41st European Rotorcraft Forum 2015

RELEVANCE OF FLYING QUALITIES DETERIORATION BOUNDARY FOR A HELICOPTER

Abdul Rashid Tajar
abdul_tajar@yahoo.co.in
Manager (Design)
Rotary Wing Research & Design Centre
Hindustan Aeronautics Limited
Bangalore (INDIA)
Phone: +919008429843

ABSTRACT

Flying Qualities is one of the very important aspects of helicopter design and operational use. The flight envelopes associated with flying qualities are to be clearly understood and established. The regulations and operational requirements are in many cases, no more than guidelines and essentially to be converted into engineering parameters. The establishment of helicopter limitations majorly depends on the theoretical analysis and component testing. These limitations are generally demonstrated during development and certification flights. The establishment of limitations also ensures the smooth extension of the flight envelope for the growth potential. The conversion of these limitations to engineering parameters is very important from the operation and safety point of view. During some flight regimes, it becomes vital to display these engineering parameters as guidance to indicate helicopter limitations. These indications also ensure safety of the helicopter by respecting the operational boundaries associated with environment. This paper examines the various levels of limitations associated with rotor stall. These flight limitations come from Engine/Transmission limits, control margins and rotor aerofoil characteristics. These limitations appear during the flight depending on the helicopter configuration and the environment. The maximum speed at low altitude is generally limited by the Transmission limit however it is limited by Engine limits at high altitudes. The Flying Qualities boundary comes into picture when the maximum speed and steady bank turn (without loss of altitude) is limited by the control margin and not by the Engine power. The flying qualities limitations are above the Engine limits at low altitude however it moves below the engine limits during high altitude operations. To achieve maximum level flight speed, pilot gets driven by engine limits. When the engines are new, the engine limits may be far from the flying qualities because of availability of higher power available from new engines. The pilot may get misguided by the power available and can still push for higher speeds. Pushing for speeds beyond flying qualities deterioration boundary results in loss of control margin and pitch, roll or yaw oscillations. The several level of limitations associated with rotor stall boundary are function of Blade loading and advance ratio. In turn, blade loading and advance ratio reflect the properties such as maximum lift coefficient, Mach number, drag divergence number and blade geometry. The prediction of flying qualities deterioration was based on the blade loading and advance ratio. The prediction of Flying Qualities (FQ) deterioration limit was also validated by availability of control margins. It was observed that the FQ deterioration limit was also related to loss of control margin. Flight tests were carried out with different All up weights and altitudes condition from low speed to maximum level flight speed. Flight tests data was gathered and stall area of the rotor disk was derived with the help of constant inflow downwash model and aerofoil data. The rotor capability was also compared for two different helicopters with same rotors. It was proved that the reduction in fuselage drag and employment of auxiliary lift source of lift such as wing improves the overall performance of the helicopter. Furthermore, a warning logic was developed to predict the flying qualities deterioration boundary for a helicopter.

1. INTRODUCTION

The helicopter performance and in particular,the flying qualities significantly affects the mission performance.The Flying qualities of the helicopter cover a wide range of aspects and rather difficult to quantify. In addition to this, the modern helicopters shall also be required to satisfy very high standards with regard to mission performance and system qualities.Sometimes it is useful to refer the existing standards while defining the helicopter specifications. However, in critical phases of flight, they are no more than just guidelines and have to be matched with the operational requirements. These guidelines prove very useful after converting into engineering parameters.Satisfying the customer and market requirements is an essential task during the phase of design and development. The diverse mission requirements also seek compromises for multi role helicopters.Experience gained over the design, development, testing and certification has allowed the helicopter manufactures to identify the potential limitation and to define the critical conditions.

The most significant parameters to define critical conditions and the potential limitations with respect to Helicopter performance and Flying qualities can be given in terms of Gross mass, C.G. Range, Operational altitude, Temperature, Speed and load factor.

This paper deals with the quantification of flying qualities limit associated with high altitude and high speed performance of the Helicopter.

Generally, for analytical prediction of flying qualities nonlinear aeromechanics mathematical models are used.This paper describes simple yet powerful method to define some of the critical performance parameters of the helicopter at high altitudes and the potential ways of improvements.

2. ANALYSIS

The load factor capability of a helicopter is a function of blade loading coefficient (CT/σ) and advance ratio (μ).The experimental testing at high altitude showed that the limiting blade loading coefficient is strongly dependent on forward speed.Apparently for a helicopter, there are several levels of limitations (Alan Faulkner and Walter) [1].

First level of limitation comes from maximum available power from the engine/transmission system which limits the maximum level flight speed (V_H), manoeuvres and banked turns (without the loss of altitude).

The second level of limitation becomes visible, as the load factor increases beyond the Engine/Transmission power levels. The deterioration of Flying qualities starts and can be seen with sluggish control response and higher control requirement required to maintain a steady flight regime. This is the indication of approaching towards rotor stall boundary. This boundary can be called as the Flying Qualities or Handling Qualities (FQ) deterioration limit.

The third level of limitation in terms of load factor and speed capability comes from Never exceed speed. The fifth level of limitation is the rotor stall limit beyond which it is difficult to maintain steady bank angles at low altitudes (sea level).

The highest level of limitation comes into picture at much high load factors wherein the pilot will reach the boundary above which it is no longer possible to trim a steady state condition for the helicopter. This limit can be demonstrated at high ‘g’ manoeuvres at low altitudes. This limit can be considered as the Transient Stall boundary. A typical load factor and speed capability of a conventional helicopter with Hingeless rotor helicopter is given in Fig. 1. The hierarchy of various limits can be seen in this diagram. The same diagram with a different hierarchy is shown in.

As indicated in Fig. 2, if the Engine limitations are above the Flying qualities limit then the performance of the helicopter will be governed by the FQ limit and not by the Engine Limit. This is typical case of flying at higher speed at high altitudes.

In other words, Maximum level flight speed (V_H) and steady bank turns (without the loss of altitude) of the helicopter will not be governed by the engine power available or turbine gas temperature at high altitude but they will be governed by the FQ limit.

To achieve maximum level flight speed, pilot gets driven by engine limits. When the engines are new, the maximum speed which can be achieved becomes higher because of higher power available from new engines for same rotors.

Pushing for speeds beyond FQ limit causes difficulty in maintaining level flight. The inability of maintaining steady level flight exists with minor pitch and roll oscillations and loss of control margin. This phenomenon occurs beyond a certain limit.

This paper describes the criteria to define this limit to estimate maximum level speed and the bank angle (without loss of altitude) at which helicopter can fly steady without any difficulty.

It was also imperative to find out the possible reasons of such behaviour and potential ways to improve the performance of the helicopter at high speed and high altitude (4 km pressure altitude and above).

The secondary aim of this work was to eventually convert the Flying Deterioration limit into engineering parameters for indication in the cockpit. A computer algorithm has been generated to indicate Flying Qualities deterioration limit. The FQ deterioration limit indicator is under development and will be installed during the prototype flight testing.

3. FLIGHT TEST RESULTS

The preliminary Flying Qualities (FQ) deterioration limit based on the aerofoil data was available. The FQ deterioration limit was a function of blade loading and advance ratio. Blade loading and advance ratio was calculated for the given rotor dimensions, all up weight, speed and load factor. All up weight, true air Speed, density and load factor were available from the Helicopter Instrumentation.

The flight test data for V_H and steady bank turns was converted into blade loading and advance ratio and was superimposed on the available FQ deterioration limit.

3.1. Conventional Helicopter (Helicopter 1)

Initially, the V_H and bank turns were based on preliminary FQ deterioration limit. The test points coincided with the FQ deterioration Limit Fig. 3.

Subsequently, the helicopter was also flown for speeds higher than the speed limit specified by the FQ deterioration limit. The flight test points were beyond the FQ deterioration limit and are given in figure 4. The flight tests results were quite satisfactory and preliminary Flying Qualities deterioration limit was validated.

The flight testing was carried out at different All up weights at different altitudes. This phenomenon was only observed for low all up weight as the speed for low all up weight is high.

The control positions for level flights and bank turns are given in Fig.5 and Fig. 6 respectively.

The longitudinal cyclic and main rotor collective requirement at V_H was almost same for 2 km and 4 km. The longitudinal cyclic and main rotor collective requirement in V_H at 6 km was more than 2 km and 4 km. The higher control requirement at V_H in 6 km was higher because it was beyond the FQ deterioration limit(Fig. 5). This test point was deliberately carried out to estimate the V_H as per FQ deterioration limit. The control positions also indirectly indicated benchmark values in line with FQ deterioration limit. The benchmark values as per the FQ deterioration limit were set as 10 and 15 % margin in longitudinal cyclic requirement and Main rotor collective requirement respectively.

Sufficient margin was available in lateral cyclic requirement and tail rotor collective requirement.

These limits were applicable for Maximum level flight speed and steady bank turns.Here, it is also worthwhile to note that the Main rotor collective margin was 5% higher the longitudinal cyclic requirement.

3.2. Conventional Helicopter with reduced fuselage drag and with Wing (Helicopter 2)

The flight testing was carried out at different All up weights at 2 km, 4 km and 6 km. The all up weight for this testing was 6-8% higher compared to the conventional helicopter. The control positions for level flights and bank turns are given in Fig. 7 and Fig. 8respectively.

The advantage of reducing fuselage drag and rotor offloading by wing was observed in the combination of control positions.

The longitudinal cyclic and main rotor collective margin for a conventional rotor with wing and reduced fuselage drag at 4 km and above was 15% and 10% against 10% and 15% for the Helicopter 1.

The decrease in main rotor collective margin and increase in longitudinal cyclic margin was justified by increasedweight (6-8%) and reduced drag of helicopter 2 compared to helicopter 1. The VH achieved with helicopter 2 was also higher by 10-15 kmph.

The load factor and speed capability for conventional helicopter with reduced fuselage drag and wing is given in Fig. 9. It can be seen from the Fig. 9 that the maximum level flight speeds and bank angle were higher than expected as per the preliminary FQ deterioration limit.

The other advantage with this helicopter was also that the difference between the Never exceed speed (V_{NE}) and V_H was higher compared to the conventional helicopter.

The capabilities of both helicopters with same rotors are compared in terms of blade loading and advance ratio and given in Fig. 10.

The improvement was estimated to be 6-8% in terms of weight carrying capacity and maximum level flight speed.

Flight tests data was also analysed to calculate the stall characteristics of the rotor. The first test point was near to VH recommended by FQ deterioration limit. The other two points were beyond the limit. The increment in stall area was around 3-4% for speed of 10 kmph higher than the speed specified by FQ deterioration limit.

The flight tests points which were beyond the FQ deterioration limit are plotted in terms of Load factor-speed capability and control positions are given in Fig. 11.The stall plots for these test points are given in Fig. 12.

4. CONCLUSIONS/RECOMMENDATIONS

This paper described the criteria to define the maximum level flight speed and bank at high altitudes. The FQ deterioration limit was based on blade loading and advance ratio. The limit was also validated by the longitudinal cyclic and main rotor collective requirement.

The rotor capability was also compared for two different helicopters with same rotors. It was proved that the reduction in fuselage drag and employment of auxiliary lift source of lift such as wing improves the overall weight and speed capability of the helicopter.

The difference between the Engine limit and FQ deterioration limit also decrease with reduction in fuselage drag. The Difference in V_{NE} and V_H also reduced at high altitude.The flying qualities deterioration limit was validated by flight testing and an algorithm was generated based on the blade loading and advance ratio to improve the crew awareness.

5. CURRENT STATUS AND FUTURE SCOPE

The FQ deterioration limit indicator is under development and due for prototype flight testing.

ACKNOWLEDGMENTS

The author would like to acknowledge the effort of Dr. M. Vijaya Kumar (General Manager) and Wing Commander (Retd.) Unni Pillai (Chief Test Pilot) for their valuable guidance and support in the performance of this work.

The author would also like to appreciate the contribution of DSD Prasada Rao, R.S.Muthu, S.P. Tripathy and Gagan Deep Singh in completion of this work.

REFERENCES

[1] Alan Faulkner and Walter Sinn., “Handling Qualities and flight performance implications of the operational envelope”
Eleventh European Rotorcraft Forum Paper No. 81 September 10-13 1985 London, England

.

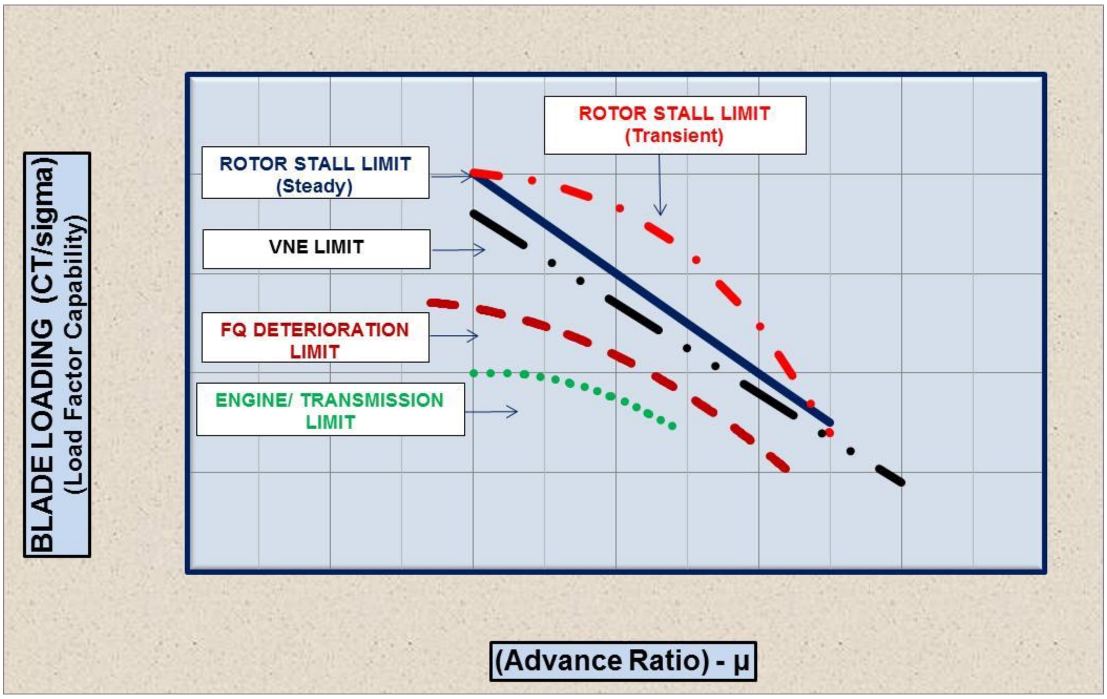

Figure 1: Load factor and Speed Capability of a Helicopter Rotor (Typical)

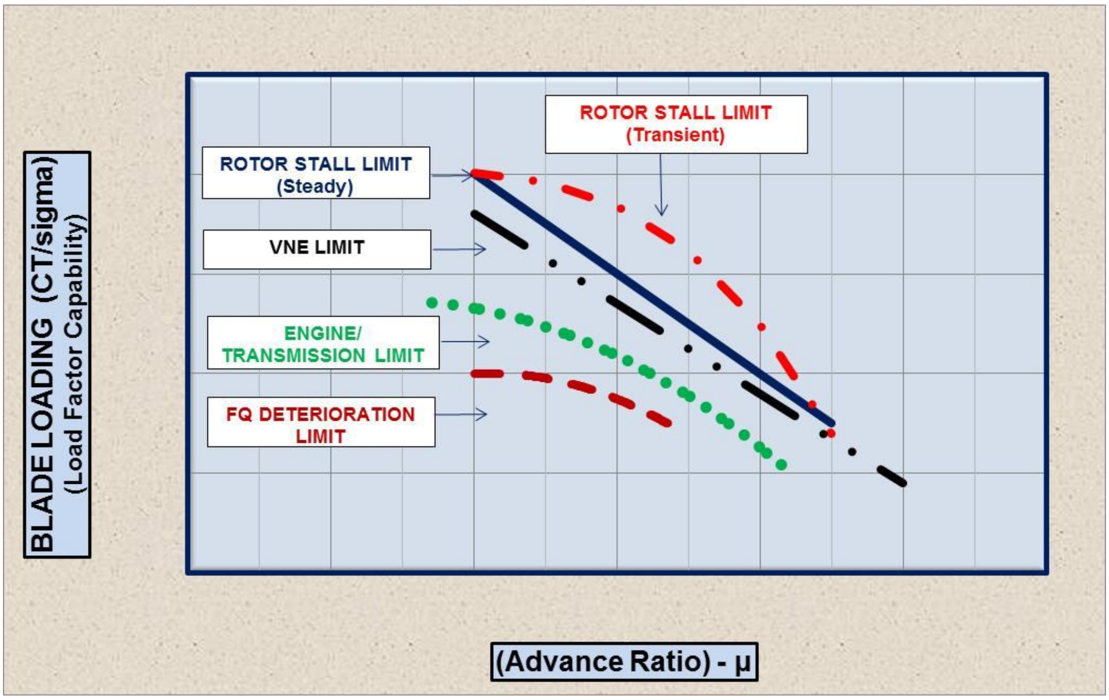

Figure 2: Load factor and Speed Capability of a Helicopter Rotor (Special case)

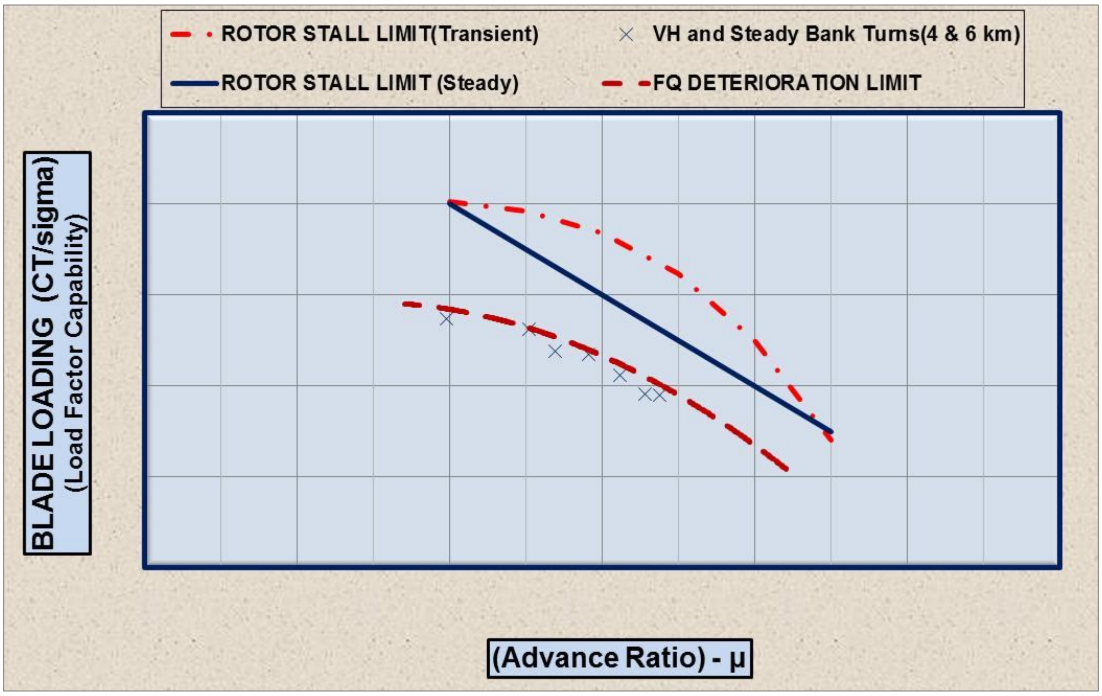

Figure 3: Load factor and Speed Capability of a Conventional Helicopter at High speed and High Altitude

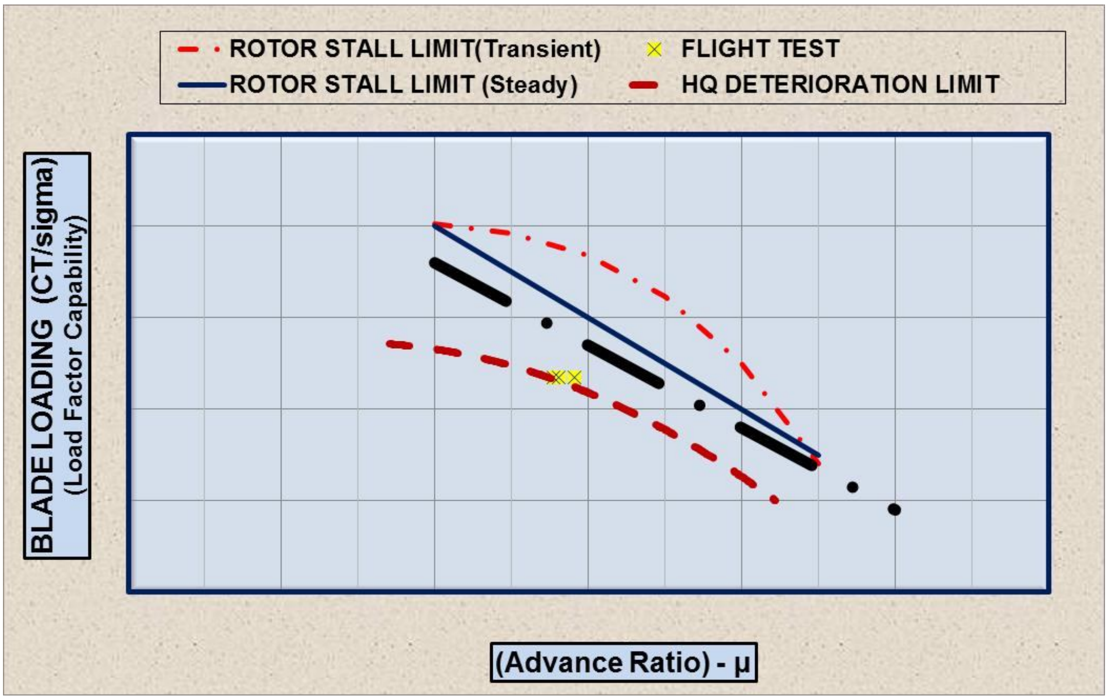

Figure 4: Load factor and Speed Capability of a Conventional Helicopter (Beyond HQ deterioration Limit)

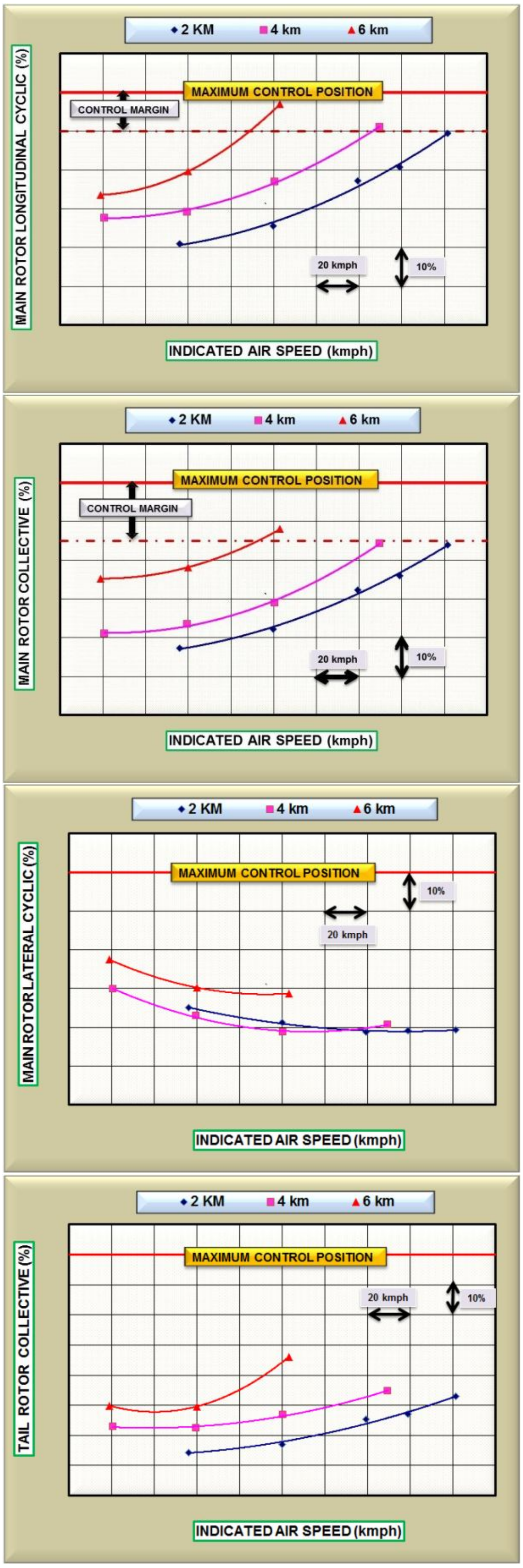

Figure 5: Control positions in level flight (Conventional Helicopter)

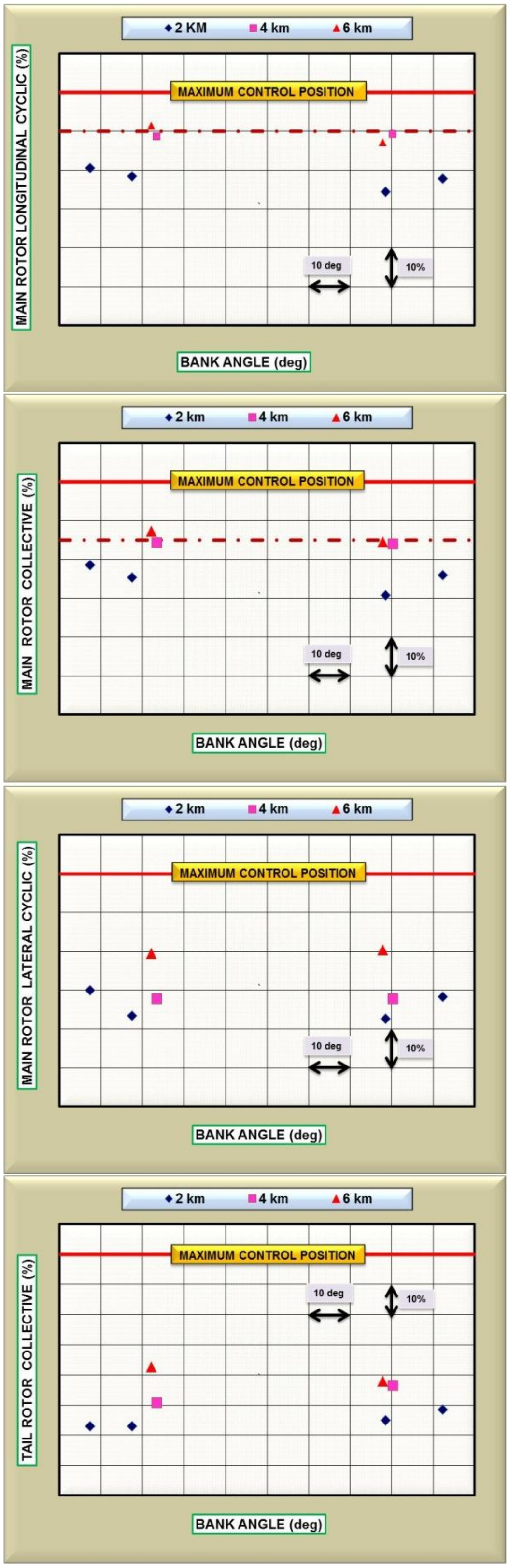

Figure 6: Control positions in Bank Turns (Conventional Helicopter)

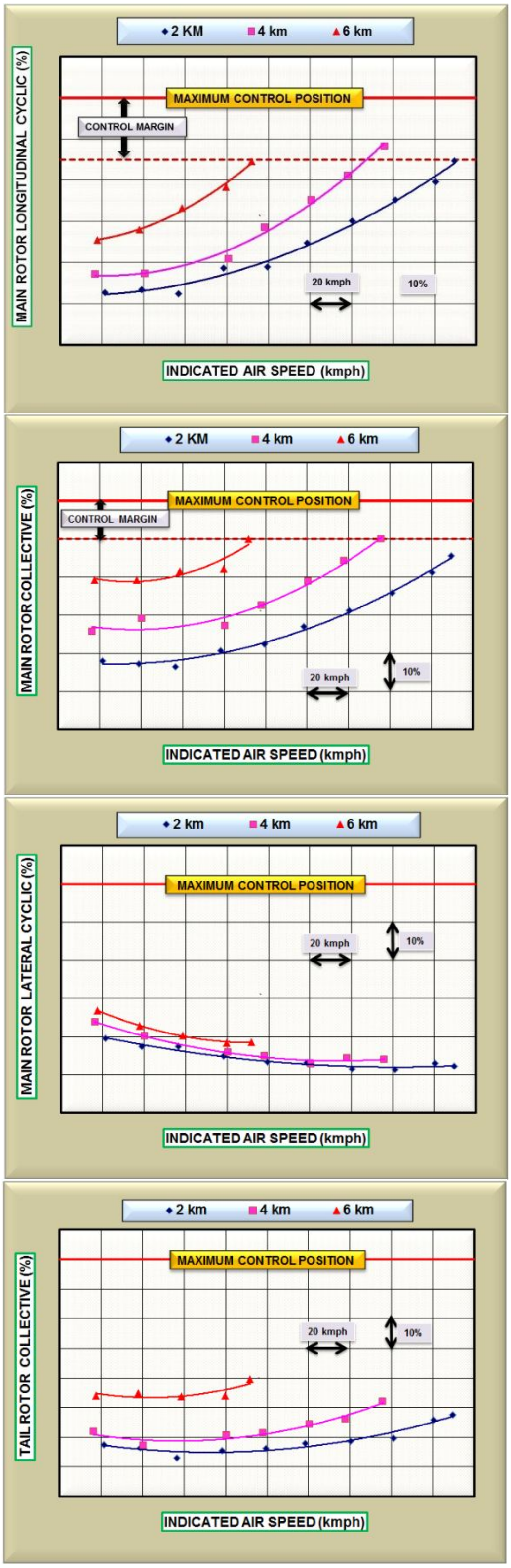

Figure 7: Control positions in level flight(Conventional Helicopter with reduced drag and Wing)

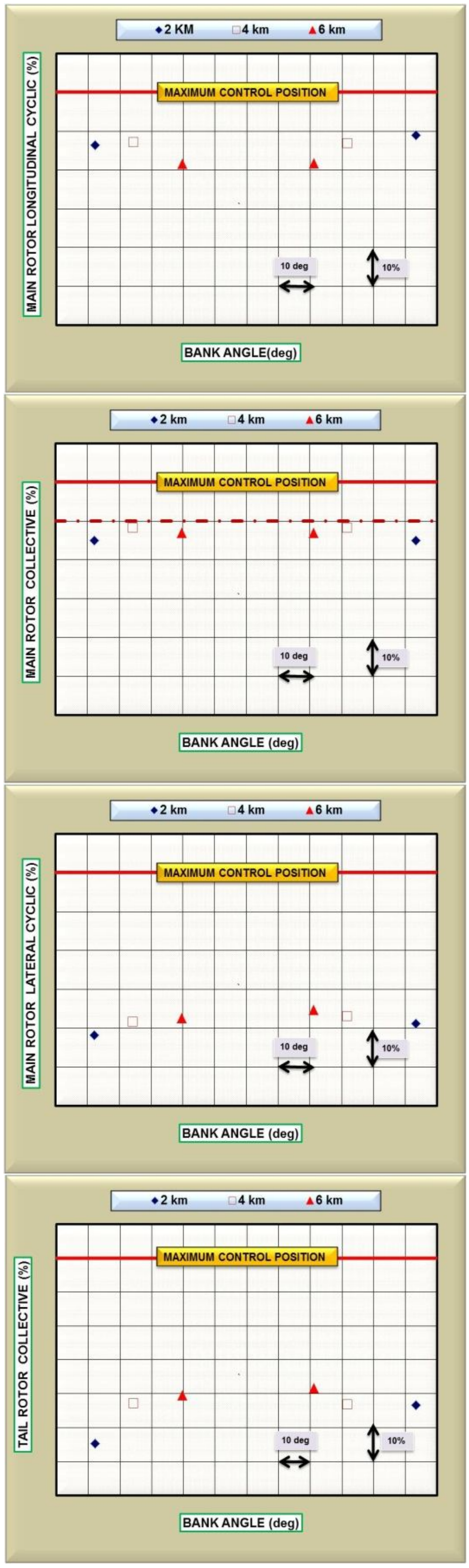

Figure 8: Control positions in Bank Turns(Conventional Helicopter with reduced drag and Wing)

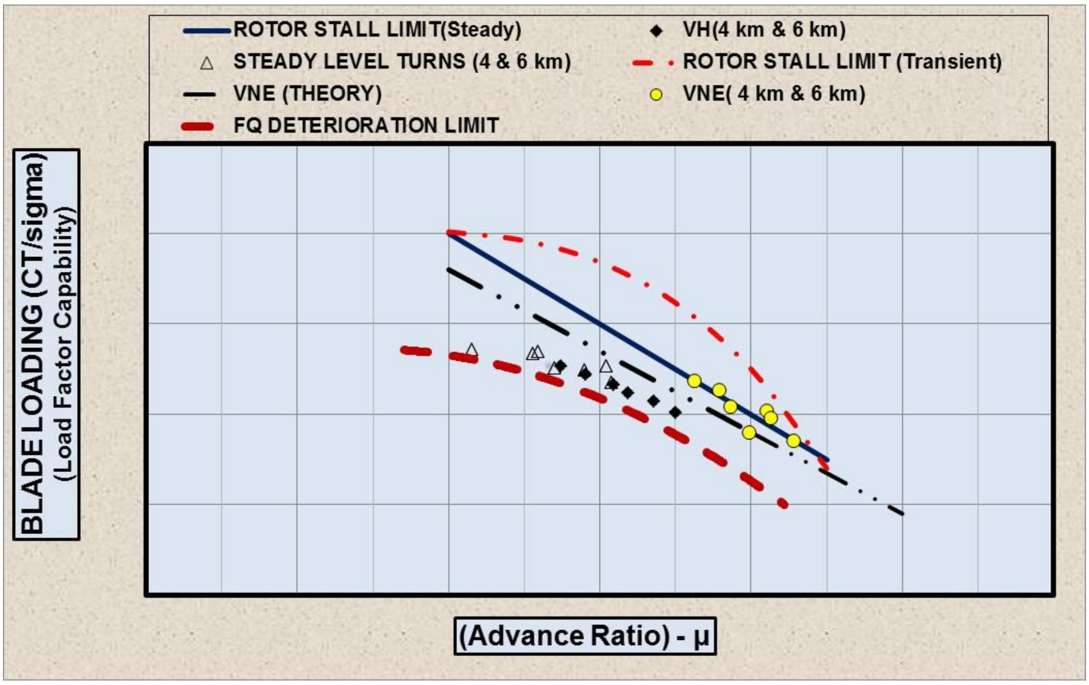

Figure 9: Load factor and Speed Capability of a Conventional Helicopter with Reduced Fuselage Drag and Wing

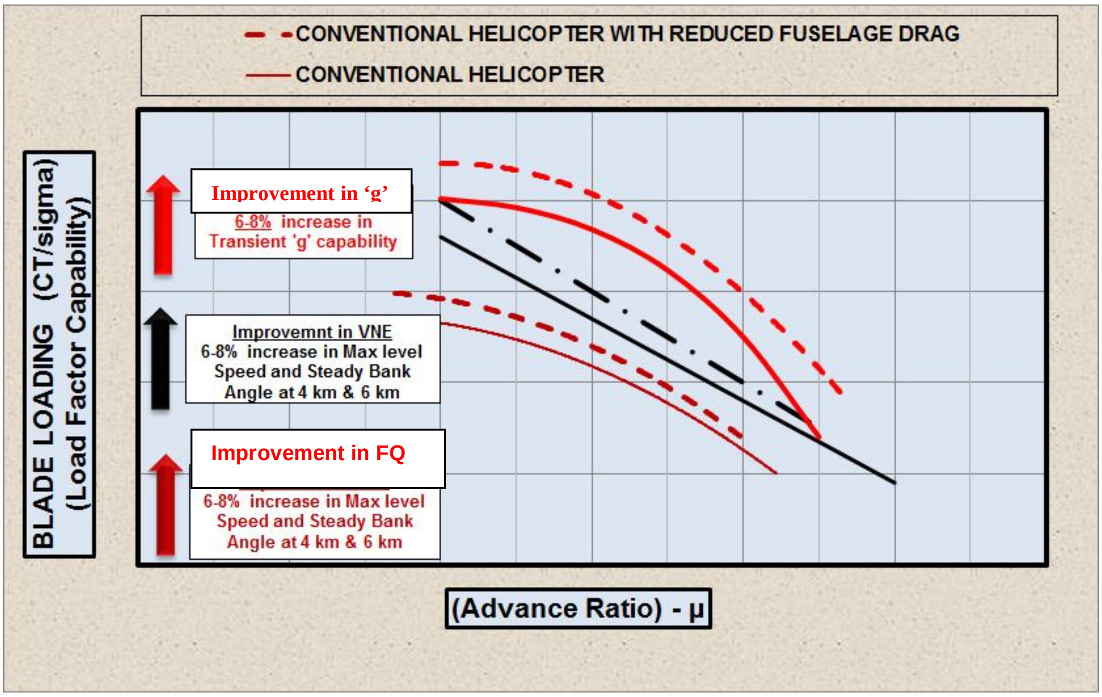

Figure 10: Improvement in Load factor and Speed Capability (Helicopter 1 &2)

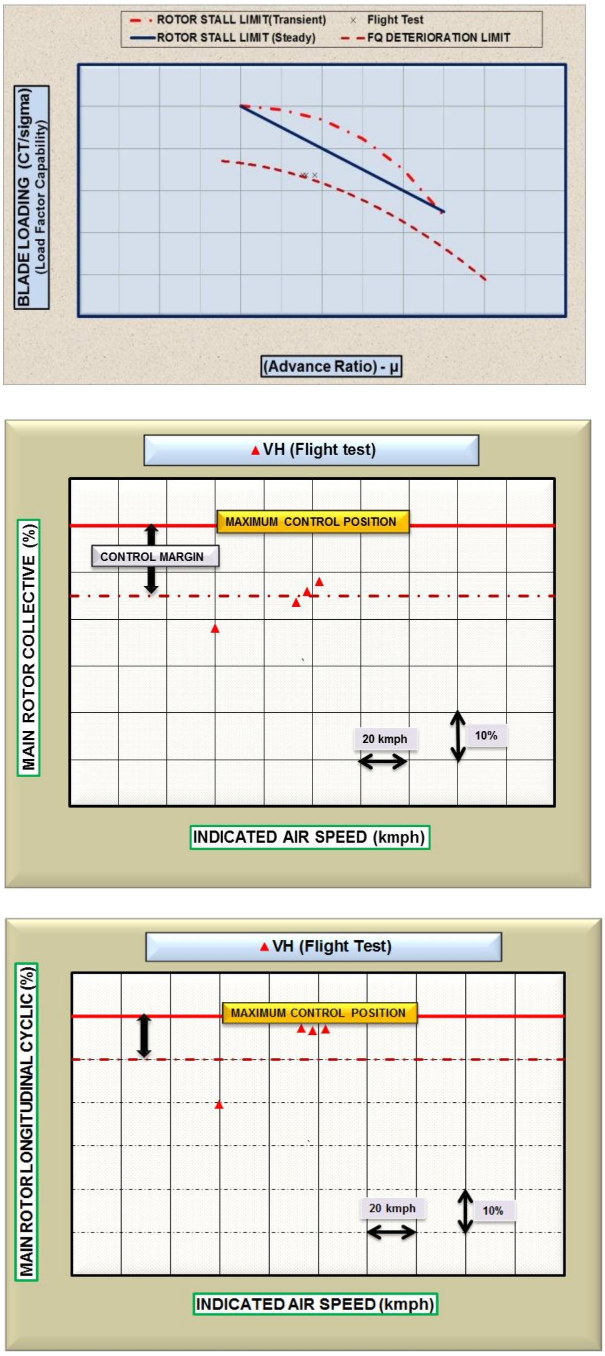

Figure 11: Flight test data beyond HQ Deterioration Limit

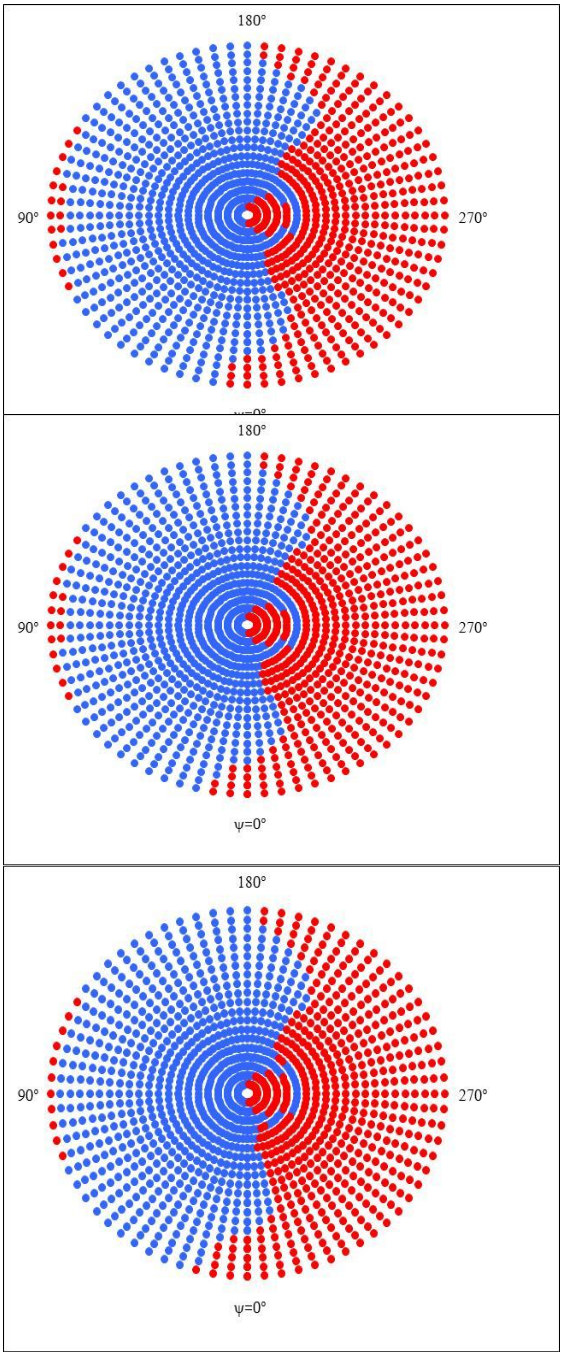

Figure 12: Flight test data beyond HQ Deterioration Limit (Stall Plots)