linear Aircraft-Pilot Interactions. Rapid control inputs can lead to actuator rate saturation and control surface position limiting. A combination of sufficient control rate capability and acceptable gain attenuation at PIO frequencies will avoid sudden phase lag in the aircraft response during closed loop tasks. AdFC systems, in particular, can be susceptible to Category II PIO due to feed-forward command models that may demand high frequency control motion. Evaluate the rotorcraft for Category II PIO tendencies by conducting large amplitude stick inputs during compensatory tasks (e.g., high gain tracking tasks). Address failed state (e.g., single stage operation of a dual stage actuator) where reduced actuator rate capability can increase PIO tendencies.

3.1.2.4.3 Category III – Highly Nonlinear Aircraft-Pilot Interactions. Unique features can precipitate Category III PIO in AdFC systems, such as control law mode changes, automatic envelope protection systems, and system reconfiguration logic. AdFC designs should not be susceptible to nonlinear characteristics that can lead to non-intuitive control inputs by the pilot to achieve a desired response. Identification of system nonlinearities that can abruptly change control response characteristics and evaluating these conditions in flight during compensatory tracking tasks is an acceptable means of showing compliance.

3.2 Pilot and Co-Pilot Dual Controls.

3.2.1 Since the current regulations assume mechanically linked controls, a specific rule does not exist to address potentially confusing aspects of non-linked controls. If the pilot and copilot controls or inceptors are not linked, then a warning to the second pilot in the loop and cutout switch may be required. If the pilot and copilot controls or inceptors are linked electronically, a demonstration of that linkage may be required.

3.2.2 Criteria for Determination. SC will be required if a compliance finding to a control input issue with § 29.779(a) is identified.

3.3 Lateral-Directional and Longitudinal Stability.

3.3.1 An AdFC allows for many possibilities in developing novel flight control laws. In the simplest form, an AdFC could replace the function of a direct link between the flight controls and the swashplate. Development of these novel flight control laws may require special airworthiness standards or an alternate means of evaluation methodology. For example, research of rotorcraft response types has resulted in concepts such as Rate Command/Attitude Hold , Attitude Command/Attitude Hold, and Translational Rate Command, where response types are related to the intended operational situation in terms of visual cues.

3.3.2 Areas for Consideration. Applicants may choose to comply with the existing requirements found in 14 CFR subpart B and Appendix B to Part 29. However, if the design will not allow an explicit showing of compliance, the applicant must propose an alternate means. These areas should be identified as early as possible in the certification plan.

3.4 Control Authority Awareness.

3.4.1 Current guidance for §§ 27.143 and 29.143 may not be adequate for the installation of AdFC systems in relation to pilot awareness issues. In order to meet the intent of these rules, address the control margins at the rotor and anti-torque system level and considered for pilot awareness of control remaining, when approaching the limits. The means of compliance (visual, auditory, or tactile cueing) must be effective during maneuvers typical to the type, especially during divided attention operations, and for representative environmental conditions.

3.4.2 The controllability requirements of § 29.143 (a), (d), and (e)(1) are compatible with typical AdFC systems. Most of the maneuverability requirements of § 29.143 (b), (c), and (e)(2) are not affected by AdFC systems, except for the control margins. This is to ensure that control margins (at the rotor and the anti-torque system level) are sufficient in the defined flight conditions to avoid loss of control (i.e., that adequate control power exists to exit potentially hazardous flight conditions). For example, AdFC systems incorporating automatic trim follow-up eliminate the direct relationship between control inceptor and cyclic or anti-torque blade pitch, so the pilot does not have physical awareness of control remaining.

3.4.3 Areas to Consider.

3.4.3.1 The flightcrew must be made aware whenever the primary control means nears the limit of control authority. This indication should direct the pilot to take appropriate action in accordance with the rotorcraft flight manual instructions. Depending on the application, suitable annunciations may include a combination of cockpit control position, annunciator light, or actuator/rotor position indicators.

3.4.3.2 Suitability of such a display or alerting should take into account that some pilot-demanded maneuvers are necessary for intended full performance, which may require full surface deflection. Therefore, consider properly balancing simple alerting systems to function in either intended or unexpected control-limiting situations between crew awareness and nuisance factors. A monitoring system, which compares airplane motion, surface deflection, and pilot demand, could be useful for eliminating nuisance alerting.

3.5 Flight Characteristics Compliance via the Handling Qualities Rating Method (HQRM).

3.5.1 HQRM is a pilot task-oriented approach for evaluating aircraft handling qualities.

3.5.2 The primary target of HQRM is degraded modes evaluation, but it can also apply to normal modes of operation. HQRM describes different failure cases of flight control systems as either "satisfactory," "adequate," or "controllable."

3.5.3 Areas for Consideration. SC for HQRM may require the applicant to show literal compliance where they will use the HQRM. This should be broken into one demonstration for degraded modes (§§ 27.1309 or 29.1309) and another for normal modes (part 27 or §§ 29.143, 29.171, 29.177, etc.).

3.6 Flight Crew Alerting.

3.6.1 The need for improved safety standards for Transport Category airplanes configured with advanced crew alerting systems caused the FAA to update § 25.1322, through amendment 131, to address crew alerting of failures or malfunctions in critical systems and functions of modern aircraft. However, the current 14 CFR parts 27 and 29 standards do not provide comparable standards for rotorcraft with AdFC systems.

3.6.2 The nature of advance flight controls requires addressing these additional clarifications through SC. Such SC should include relevant portions of § 25.1322.

3.7 Command Signal Integrity.

3.7.1 The primary AdFC signals that provide the sole control of the aircraft must have an additional level of scrutiny that is not covered in the current Part 27 and 29 regulations, since those regulatory requirements only address mechanical flight control systems. As such, the regulations do not consider unintentionally altered signal characteristics for new electronic systems utilizing digital command and control over standard wiring.

3.7.2 Areas of Consideration for altered signal characteristics.

3.7.2.1 Maintain stable gain and phase margins for all aerodynamically closed loop systems, excluding pilot in the loop control.

3.7.2.2 Spurious signals causing an uncommanded motion of a control actuator must be readily detected and deactivated, or the surface motion must be arrested satisfactorily by other means. Small amplitude residual system oscillations may be acceptable.

3.7.2.3 Demonstrate that uncommanded sustained oscillations, the result of coupling between electronic or electrical command signals, and the motion of the mechanical actuator drive system together with the interfacing structural components do not occur over the spectrum of operating frequencies. Thoroughly investigate, document, and understand the effect of instabilities.

3.8 Flight Envelope Protection (FEP).

3.8.1 When including a type of FEP in an AdFC system, use the guidance listed for each type of operation under paragraph 3.8.2 below and consider the particulars of an application of the system.

3.8.2 Criteria for Determination.

3.8.2.1 Normal Operation.

3.8.2.1.1 Use of FEP prevents the pilot or an autopilot system from making control commands that would force the aircraft to exceed its structural or aerodynamic operating limits.

3.8.2.1.2 Onset characteristics of each envelope protection feature must be smooth, appropriate to the phase of flight and type of maneuver, and not in conflict with the ability of the pilot to satisfactorily change aircraft flight path, speed, or attitude, as needed.

3.8.2.1.3 Limit values of protected flight parameters and, if applicable, associated warning thresholds, must be compatible with:

- Aircraft structural limits.
- Required safe and controllable maneuvering of the aircraft.
- Margin to critical conditions.

Note: Unsafe flight characteristics or conditions must not result from dynamic maneuvering. Airframe and system tolerances (both manufacturing and in-service) and non-steady atmospheric conditions, in any appropriate combination and phase of flight, should not produce a limited flight parameter beyond the nominal design limit value.

3.8.2.1.4 The aircraft must be responsive to intentional dynamic maneuvering to remain within a suitable range of the parameter limit of the approved flight envelope.

3.8.2.1.5 When simultaneous envelope limiting is active, adverse coupling or adverse priority must not result.

3.8.2.2 High Speed Limiting.

3.8.2.2.1 The maximum airspeed for a conventional helicopter is mainly constrained by the retreating blade stall and the advancing blade compressibility. When operating in close proximity of these flight regimes, the aircraft experiences a marked increase in power required, an increase in vibrations, and potential loss of controllability. The increase in power is due to the increases in drag on the rotor blades, in the expanded stall zone, or due to drag divergence.

3.8.2.2.2 Limit values pertaining to high airspeed should be set such that:

3.8.2.2.2.1 Vibrations or oscillatory loads due to large changes in blade torsional moments do not exceed aircraft structural limits.

3.8.2.2.2.2 Advancing and retreating blades maintain acceptable aerodynamic properties (i.e., drag divergence or transonic regimes).

3.8.2.2.2.3 Reduction of controllability is allowable as long as the aircraft can continue in safe flight and landing.

3.8.2.3 Rotor Speed.

3.8.2.3.1 Address both high and low limitations when determining an acceptable rotor speed. Rotorcraft are designed with an ideal operating rotor speed. Departures above this design speed are allowable to a certain extent. A major consideration for preventing rotor overspeed is the direct relationship between the rotor speed and blade loads. The higher loads are a result of the increased centrifugal forces on the blades. Additional factors to consider when determining rotor high speed limits are loads on the driveshaft, driveshaft bearings, hub moments, and supports. The low rotor speed envelope can be limited in hover through tail rotor authority. Low rotor speed reduces the tail rotor thrust producing capability. In single main rotor with tail rotor designs, the main and tail rotors are usually geared together. This effect makes directional control in hover a primary concern at low rotor speeds. The low rotor speed envelope in forward flight can be limited by such factors as blade stall and limit operating speeds for drive train-driven generators and pumps.

3.8.2.3.2 Limit values pertaining to rotor speed should be set so that:

3.8.2.3.2.1 The loads on the rotor blades, driveshaft, bearings, gears, and supports do not exceed rotorcraft structural limits.

3.8.2.3.2.2 Acceptable tail rotor authority is available to maneuver the rotorcraft and maintain directional stability.

3.8.2.3.2.3 During forward flight, the retracting blade does not stall.

3.8.2.3.2.4 Sufficient power is available to operate train-driven systems.

3.8.2.4 Load Factor Limiting.

3.8.2.4.1 The minimum load factor boundary for a rotorcraft is more restrictive than that of a fixed wing aircraft. The amount of control authority available is directly related to the load factor. It is possible for the load factor to decrease to a point where the pilot loses all cyclic control effectiveness. (This point is positive load factor (N_z)=0 for a teetering-rotor and some $N_z < 0$ for rotorcraft with a flapping-hinge offset.)

3.8.2.4.2 The maximum N_z of a rotorcraft is typically lower than the maximum N_z for the fixed-wing aircraft. One reason for this is that the same turn rate is achievable at a lower N_z at the lower speeds of the rotorcraft. In forward flight, the lift generating capability of the rotorcraft is typically less than that of the fixed wing and reduces as speed increases because of the retreating blade stall phenomenon. As load factor is increased, the blade loading is increased. Enough load factor (blade loading) can also drive the main rotor into blade stall even at moderate forward speed.

3.8.2.4.3 Load Factor limitations should be set such that the maximum positive load factor prevents:

3.8.2.4.3.1 The increased blade loading from driving the main rotor into blade stall.

3.8.2.4.3.2 The structural loads from exceeding the static strength limitations of the rotorcraft.

3.8.2.4.4 The minimum load factor threshold should be set at some margin above the value where loss of control effectiveness would occur due a negative load factor.

3.8.2.5 Body Rate Limiting.

3.8.2.5.1 The rotorcraft maneuverability must be limited to ensure blade flapping angles do not exceed design specifications. Excessive blade flapping can result in mast bumping (in teetering rotorcraft) or excessive mast bending moments. Mast bumping is when the rotor hub contacts the rotor mass. This generally results in catastrophic failure. Flight conditions such as near zero “g” flight coupled with inappropriate maneuvers, out of center of gravity conditions, or abrupt cyclical control movement increase the risk of mast bumping. During a perfect hover, the loads present in the mast are mainly axial tension, compression, and torque forces. However, during maneuvering, bending moments are introduced into the mast and other rotor assembly components. If the rotorcraft maneuvers outside its operating limits, excessive loadings and bending may develop within the mast.

3.8.2.5.2 Body rate envelopes defined in rotorcraft pitch and roll rates and cyclic control position should be established, and any FEP that is present that limits body rates should prevent mast bumping and ensure that no structural limits within the mast or other rotorcraft components are exceeded.