FURTHER STUDIES OF THE RESPONSE OF SINGLE ROTOR HELICOPTERS TO VORTEX ENCOUNTERS

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INTRODUCTION

This report is a continuation of the studies described in Reference 1 where a simplified approach to the problem of predicting the uncontrolled response of a single rotor helicopter to an encounter with the wing tip vortex of a large transport aircraft is presented. This investigation presents additional results assuming that the pilot of the helicopter responds to the motion of the helicopter induced by the vortex encounter by applying control deflections. It is assumed that the pilot's response can be modelled as a simple feedback system. Control deflection proportional to helicopter attitude is assumed and only single loop closures are investigated.

It was noted in Reference 1 that the longitudinal motions of the helicopter in response to a vortex encounter were of large amplitude. In fact for two of the helicopters studied in this report the OH-6A and the BO-105C, no longitudinal responses were presented due to the fact that unrealistically large motions are predicted due to the lack of longitudinal stability inherent in these single rotor helicopters. The analytical approach predicts that even the UH-1H which exhibits the best longitudinal stability characteristics of the three helicopters experiences very large uncontrolled motions in the longitudinal response to the vortex gust field. Therefore it was considered that insight into the controllability of the longitudinal motion of the helicopters could be obtained by examining the effect of pitch attitude feedback as might be applied by the pilot responding to the gust.

In contrast to the longitudinal response which was quite smooth, the lateral/directional response exhibited a higher frequency osillatory behavior partly due to the presence of the relatively high frequency, lightly damped dutch roll mode and in part due to the difference in shape of the lateral disturbance compared to the longitudinal disturbance. Figure 1 shows the input functions, with the aerodynamic roll input primarily producing a longitudinal motion and the lateral velocity input producing primarily lateral/directional motion.

The maximum amplitudes encountered in the uncontrolled lateral directional response are also large and therefore it was considered of interest to examine feedback in the lateral-directional axes as well.

The prediction method developed in Reference 1 is also used to compare prediction with the flight test data of Reference 2. A brief discussion of tail rotor flapping induced by the vortex encounter is also included.

DISCUSSION

Various studies have indicated that particularly in single loop tracking tasks it is possible to model the action of a pilot as a quasi-linear feedback system in order to judge the flying qualities of an aircraft. In this study simple single loop closures are examined to determine their effect on response of a helicopter to the tip vortex of a large transport aircraft in order to obtain an indication of the ability of the pilot to reduce the amplitude of the response of the helicopter. Three cases are examined; feedback of equivalent longitudinal control (longitudinal cyclic pitch) proportional to pitch attitude; feedback of lateral control (lateral cyclic pitch) proportional to roll attitude; and feedback of rudder (tail rotor pitch) proportional to yaw attitude. These feedbacks should provide simplified representation of possible pilot action to counter the effect of the vortex gust field on the helicopter response. Since the lateral/directional response includes the dutch roll motion which is of relatively high frequency, the effect of a lag in the directional axis (tail rotor pitch) feedback is also examined.

Feedback gains are expressed in terms of inches of equivalent control motion per attitude change and Table I gives the conversions to actual control deflections and shows the feedback loops assumed. In all cases, the maximum control deflection amplitudes were relatively modest.

No attempt was made to examine more complex multi-loop control laws to minimize the response.

Longitudinal Response

Typical effects of pitch attitude feedback on the longitudinal motions of the UH-1H and OH-6A at 60 knots are shown in Figs. 2 through 7. Three responses are illustrated for each helicopter: the response with no feedback; the response for a pitch attitude to control deflection gain K_A = 10 in/rad (.17 in/deg) and the response for a gain of K_A = 20 (.35 in/deg). It can be seen that modest levels of attitude feedback are very effective in suppressing the longitudinal motion. The maximum feedback gain investigated of 0.35 inches of longitudinal stick deflection per degree of attitude change reduces the maximum pitch amplitude encountered during the motion to about 5 degrees or less tending to indicate that the longitudinal response is readily controllable. This result appears consistant with the results of the flight investigations of Reference 2 where it appears that the pilot was effective in countering the longitudinal response by small control actions. Note that in this reference the vortex encountered was generated by a C-54 aircraft and consequently is considerably smaller than the one used in this study.

Lateral Response

Figures 8 through 12 show the influence of feedback of lateral control deflection proportional to roll attitude on the lateral-directional response. Figures 8, 9 and 10 show the response with no feedback and the response with two levels of roll attitude feedback for the three helicopters at 60 kts. It can be seen from Figs. 8 through 10 that this feedback reduces the amplitude of the rolling motion induced by the gust field, however it has little effect on the yaw-slip motion. The influence of this feedback is quite similar for all three of the helicopters examined. This result is to a large extent due to the fact that the dutch roll motion is primarily a yaw-slip motion and would still exist when the roll response is identically zero. Roll attitude feedback thus has little influence on the yaw-slip motion. Figures 11 and 12 show low speed vertical climb cases where this feedback does reduce the lateral translation of the helicopter as well as the roll attitude.

Directional Response

Figures 13 through 19 show the effect of yaw attitude feedback to rudder (tail rotor pitch) for the three helicopters. There is a distinct difference between the effect of this control on the UH-1H and the other two helicopters as shown by the responses at 60 kts presented in Figs. 13 through 15. For the UH-1H the directional control feedback is quite effective in suppressing the yaw motion and in fact also reduces the roll motion. However, in the case of the OH-6 and BO-105 the yaw feedback results in considerable amplification of the rolling motion. This difference in roll response appears to be primarily due to the difference in the size of the dihedral effect of these three helicopters coupled with the fact that the yaw feedback reduces the lateral velocity of the aircraft thus increasing the sideslip velocity (the difference between the gust velocity and the helicopter velocity) thus increasing the rolling response of the aircraft through the dihedral effect. The dihedral effect of the OH-6 is about five times that of the UH-1 and the BO105 dihedral effect is about eight times as large. Similar trends exist at 100 kts as shown in Figs. 16 and 17. The low speed cases shown in Figs. 18 and 19 are also similar.

Thus these results indicate that the offset and hingeless rotor helicopters appear to present more of a problem in terms of pilot action to suppress the effect of the vortex gust field. The nature of the results obtained from this simple simulation indicate that it is highly desirable to consider pilot-in-the-loop simulations of these encounters as the simplified approach presented here can only be viewed as indicating trends.

The last case examined is the investigation of the influence of lag in pilot action the tail rotor feedback cases. Results are shown for the three helicopters in Figs. 20-23, where it can be seen that the presence of a lag in tail rotor/yaw feedback leads to an unstable response indicating that it maybe difficult for the pilot to suppress yaw disturbances. In the case of the UH-1H at 60 kts a 0.3 sec lag in the feedback produces a closed-loop instability while a 0.1 sec lag results in instability in the lateral-directional response of the other two helicopters.

Figure 24 shows a comparison of the predicted response of the UH-1H with flight test data presented in Reference 2. It should be noted that the vortex generating aircraft for these experiments is a C-54 and consequently the vortex disturbance is considerably smaller than that used in the other examples in this report which corresponds to a B-747 vortex.

SUMMARY

A simplified approach to the problem of controlling the response of a helicopter in an encounter with the trailing vortex of a large transport aircraft indicates the following:

1.) The uncontrolled longitudinal motions of a helicopter induced by the vortex field are of large amplitude. The effectiveness of a simple attitude feedback tends to indicate that it should be relatively easy for the pilot to suppress the longitudinal motion.

2.) The roll of the helicopter can be suppressed by lateral control feedback, however, this feedback does little to suppress the yawing motion.

3.) Directional control feedback supresses the yawing motion but on two of the helicopters tends to amplify the rolling motion. The effectiveness of the yaw suppression is sensitive to pilot lags.

4.) The nature of these results indicating that suppression of the lateral-directional motion is clearly a multi-loop task and sensitive to pilot time lags indicates that pilot-in-the-loop simulation experiments are highly desirable.

TABLE I

CONTROL GEARING FOR EXAMPLE HELICOPTERS

Pitch Axis. Degrees Cyclic Per Inch Stick Deflection

UH-1H	1.85 deg/in
OH-6A	1.92 deg/in
BO-105C	.83 deg/in

Roll Axis. Degrees Cyclic Per Inch Stick Deflection

UH-1H	1.54 deg/in
OH-6A	1.17 deg/in
BO-105	.93 deg/in

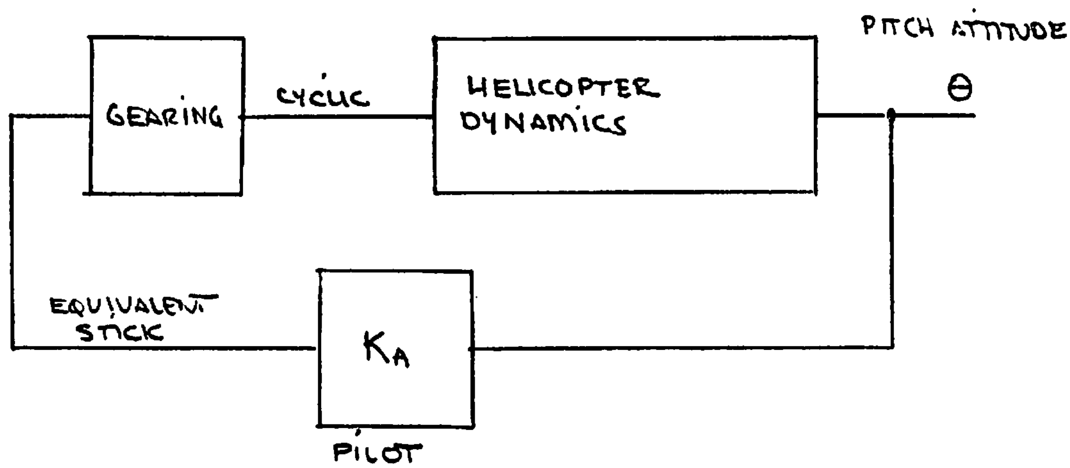
Yaw Axis. Degrees Tail Rotor Pitch Per Inch Rudder Pedal Deflection

UH-1H	4.51 deg/in
OH-6A	10.64 deg/in
BO-105C	3.69 deg/in

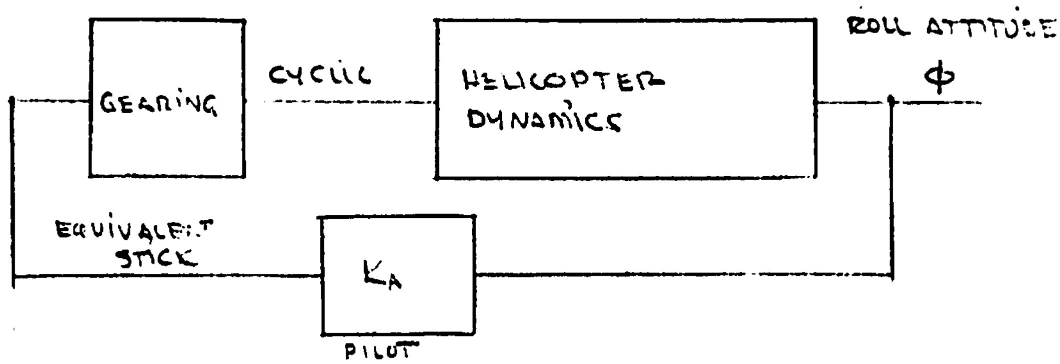
TABLE I (Con't)

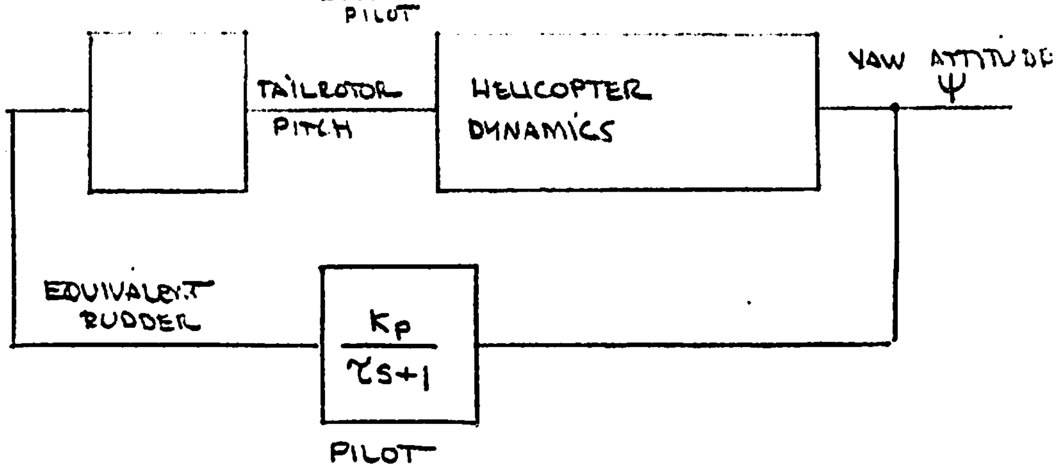
FEEDBACK LOOPS

LONGITUDINAL



LATERAL/DIRECTIONAL





REFERENCES

1.) Curtiss, H. C., Jr., Zhou, Zheng-Gen, "A Preliminary Study of the Response of Single Rotor Helicopters to Vortex Encounters", Princeton University, Mechanical and Aerospace Engineering Department Report MAE 1699, April 1985.

2.) Mantay, W. R., et al., "Flight Investigation of the Response of a Helicopter to the Trailing Vortex of a Fixed Wing Aircraft", AIAA Third Atmospheric Flight Mechanics Conference, Arlington, TX, June 7-9, 1976.

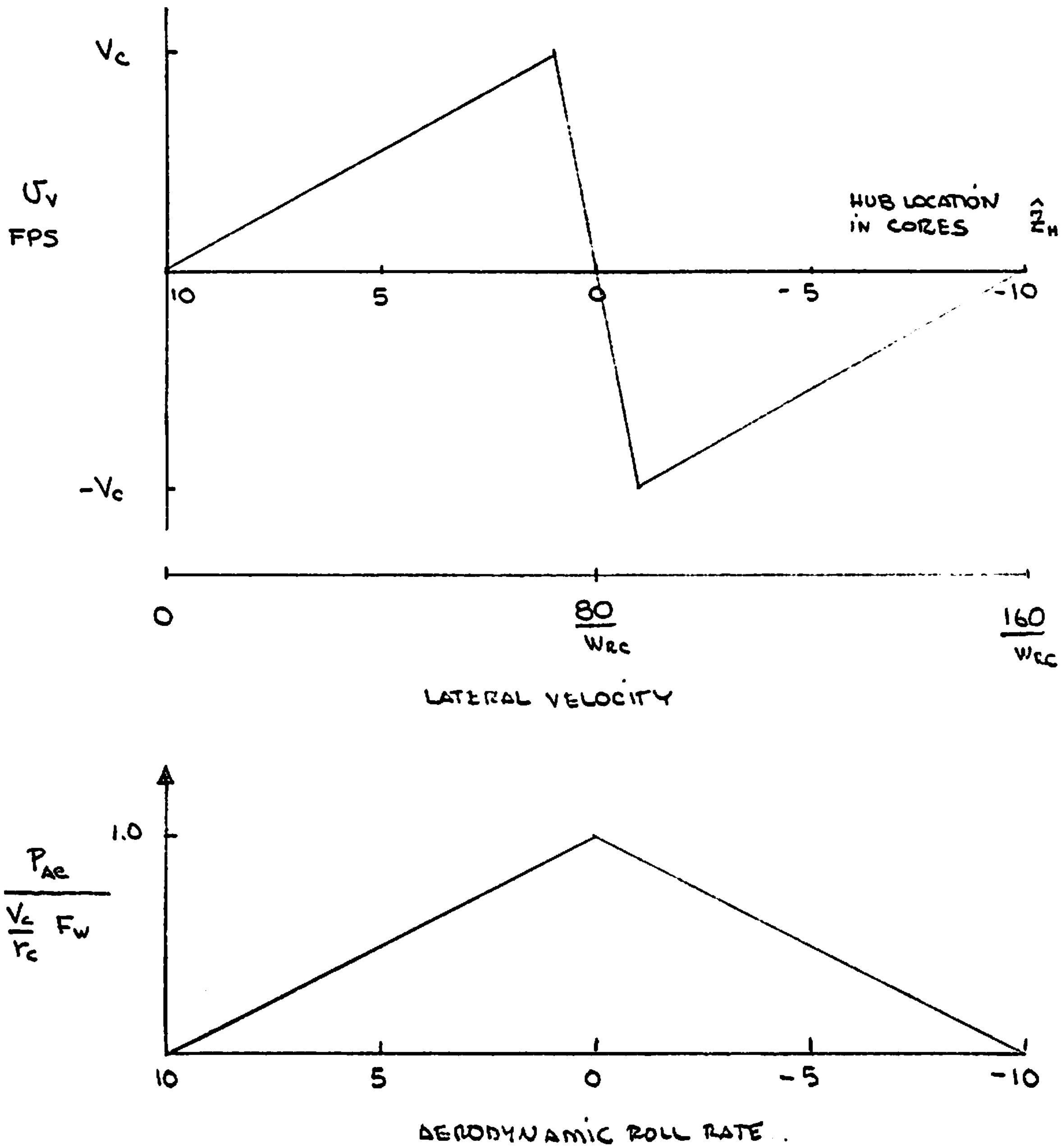


Figure 1. Vortex Disturbance Velocities.

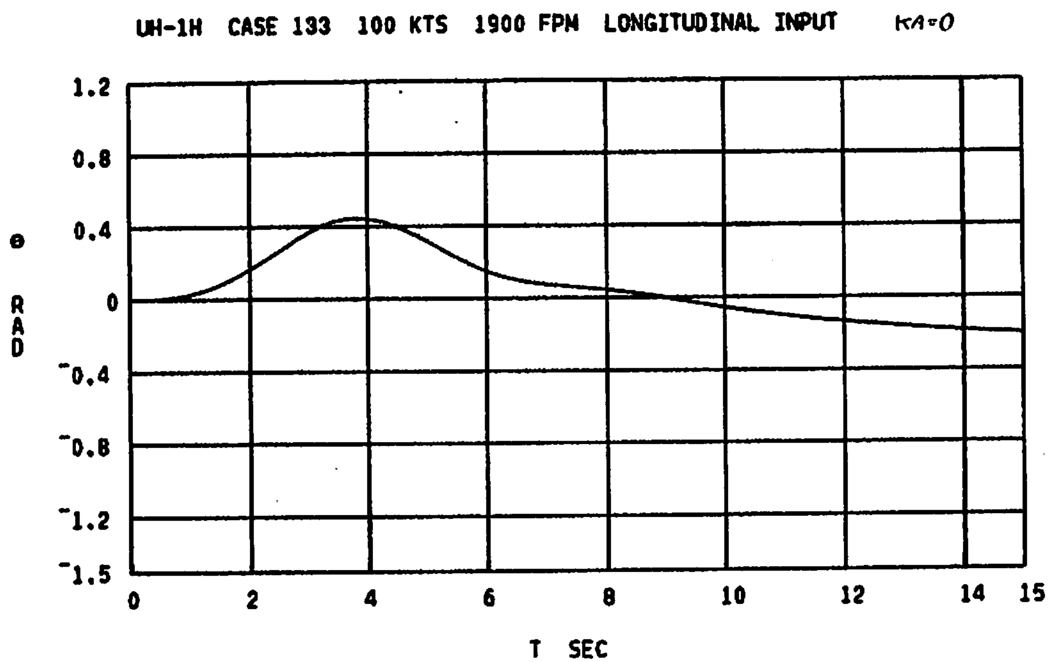
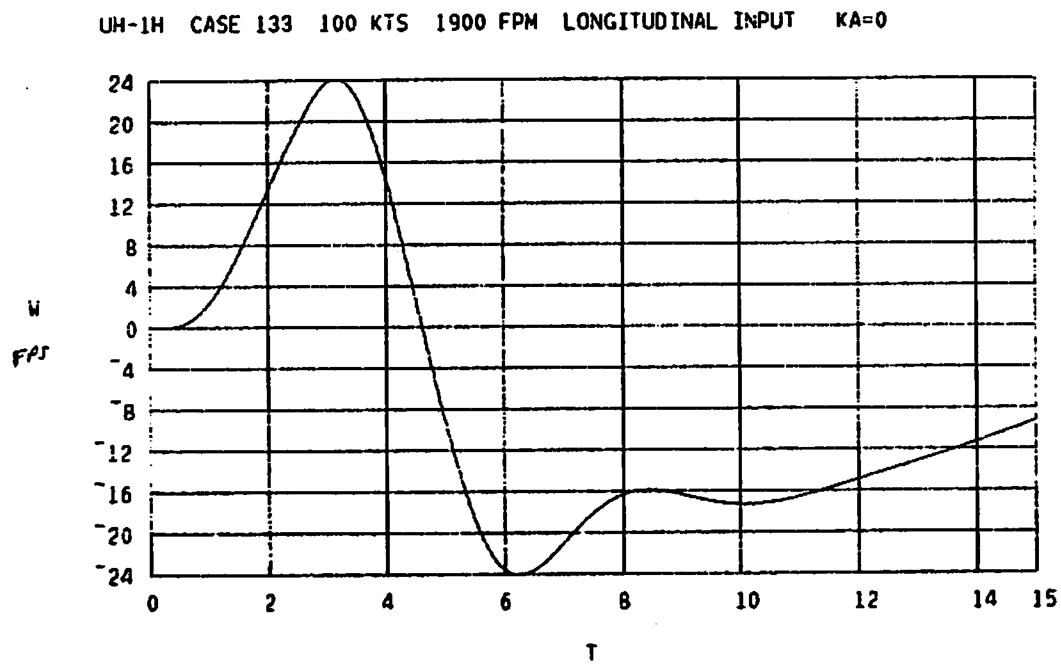


Figure 2. Longitudinal Response, UH-1H, 60 kts, No Feedback.



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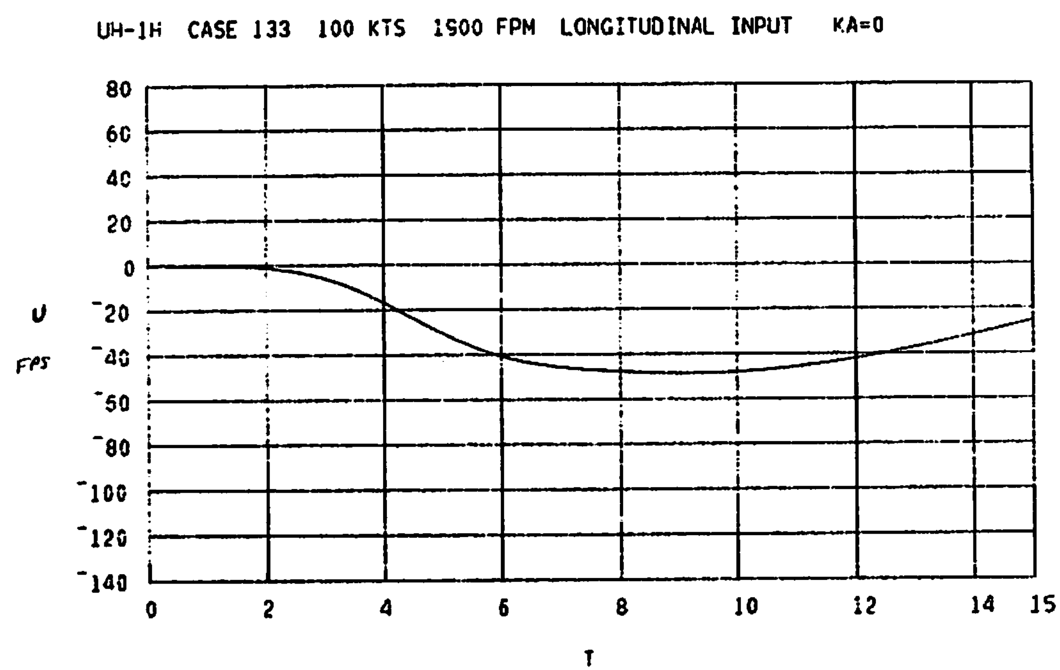

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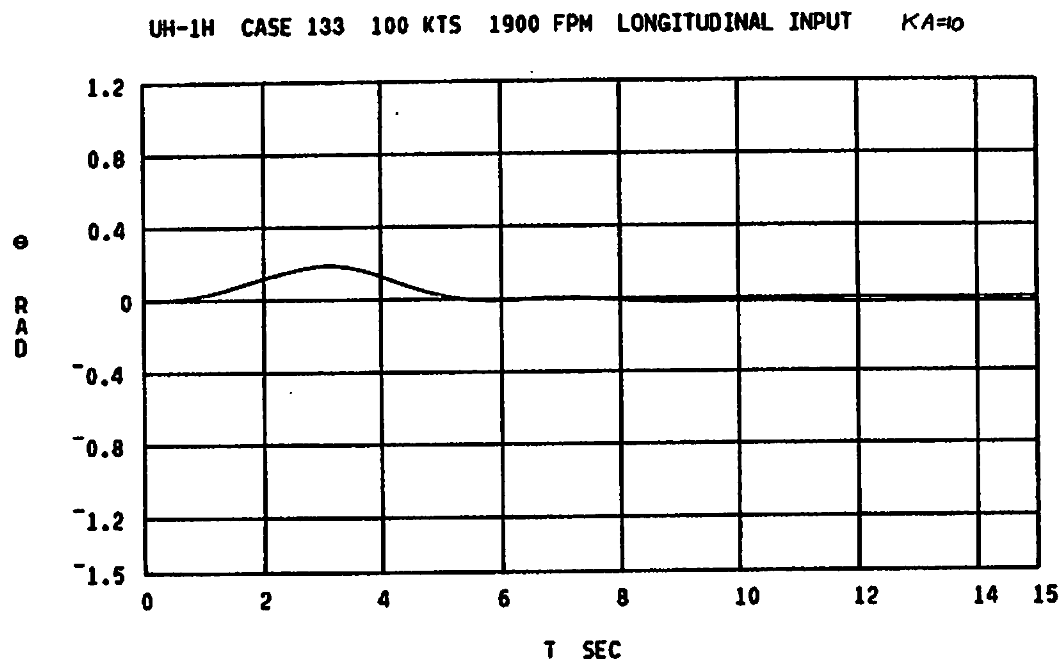
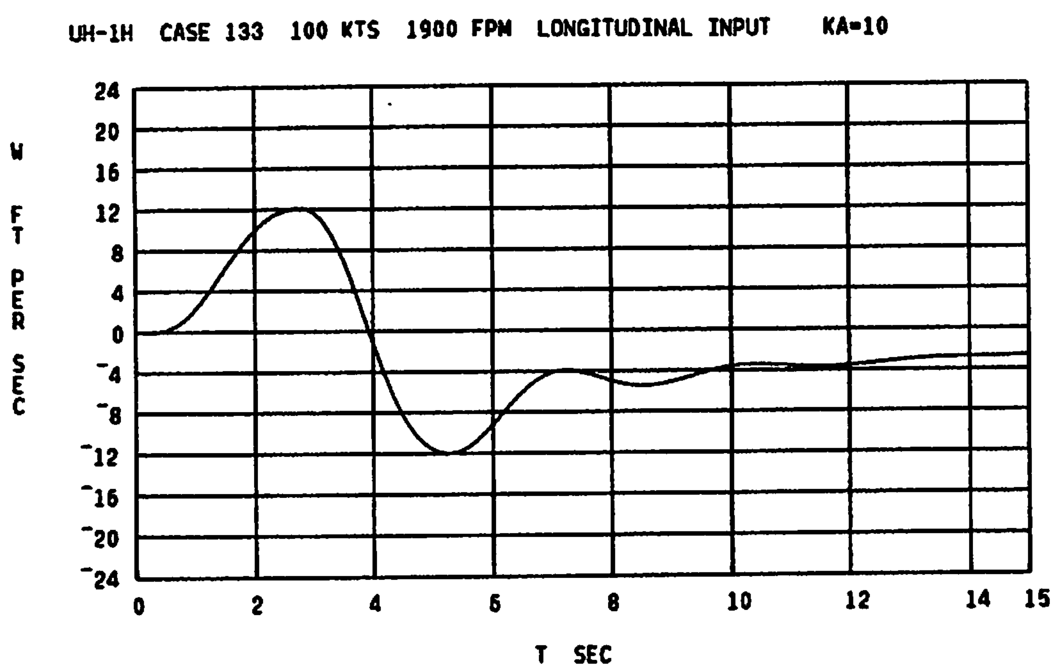


Figure 3. Longitudinal Response, UH-1H, 60 kts, K_A = 10 in/rad.



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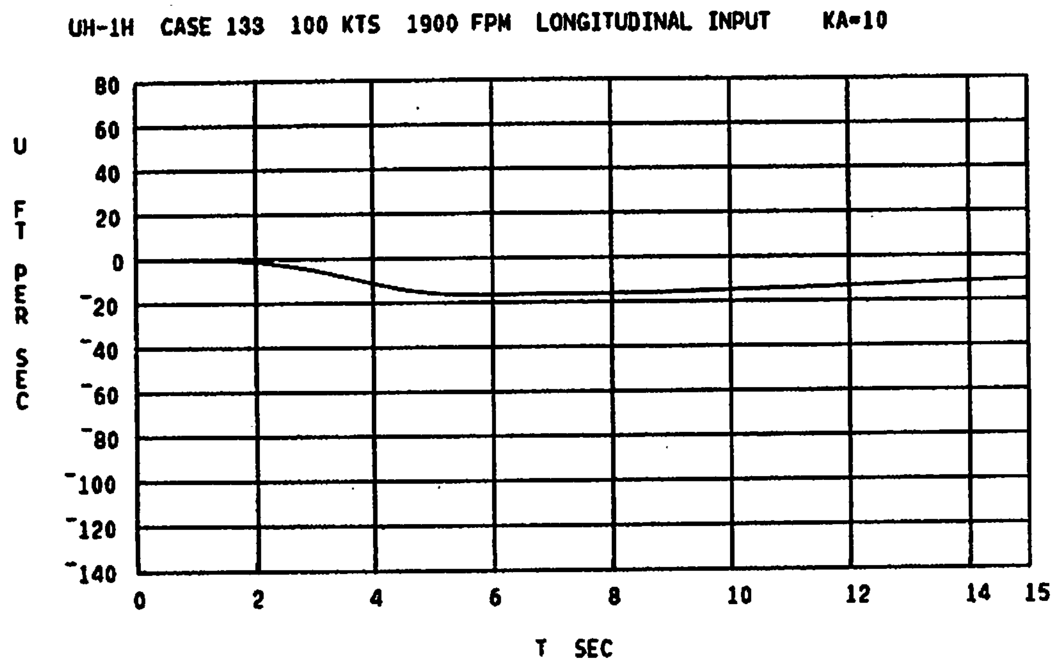

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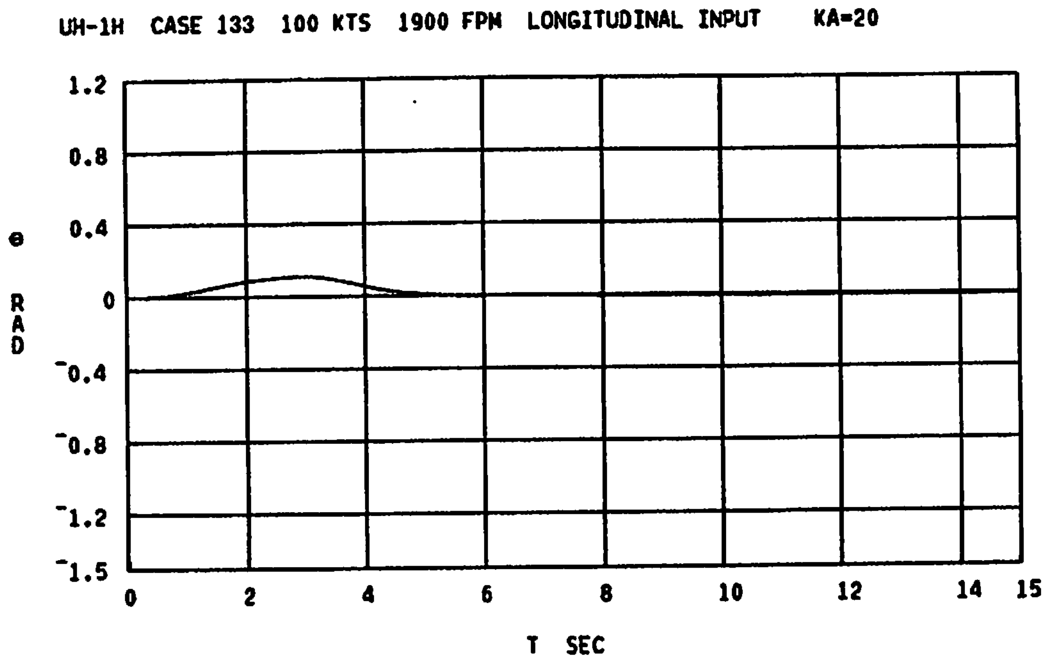
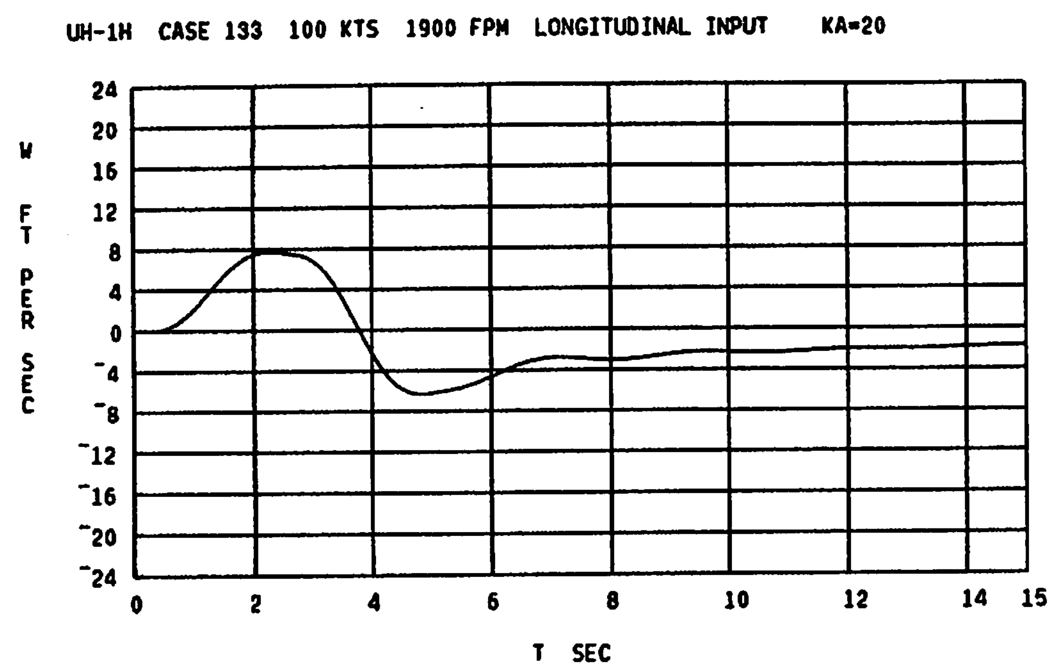


Figure 4. Longitudinal Response, UH-1H, 60 kts, K_A = 20 in/rad.



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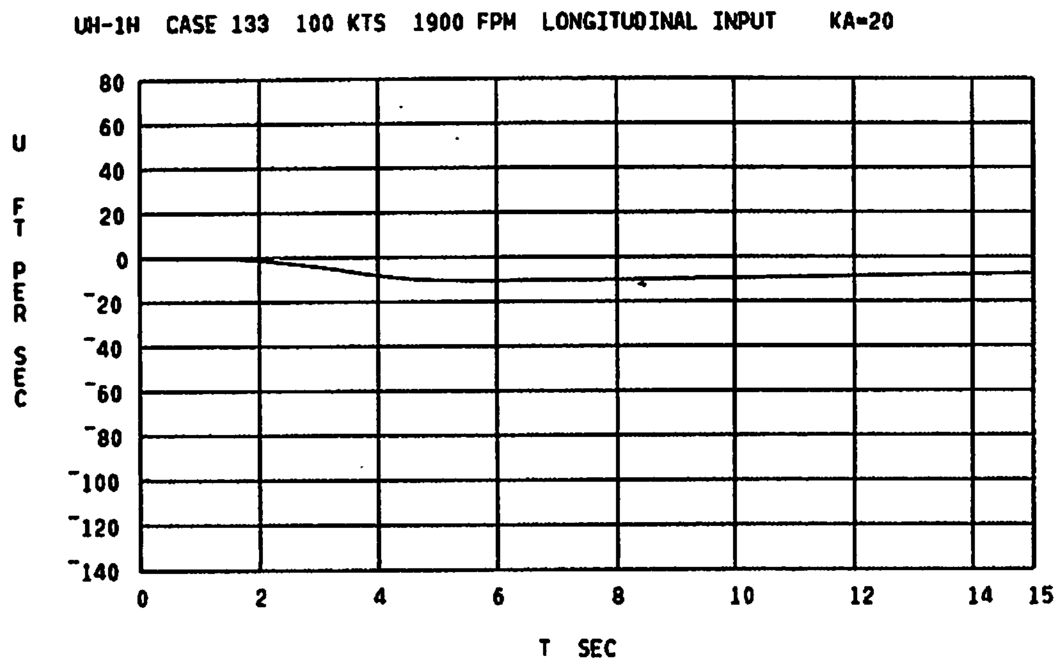

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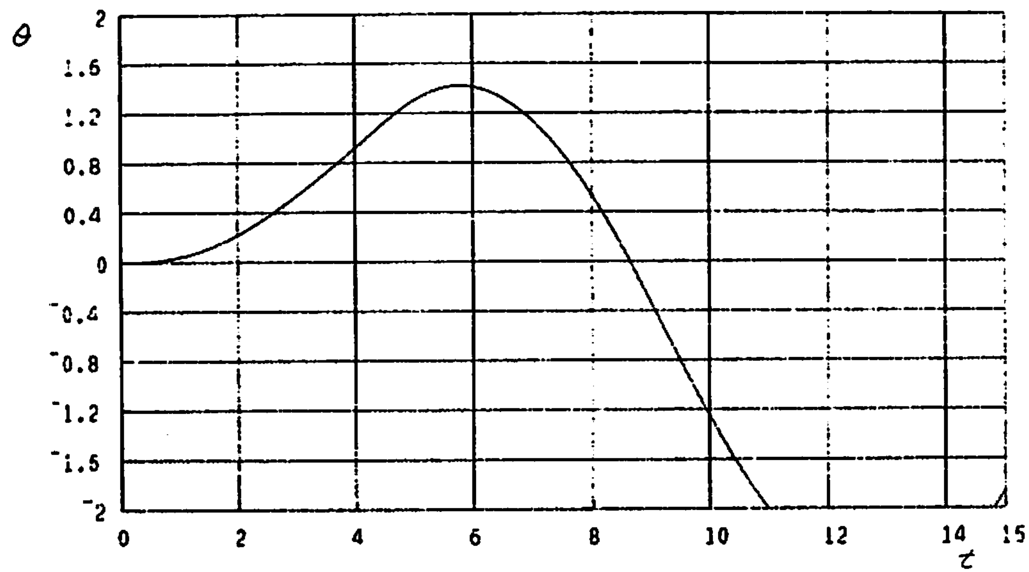
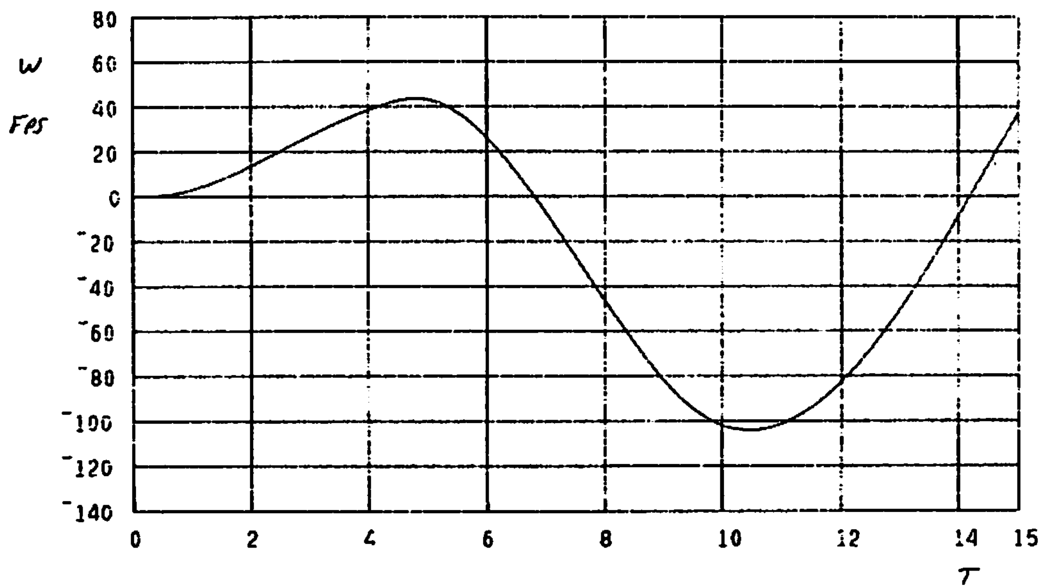


Figure 5. Longitudinal Response, OH-6A, 60 kts, No Feedback.



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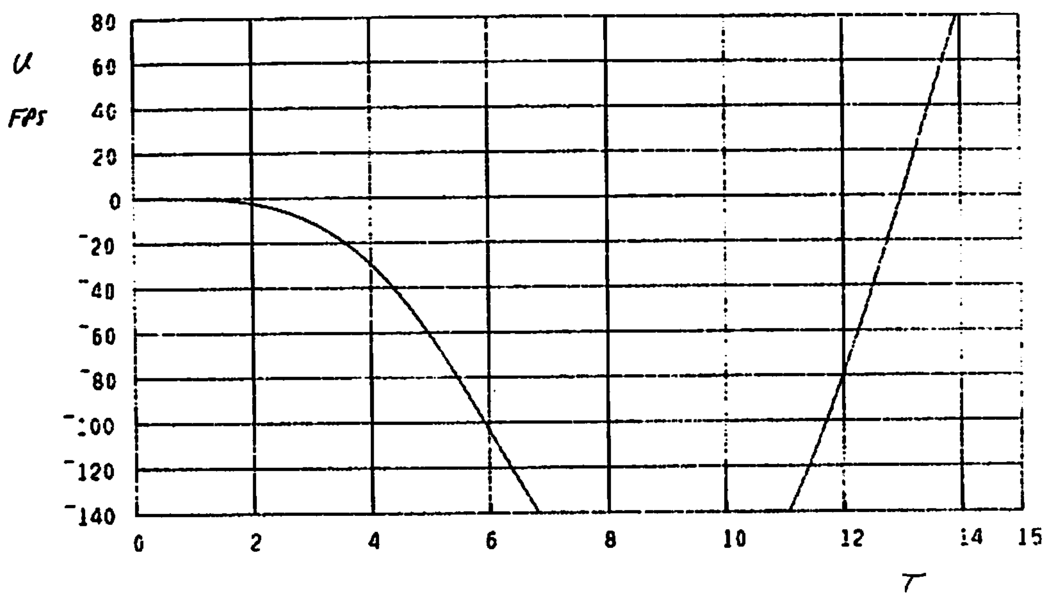

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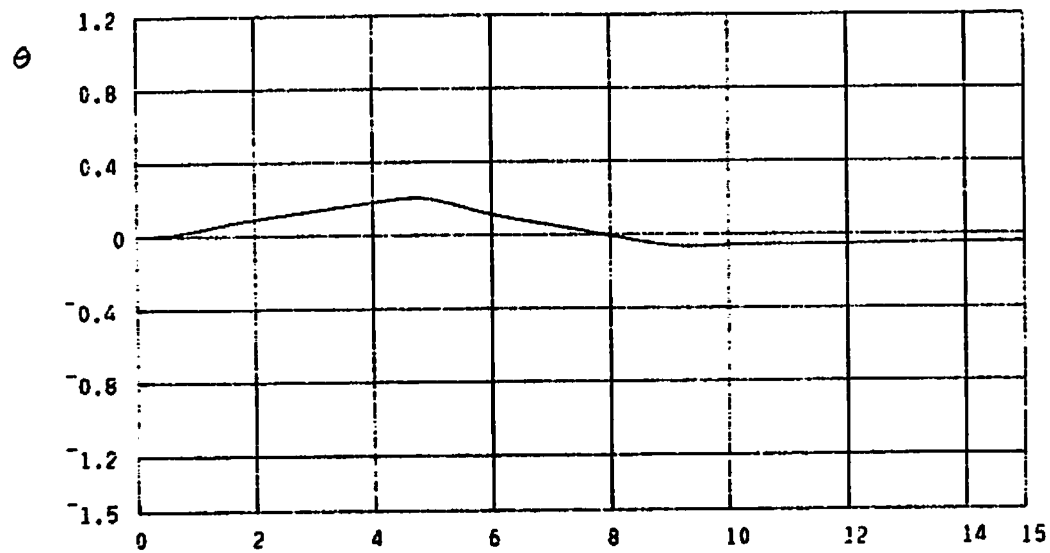
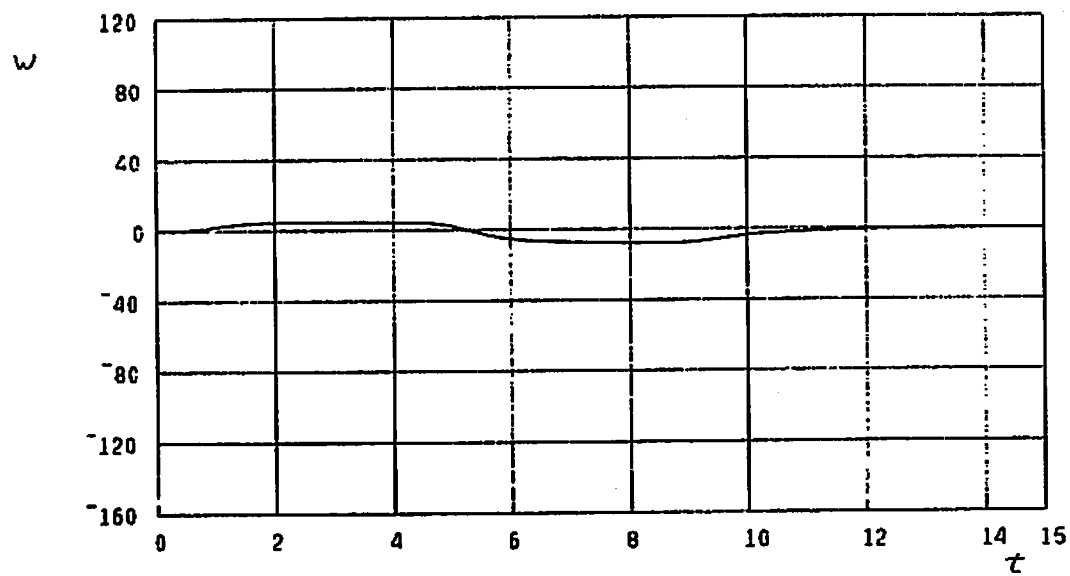


Figure 6. Longitudinal Response, OH-6A, 60 kts, K_A = 10, in/rad.



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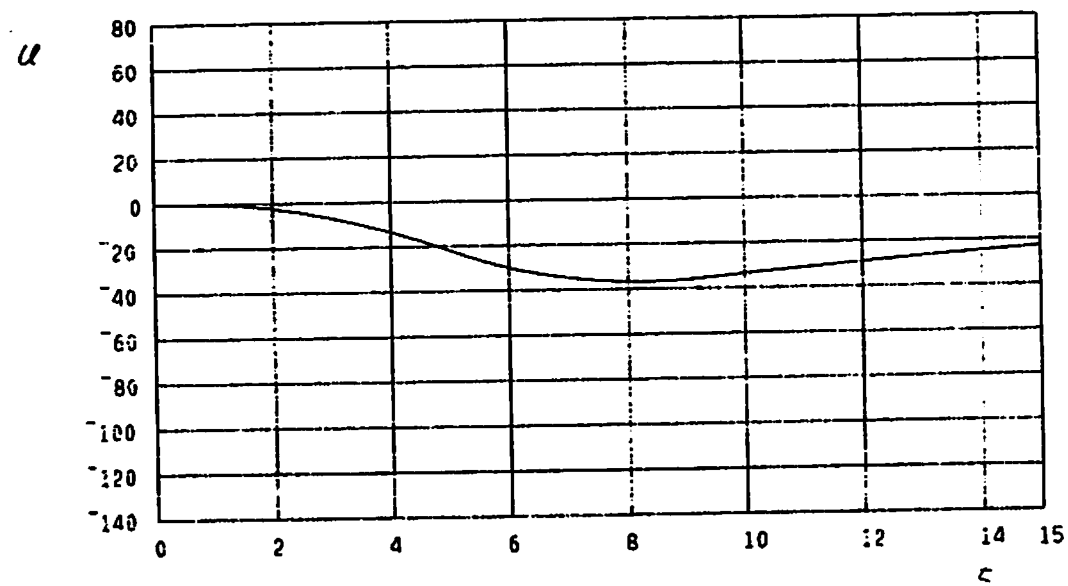

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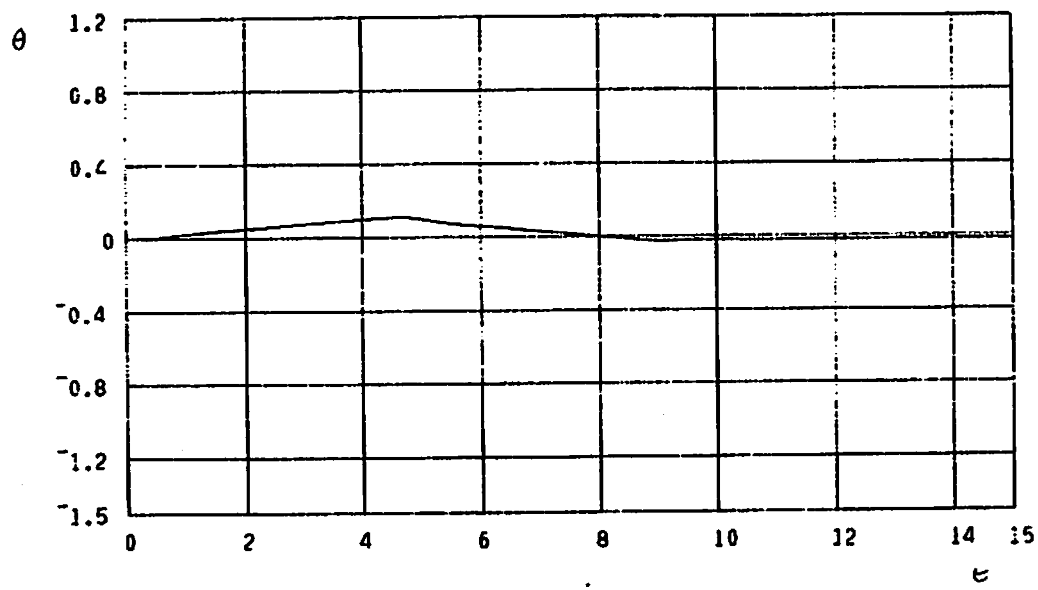
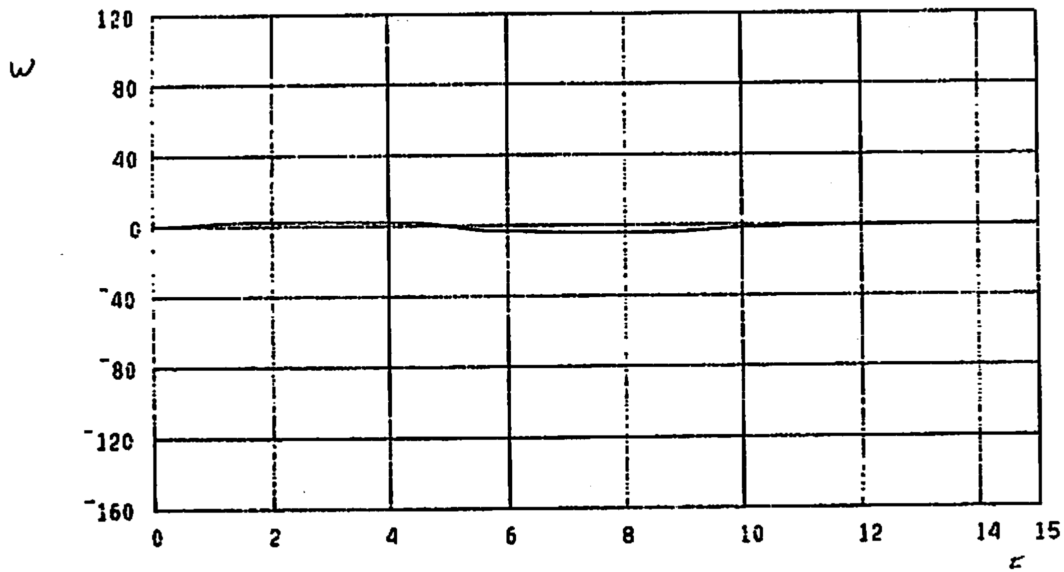


Figure 7. Longitudinal Response, OH-6A, 60 kts, K_A = 20 in/rad.



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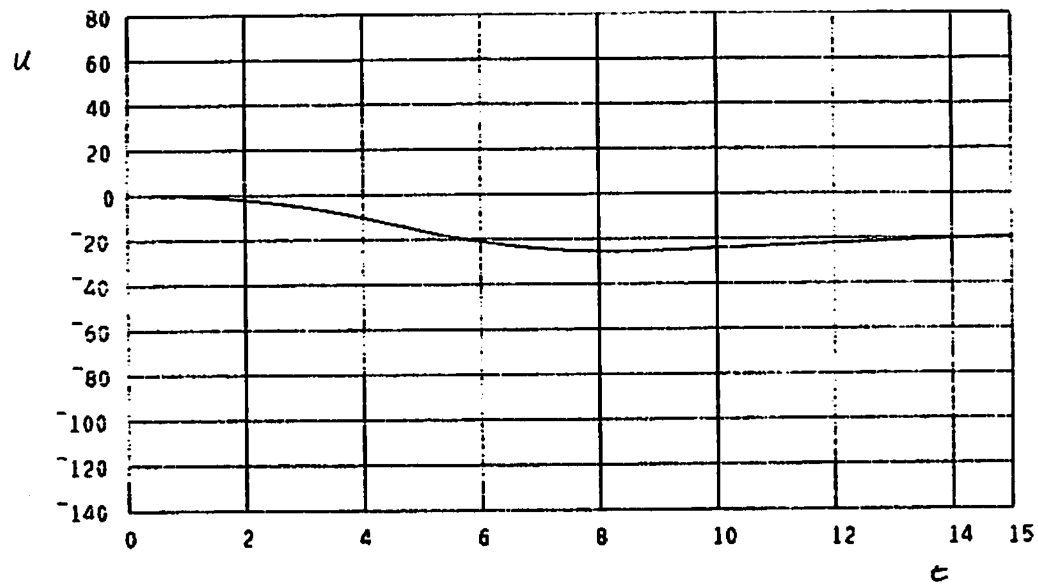

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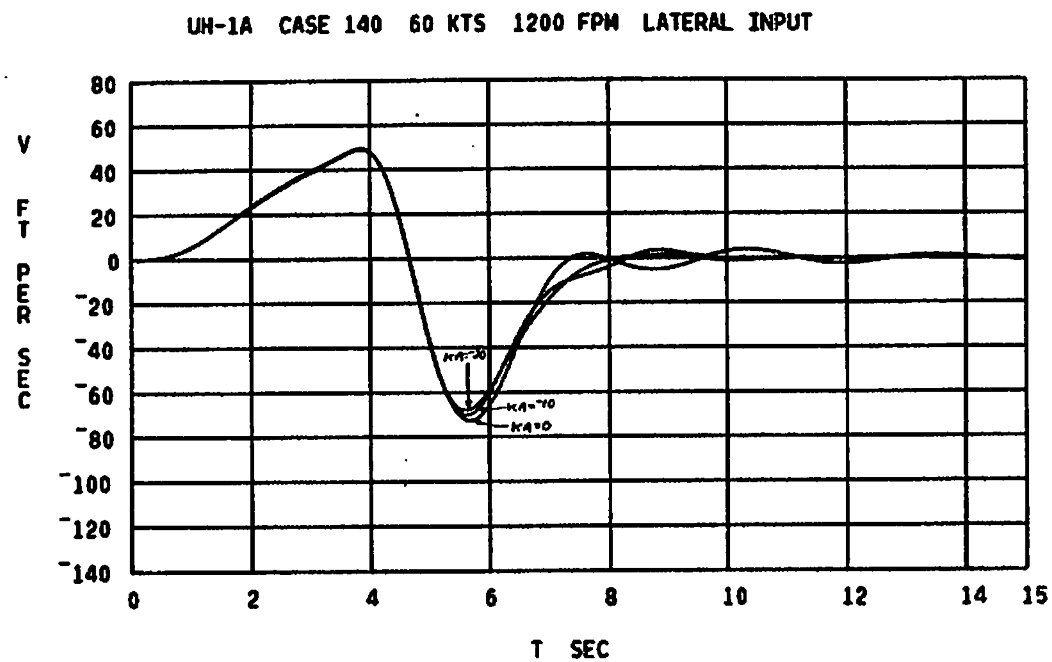
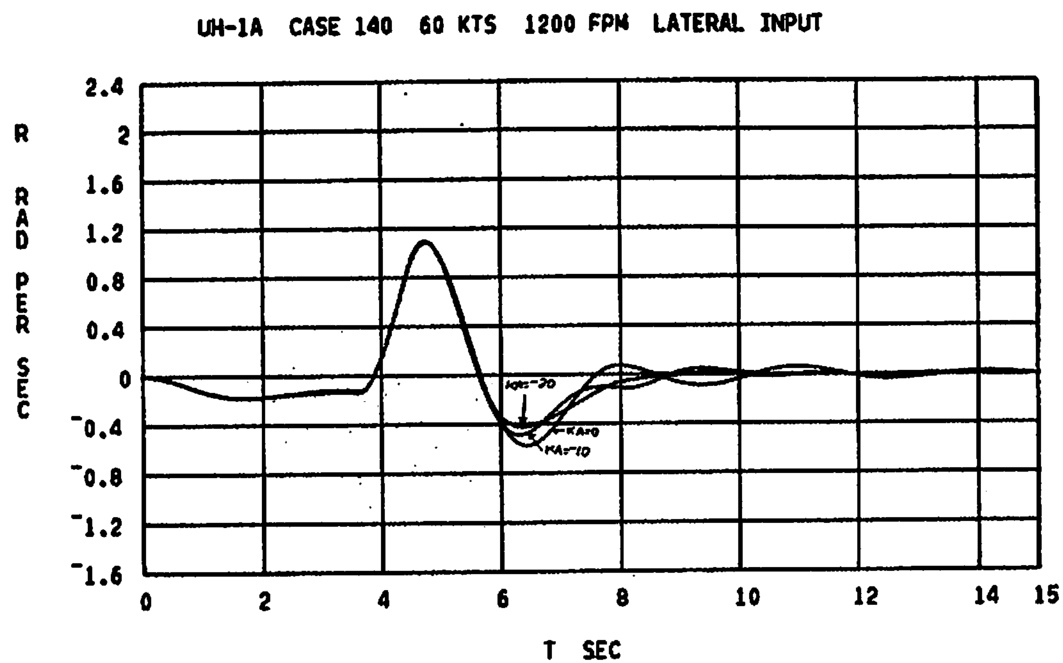


Figure 8. Lateral-Directional Response, UH-1H, 60 kts, Roll Angle to Lateral Control Feedback.



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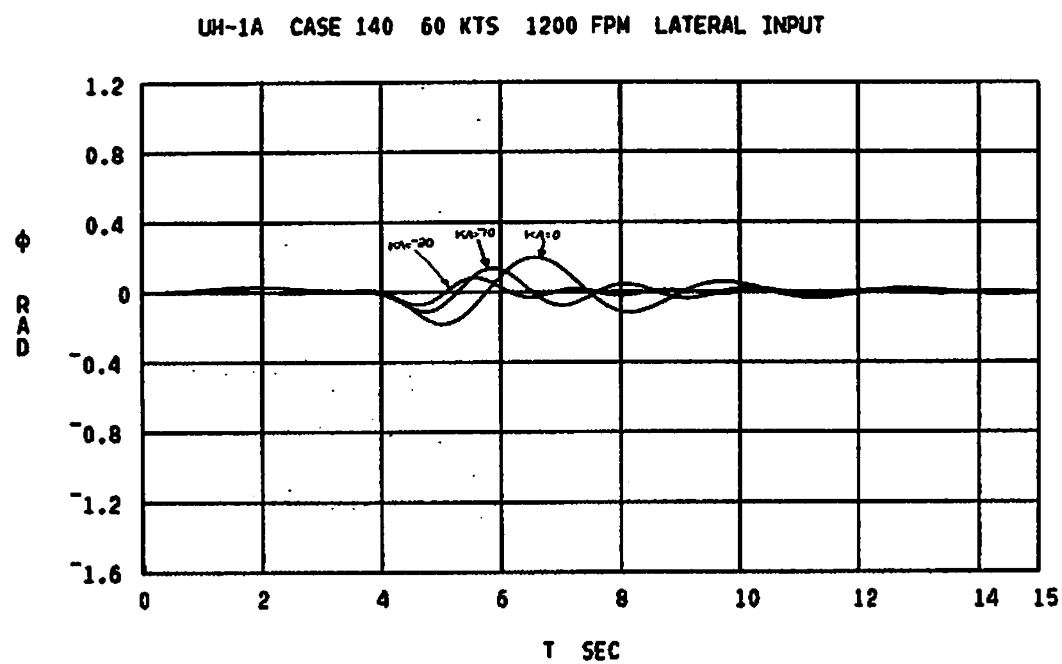

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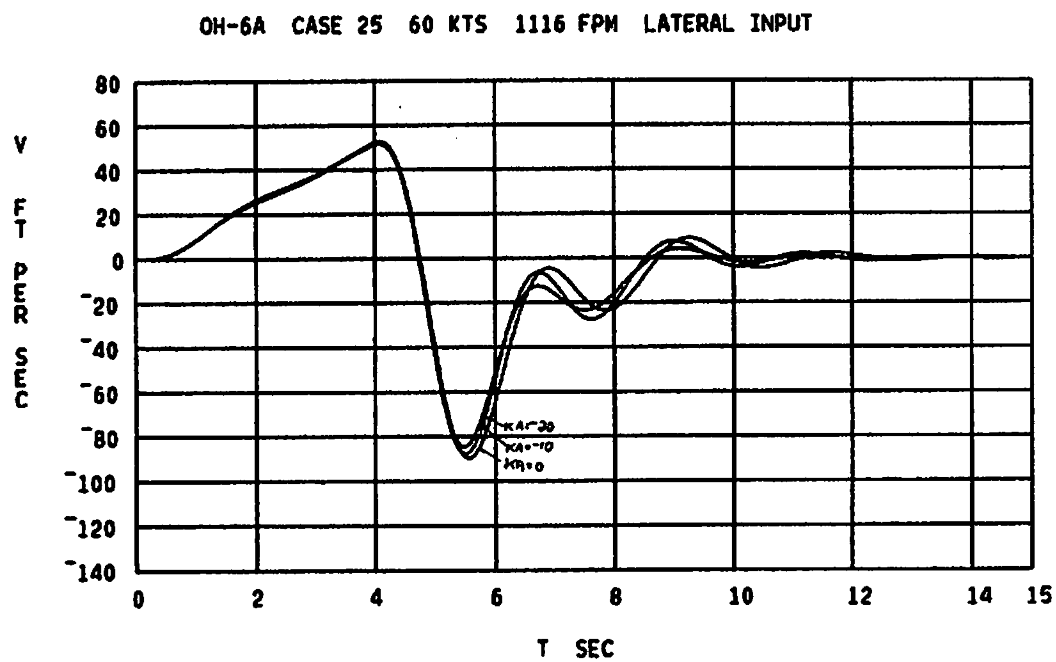
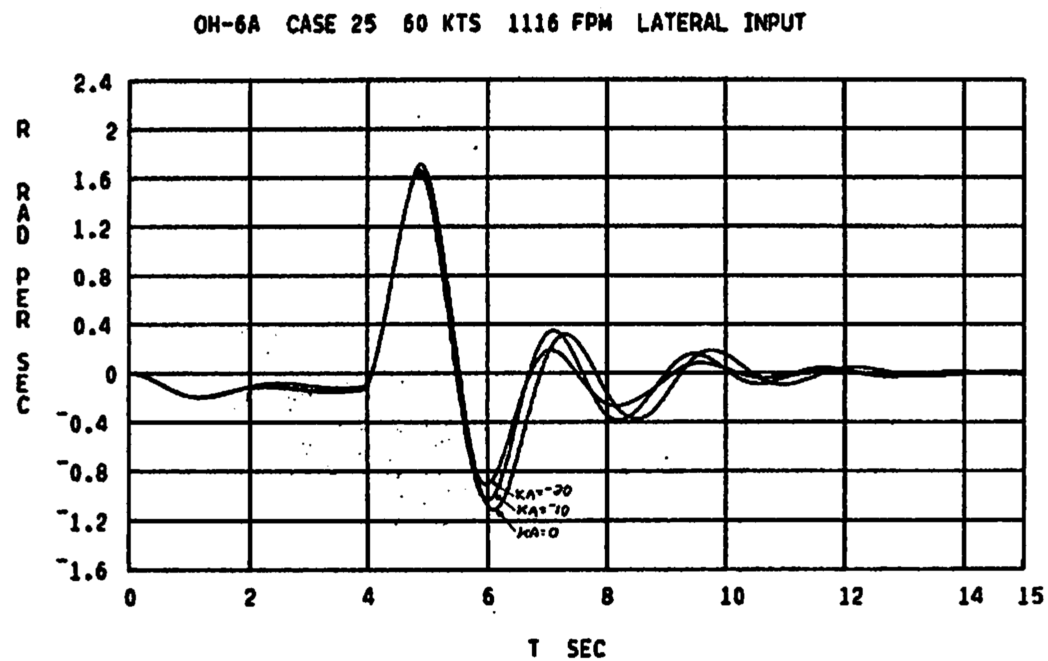


Figure 9. Lateral-Directional Response, OH-6A, 60 kts, Roll Angle to Lateral Control Feedback.



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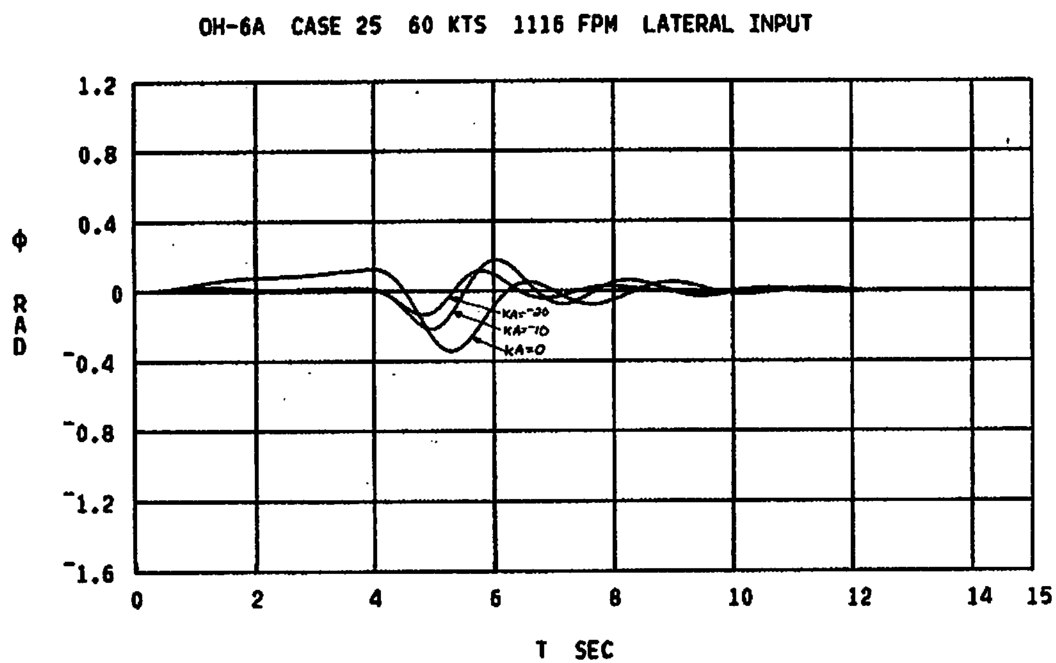

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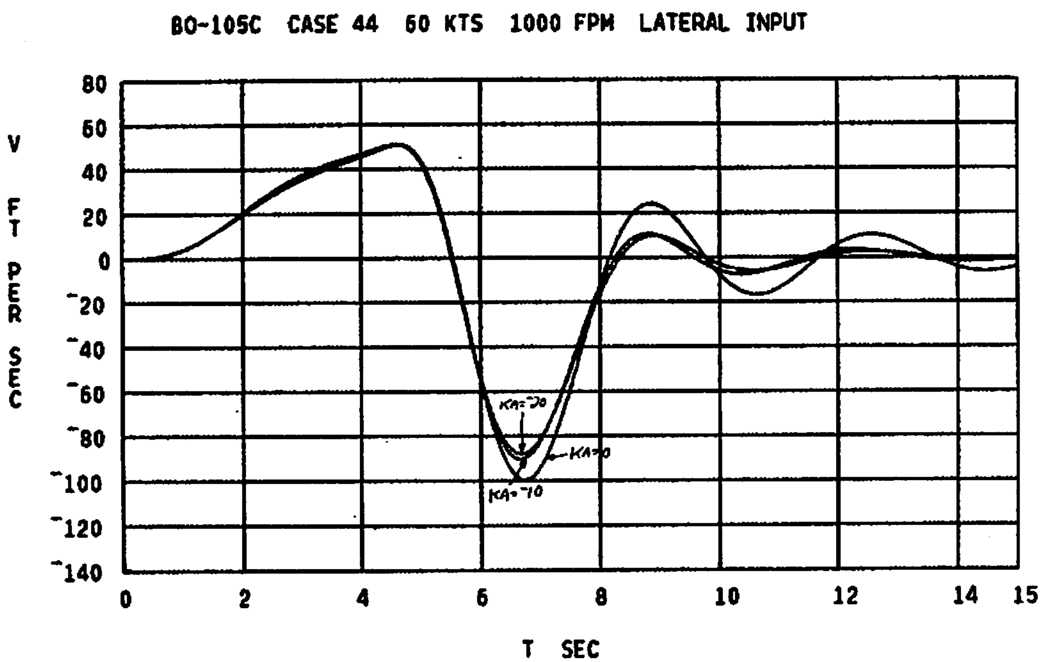
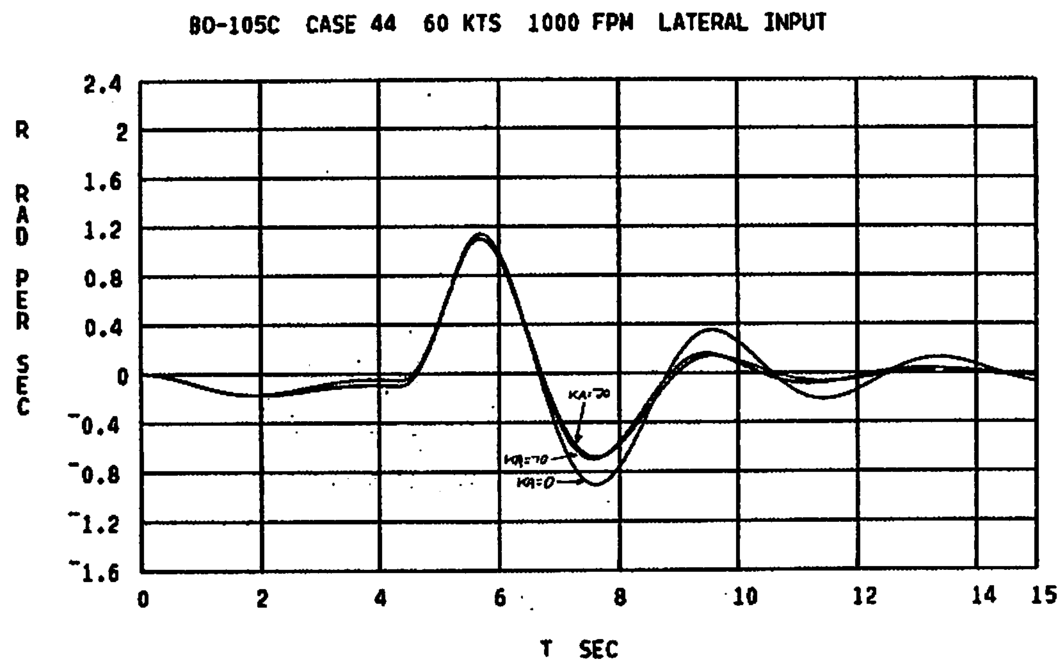


Figure 10. Lateral-Directional Response, BO-105C, 60 kts, Roll Angle to Lateral Control Feedback.



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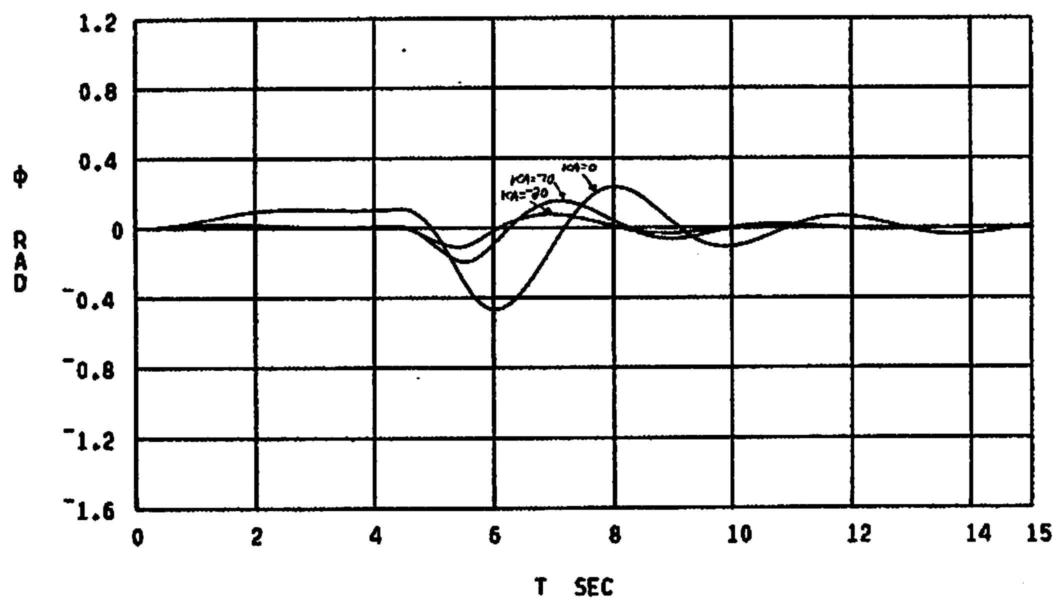
BO-105C CASE 44 60 KTS 1000 FPM LATERAL INPUT



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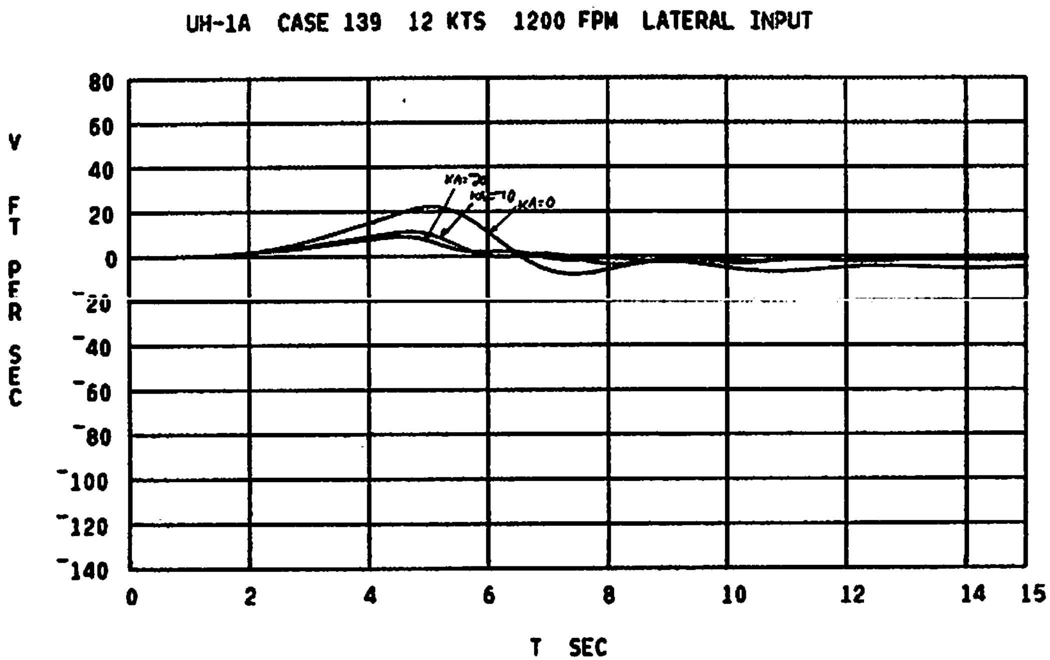


Figure 11. Lateral-Directional Response, UH-1H, Vertical Climb, Roll Angle to Lateral Control Feedback.

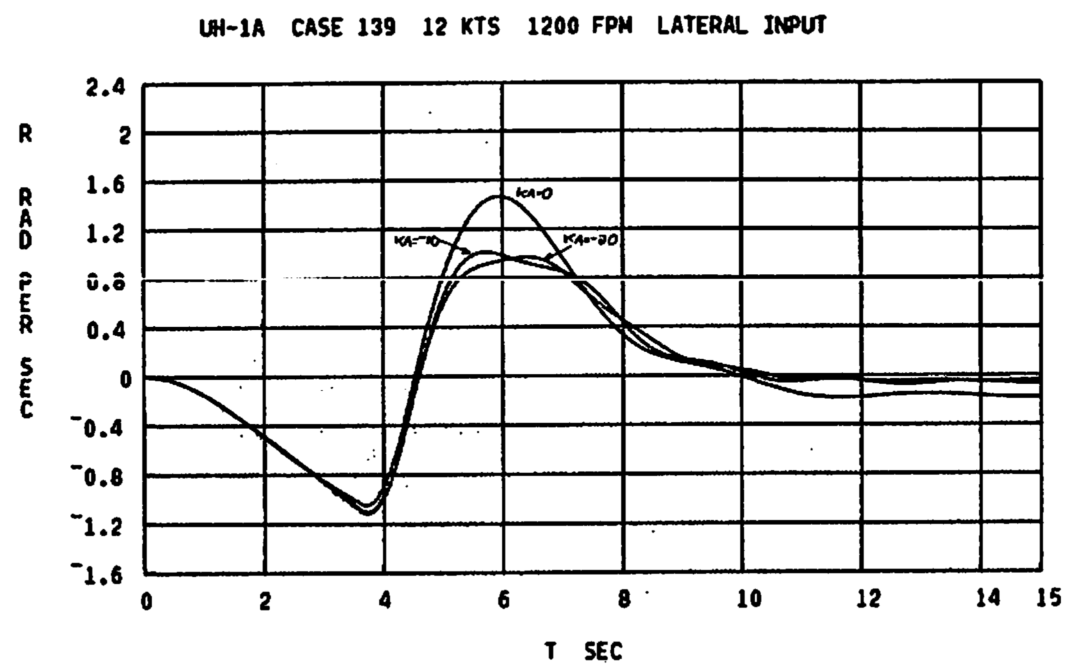
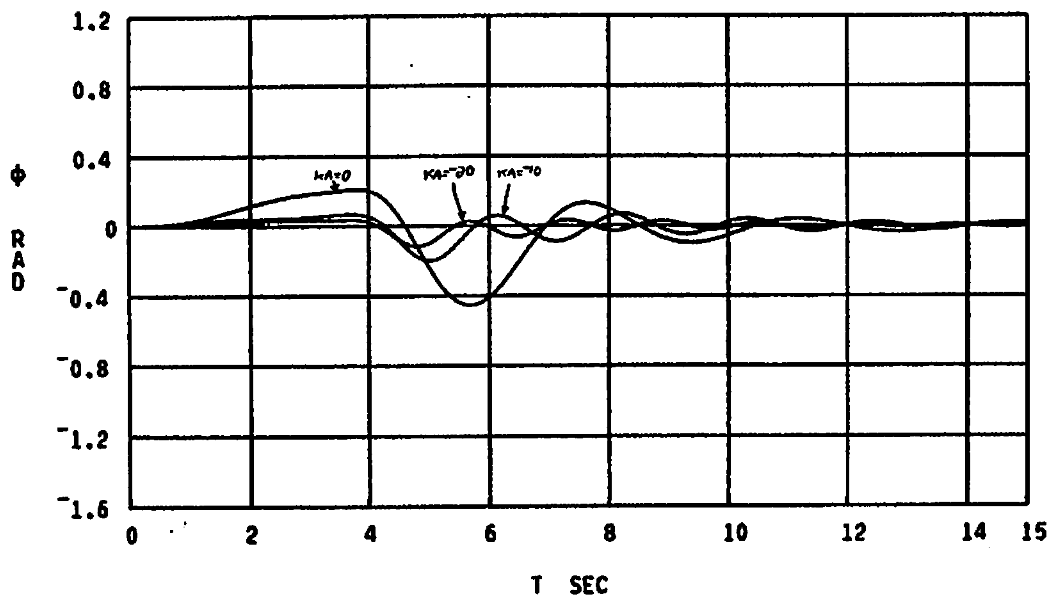


Figure 11. Continued.

UH-1A CASE 139 12 KTS 1200 FPM LATERAL INPUT



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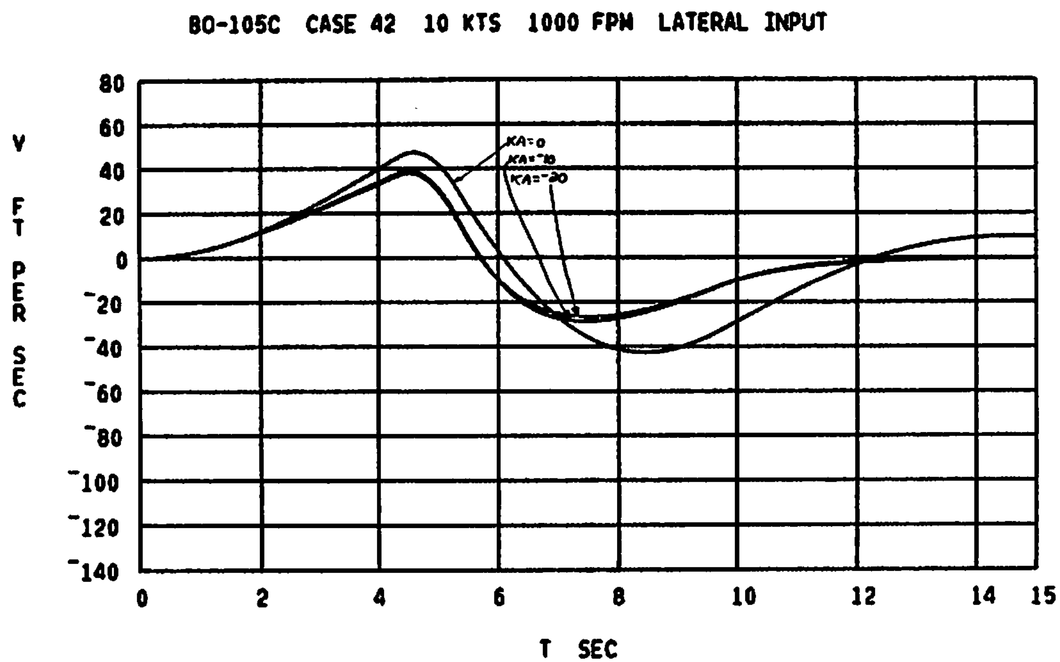
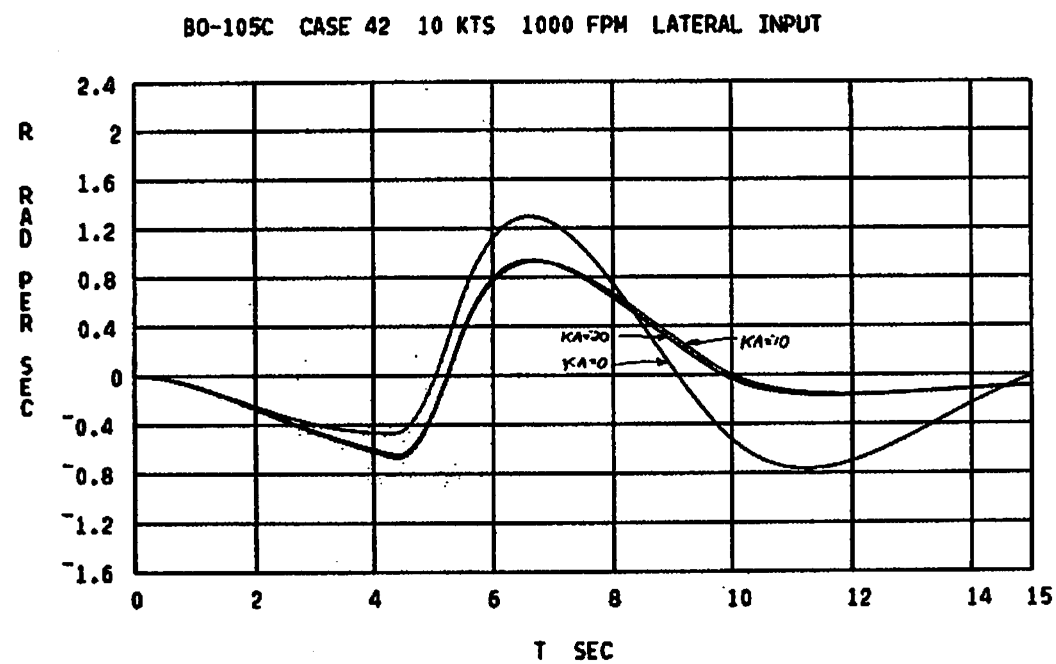


Figure 12. Lateral-Directional Response, BO-105C, Vertical Climb, Roll Angle to Lateral Control Feedback.



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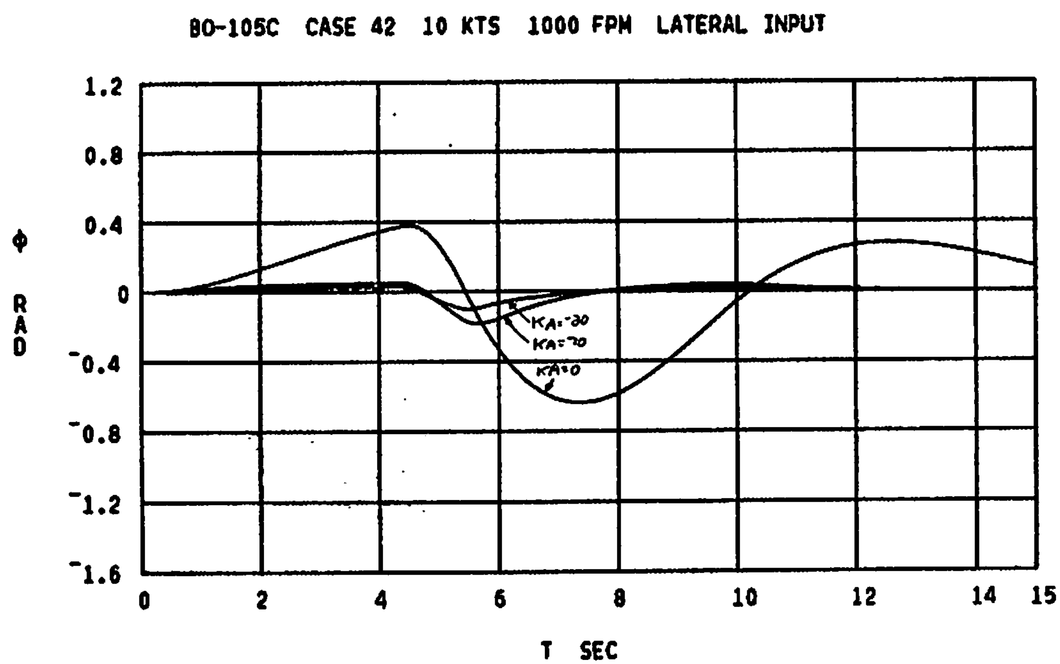

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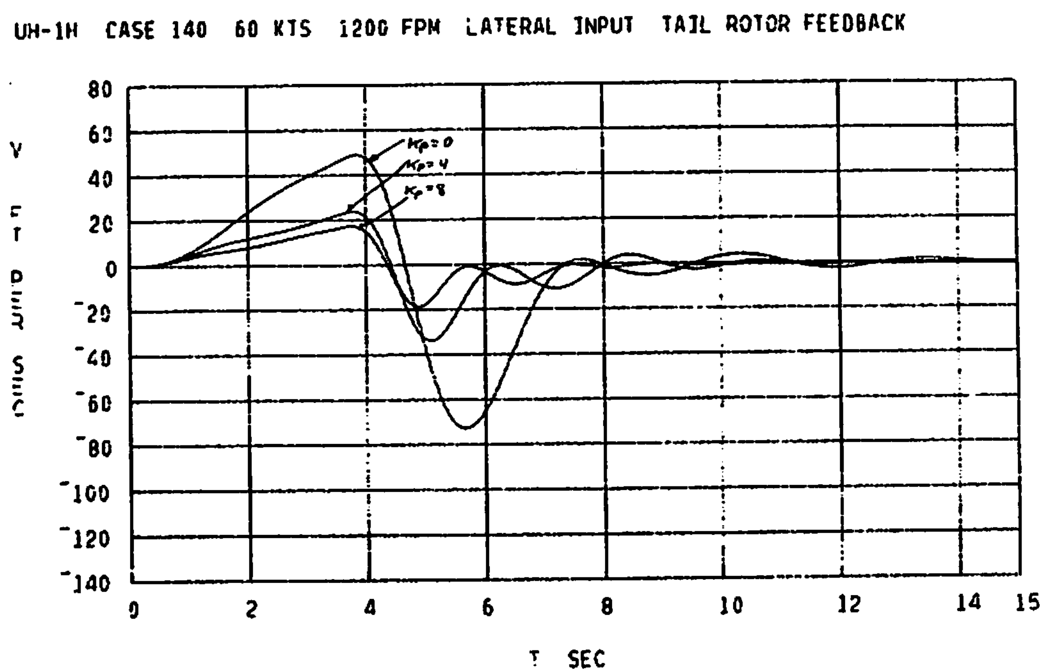
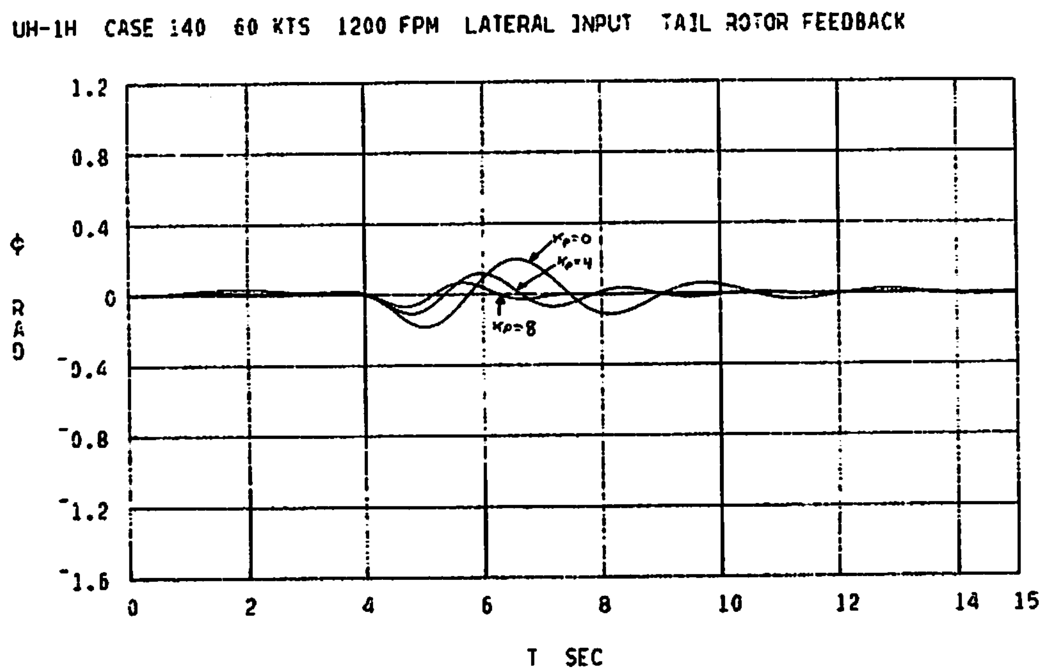


Figure 13. Lateral-Directional Response, UH-1H, 60 kts, Yaw Angle to Tail Rotor Pitch Feedback.



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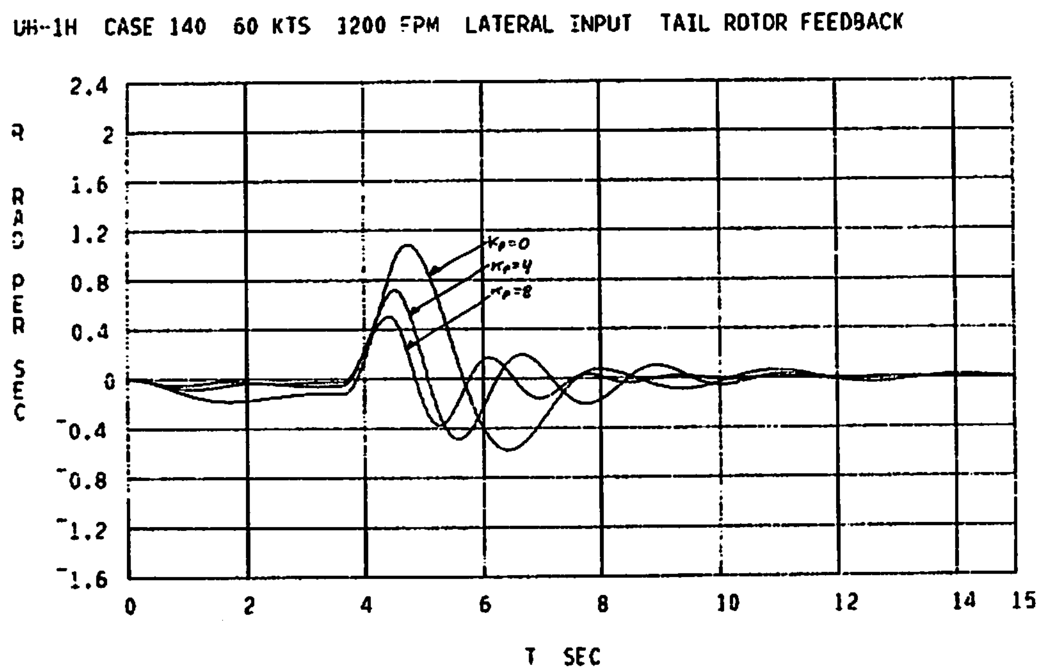

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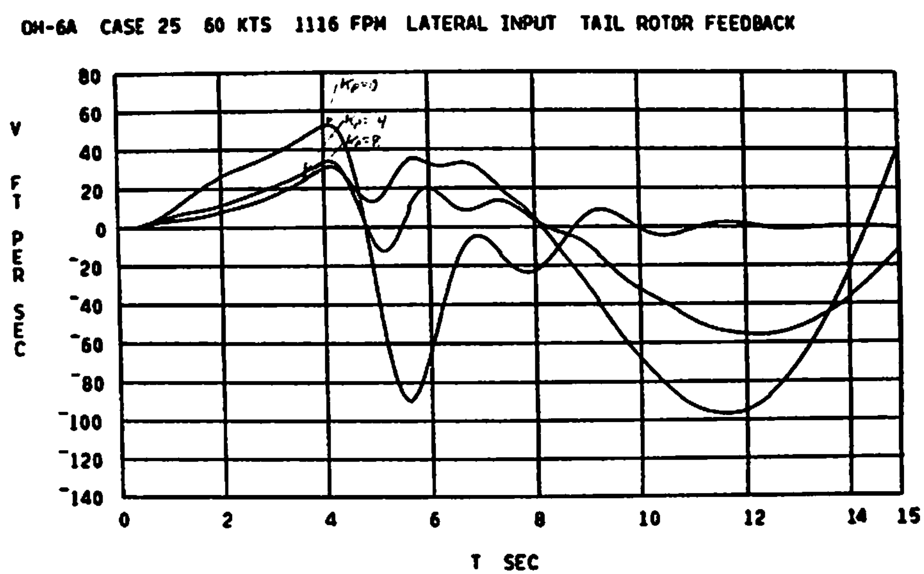
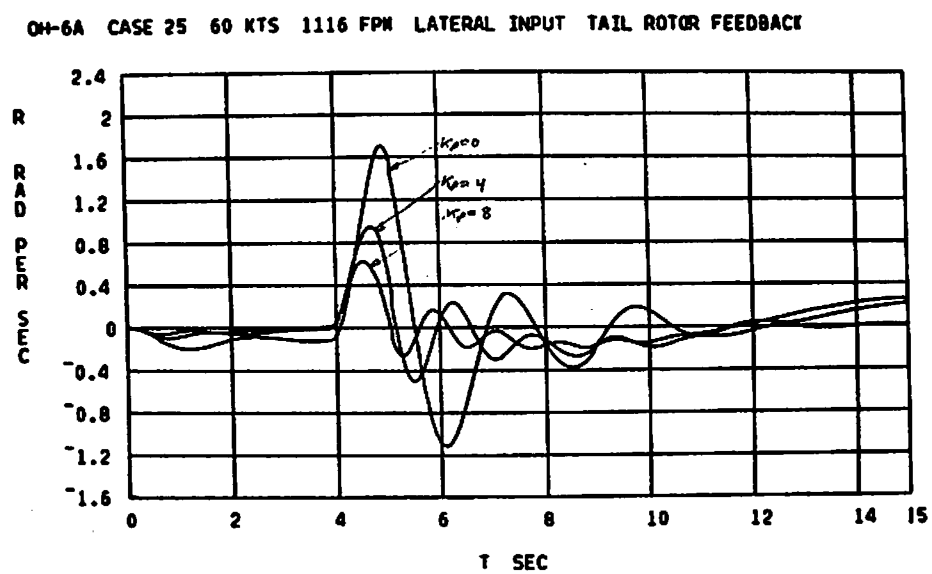


Figure 14. Lateral-Directional Response, OH-6A, 60 kts, Yaw Angle to Tail Rotor Pitch Feedback.



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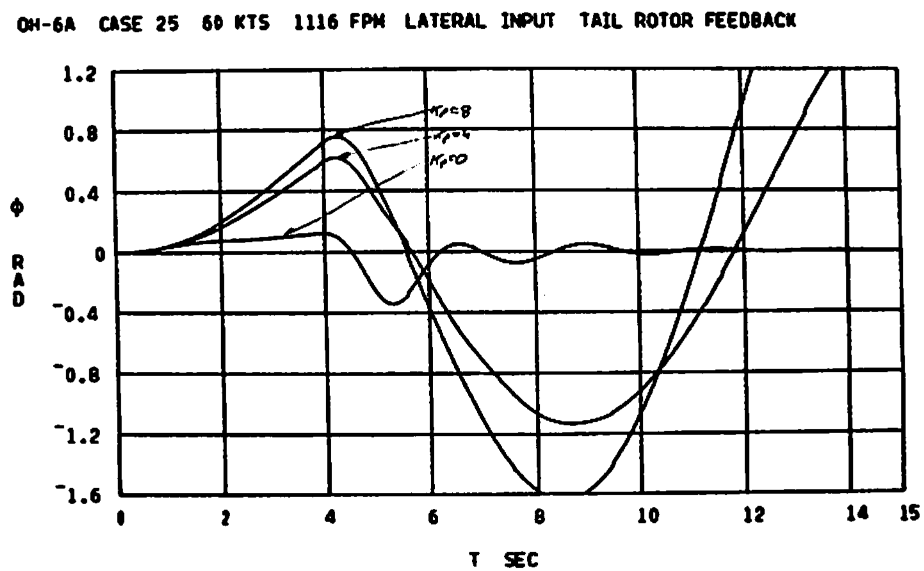

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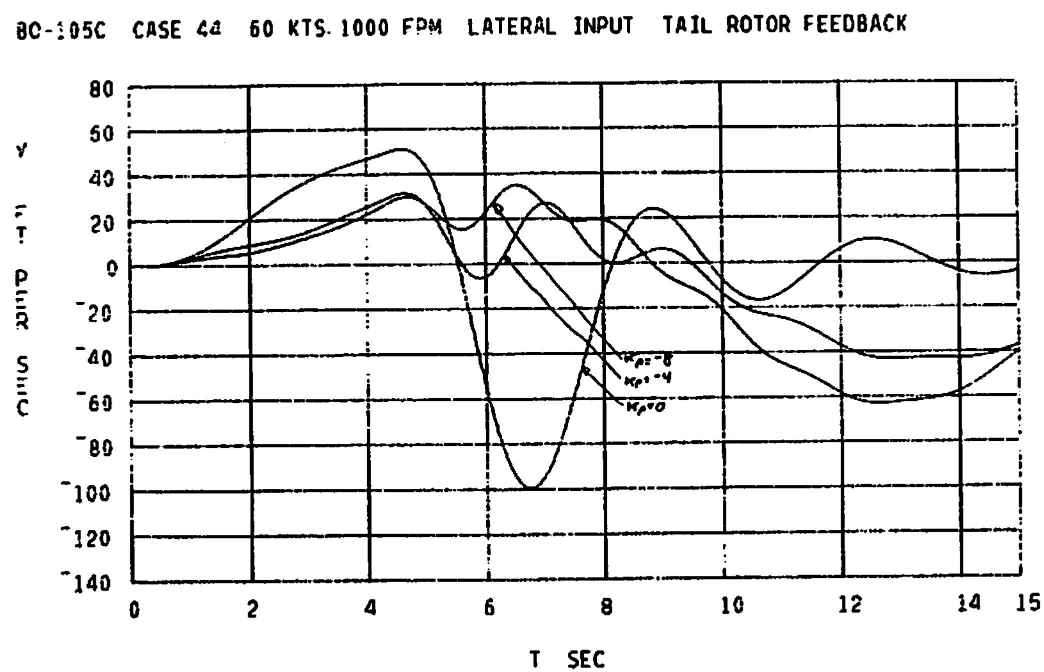
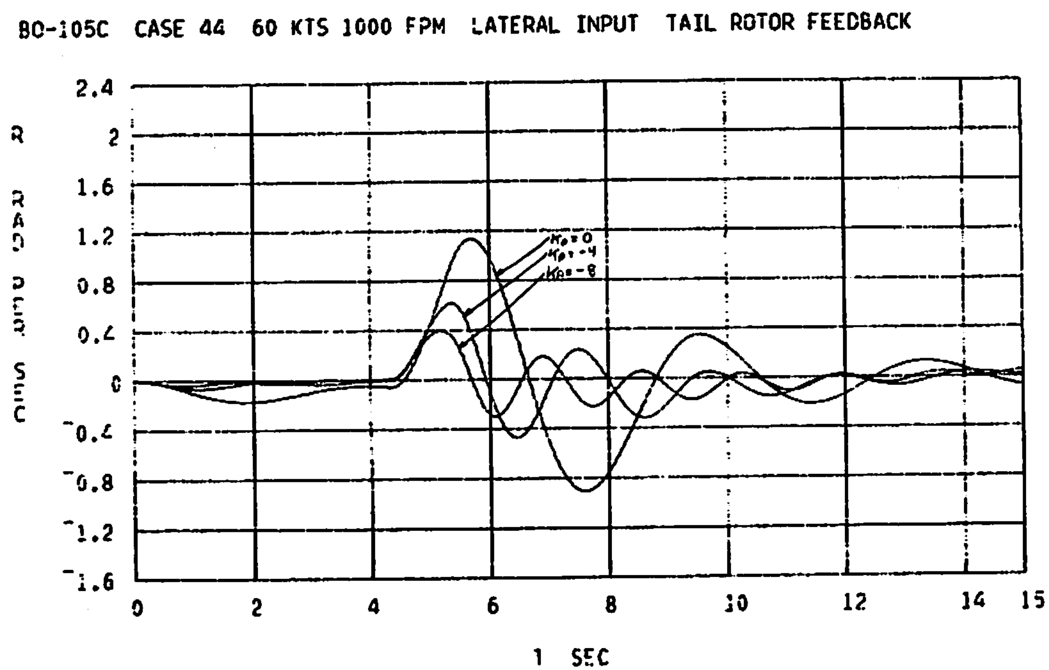


Figure 15. Lateral-Directional Response, BO-105C, 60 kts, Yaw Angle to Tail Rotor Pitch Feedback.



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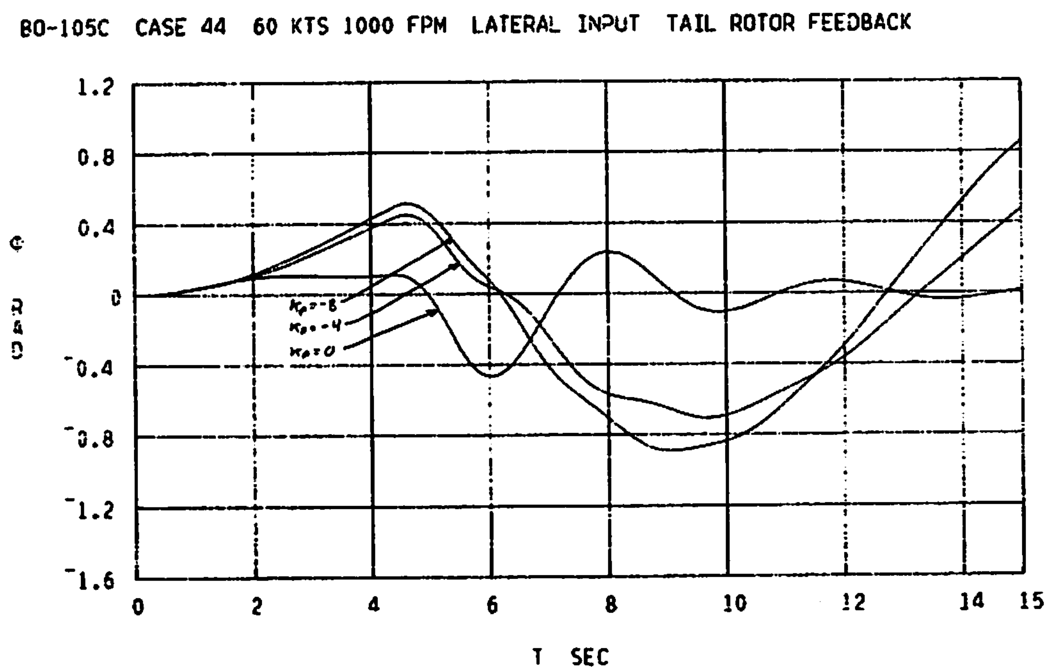

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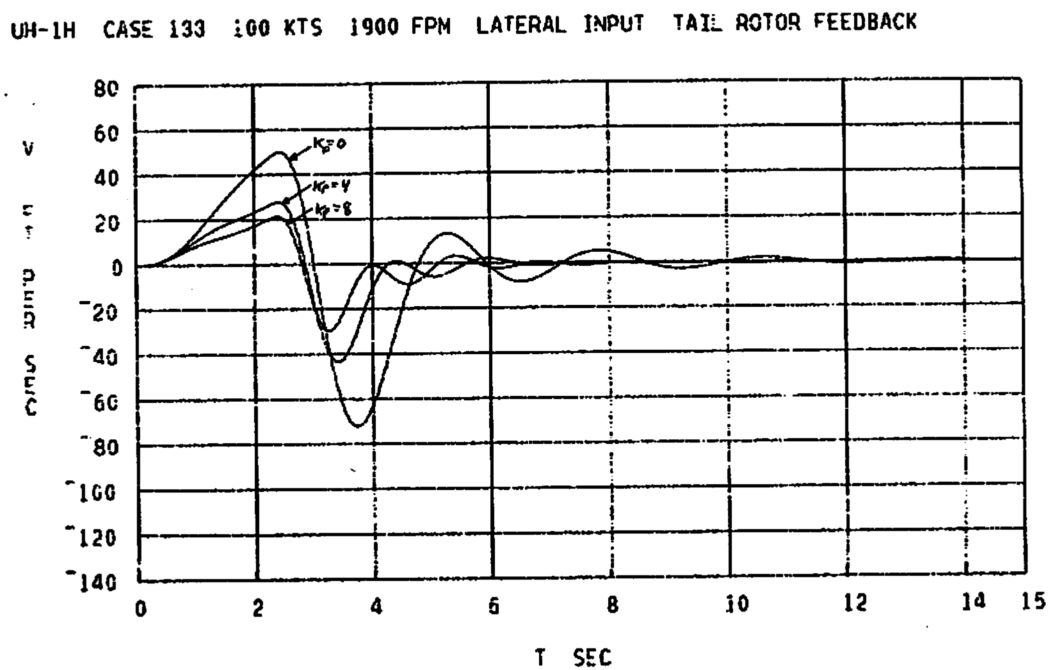

Figure 16. Lateral-Directional Response, UH-1H, 100 kts, Yaw Angle to Tail Rotor Pitch Feedback.

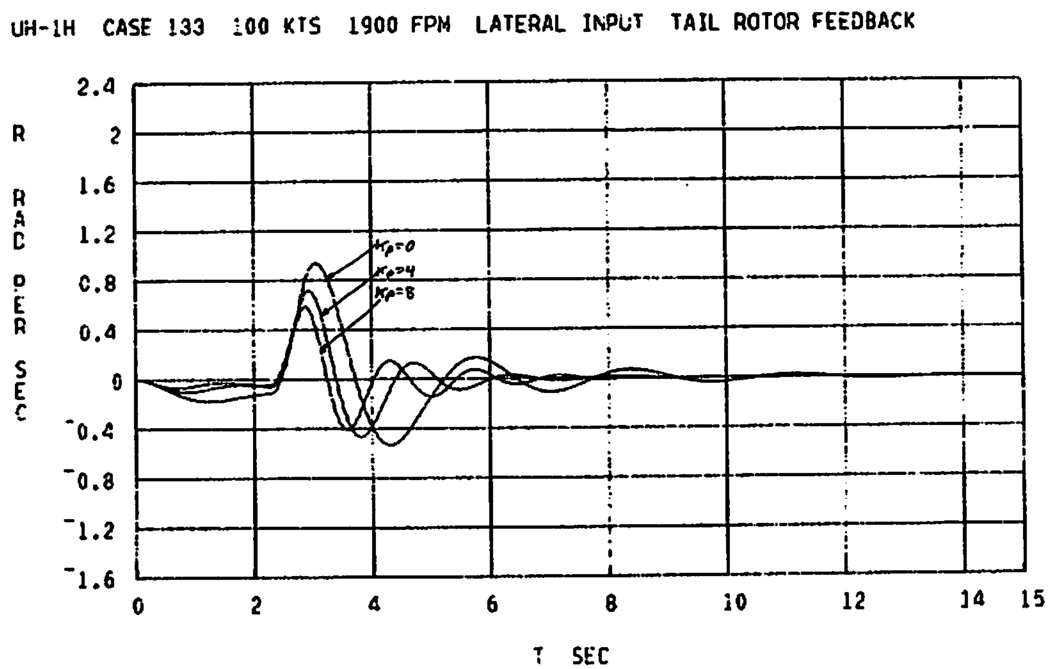

Figure 16. Continued.

UH-1H CASE 133 100 KTS 1900 FPM LATERAL INPUT TAIL ROTOR FEEDBACK

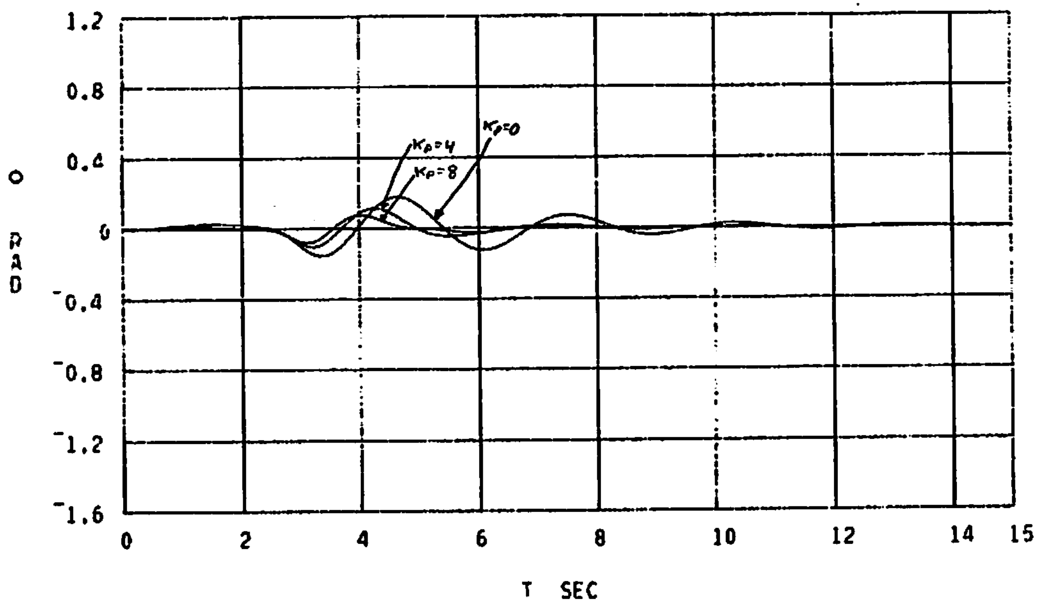

Figure 16. Continued.

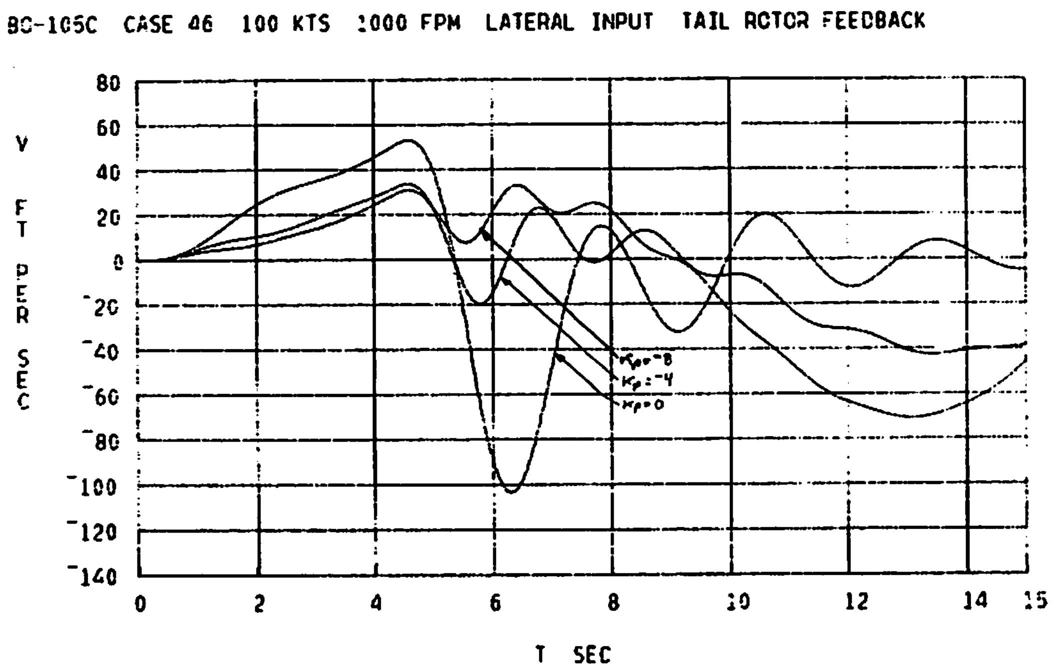

Figure 17. Lateral-Directional Response, BO-105C, 100 kts, Yaw Angle to Tail Rotor Pitch Feedback.

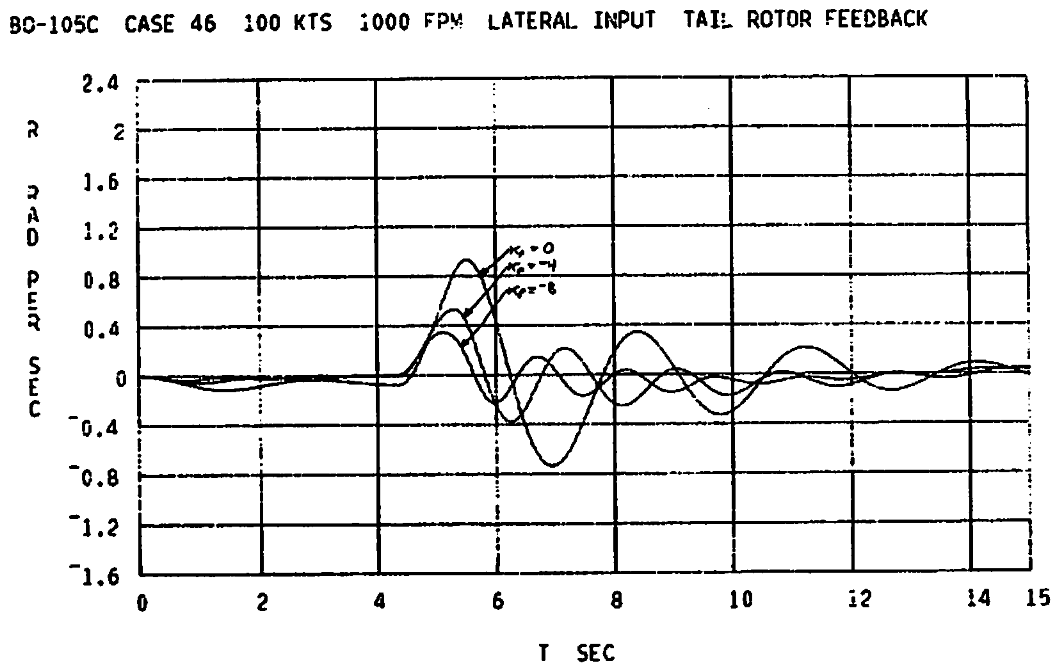

Figure 17. Continued.

BO-105C CASE 46 100 KTS 1000 FPM LATERAL INPUT TAIL ROTOR FEEDBACK

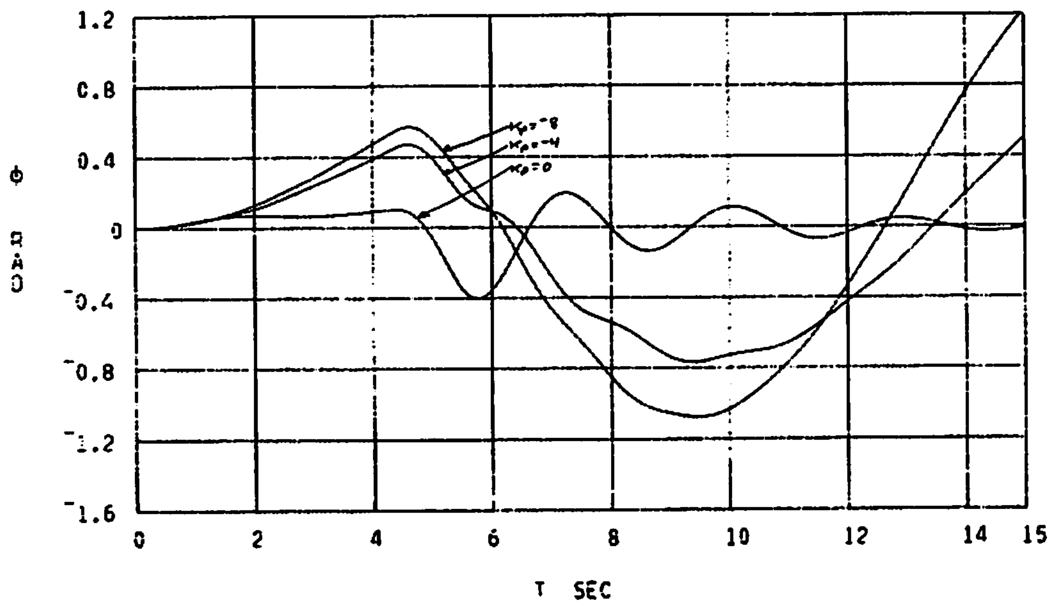

Figure 17. Continued.

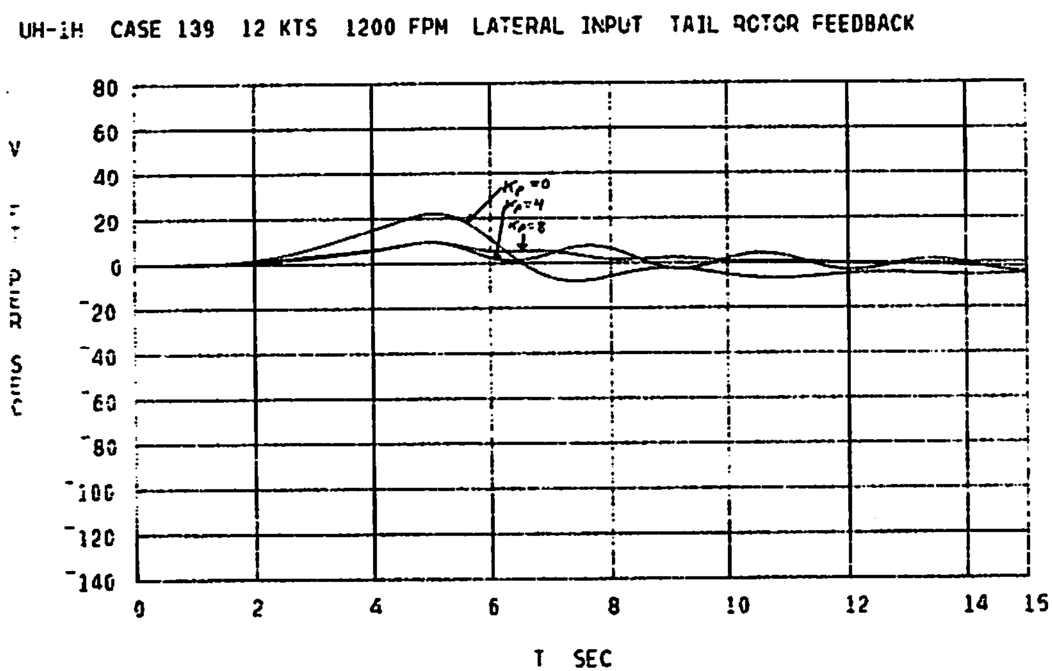

Figure 18. Lateral-Directional Response, UH-1H, Vertical Climb, Yaw Angle to Tail Rotor Pitch Feedback.

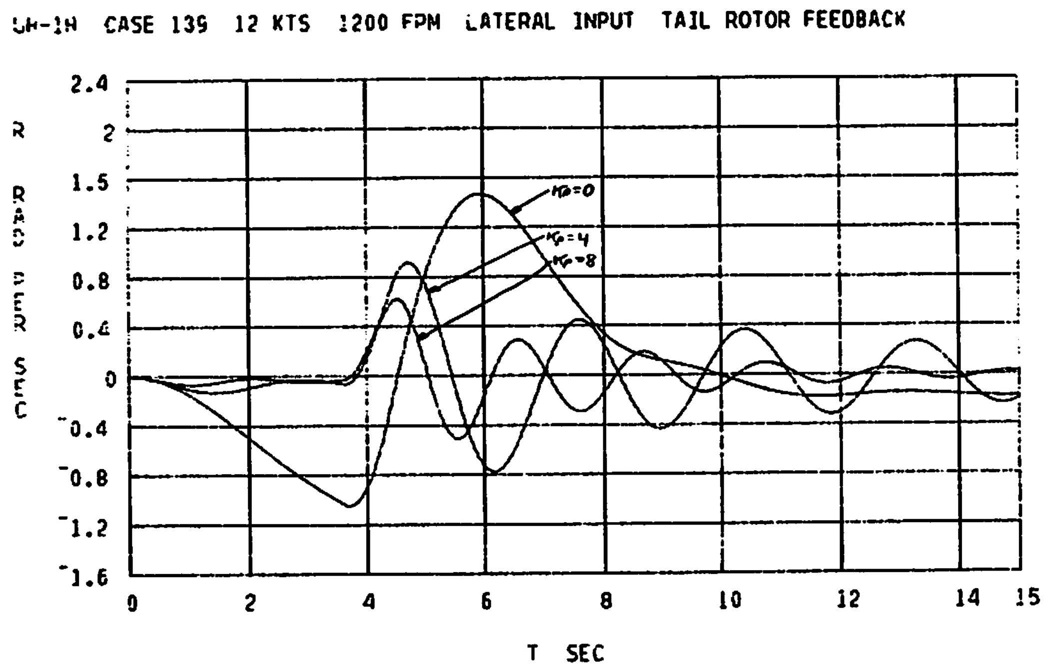

Figure 18. Continued.

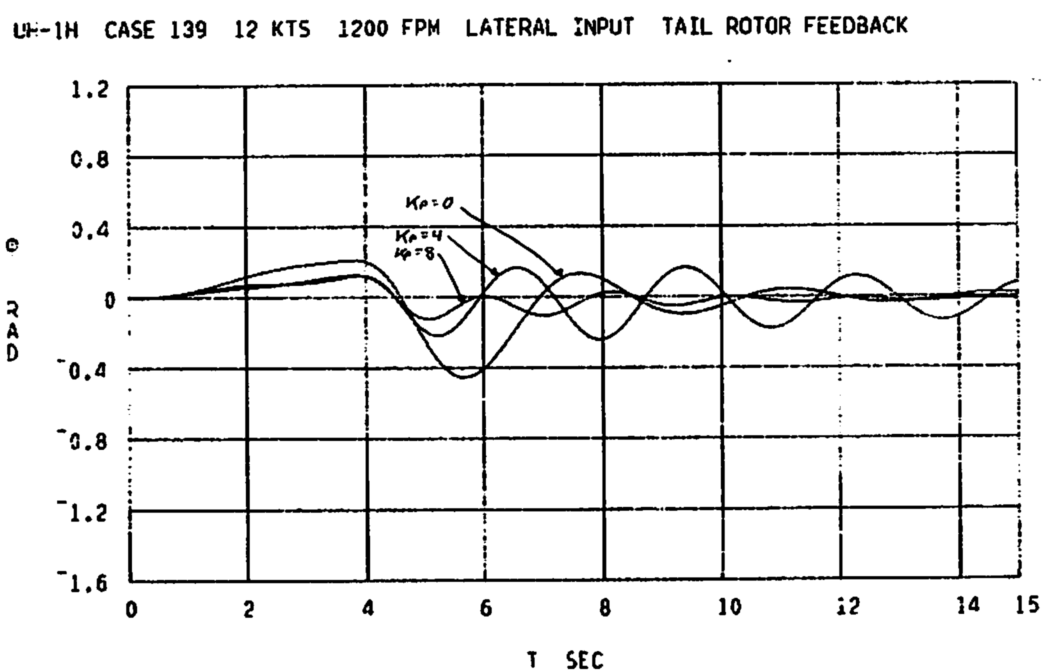

Figure 18. Continued.

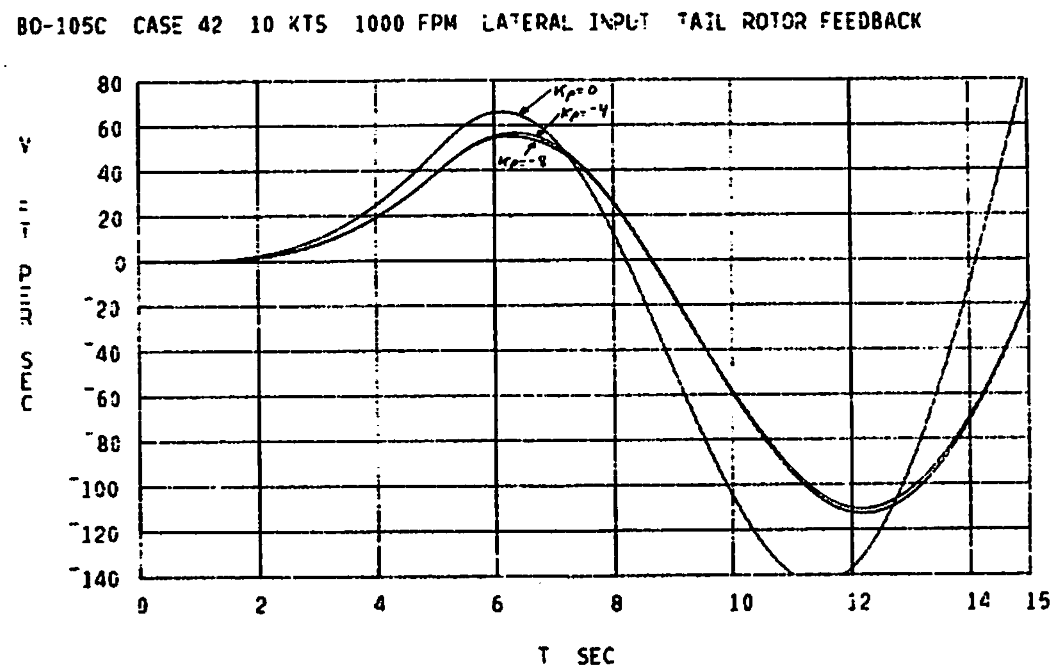

Figure 19. Lateral-Directional Response, BO-105C, Vertical Climb, Yaw Angle to Tail Rotor Pitch Feedback.

BO-105C CASE 42 10 KTS 1000 FPM LATERAL INPUT TAIL ROTOR FEEDBACK

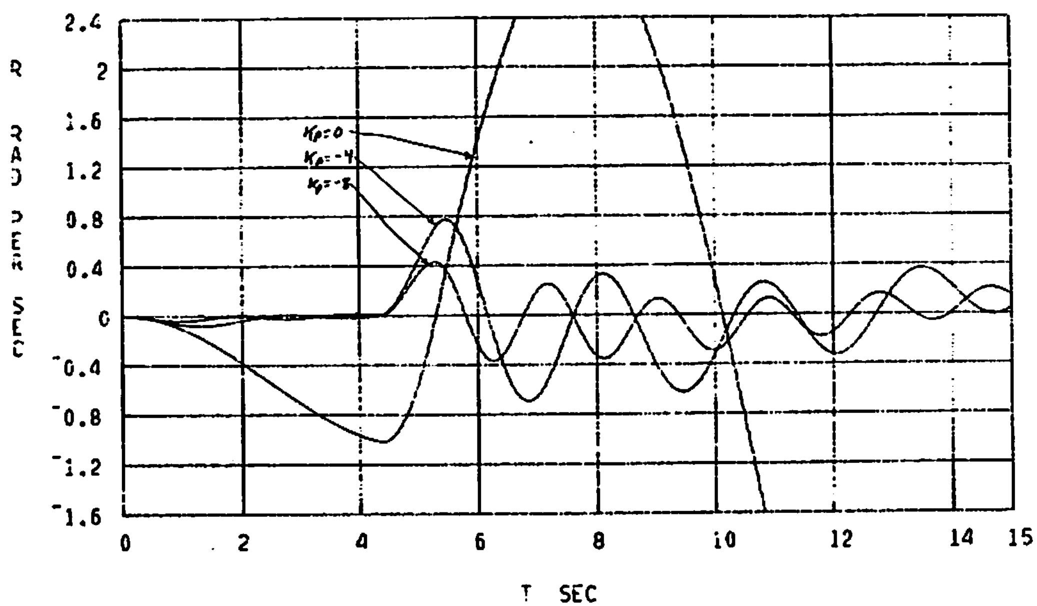

Figure 19. Continued.

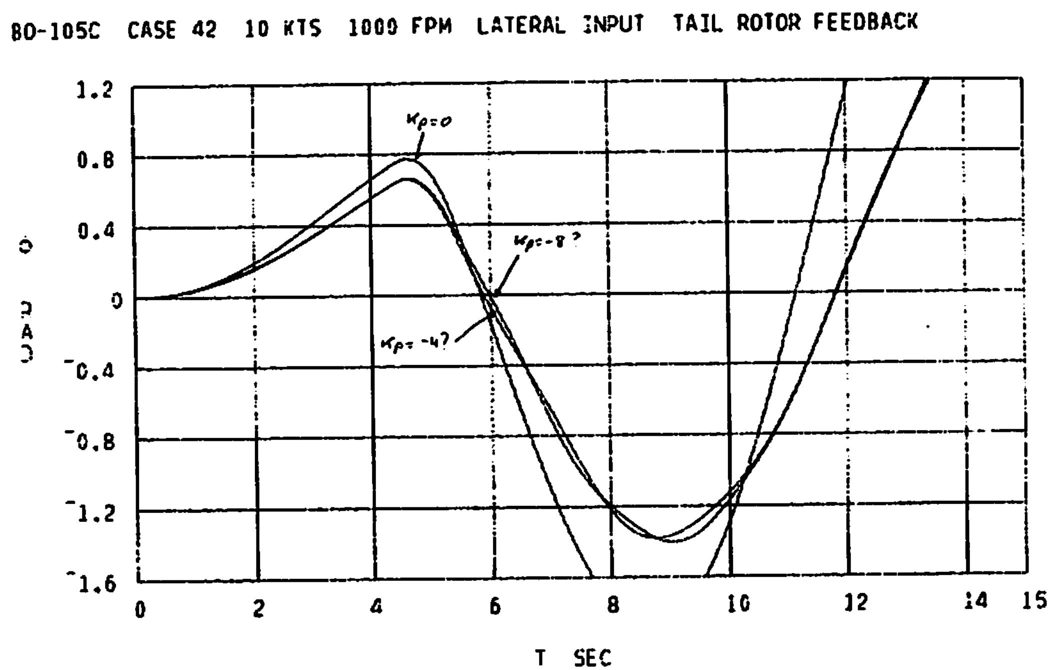

Figure 19. Continued.

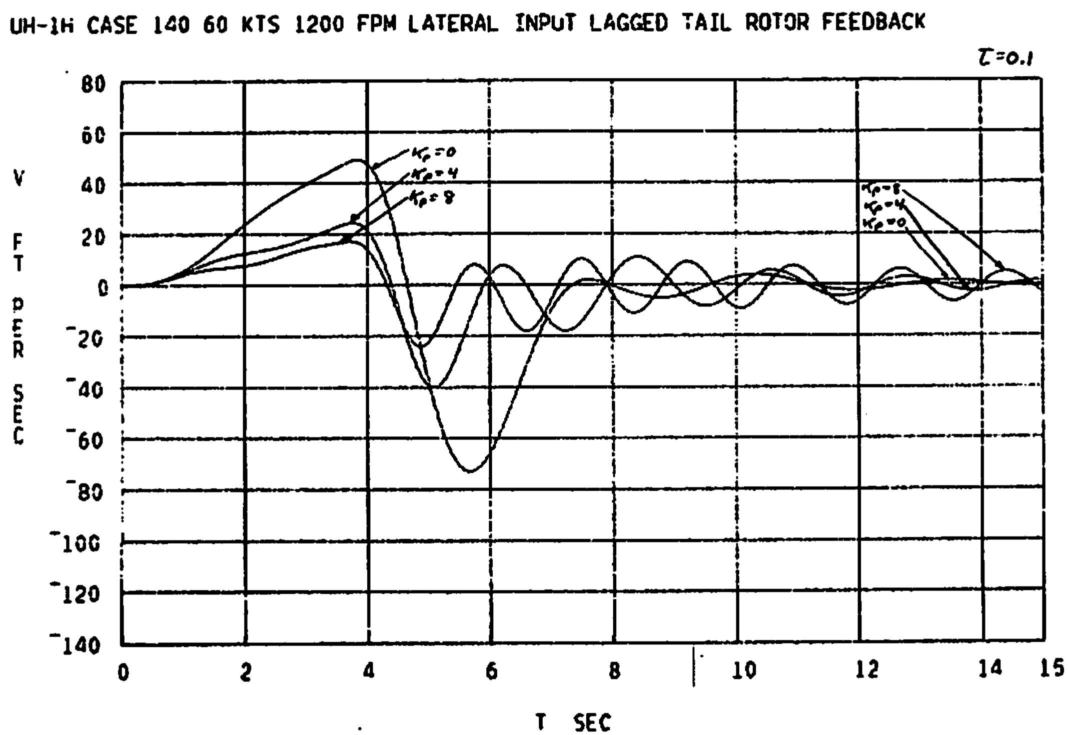

Figure 20. Lateral-Directional Response, UH-1H, 60 kts, Yaw Angle to Tail Rotor Pitch Feedback with Lag, (τ = 0.1 sec).

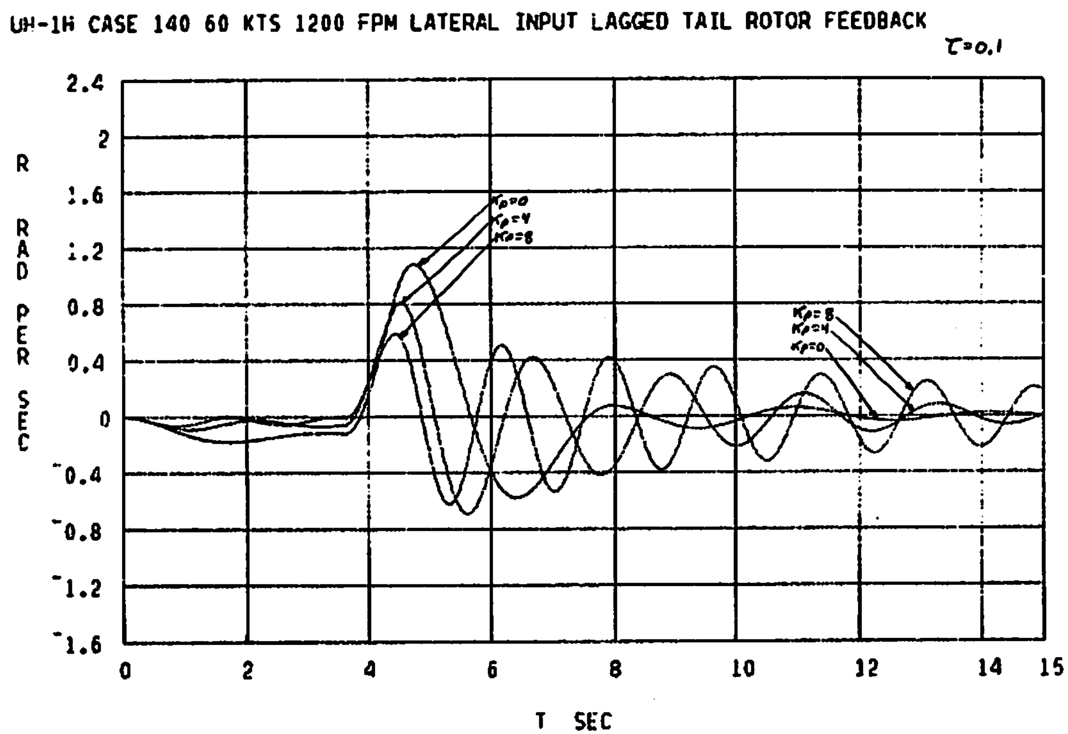

Figure 20. Continued.

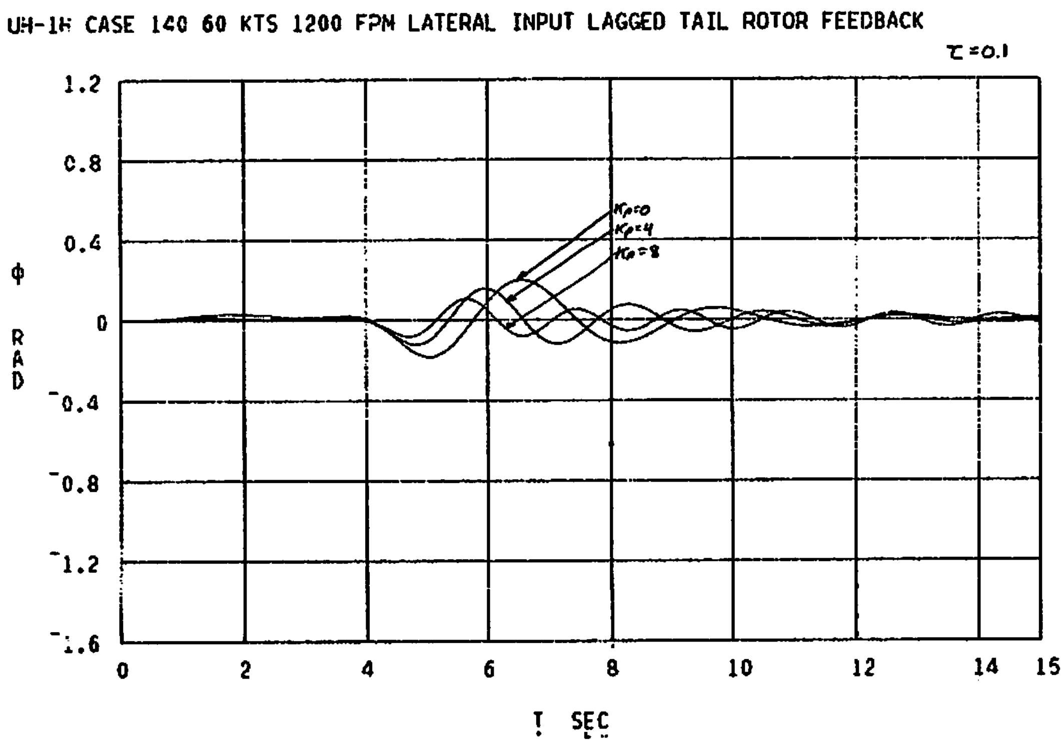

Figure 20. Continued.

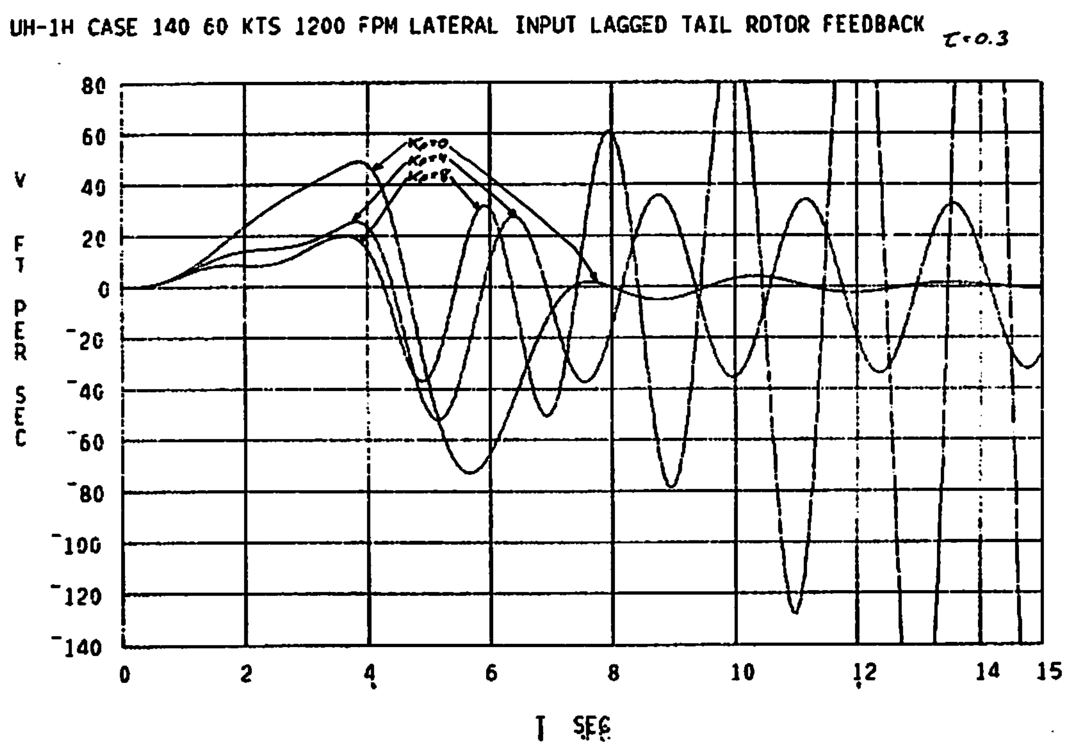

Figure 21. Lateral-Directional Response, UH-1H, 60 kts, Yaw Angle to Tail Rotor Pitch Feedback with Lag, (τ = 0.3 sec).

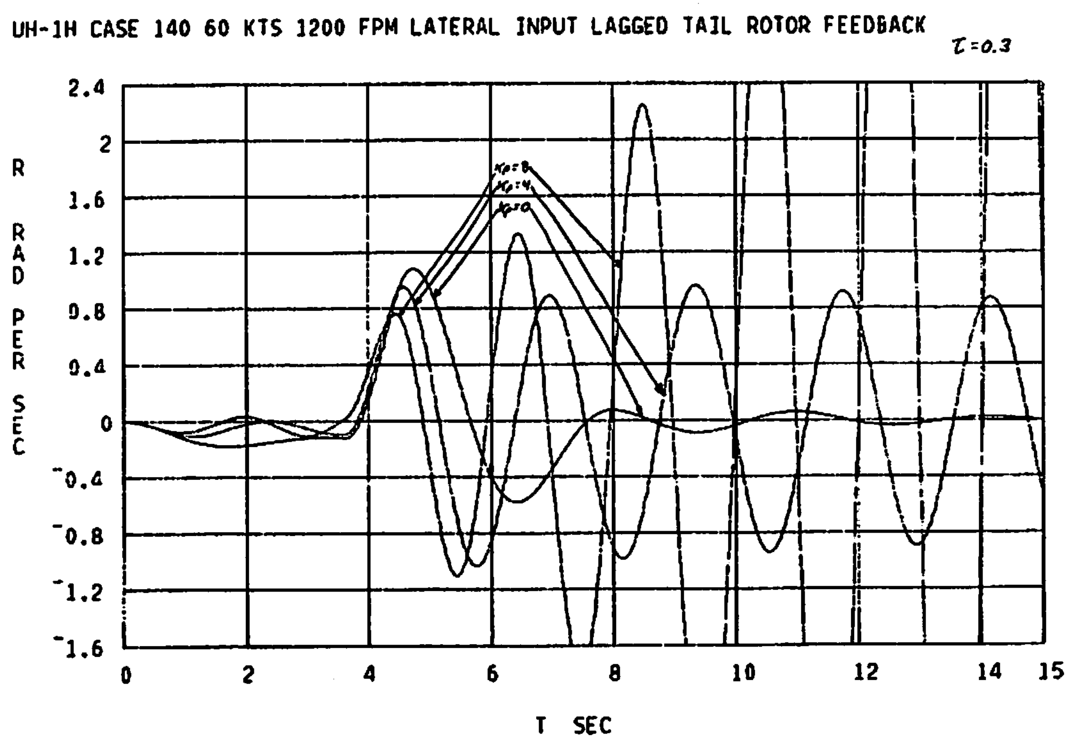

Figure 21. Continued.

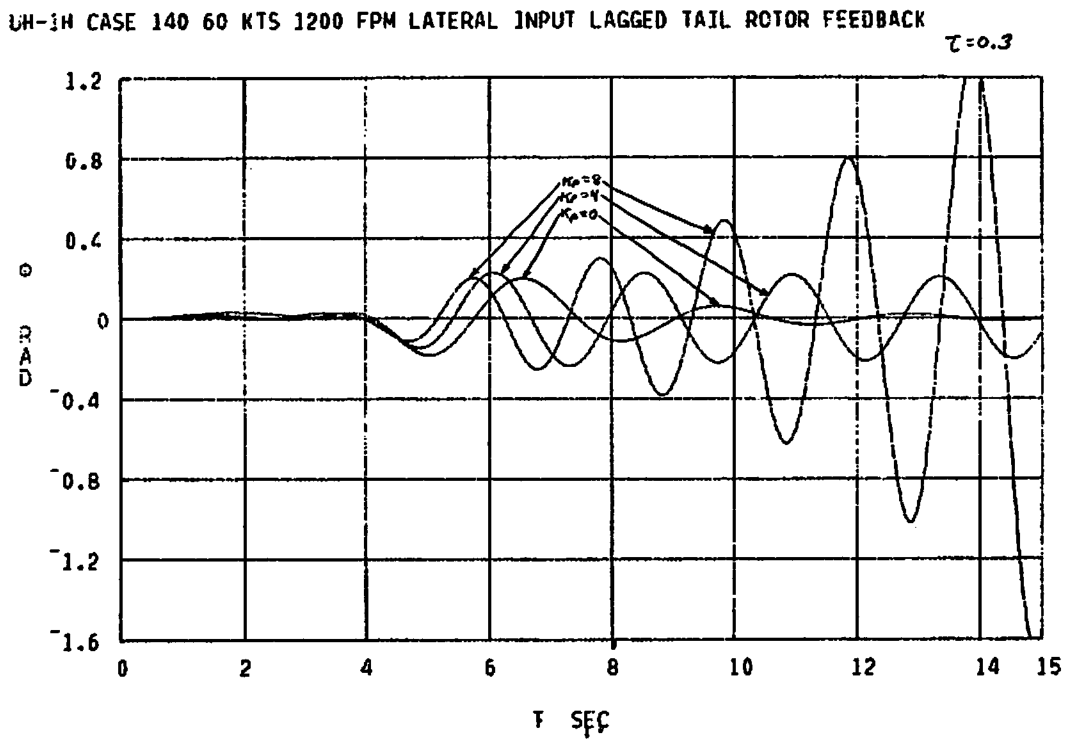

Figure 21. Continued.

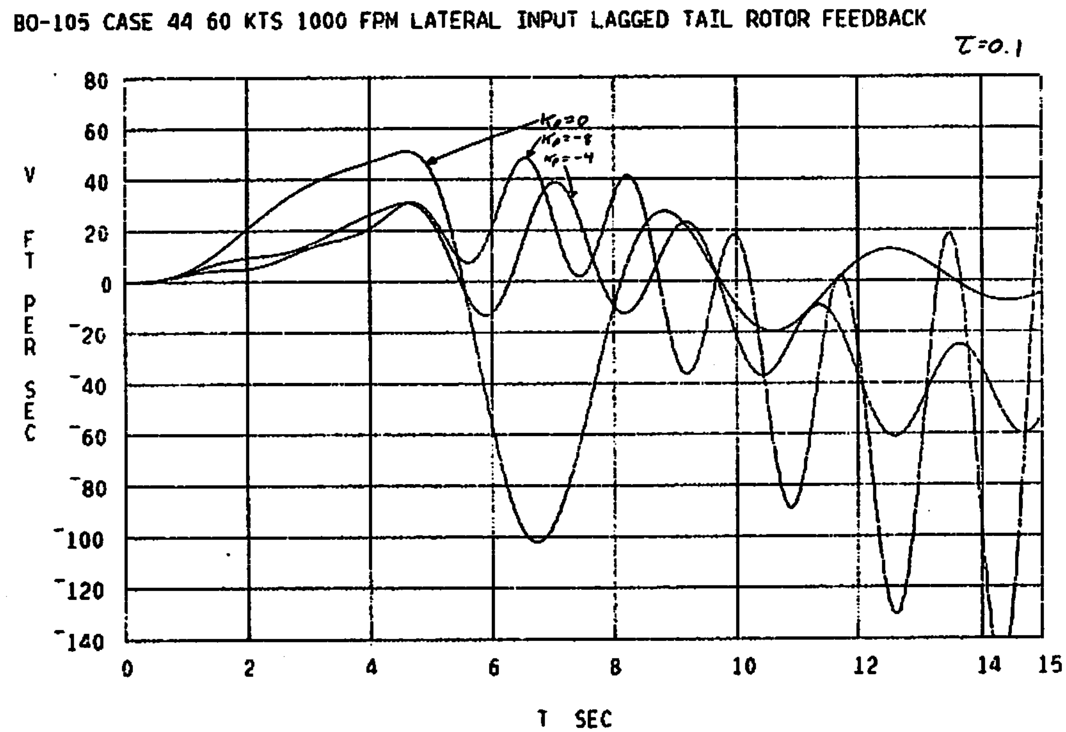

Figure 22. Lateral-Directional Response, OH-6A, 60 kts, Yaw Angle to Tail Rotor Pitch Feedback with Lag, (τ = 0.1 sec).

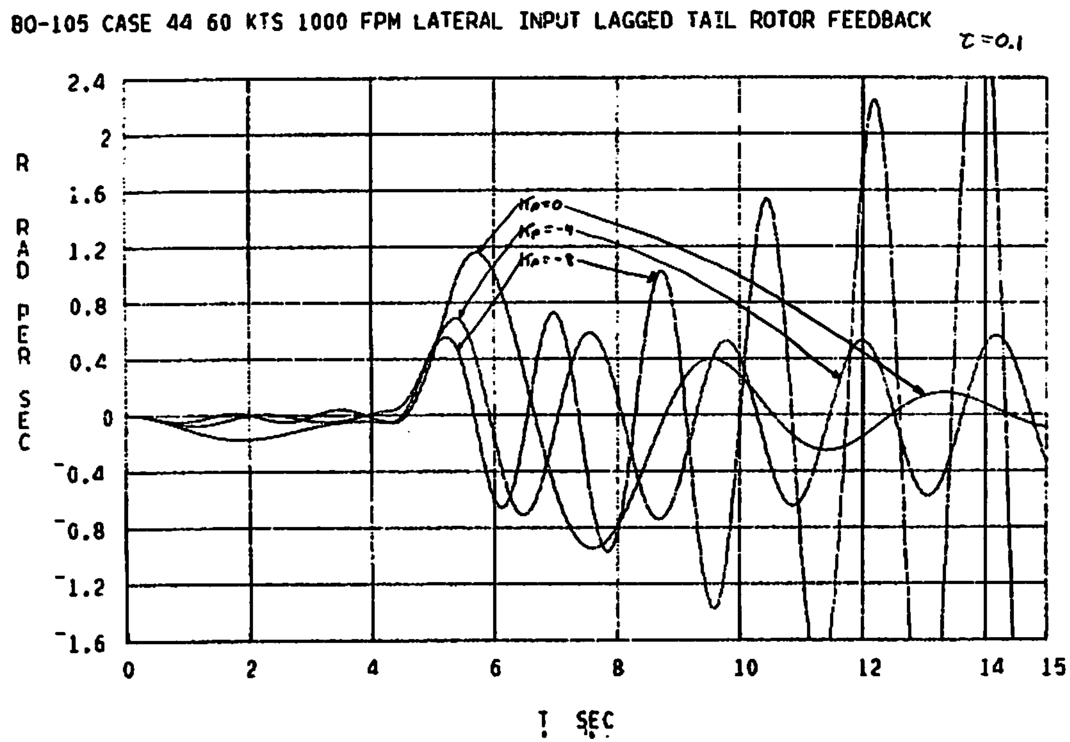

Figure 22. Continued.

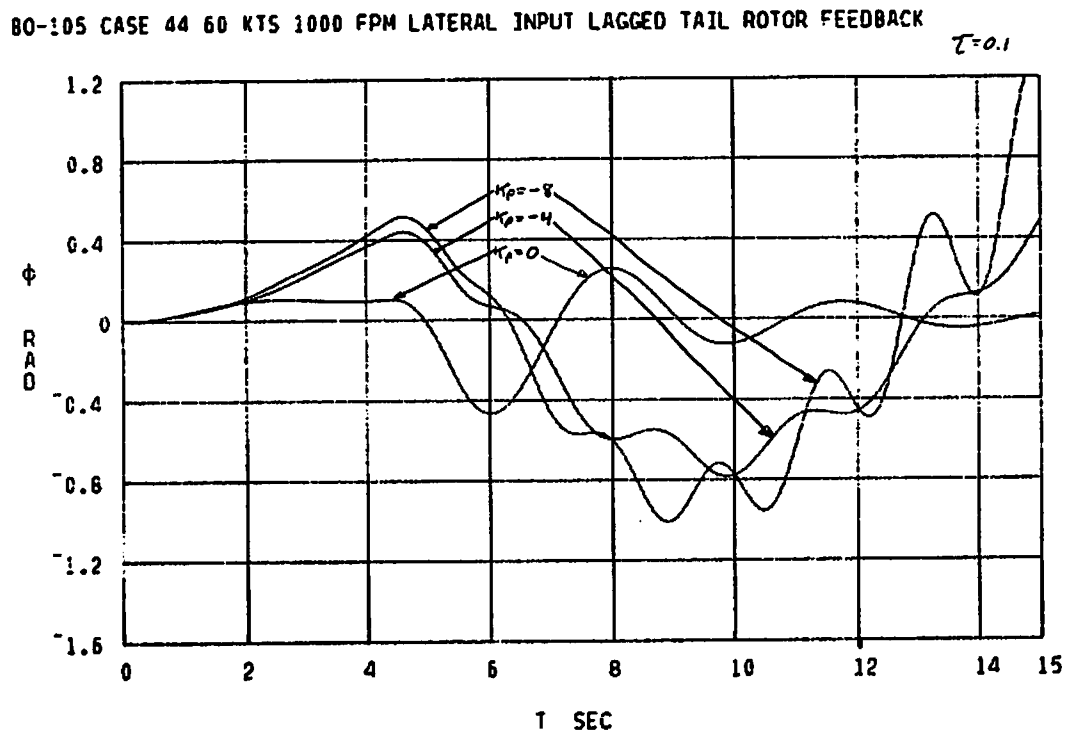

Figure 22. Continued.

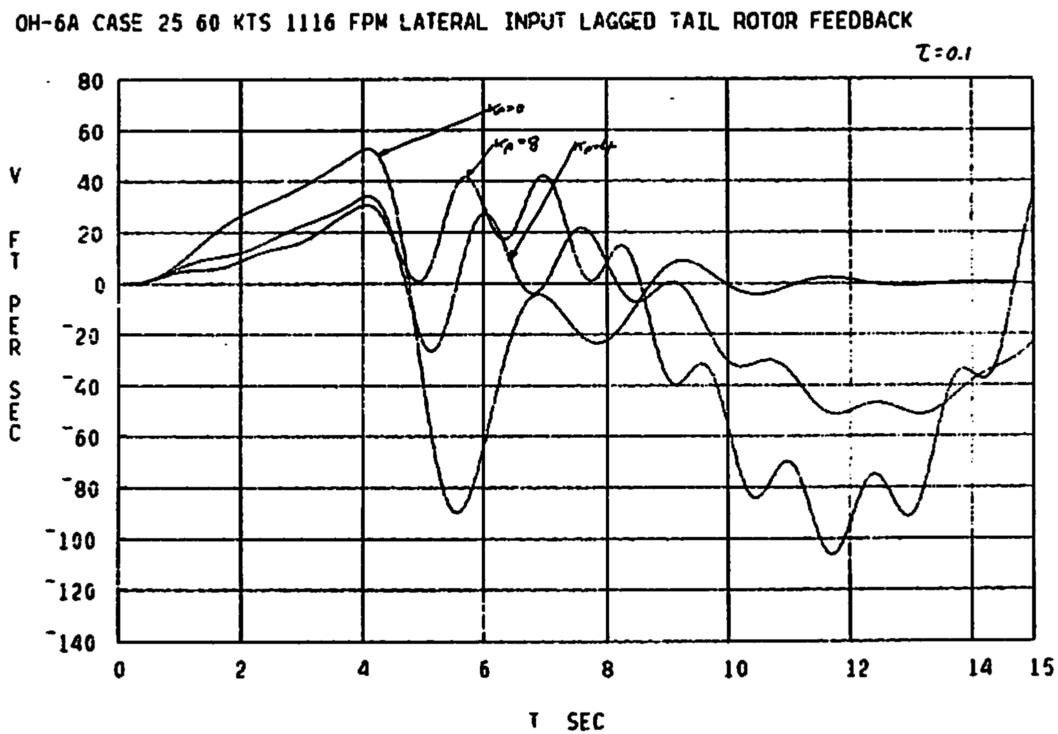

Figure 23. Lateral-Directional Response, BO-105C, 60 kts, Yaw Angle to Tail Rotor Pitch Feedback with Lag, (τ = 0.1 sec).

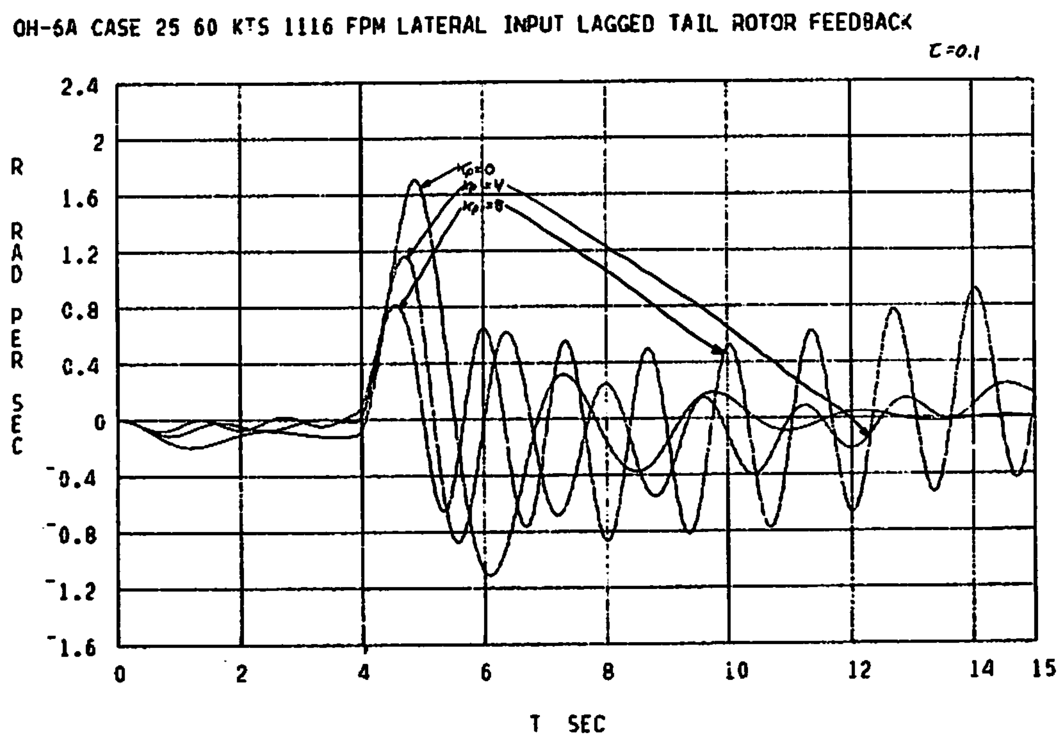

Figure 23. Continued.

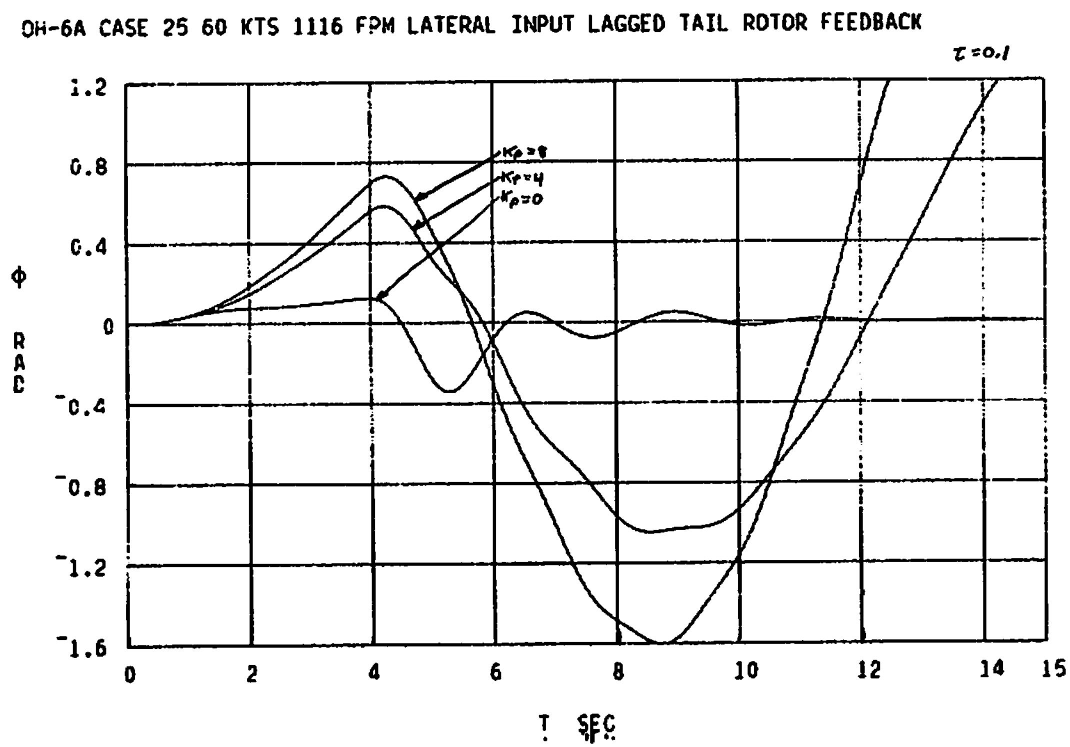

Figure 23. Continued.

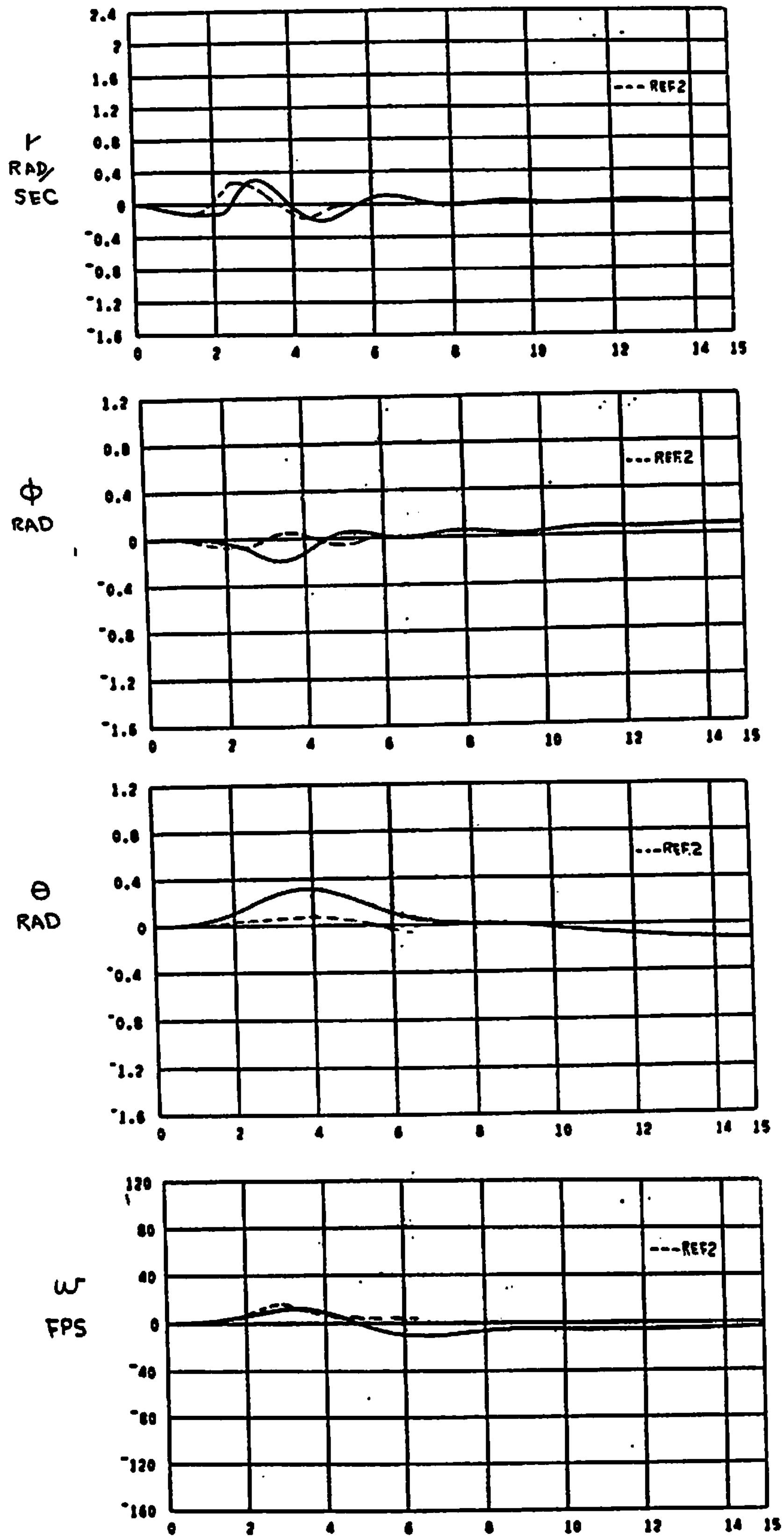

Figure 24. Comparison of Predicted Response of UH-1H with Flight Test Data of Reference 2.