HIGHER AUGMENTED CONTROL OF A UTILITY HELICOPTER USING MODEL FOLLOWING CONTROLLERS

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Abstract

Higher augmented control of a medium sized utility helicopter with fly-by-wire controls is accomplished by implementing translational rate command position hold (TRCPH) type controllers. These control algorithms complements previously designed attitude command attitude hold (ACAH) type inner loops in a cascaded manner. ACAH controllers are based on two different design approach: explicit model following (EMF) and optimal model following (OMF). TRCPH mode is optimized for pilot workload alleviation based on ADS-33E-PRF specifications. Four sample mission task elements (MTEs) are performed in a desktop simulation environment with both EMF and OMF. A modified pilot model and power frequency metric are used to get some sense about qualitative pilot opinion..

1. INTRODUCTION

Problems in control precision, high pilot attention demand and poor situation awareness in low speed and maneuvering flight makes a helicopter operation prone to mishaps [1]. Firefighting operations, take-off/landing from oilrigs, search and rescue (SAR) operations often take place in degraded visual environments (DVE). Same conditions also apply for military missions like reconacance, combat SAR or close air support, that is why; ADS-33E-PRF demands higher augmentation than attitude command attitude hold (ACAH) type in DVE for significantly reduced pilot workload and enhanced safety in close proximity to ground obstacles [2][3]. Supporting this demand, the comprehensive study of Couch and Lindell proved a direct relationship between rotorcraft survivability and good handling qualities (HQ) **Hata! Başvuru kaynağı bulunamadı.**. Two control mode improvements on top of ACAH are vertical rate command and translational rate command / position hold (TRCPH) to ease collective and cyclic workloads respectively.

TRCPH is especially effective in hover and low speed nap-of-the-earth flight operations. TRCPH mode demands the longitudinal and lateral translational speeds to follow the cyclic stick inputs. A step cyclic deflection produces a first order steady translational rate response in the appropriate direction. Maximum and minimum rise time requirement of the first order response is specified in ADS-33E-PRF. No pilot cyclic input or a centered stick means zero ground speed command, which is equivalent to position hold. That is, position hold comes as an integral part of translational rate command hence the name TRCPH.

The vertical rate command is defined as when a constant deflection of the vertical axis controller from trim position produces a constant steady-state vertical velocity. Unlike TRCPH, vertical rate command does not imply height hold. Forcing the vertical rate to zero do not guarantee a constant altitude since disturbances can put the helicopter to a different elevation with no vertical speed at steady state. An additional feedback loop for altitude is required to obtain a vertical rate command and height hold (RCHH).

Higher augmentation modes of an AFCS, like TRCPH, require lots of attention during testing phase for desirable, carefree maneuvering especially when it comes to qualitative pilot assessment. However, research and development of a flight control algorithm based on flight-testing is not an optimal choice. Tischler states that flight-testing for flight control system development is estimated to be about $75k/flight-hr at modern industrial facilities. Overcoming control problems during design phase reduces the cost 50 to 150 times compared to a solution during flight testing [5].That is the reason for building flight dynamics simulation models and trying to predict aircraft behavior beforehand so development costs and time can be reduced. “Test to validate” flight-test approach is a perfect example of this and it grows more and more among the industry [6]. That being said, a comprehensive flight control system assessment does not only content with quantitative engineering evaluation but also requires qualitative evaluation from the pilots. One of the most commonly used practice for quantitative assessment is to test algorithms on a real time simulator with pilots-in-the-loop. However, apart from the sophisticated hardware requirements based on selected simulator configuration, running a simulator requires a dedicated team of design engineers, technicians, pilots and flight test engineers. Managing this many of specialized personnel and resource adds to time and cost. Thus, there still is certain development and testing necessary even before deploying flight controllers in the simulator

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environment. In the presence of a reliable helicopter flight dynamics model, desktop simulation becomes a quick solution for these issues. In addition to a pilot model, a metric that can transform pilot input time histories into sensible handling quality ratings is necessary for this quick solution. Using an accurate helicopter simulation model [7], a model based pilot model/controller (MBPC) [8] and with a power frequency metric capable of predicting pilot HQ ratings when tuned accordingly [9], this work tries to achieve realistic pilot evaluation without actually utilizing a pilot, making rapid controller algorithm testing simply a one-man job.

In prior work, two different full authority model following controllers, explicit model following (EMF) and optimal model following (OMF), were designed to achieve ACAH response type for a light utility helicopter. Controllers were optimized against selected ADS-33E-PRF ACAH specifications to obtain minimum pilot workload during flight. Pilot workload evaluations for both controllers were performed using MBPC and power frequency. Depart/Abort and Lateral Reposition mission task elements (MTEs) were practiced for this evaluation, so power frequency metrics obtained from OMF and EMF simulations would be comparable. It should be noted here that ACAH workload evaluation favors EMF rather than OMF. Additionally EMF provides a more transparent structure for design tuning compared to OMF, since the latter depends on modern control techniques [10].

Building on top of this effort, this paper uses these two ACAH controllers as a basis and proposes a well-known structure for TRCPH type control. The possibility of using the same TRCPH design with two different inner loop structures is shown. In order not to compromise from qualitative HQRs or from robustness levels achieved before, both controller structures are optimized using the same outer TRCPH loop with design margins on top of Level 1 requirements. Four different MTEs are performed with MBPC on desktop simulation environment. The idea here is to be able to obtain some sort of qualitative evaluation, with MTEs being specifically tailored tasks that exposes potential HQ problems related with augmenting the quantitative performance metrics [11]. To this end MBPC structure and parameters are re-evaluated to prevent issues associated with changing the augmentation type of bare helicopter. Just as in the prior work, power frequency metric is used to get a feel about the qualitative pilot opinion paving the way for a more accurate workload evaluation.

2. TOOLS

Tailoring a high augmented control algorithm is all about pilot opinion. Ideally, after each design iteration of the controller, pilot opinion should be taken to reveal qualitative aspects of flight control system. This way, control design engineer would have a much more comprehensive understanding of the pilot needs and can tailor the flight control system accordingly. However as mentioned before, it is not feasible to demand piloted tests to be a part of controller design loop.

Excluding pilot without giving up the qualitative assessment necessitates a variety of tools that can, at least to some extent, reflect helicopter behavior, pilot reaction to helicopter behavior and pilot qualitative evaluation of his/her reaction.

2.1. Flight Dynamics Model

Helicopter mathematical model was built in TOROS and validated against COTS software FLIGHTLAB® in terms of trim and non-linear response performance [7]. TOROS is a high fidelity helicopter flight dynamics simulation tool including, rotor, airframe, engine, actuator, sensor and landing gear dynamics. It has capability to trim the helicopter at a given sensible trim condition, perform linearization analyses around said trim condition or run nonlinear simulations starting from the trim condition. Linearization procedure of TOROS is constantly being validated as the model is updated by comparing the frequency responses of the linearized system with identified frequency responses from frequency sweep time domain simulations of the nonlinear model. Figure 1 shows the time domain agreement between the linear and nonlinear responses. For this analysis 1% doublet inputs on all channels are introduced to the helicopter within the first second of the simulation during a stabilized hover at 4000 feet.

Good match on the helicopter angular

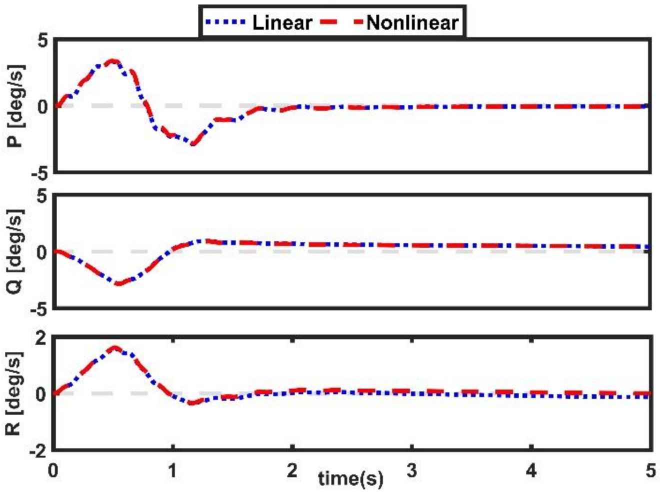

Figure 1. Linear vs Nonlinear Angular Velocities

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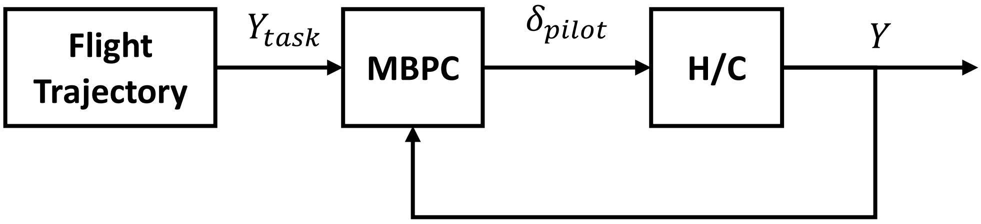

Figure 2. MBPC integration with Helicopter Model

velocities is a direct result of the linearization validation of TOROS. The importance of linearization validation is twofold for this work since control system development is based largely on linearized models of helicopter behavior and the MBPC is highly dependent on linear models for mimicking the pilot perception of helicopter behavior.

Developed in MATLAB-Simulink® environment, TOROS has a reconfigurable and user-friendly plot and visualization routines allowing easy illustration of selected data and 3D animations of performed helicopter simulations. TOROS is being developed by Turkish Aerospace Helicopter Flight Mechanics division as part of the Turkish Light Utility Helicopter (TLUH) program.

A light utility helicopter, designated as T-625, with a maximum take-off weight of 6050 kilograms, is modeled in TOROS environment. T-625 has two engines and classical main rotor / tail rotor configuration. Main rotor is a five bladed articulated type. T-625 is currently under test and evaluation phase and it successfully demonstrated maiden flight on sixth of September 2018. As of right now, the testing flights continue and mathematical model validation effort is underway with some promising results.

TLUH originally has a limited authority flight control system; however, for this study the flight control system is considered as a full authority fly-by-wire like system with main actuator models that have 6 Hz (~38 rad/s) cut-off frequency.

2.2. Optimization Tool

State-of-the-art flight control algorithms need an optimization process to reflect perfect performance against requirements. Manually checking each quantitative requirement against guideline boundaries is a cumbersome method. This check should also be done for every iteration of flight control system development process. With the advancements on multi objective optimization algorithms, automating this process became available for flight control engineers. CONDUIT® is a software solution that utilizes multi-objective feasible sequential quadratic programming to optimize a given set of design parameters based on the specifications defined by the user [2]. It has been used extensively for both fixed wing and rotary wing platforms on a variety of development programs and is a proven tool [12][13][14].

For this work, CONDUIT proved to be a suitable tool while checking the convenience of ACAH controller gains for TRC as an inner loop as well as determining TRC gains directly for a simplistic higher augmented controller structure while maintaining Level 1 HQ requirements.

2.3. Model Based Pilot Model/Controller

To get qualitative pilot opinion without a pilot, a pilot model is essential. Pilot can be thought as the outmost loop of a flight dynamics model.

This work uses a modified model-based pilot controller (MBPC) which is used to simulate pilot behaviour (Ref. 10). MBPC utilizes optimal estimation and modern control theory to represent pilot control actions computationally while taking the majority off psychophysical limitations of an actual human into account. These limitations may include, but not limited to, nerve conduction, perceptual delay, data processing activities in the central nervous system, neuromuscular lags and so on.

While operating in degraded visual environments (e.g. UCE = 3 definition of ADS-33) pilots depend heavily on flight instruments to complete their task. An experienced pilot is able to generate an expectation of general helicopter behavior and create control inputs accordingly [15]. Thus, an optimal state estimator to predict helicopter states to represent experienced pilot expectations, and a linear quadratic controller based on estimator states to represent experienced pilot control actions can together form a perfect pilot model. Adding pilot psychophysical limitations to the perfect pilot model, an experienced pilot can be represented for simulating pilot actions in degraded visual environments. MBPC is the result of this thought chain. Resulting pilot model takes tasks flight trajectory as input and generate realistic pilot inputs for helicopter simulation model. General block diagram can be seen in **Figure 2**. Flight trajectories of predefined ADS-33 MTEs are created in the flight trajectory calculation block. Then, task applicable measurements are fed to

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the MBPC. MBPC compares desired task measurements (Y_{task}) with actual helicopter measurements (Y) and generates pilot inputs accordingly (δ_{pilot}).

For this work, MBPC needed a major re-evaluation. MBPC was originally developed according to a limited authority control system with SAS mode active. With a Helicopter that has SAS only, with 10% authority, stabilization was an issue as well as control system saturation. However with a higher augmented control mode MBPC actually has a lot less to accomplish, just like a pilot would during real flight , to achieve a realistic simulation data. Thus, one of the major concerns was simplifying and modifying the MBPC.

Since MBPC uses an optimal observer in its core, it needs the linear helicopter dynamics with the active controller on, as well as some tuning for the cost function weighing matrices. This configuration originally mandated MBPC to be scheduled according to longitudinal and lateral speeds, since SAS does not guarantee stability and with a SAS level compensation, it is not practical to use a single linear model in MBPC observer for low to moderate flight speeds. The tuning task, on the other hand, is helicopter, task and fight control system specific. Each MTE (Depart/Abort, Lateral Reposition, Hovering Turn and Pirouette) and each control mode (ACAH, TRC) requires a new set of weighing matrices.

Initially, scheduling based on speed is removed. Since ACAH loop is always active during simulations, the expectation was to have an augmented helicopter that does not change character for low to moderate speeds just as the previous study points out [10]. That is, in fact, also the reason for designing only one TRC loop for two different inner loop ACAH controllers.

Secondly, MBPC was modified so that it can perform with linear models that have different number of states. OMF and EMF, by design, contain different number of states. Additionally, linear models that OMF and EMF was designed for had different number of states. Specifically OMF is based on 9 state linear models and EMF is based on 31 state linear models. This state number difference was evaluated to be flight control design issue and if MBPC is to be used for different types of controllers, it needs to be compatible. Therefore, in order not to restrict flight control design, MBPC is modified and now can be used with models that can have different number of states.

Finally, weighing matrices of MBPC was tuned for each flight condition. Guided by [16], weighing matrices were tuned by considering the observer pole locations, controller pole locations and the neuromuscular delay values.

The result is, hopefully, a pilot model that generates stick controls similar to an experienced pilot. However, it should be kept in mind that further tuning might result in results that are more realistic. For this work, weighting matrix tuning was done specifically for satisfying the MTE requirements without abandoning the guidelines of [16].

2.4. Power Frequency Metric

To get a feel about the qualitative MTE evaluation, power frequency method [16] is utilized. This frequency domain based metric allows the user to see the temporal variations in the pilot workload. The signal power variations of the stick activity and the time-varying cut-off frequency of the pilot activity are taken into account to obtain a metric that represents the pilot workload in a time-varying manner. It is also possible to correlate power frequency metric to qualitative ratings like Handling Quality Ratings (HQR) or Bedford Work Load Rating Scale (BWLRS) [17]. Both maximum and average values of the power frequency readings can be related to HQR. Although there are various other metrics that are being used as pilot workload evaluation qualities [18], this work uses maximum value of the power frequency encountered for a given flight task to specify the workload based on prior experience with the power frequency metric.

3. TRANSLATIONAL RATE COMMAND – POSITION HOLD CONTROLLER

3.1. Higher Augmented Controller Structure

Common approach to flight control design is based on linear models of H/C response. ACAH controllers for this work selected linearization points around hovering flight, 40 knots level flight, and 70 knots level flight. Although this is a proven method, linear models lacks some key nonlinearities of the actuators. Including rate and position saturation of actuators during design phase prevents degradation of stability margins and increased phase lags. That is why this study uses linear models in conjunction with nonlinear actuator models to design control loops.

Since former work satisfied quantitative Level 1 HQ ratings in terms of ADS-33E-PRF, it was reasonable to try built on top of that performance to obtain vertical rate command and TRC. With ACAH type controllers in the inner loop, rate control problem reduces to generating viable attitude references. This practice is also the common approach in literature [19].

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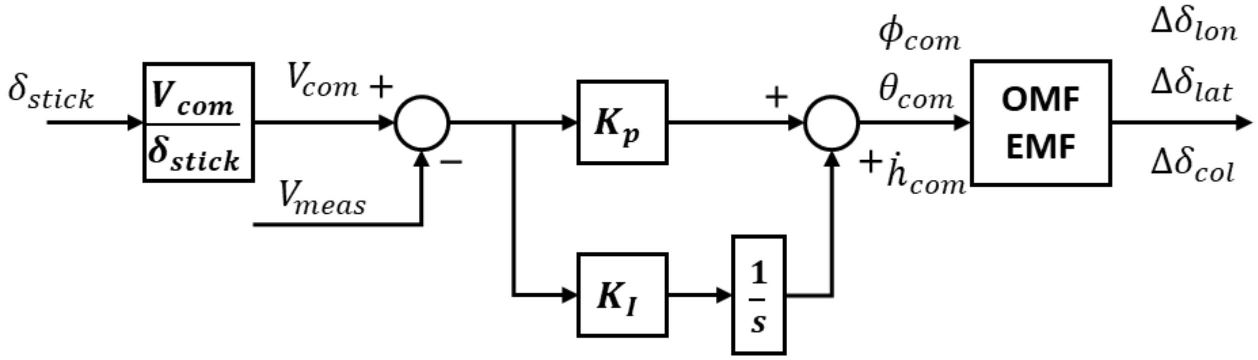

Figure 4. TRCPH Vertical Rate Command Control Loops

In line with this, cascaded controller structures are designed which uses translational velocity feedback on three orthogonal axes; longitudinal, lateral and vertical. **Figure 4** illustrates the control algorithm used to obtain TRCPH and vertical rate command. Stick inputs from the pilot initially fed through a scaling factor, which converts stick deflections in percent, to velocity commands in meters per second. These velocity commands in three orthogonal axes are then passed through PI controllers so attitude and vertical velocity reference signals generated. These reference signals are then supplied to the ACAH controllers; either OMF or EMF. The inner loop ACAH controllers also generate pedal inputs for heading hold; however, it is not depicted in the figure to avoid confusion. Both ACAH controllers in the inner loop use the same TRCPH outer loop structure and gains.

3.2. Controller Optimization

The design parameters for these cascaded loops, namely the controller gains are tuned with the help of CONDUIT. Table 1 summarizes specifications for the optimization process. Specification selection is done to ensure that each specification is effected by at least one design parameter and the design space is properly constrained. Each specification is assigned a type as hard constraint (H), soft constrained (S) or summed objective (J) to reflect their priority during optimization. Detailed information for design specifications and their effects on control performance can be found in [5].

For increased robustness, a 10% design margin is set which means the optimizer tries to reduce the cost value 10% lower than limits defined in the specifications.

Table 1. Specification Set for Optimization.

Properties	Type	Comments
Damping Ratio	H	Sufficient Damping
Eigenvalues	H	Stability
Robust Stability	H	Robust Stability
Gain/Phase Margins	H	Gain/Phase Margin
Piloted Bandwidth	S	Short Term Response
Min. Crossover Freq.	S	Acceptable Crossover
Dist. Rej. Bandwidth	S	Disturbance Rejection
Dist. Rej. Peak	S	Damping for Dist. Rej.
Model Foll. Comp.	J	Reference Tracking
Crossover Frequency	J	Over Design
Actuator RMS	J	Over Design

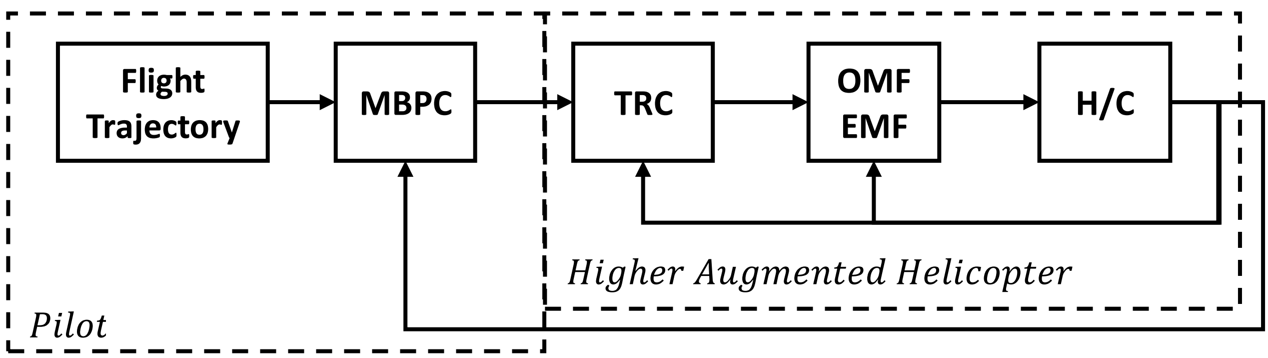

Figure 3. General Simulation Environment Block Diagram

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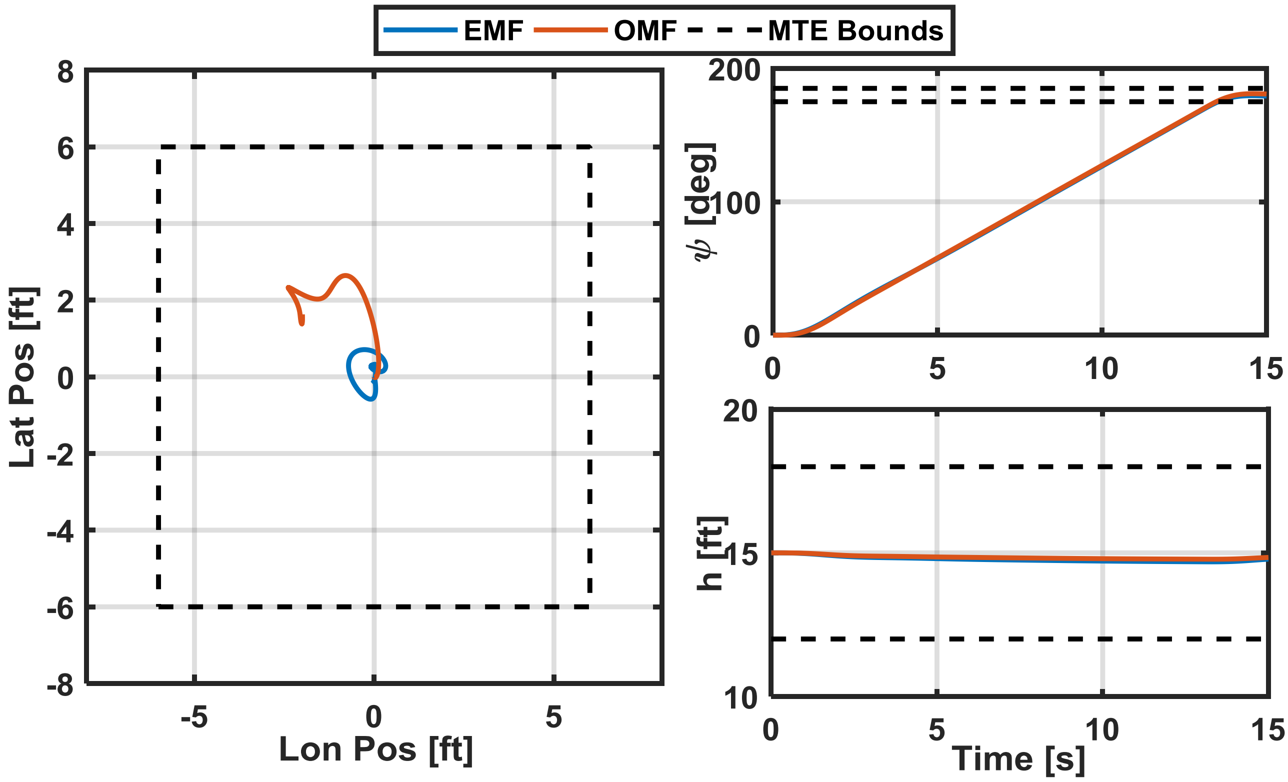

Figure 5. Hovering Turn MTE

4. RESULTS & DISCUSSION

After integrating each element into simulation environment, general simulation diagram is formed as in Figure 3. Four MTEs from ADS-33 are performed within this framework. Every MTE is performed with OMF and EMF inner ACAH loops active so any difference resulting from OMF or EMF performance can be revealed, with same TRC loop is active. Helicopter, was assumed to in a highly degraded visual environment (UCE=3). For each task, desired performance within UCE=3 was aimed. Resultant helicopter movement and pilot workload in terms of the power frequency metric are presented.

Hovering turn MTE is performed to assess HQ in a moderately aggressive turn. Helicopter is expected to complete a 180 degree turn while maintaining the longitudinal and lateral position within 6 feet by 6 feet box. Altitude change should be less than 3 feet. Whole maneuver should be completed under 15 seconds. This task can reveal undesirable inter-axis couplings.

Figure 5 shows simulation results for hovering turn MTE with OMF and EMF. Adequate performance can be achieved with both controllers. OMF position deviated more than EMF position but it is hard to deduct controller performance from this slight deviation. **Figure** 6 reveals that pilot cyclic control is minimal, evidencing that TRC loop is doing its job. Comparing cyclic workloads, provides a little more insight to OMF and EMF performance. Figure 7

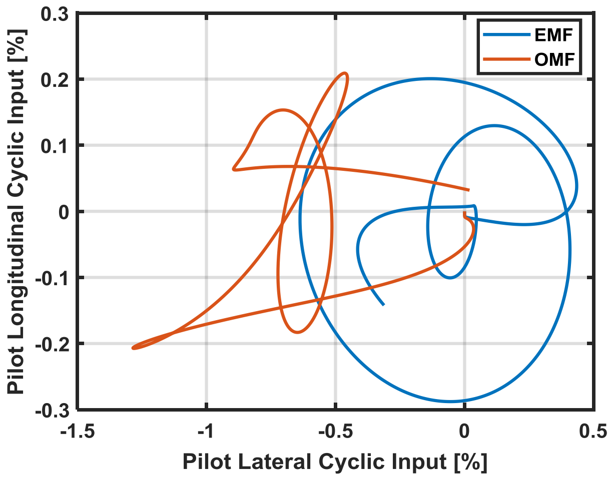

Figure 6. Hovering Turn MTE Pilot Cyclicl Inputs

illustrates that throughout the task, OMF pilot workload on lateral cyclic is more than EMF. This can be further supported by the position deviation of the helicopter. These results indicate a superior cross coupling performance on EMF controllers' part. Longitudinal cyclic workloads favor OMF if one looks only at the maximum power frequency value. However, comparing the mean values for longitudinal workloads indicates the same cross coupling superiority for EMF. It should also be noted that, for a two second interval after fourth second, pilot workload is indeed higher in longitudinal axis for EMF. This shows the suitability of power frequency metric for such applications. Since power frequency gives

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workload in a time based manner, it can reveal at which portion of the maneuver pilot is concentrating more to which control axis.

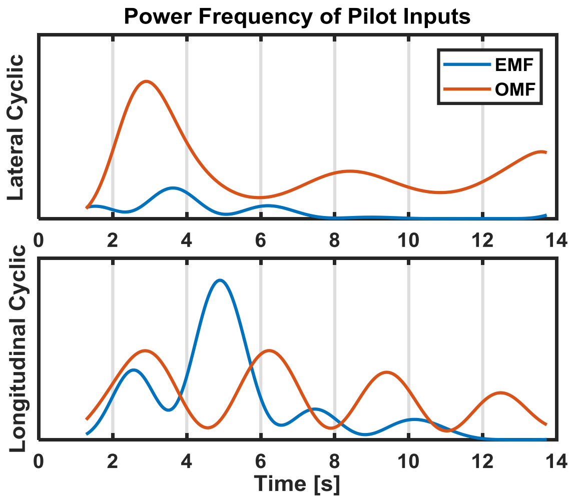

Figure 7. Hovering Turn MTE Pilot Cyclic Workload

Depart/Abort MTE, as defined in ADS-33, requires a helicopter to accelerate and decelerate longitudinally to cover an 800 feet range. Deceleration should start only after reaching a minimum of 40 knots groundspeed. Maneuver should start and end in stabilized hover conditions. Radar altitude of the helicopter should be kept under 50 feet. Whole maneuver should take a maximum of 25 seconds. 10 degrees of heading deviation and 10 feet lateral track deviation is permitted. At final instant helicopter should be within 20 feet of the intended endpoint.

Figure 8 and Figure 9 shows results of Depart/Abort MTE with restrictions indicated as dotted lines. It possible to perform the MTE with both EMF and OMF active. For EMF case, most demanding restriction was keeping the lateral track. Unlike the hovering turn MTE, for Depart/Abort OMF controller shows better off-axis characteristics. Off-axis EMF response needs to be neutralized using pilot input, which can also bee seen in pilot workload from Figure 11. On the other hand, OMF off-axis workload seems a lot more manageable. Longitudinal workloads for both controllers are similar to each other. Minimum requirement of 40 knots ground speed is achieved with both controllers. It is possible to perform the task element within the given adequate margins with TRCPH in upper level and EMF and OMF active in the inner loop.

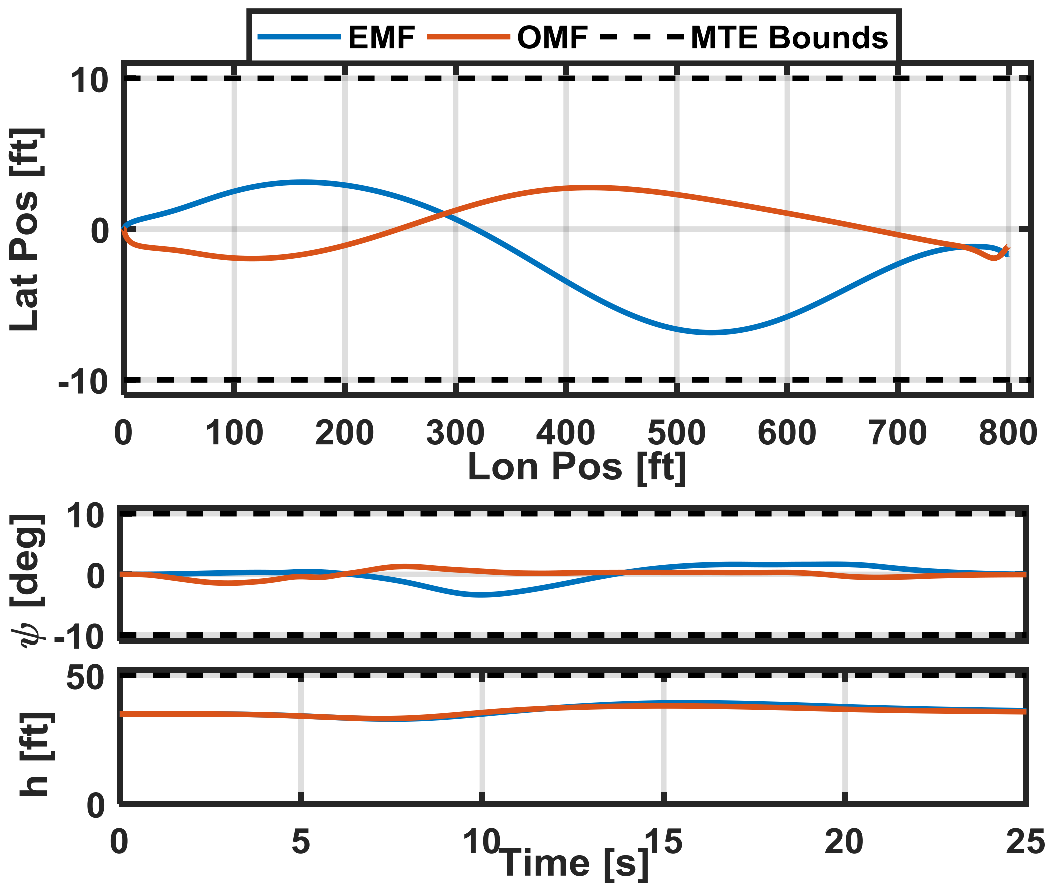

Figure 8. Depart/Abort MTE

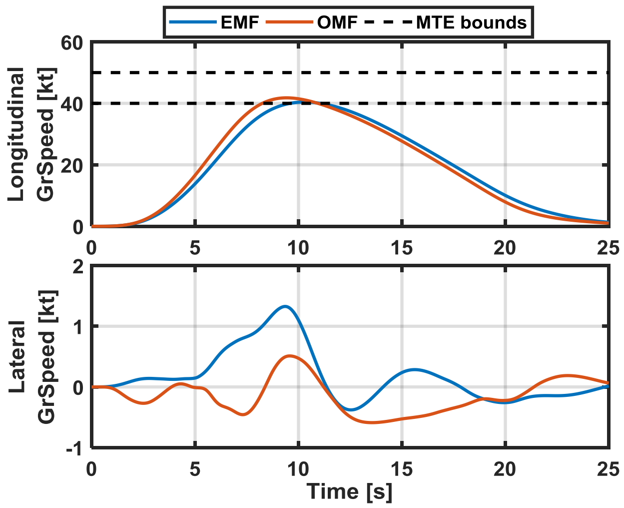

Figure 9. Depart/Abort MTE

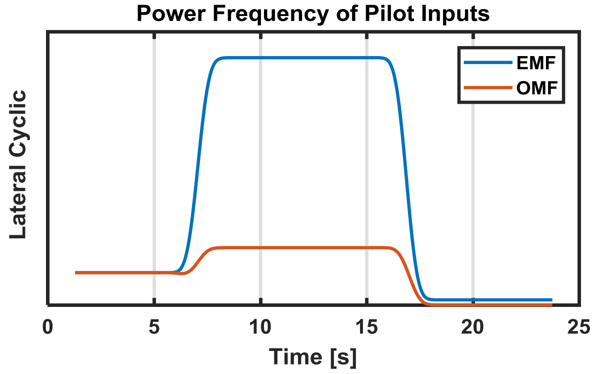

Figure 11. Depart/Abort MTE Lateral Workload

Description of Lateral Reposition MTE is not that different from the Depart/Abort mission. A helicopter should accelerate and decelerate laterally to cover a 400 feet range. Maneuver should start and end in stabilized hover conditions. Deceleration should start after approximately 35 knots of ground speed is reached. Altitude and longitudinal track deviations should be no greater than 10 feet. Maximum heading variation of the helicopter should be under 10 degrees. Whole maneuver should take a maximum of 18 seconds and the helicopter must be within 10 feet of the end-point at the end of the maneuver. The acceleration and deceleration phases should be accomplished as single smooth maneuvers. At the end of the mission task, helicopter should be brought to a stable hover within the longitudinal and lateral limits specified. Unlike Depart/Abort MTE, overshooting is permitted during deceleration.

Results of the Lateral Reposition MTE with the defined restrictions are shown on Figure 10 and Figure 12. MBPC is again able to perform this MTE with tuning of the gain matrices. It should be noted that 35 knots of ground speed is barely reached during reposition and off-axis control is an issue for the both controllers for this maneuver. 10 feet longitudinal deviation is very easy to exceed and several iterations were required to complete the maneuver in adequate margins. Heading response of EMF, although

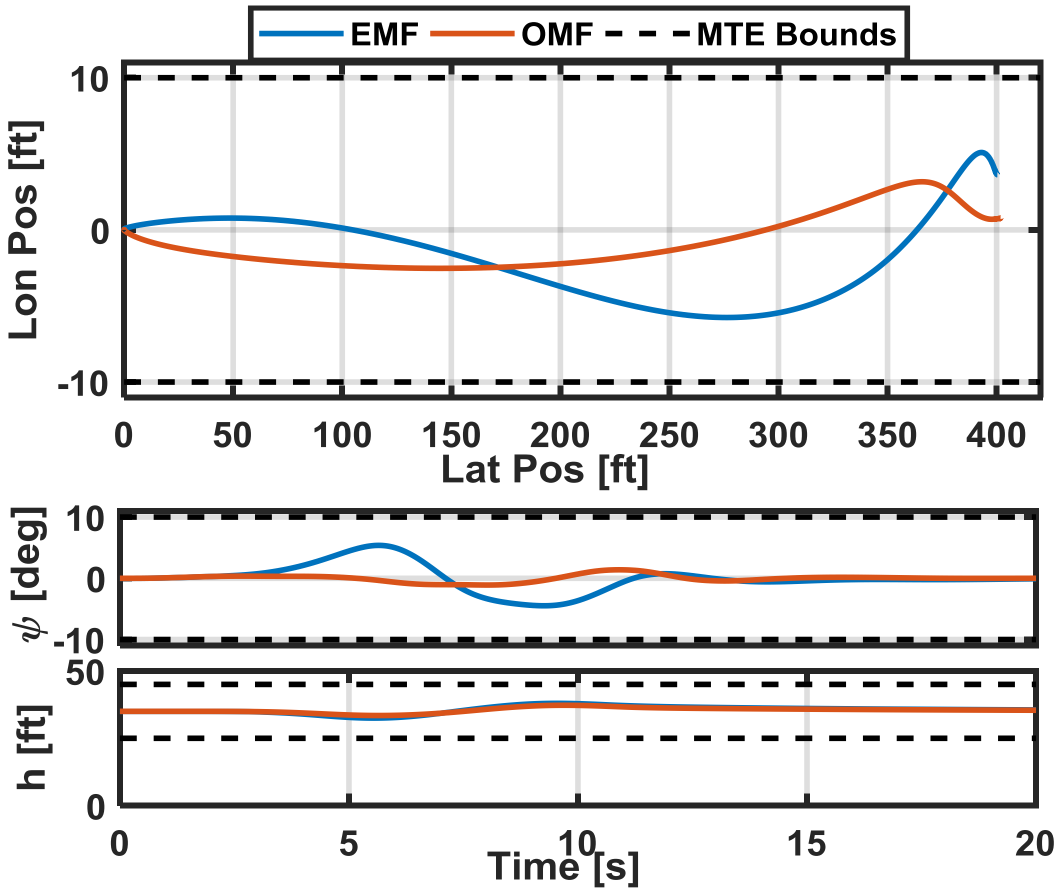

Figure 10. Lateral Repositioning MTE

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within adequate margins, is significantly worse than EMF. The power frequency metrics are again similar in on axis, but EMF is far worse in off-axis.

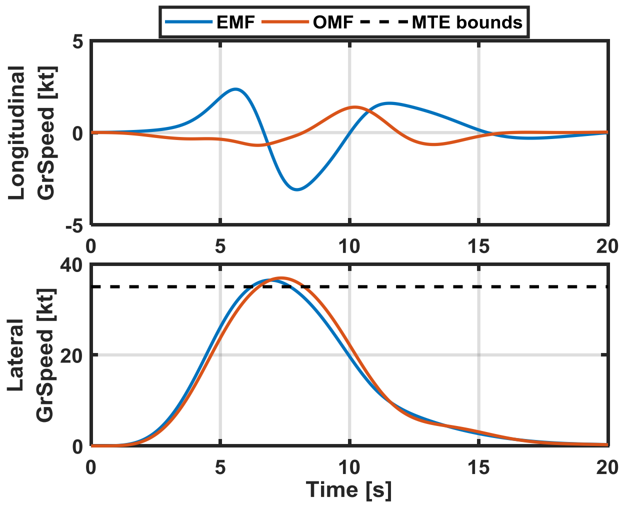

Figure 12. Lateral Repositioning MTE

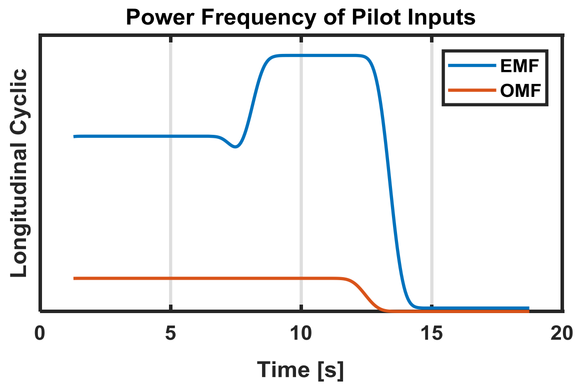

Figure 13. Lateral Repositioning Longitudinal Workload

Lastly, pirouette MTE is performed. This maneuver is initiated from a stabilized hover over circumference on an imaginary 100 feet radius circle with rotorcraft heading is pointed towards the center of the circle. A lateral translation while keeping the aircrafts heading at the center is performed. The task starts at 10 feet altitude above ground level and altitude error should be kept within 4 feet. Helicopter should start and finish the maneuver with a stabilized hover over the same point on the circumference. There is a time limit of 60 seconds for highly degraded usable cue environments. This task checks the ability to accomplish precision control of the helicopter in the pitch, roll, yaw and heave axes. Therefore, it is the most demanding task in this paper.

Figure 14 and Figure 16 shows the results of pirouette maneuver with OMF and EMF separately while the same TRC loop is active on top of them.

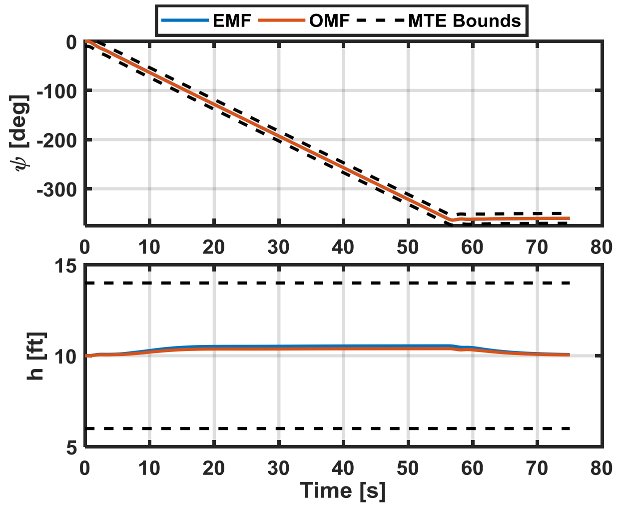

Figure 14. Pirouette MTE

Heading of the helicopter fallows the center point during the whole maneuver, as requested by the MTE adequate limits. Altitude deviation is kept under 1 feet by the height hold controller without any correction by the pilot. Figure 16 shows the circle that was fallowed by the helicopter with the MTE bounds on. Right side of the figure depicts the starting point more closely to show at the end of the maneuver helicopter is indeed comes to a stabilized hover within the defined adequate limits.

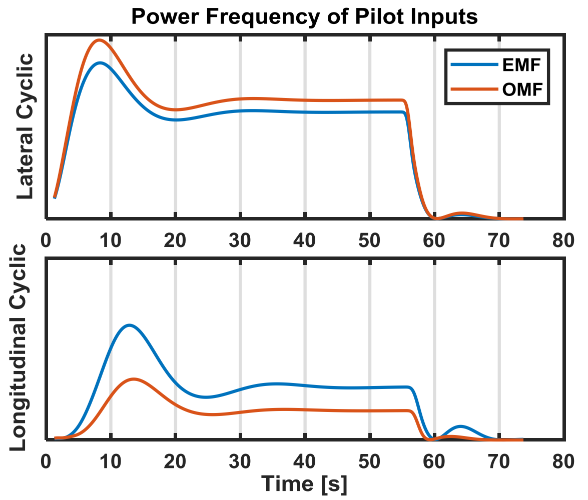

Figure 15. Pirouette Pilot Workload

Cyclic stick demands more attention for this task, since heading and height controllers perform sufficiently well. Figure 15 shows pilot work load on longitudinal and lateral axes separately. Lateral workload seems similar with OMF being slightly more demanding. In longitudinal cyclic however, OMF requires less

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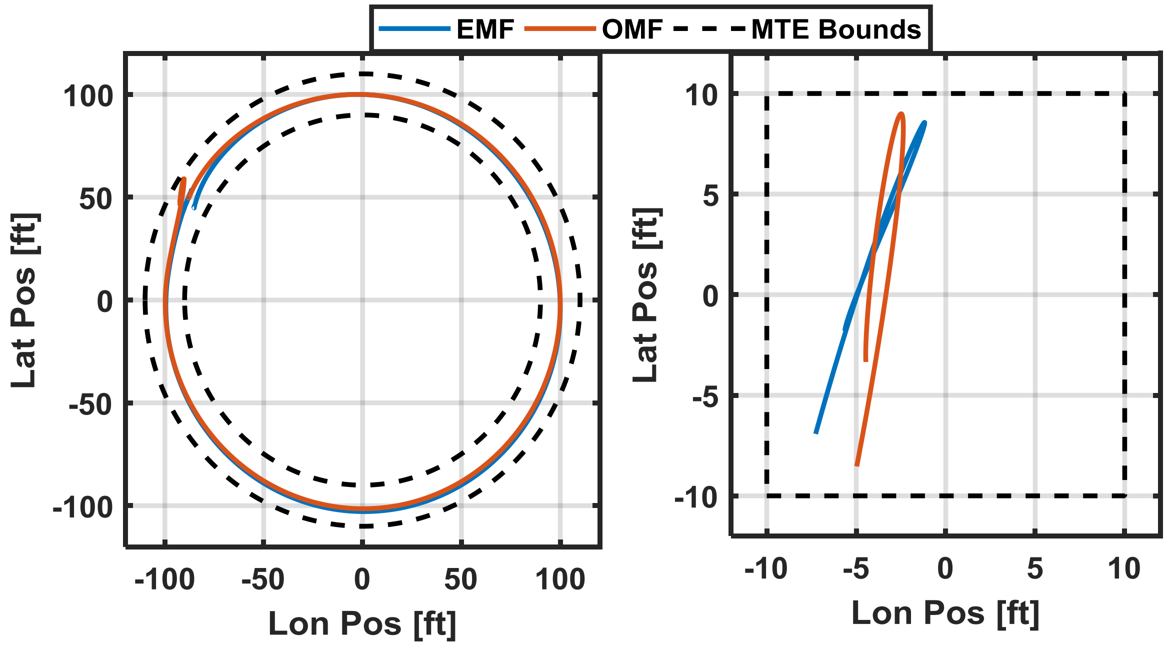

Figure 16. Pirouette MTE

attention. The cyclic movement for the maneuvers in Pirouette was proved to be a complex and highly demanding maneuver, even with a higher augmented helicopter. Tuning the pilot model for this task was the most time consuming part.

Hovering Turn, Depart/Abort, Lateral Reposition, Pirouette MTE results indicate that the devised TRCPH controller is able to perform high demand tasks adequately utilizing different ACAH inner loops. A complete workload comparison in terms of maximum power frequency metric encountered throughout the maneuver is presented at Figure 17. Both EMF and OMF requested lower workloads during different mission tasks. It is evident that the most demanding task was the pirouette, and the most basic one was hovering turn.

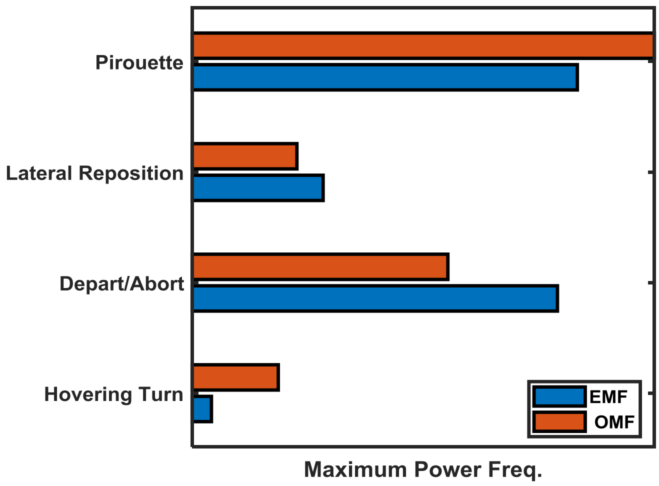

Figure 17. Workload Comparison

5. CONCLUSION

A TRCPH improvement is devised for two different model fallowing ACAH type controllers. This translational command controller is tuned to work with both inner loops and have Level 1 qualitative requirements satisfied. The tuning is done via multi-objective optimization. Four different MTEs from ADS-33E-PRF are simulated in desktop environment with the TRC mode while two different inner mode controllers were active. For realistic pilot behavior a modified pilot model is utilized throughout the maneuvers. In order to get a feel about the qualitative aspect of the pilot workload, the power frequency metric utilized. These MTEs include low to moderate speed missions. The performance of different model fallowing inner loops and the overall pilot workload during the maneuvers is discussed. No overall superiority over one controller to another was determined. The comparison of controllers in question is a case study for the method that this paper presents.

This method to acquire qualitative evaluation without actually utilizing a pilot, is presented. The method can be used for rapid prototyping of new control algorithms, which can be refined on desktop environment, way before going into simulator tests, which can save valuable time and resources. After this desktop environment evaluation, piloted tests in simulator can be of more value.

For future progress, the power frequency metrics acquired herein should be compared to a real piloted simulator test. Enough piloted test data can lead to a mapping function that converts power frequency values to meaningful HQ ratings.

Another improvement would be to study transition characteristics between ACAH and TRCPH modes. Transition will be inspected and

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optimized for smooth, un-bothering mode switches. However, MBPC is composed of a linear observer and controller, and thus; needs a major upgrade to be able to cover mode transitions. Two different Kalman filters, one for ACAH and one for TRCPH mode can be integrated simultaneously to the MBPC, and a higher level particle filter can be used to estimate the actual mode helicopter is flying with.

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