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MAXIMUM NORMALIZED RATE AS A FLYING QUALITIES PARAMETER

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ABSTRACT

Discrete attitude commands have become a standard task for flying qualities evaluation and control system testing. Much pilot opinion data is now available for ground-based and in-flight simulations, but adequate performance measures and prediction methods have not been established. The Step Target Tracking Prediction method, introduced in 1978, correlated time-on-target and rms tracking data with NT-33 in-flight longitudinal simulations, but did not employ parameters easily measured in manned flight and simulation. Recent application of the Step Target Tracking Prediction method to lateral flying qualities analysis has led to a new measure of performance. This quantity, called Maximum Normalized Rate (MNR), reflects the greatest attitude rate a pilot can employ during a discrete maneuver without excessive overshoot and oscillation. MNR correlates NT-33 lateral pilot opinion ratings well, and is easily measured during flight test or simulation. Furthermore, the Step Target MNR method can be used to analyze large amplitude problems concerning rate limiting and nonlinear aerodynamics.

INTRODUCTION

Although the lateral roll mode of a conventional aircraft is perhaps the most easily understood aspect of aircraft dynamics, there exists at the present time a number of unresolved aspects relating to roll performance. On the one hand, theoretical and fixed-base flight simulation data dictate that the shortest roll mode time constants should characterize an ideal configuration. On the other hand, in-flight simulations and experience with real-world aircraft development programs show clear disadvantages in such highly damped aircraft. This in-flight experience is exemplified in the fundamental data

base obtained using the NT-33 aircraft. This is published in two volumes as AFWAL-TR-81-3171, "Lateral Flying Qualities of Highly Augmented Fighter Aircraft" by Monagan, Smith, and Bailey, Reference 1. Part of this difficulty lies in a confusion of real-world aircraft considerations such as ride qualities and control system actuator response, with pure isolated flying qualities of closed-loop pilot control dynamics as seen in analysis and flight simulators.

Beyond this, the plaguing occurrence of roll ratcheting has caused the appearance of numerous articles on lateral flying qualities in recent years, References 2, 3. If these publications are examined, it becomes clear that an insufficient flight data base is at the root of this failure to understand these aspects of lateral flying qualities. The associated lack of comprehensive criteria is now a major concern in the development of highly augmented tactical aircraft. The resolution of the above dichotomy between ideal aircraft response, and real-world aircraft constraints constitutes the main problem of designing roll command augmentation systems (roll CAS) for state-of-the-art, highly augmented tactical aircraft. The aircraft control system designer's primary objective can be stated:

DESIGN OBJECTIVE:	Alleviate the aircraft constraints as much as possible so that the best control dynamics can be realized.

The main categories of "Ideal Dynamics," and "Real Aircraft Constraints" are shown in Figure 1 in relation to the above DESIGN OBJECTIVE.

As indicated in Figure 1, the design process is a contest between the ideal and the real. Northrop is currently pursuing this tradeoff roll CAS technology through four basic approaches:

- Review and analysis of current literature and flight test data.
- Development of more discriminating analysis methods.
- Ground-based flight simulation.
- Contractual participation with NASA Dryden Flight Research Facility in a "Cooperative Program for Investigation of Superaugmented Aircraft Lateral Flying Qualities," involving in-flight simulation using the DFBW F-8 aircraft.

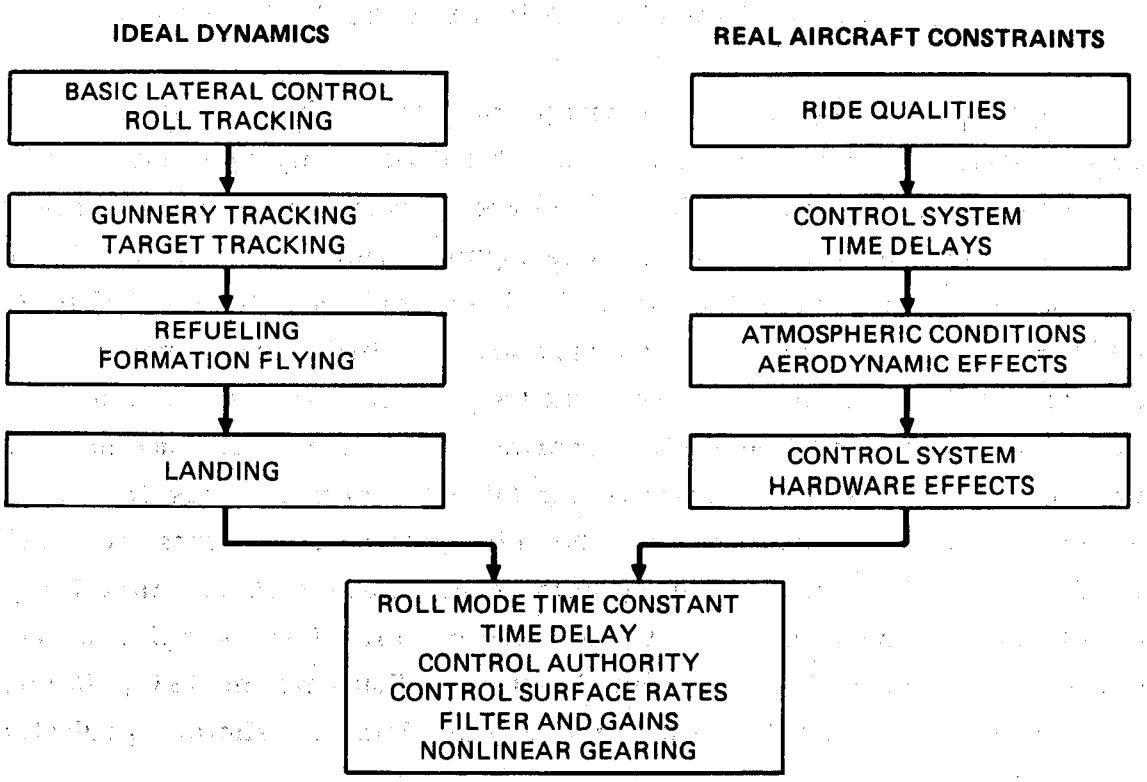

FIGURE 1. ROLL COMMAND AUGMENTATION DESIGN SELECTION

The following presentation will summarize an analysis of existing data using a new flying qualities concept, and show how this method is being used to evolve test matrices for ground-based and in-flight simulations.

ANALYSIS OBJECTIVES AND SELECTION OF METHOD

Although historically the design of lateral flight control systems has been a somewhat routine activity, the advent of highly augmented and unconventional aircraft configurations requires a much more careful selection of dynamic characteristics for acceptable flying qualities. In fact, the in-flight experiment of Reference 1, which will be referred to as LATHOS – for LATeral High Order System, has partially supplied a much needed data base including roll mode time constant, control system time delay, a limited variation of prefilters, nonlinear stick gearing, and Dutch roll damping. In addition to the difficulties in interpreting lateral flying qualities in the presence of high lateral acceleration at the pilot station, attempts to verify the resulting LATHOS criteria for acceptable roll mode time constant by ground-based flight simulation has not been successful. For example, a fixed-base study was performed at McDonnell Aircraft Company in 1982, Reference 4. The relation of the LATHOS and McAir data is shown qualitatively in Figure 2.

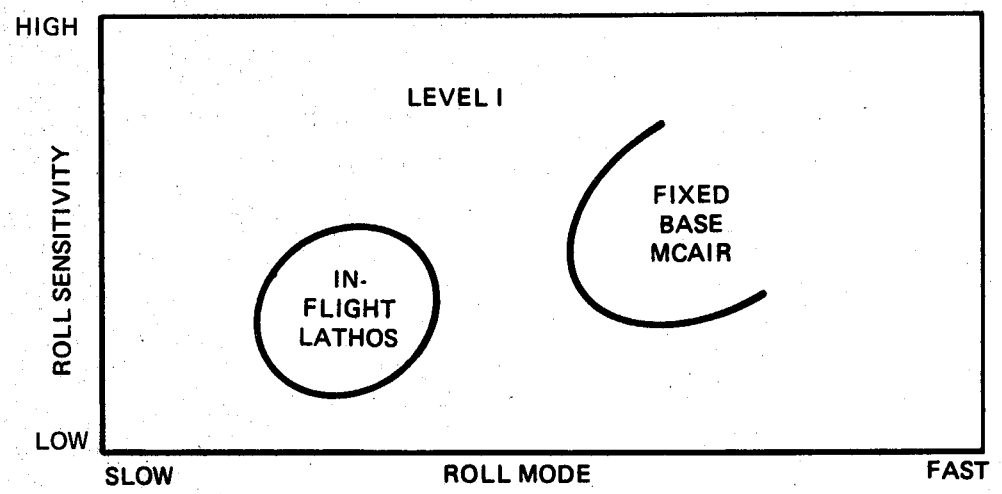

FIGURE 2. DIFFERING CRITERIA FROM IN-FLIGHT AND FIXED-BASE SIMULATION

This discrepancy in placement of roll mode time constant for Level I flying qualities presents a fundamental problem in aircraft control design. For this reason, study of the LATHOS data base using closed-loop pilot-vehicle methods was undertaken at Northrop in 1983.

There were four basic objectives in this undertaking:

1) Develop a methodology that will be applicable to nonlinear lateral flight control systems including prefilters and actuator limiting.

2) Identify a minimal dimensional metric that can be correlated with the LATHOS pilot rating data so that interpolations of the LATHOS test matrix can be made.

3) Employ the metric of 2) to analyze discrepancies in the LATHOS data, identify sensitivities, and recommend improved test procedures.

4) Interpolate the LATHOS survey to develop test matrices that will augment the existing data base in a manner resolving deficiencies and inconsistencies.

The first objective requires that the methods used can incorporate nonlinearities. For this reason, time domain methods were selected.

The LATHOS program included a HUD tracking task consisting of discrete bank angle commands as shown in Figure 3, redrawn from Reference 1.

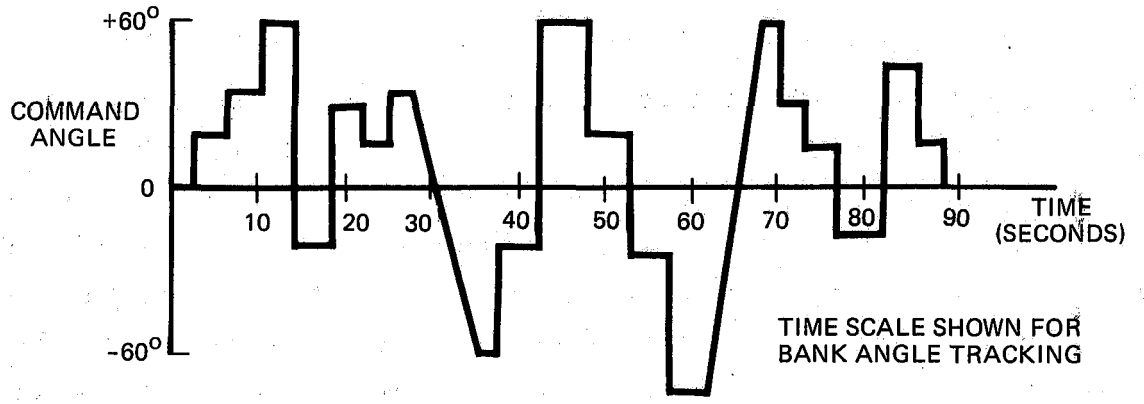

FIGURE 3. LATHOS HUD TRACKING COMMAND TIME HISTORY

This task was selected for analysis of the bank angle tracking task. In the LATHOS program, the HUD task was also flown in a heading task, and the other evaluations consisted of air refueling, formation flying, and gun tracking. These are multiloop lateral-directional tasks; thus they do not qualify for a lateral analysis. Even so, correlations between pilot data for these tasks and the lateral analysis results are possible and will be presented.

For these reasons, it is natural to employ a method developed to solve a similar discrete tracking problem in longitudinal flying qualities, the Northrop Step Target Tracking Method. For the sake of completeness, this method is briefly described next for a pitch step attitude tracking task.

INTRODUCTION TO THE STEP TARGET METHOD

Current flight test and flight simulation practice make extensive use of piloted attitude capture tasks as diagnostics for flight control performance. This procedure consists of having the pilot close on a target attitude as rapidly as he can without exciting excessive residual oscillations. Although this is a simple and effective flight simulation method, there are the following advantages in approximating such results by purely analytical means:

- Simulation time can be reduced
- Uniformity in pilot techniques can be maintained
- An assessment of task severity can be made
- An exact comparison of control system variants can be made.

An analytical method for accomplishing this has been developed and reported in References 5 and 6. These reports should be consulted for further details of the method. Briefly, the calculations consist of the following: For a typical analysis, a step attitude command of 0.1 radian is presented to a mathematical model of the pilot and aircraft. For a total tracking time of 5 seconds, the performance is scored by two statistics, Time-on-Target (TOT), and the normalized root mean square tracking error (RMS). TOT is totaled up with respect to an error tolerance of 0.0025 radian and represents a measure of how much time during the 5 second tracking period that the aircraft is within tolerance of the commanded value. The other statistic, RMS, is primarily a measure of rise time and, in some cases, overshoot. In this way, the TOT and RMS pair give a description of how quickly the aircraft can respond to the step pitch command, and how well it will settle to the commanded value.

There are two elements in the step target method – the airframe and the pilot. The aircraft is modeled by aerodynamic and control descriptions

that represent the aircraft along with appropriate position and rate limits on the control surfaces. The equations of motion are either fixed point or fully general large angle body axes equations and the time histories are generated using a suitable integration and frame time. These can be chosen so that the difference equations represent the control system filters exactly corresponding to the on-board flight control computer algorithms.

The pilot model reflects the following capabilities and limitations of the human controller:

- Ability to generate control compensation consisting of a proportional blend of error, error rate, and integral control.
- Ability to use, if required, separate control compensation for the initial response and final precision tracking phases of the tracking task.
- The limitation of a total cerebral and neuromuscular human equivalent transport delay of 0.3 seconds.

The definition of the model and the full pitch task is shown in Figure 4.

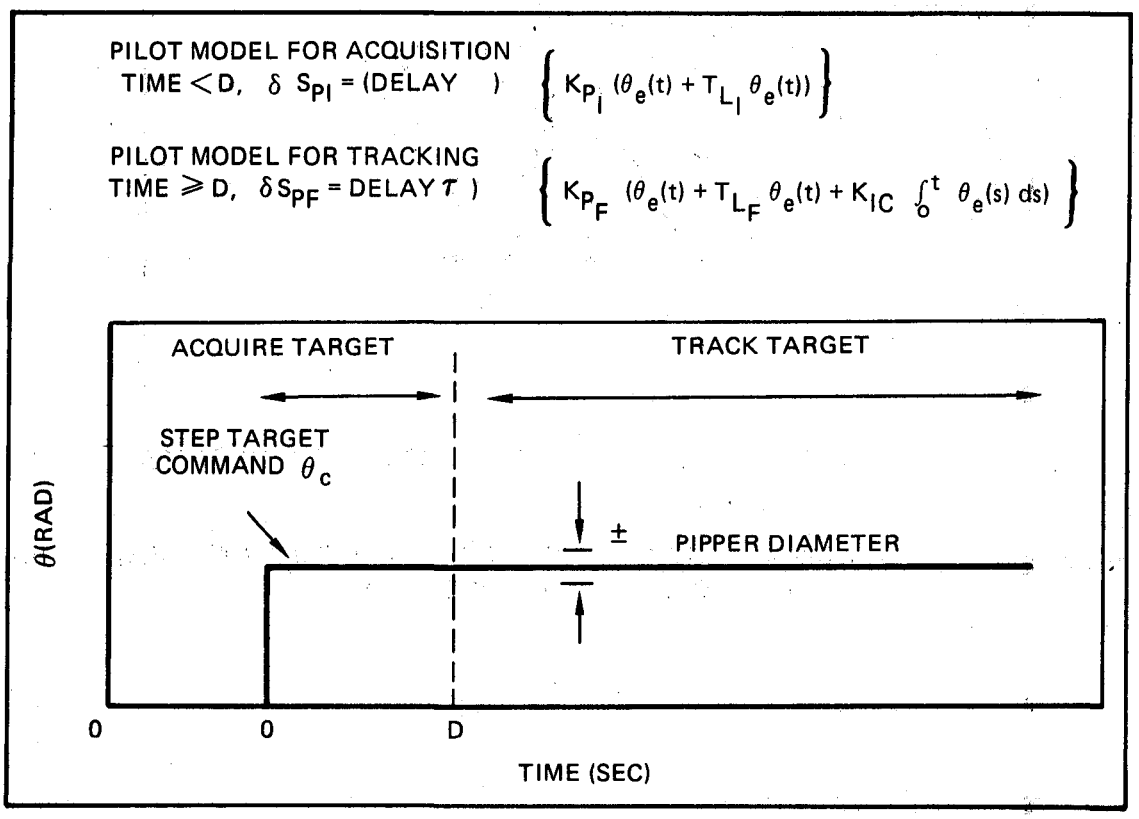

FIGURE 4. DEFINITION OF PITCH STEP TARGET TRACKING TASK

The adjustment rule for the pilot model is simple: maximize TOT. This is done by adjusting the gains K, and lead coefficients T_L. The time at which the tracking phase is initiated, D, is also a parameter along with K_{IC}.

Validation of this approach is provided in Reference 6 and further demonstrations of the utility of this approach have been made in applications to both pitch and yaw CAS systems during aircraft development. The method is also described in the USAF specification MIL-F-8785C, Reference 7.

An analysis of NT-33 in-flight simulation of longitudinal flying qualities performed by Neal and Smith shows an essential two-dimensional relationship between the time-on-target, TOT, and the RMS statistics as shown in Figure 5, which is reproduced from Reference 7.

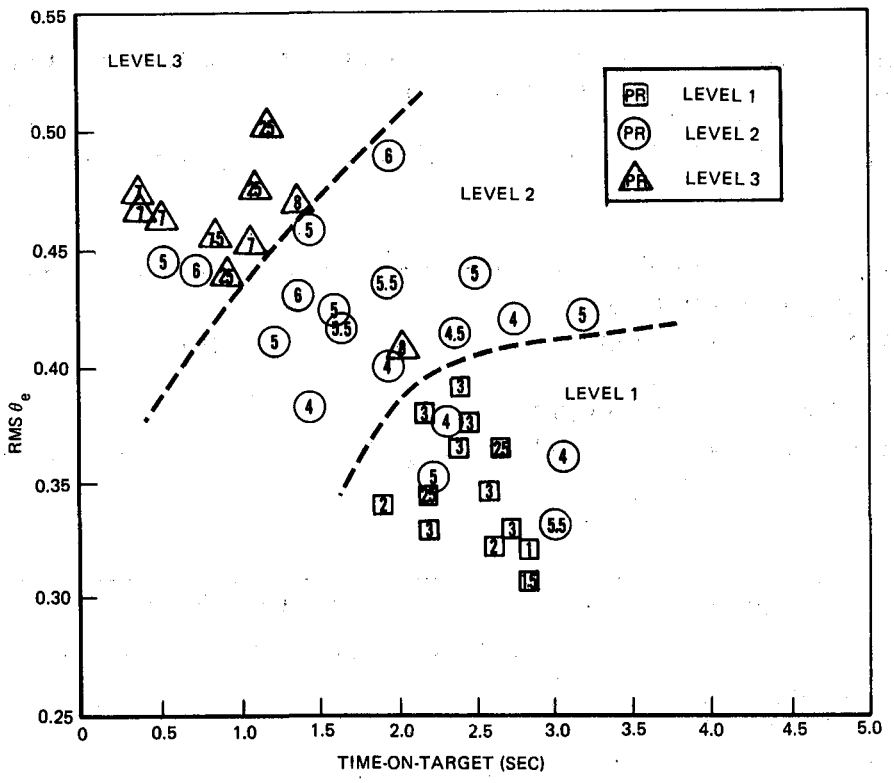

FIGURE 5. PILOT RATINGS AS FUNCTIONS OF RMS AND TIME ON TARGET FOR FIVE SECOND TRACKING TASK

APPROPRIATENESS OF THE STEP TARGET METHOD

The appropriateness of the step target method as a means of analyzing the LATHOS data base and suggesting further test requirements can be summarized as follows:

- The LATHOS experiment used a succession of step target commands exclusively for all HUD evaluations of lateral control. Thus the method models and studies this exact LATHOS flight test maneuver.
- The method gives good resolution in the Level I region where information is usually difficult to obtain.
- The method with its two stage acquisition – track model generates realistic time-varying pilot control strategies. In these cases, steady-state concepts such as gain or phase margins, and bandwidth are not even definable.
- All system nonlinearities can be incorporated along with full control and aerodynamic models where necessary. Thus exact time delays and amplitude-related nonlinear characteristics can be analyzed.

The following analysis will develop a promising new parameter easily obtained from in-flight or ground-based simulations as well as from flight tests:

- The time-on-target and RMS statistics are highly correlated with the amount of roll rate that the pilot can generate without overshoot and oscillation. This quantity normalized by commanded step size is an invariant that is easy to measure in piloted flight or simulation and is related to closed-loop bandwidth.

STEP TARGET ANALYSIS OF THE LATHOS DATA

An attempt to analyze the LATHOS data using the approach outlined above was documented by the authors in 1983, Reference 8. Since then, improvements in the methods used to optimize time on target, TOT, along with greater care in applying the LATHOS pilot opinion rating data, have led to considerable refinement of this earlier preliminary analysis. Fortunately, the basic conclusions of Reference 8 remain valid, and the improved resolution of the method allows greater insight into the discrete lateral step bank angle maneuver. A full analysis of this problem is not yet completed, however, a summary of current findings will be presented next.

Objectives of LATHOS Step Target Analysis

There are a number of questions to be addressed in the analysis:

1) Will analysis using the optimized single-stage step target suffice, or is the two-stage model necessary?

2) Do HUD POR data correlate with the step target parameters RMS and TOT?

3) Is there a one-dimensional metric obtainable from the step target analysis that correlates with HUD POR data?

4) Are correlations independent of the source of lateral flying qualities characteristics i.e., time delay, roll mode time constant, or prefilter coefficients?

A further question regarding the multiloop control flight tasks:

5) Do the metrics used in the analysis of the HUD tasks correlate with the gun tracking and formation flying tasks?

Selection of Baseline LATHOS Pilot Rating Data

The first task in the analysis is to identify the LATHOS evaluation flights which are applicable to the study of the HUD discrete maneuver problem. A validation data base is required for calibration of the metrics used in the analysis in terms of pilot opinion ratings, POR. The analysis presented here will be confined to one pilot supported by the corresponding safety pilot POR data. The pilot selected, "B" of Reference 1, demonstrated the best self-consistency, the broadest participation in the experiment, the widest range of ratings, and the best agreement with the safety pilot ratings. Since this analysis will assume ideal pilot-controller interface characteristics, evaluation flights suitable for the validation baseline data set must meet the following criteria:

1) The principal evaluation task must be the HUD task.

2) There must be no significant pilot comments expressing dissatisfaction with control forces, stick sensitivity, or control harmony.

3) Of various stick sensitivities tested, the configuration with best POR must be used.

With these restrictions a set of LATHOS flight evaluations was selected which will be referred to as the HUD validation data set. A second set of

evaluations was also selected for the tasks of gun tracking, TR, and formation flying, F, performed together. Gun tracking performed alone was also considered.

The complete list of the selected NT-33 evaluation flights is contained in Table I.

Single-Stage Analysis of the LATHOS Data

In accordance with the above description of the single-stage step target model, the validation data configurations were optimized for maximum TOT using a computerized exhaustive search algorithm. The results for the combined data sets are presented in Table I. The significance of these data is more clearly understood when viewed graphically. In analogy to Figure 5, Figure 6 presents the HUD validation data in the form of pilot ratings placed at their coordinates of TOT and RMS.

Figure 6 shows two characteristics of importance:

- The rating data lie on a well defined line in the RMS versus TOT plane.
- The POR data are monotonic increasing along this line.

These two observations indicate the possible existence of a single dimensional metric. In addition to TOT and RMS, another measure of this performance was identified, the Maximum Normalized Rate, MNR. This quantity is the maximum rate that the pilot can use and yet avoid overshoot and oscillation, normalized by the commanded step size. MNR can be interpreted in terms of flying qualities as expressed in Section 6.2 of Reference 9 in which Neal and Smith comment:

> "The first step in the analysis is to identify the performance which the pilot is trying to achieve when he "adapts" to an airplane configuration. The pilot comments indicate quite clearly that he wants to acquire the target quickly and predictably, with a minimum of overshoot and oscillation. The question that remains is how to translate this observation into mathematical terms."

TABLE 1. SINGLE-STAGE STEP TARGET ANALYSIS DATA FOR VALIDATION LATHOS CONFIGURATIONS

CONFIGURATION	EVAL NO.	TASK	POR	SPOR	TOT	RMS	MNR
2-3T2	95	F, TR	5	5	2.925	0.4784	0.909
2-4	17	HUD	2	3	3.200	0.4430	1.021
2-4F1	18	HUD	4	4	3.000	0.4672	0.922
2-4F2	179	TR	3	3	2.825	0.4851	0.847
3-3	44	F, TR	5	4	3.375	0.4233	1.153
3-3F3	135	HUD	7	7	2.825	0.4848	0.853
3-4F4	213	HUD	8	7	2.575	0.5090	0.751
1-3T2	112	TR	8	9	2.725	0.4989	0.809
2-2T1	45	F, TR	2	2	3.000	0.4698	0.935
2-2T4	15	HUD	9	8	2.600	0.5186	0.799
2-4F3	94	F, TR	7	7	2.525	0.5137	0.734
2-3T1F1	113	TR	6	7	2.800	0.4924	0.853
3-4F5	97	F, TR	8	8	2.150	0.5431	0.629
3-3T1F1	125	TR	7	7	3.025	0.4700	0.966
5-2	12	F, TR	7	7	3.500	0.4072	1.276
5-2F2	127	TR	5	5	3.225	0.4436	1.062
5-3F3	188	TR	4	4	3.025	0.4647	0.945

DEFINITIONS:
POR – PILOT OPINION RATING FOR PILOT "B"
SPOR – SAFETY PILOT RATING
CONFIGURATION – SEE REFERENCE 1 FOR CODE
TOT – TIME-ON-TARGET
RMS – NORMALIZED ROOT MEAN SQUARE TRACKING ERROR
MNR – MAXIMUM NORMALIZED RATE – MAXIMUM ROLL RATE DEVELOPED IN OPTIMIZED MANEUVER NORMALIZED BY THE COMMAND STEP SIZE
TASK – F: FORMATION FLIGHT, TR: GUN TRACKING, HUD: HEAD UP DISPLAY STEP ATTITUDE TRACKING

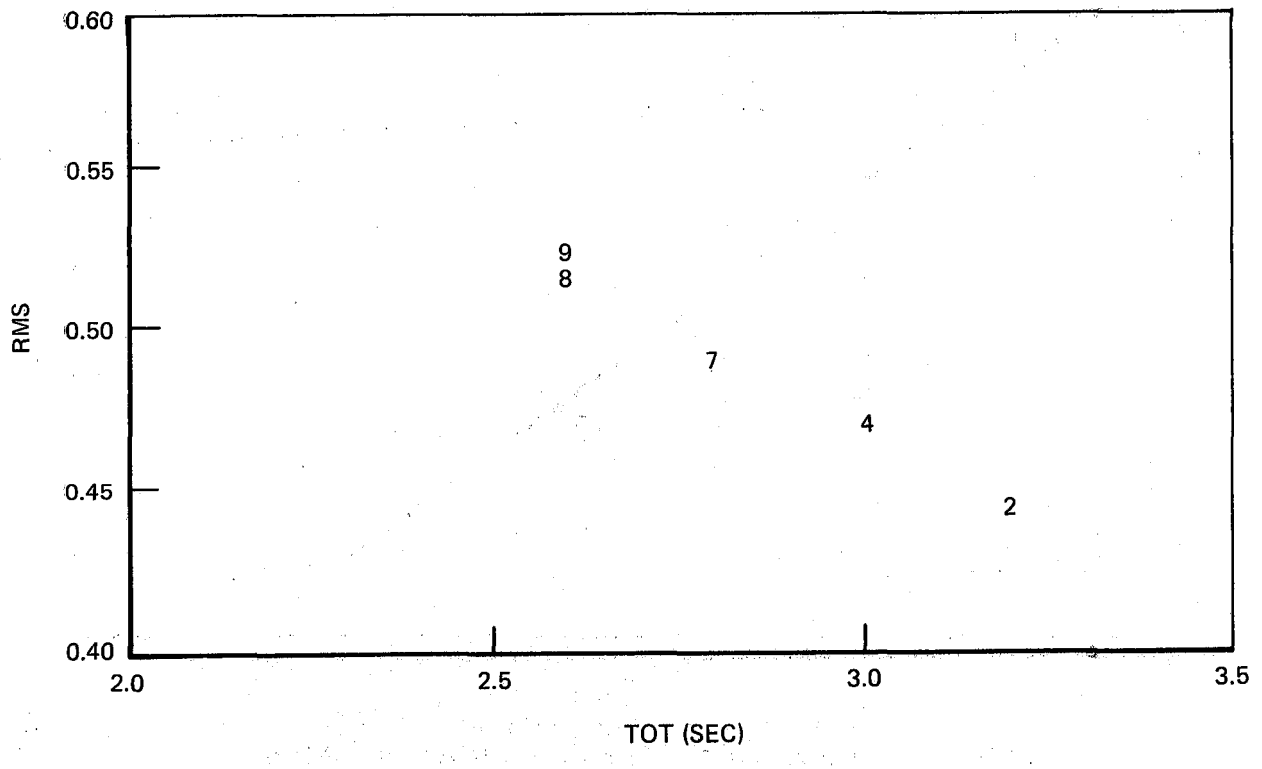

FIGURE 6. HUD PILOT RATINGS AS FUNCTIONS OF TOT AND RMS

Viewed in this way, the step target method with MNR as a metric suffices for two reasons:

- The optimized TOT corresponds to the condition of "acquiring the target quickly and predictably with a minimum of overshoot and oscillation."
- The MNR is a measure of just how quickly the pilot can undertake the maneuver in response to the requirement "to translate this observation into mathematical terms."

If POR data are plotted versus MNR for the HUD cases, the result is a strong linear correlation as shown in Figure 7.

With this successful correlation for the HUD tasks, it is natural to look for agreement of the multiloop lateral-directional pilot ratings with the inner loop MNR data. Interpretation in this case becomes more difficult and uncertain owing to the intrusion of ride qualities effects, and possible insufficiency of the tests used to evaluate the configurations. Figure 8 presents both the HUD and the multiloop evaluations consisting of gun tracking and formation flight performed together in each evaluation.

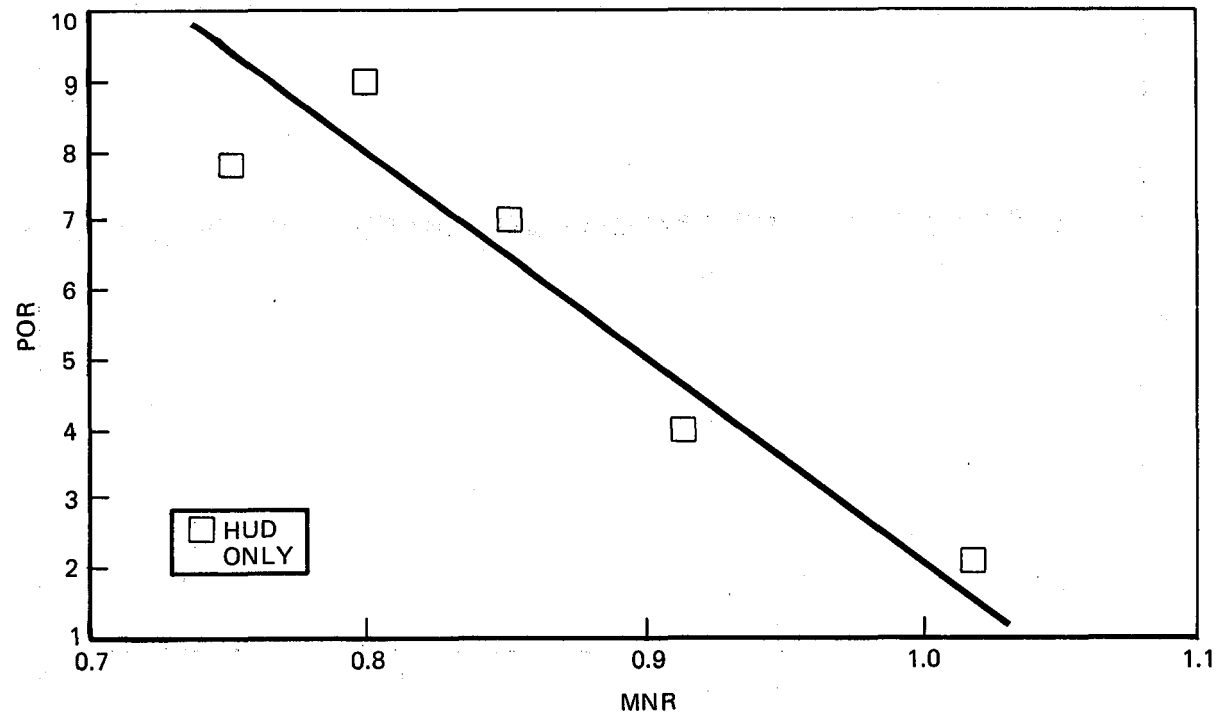

FIGURE 7. POR vs. MNR FOR HUD VALIDATION CASES

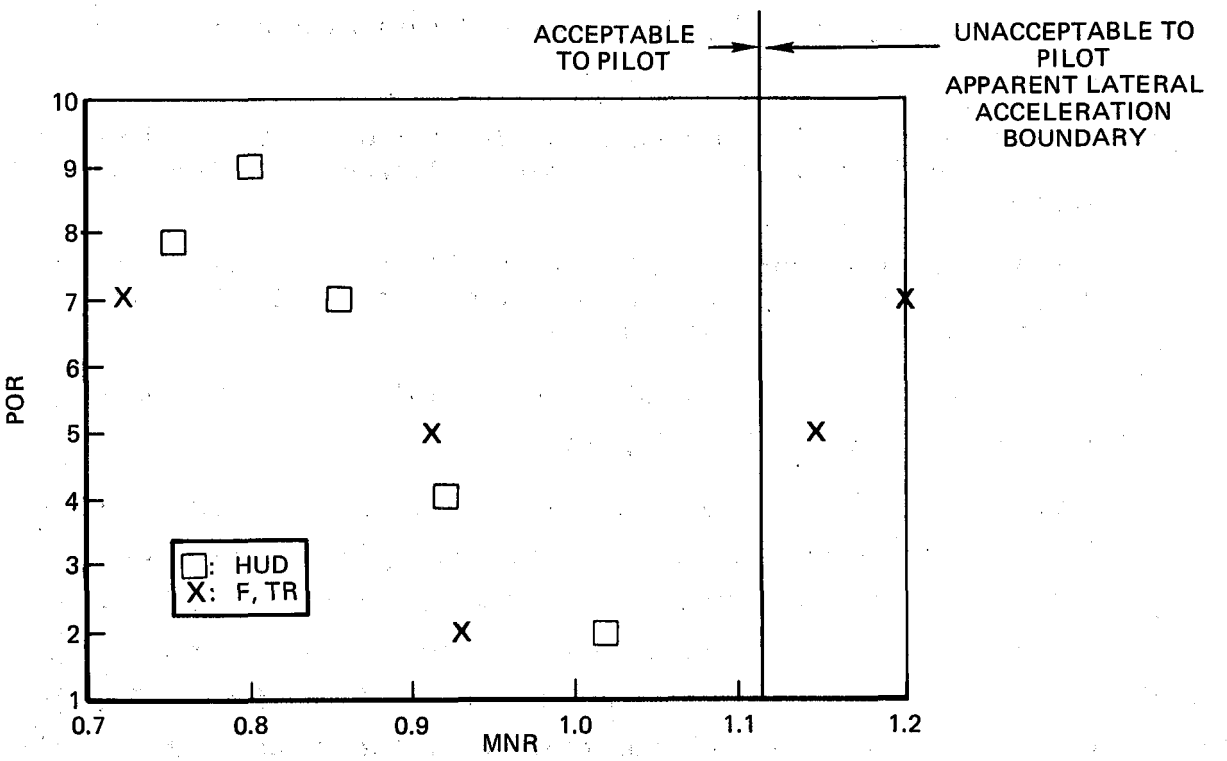

FIGURE 8. POR vs. MNR FOR HUD AND F, TR TRACKING TASKS

Examination of Figure 8 shows a general agreement between the F, TR tasks and the HUD cases for sufficiently low MNR. For MNR greater than 1.1, there are very sharp pilot rating degradations. In both of these cases, the roll mode time constant is 0.15 sec, and in the worst case the pilot comments indicate "quick, sharp ratcheting."

On the other hand, if the gun tracking cases are plotted against MNR, the result is as shown in Figure 9.

The wide scatter of Figure 9 in contrast to the linear correlations of Figures 7 and 8 indicate that the gun tracking task alone may not lead to consistent evaluations with the HUD and formation flying tasks. This difficulty is possibly exhibited in the data reported in Reference 1 where the LATHOS POR data is presented in the form of inter and intra pilot rating correlations which are poor in some cases. Furthermore, the correlation of the HUD and other tasks shows a strong trend, but includes points that are as far as 4 units of POR from the line of agreement, and with a spread of 5 units of POR in several cases. Figure 9 might explain some of this disagreement, however, it seems inescapable that there are dynamic considerations beyond the closed loop piloted control of inner loop roll angle required to fully understand the outer loop maneuvers.

Two-Stage Analysis of the LATHOS Data

From the above data presentations, it is clear that MNR derived from the single-stage step target model leads to sharp and discriminating analysis of control configurations with variations in time constant, time delay, and prefilters. Even so, it is natural to inquire into the possible use of the two-stage model illustrated in Figure 4. Automatic computer optimization algorithms were developed for this problem, and the results obtained were of little use, not because the method broke down in this instance, but because the problem was not sufficiently well defined.

The difficulty lies with the distinction between open loop maneuvers and closed loop tracking. With the single-stage model, the model coefficients are maintained constant throughout the 5-second tracking interval so that the compensation must be stable. This places a considerable compromise on the initial transient response and the final tracking compensation compared to the

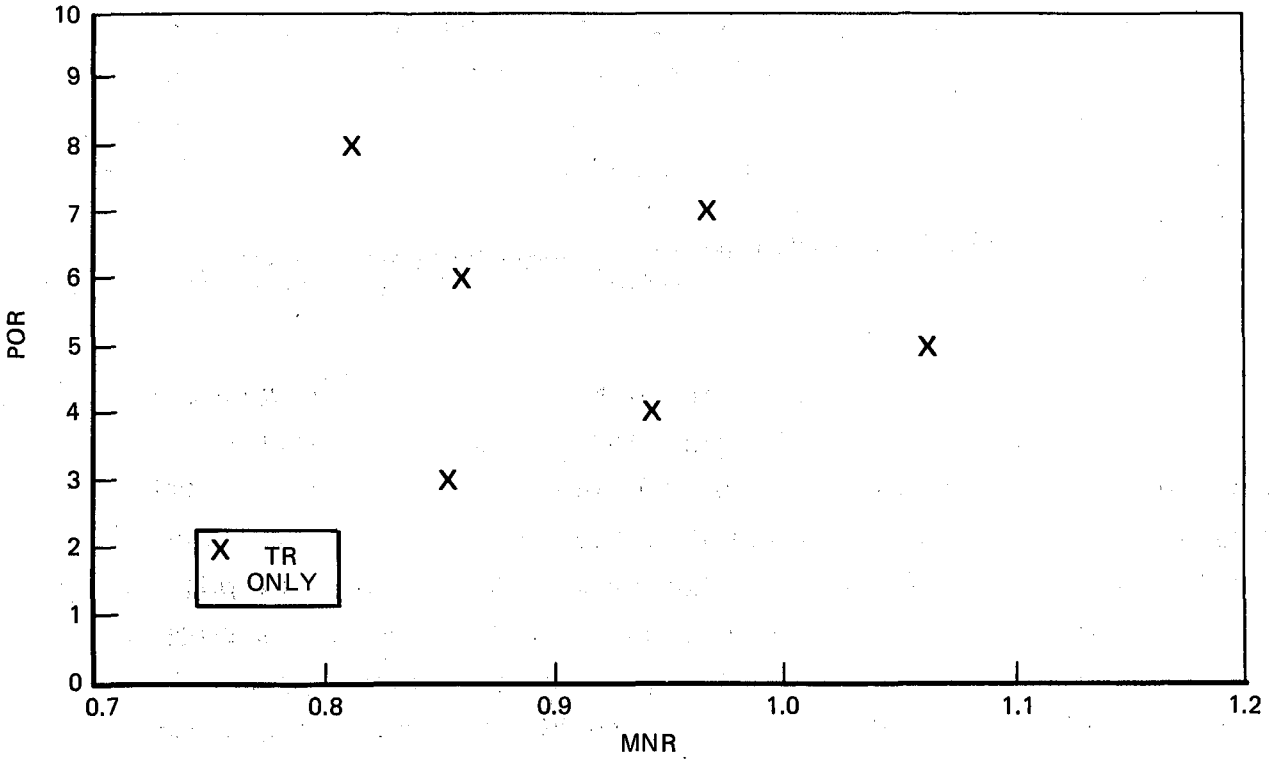

FIGURE 9. POR vs. MNR SHOWING POOR CORRELATION FOR TR ONLY TRACKING TASKS

two-stage model. In the two-stage case, the initial coefficients can be maintained for a short period at values that in a steady-state sense would be unstable. This can then be followed by a set of coefficients that correctly terminate the initial transient and provide a sufficient amount of error correction during the final tracking stage to prevent drift, or to correct small offset at the end of the acquisition phase of the problem.

This advantage of the two-stage model leads to unrealistic TOT and associated MNR for most of the LATHOS cases. The situation is this: For the idealized model consisting of just the transfer functions of the prefilter, the roll mode, and the Dutch roll dynamics plus the time delay, there is no restriction of "real world" characteristics encountered in the actual flight tests.

These considerations are of two basic kinds:

1) The NT-33 has finite surface rate limits. The two-stage model in many cases generates extremely high roll accelerations depending on instantaneous surface rates.

2) The human pilot has resolution limitations in 1) judging the exact command magnitude, 2) adopting exact compensation ratios of error to error rate, and 3) initiating of any discontinuities he may use to perform the maneuver.

If the pilot is allowed to fly the exact same step over and over, his performance can be dramatically improved, but in this case he is developing an open loop control history, and is abandoning closed loop tracking. Each of the above two limitations can be built into the two-stage model, and work in this direction is in progress.

This difficulty in maintaining a suitable distinction between open loop maneuvers and closed loop tracking is a feature of discrete flying qualities where both kinds of maneuvers need to be studied. The MNR metric for the two-stage model has difficulty, not because of model deficiencies, but because it is sensitive to all aspects of aircraft model, task definition, and human pilot characteristics. For these reasons, it is anticipated that the step target method with the MNR metric will lead to sensitive and discriminating methods for assessing the influence of control and aerodynamic nonlinearities as well as pilot/aircraft interface problems of controllers and displays.

Summary of Step Target LATHOS Analysis

At this point the five questions listed at the front of this subsection can be answered. In brief:

1) For the LATHOS analysis, the single-stage step target model suffices.

2) HUD POR data correlate well, linearly in fact, with RMS and TOT, Figure 6.

3) MNR is a suitable one-dimensional metric for lateral flying qualities evaluation, Figure 7.

4) The correlations include configurations with variations in roll mode time constant, control system time delay, and prefilters. Thus the method can account for all these influences on pilot ratings, Figure 7.

5) POR data for gun tracking and formation flying performed during the same evaluation correlate acceptably with the HUD data, Figure 8. Gun tracking alone is not correlated with the HUD data in terms of MNR, Figure 9.

This completes the analysis of the LATHOS data of Reference 1. However, there are a number of further comments and applications of the MNR metric of the step target method that will be presented next.

OTHER APPLICATIONS OF THE MNR METRIC

There are several practical considerations of MNR as a flying qualities parameter that project a wide range of applications. Although little data has been obtained for these applications, they appear promising and are presented in the hope that some of the ideas may help clarify several troublesome problem areas.

Effects of Actuator Rate Limiting on Lateral Flying Qualities

In the last section, limiting of surface deflection rates was identified as a "real world" aspect of flying qualities to which the two-stage model MNR was sensitive. In fact, the single stage model is also sensitive to actuator rate limiting. Consider the aircraft model shown in Figure 10.

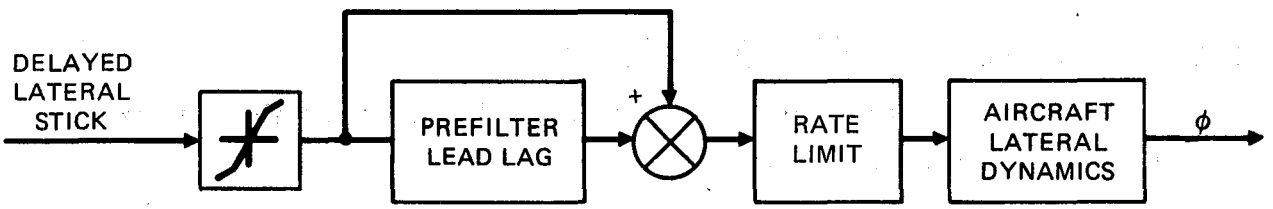

FIGURE 10. RATE LIMITING AIRCRAFT MODEL

For a given rate limit, the command step size will determine the extent to which the limiting is encountered. To apply the step target MNR metric, the model is optimized for each command size of interest. As the command step size increases, the limiting retards the maneuver onset acceleration resulting in reduced MNR, even for the model fully optimized for the particular step size. This is illustrated in Figure 11 for a roll mode time constant of 1.0 sec. The maximum slope, thus normalized, is MNR for each curve.

Equivalently, the rate limit for the actuator can be varied for a fixed commanded step size. Figure 12 presents data in this form for a configuration with a roll mode time constant of 0.5 sec and a control system time delay of 100 ms. Dutch roll and prefilter dynamics are also present.

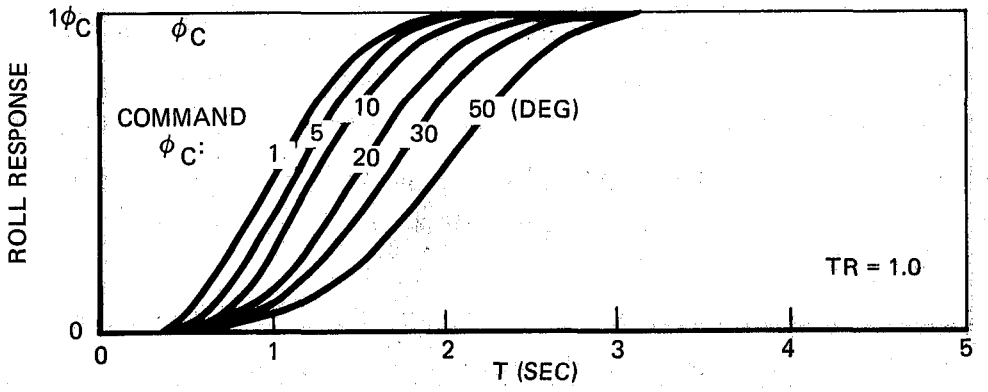

FIGURE 11. EFFECT OF RATE LIMITING ON OPTIMIZED STEP TRACKING RESPONSE

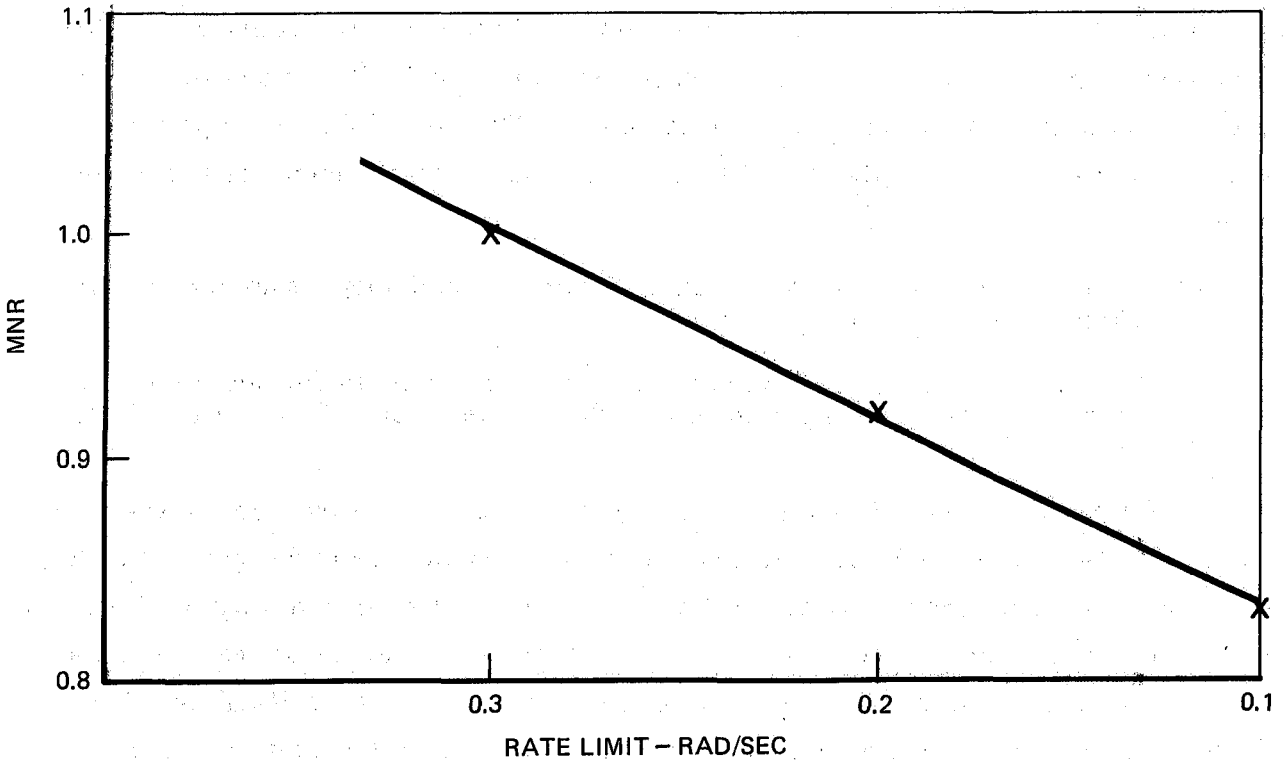

FIGURE 12. DEGRADATION OF MNR WITH DECREASING ACTUATOR RATE LIMIT

The importance of this example illustrates two useful attributes of the MNR metric:

- The MNR metric using the single- or two-stage model can incorporate all system nonlinearities.
- The MNR metric can be used to assess amplitude dependent flying qualities aspects.

In this way, MNR can be used to assess the characteristics of roll control not only for small perturbation maneuvers, but large amplitudes as well. By examining the profile of MNR versus command amplitude, many aspects of the large maneuver problem can be approached by analysis or in simulation. The use of MNR as a flight test and simulation performance measure will be discussed next.

MNR as a Flight Test and Simulation Performance Measure

When the step target method was first developed, the idea was put forward to use TOT and RMS as experimental measures of step attitude acquisition tasks. Such tasks are now standard in control system development and flying qualities assessment, and with the success of the analytical measures it seemed natural to obtain RMS and TOT in experimental testing. However, attempts to obtain these data were frustrated for two reasons:

1) The distinction between open- and closed-loop maneuvers was clouded in the tests.

2) The TOT metric is extremely sensitive to small variations in piloted compensation. Consequently, the data for TOT was badly scattered.

The first problem will always remain, and must be addressed in the design of the test, the task descriptions and performance criteria given to the test pilot, and the order of presentation of the steps in training and data flights and simulations. Thus it can be controlled, or at least made consistent in a known manner. The second problem is much less critical for MNR. For variations in pilot model parameters in the step target model that produce great variations in TOT, the variations in MNR remain small. Flight simulations are now being developed at Northrop to investigate MNR as an experimental performance parameter.

Quantification of Control Harmony in Terms of MNR

If MNR is regarded as a piloted flight or simulation performance parameter or as an analytically derived quantity, the ability of MNR to analyze amplitude dependent flying qualities may provide a way to quantify control harmony.

Control harmony has always been one of the most elusive aspects of flying qualities. It is neither quantified by performance in the sense of tracking data, nor by workload as such, yet has strong influence on the Cooper Harper ratings of test pilots. This influence is mostly in the form of annoyance, as expressed in pilot comments. There is one aspect of harmony, at least, that MNR should be able to identify, predict, and analyze.

Consider an aircraft which has a certain falloff of roll MNR with increasing step command size. Now suppose that the pitch MNR falls off at the same rate. In such a case, if the relative control gearings and forces are well-chosen for small amplitudes, the pilot has only to restrain his aggressiveness for the larger maneuvers. However, if the MNR of one axis decreases more sharply than the other, or if one should in fact increase, then the pilot is faced with restraining one axis while staying or becoming more aggressive on the other. This would seem to be a circumstance that could be quite annoying, and might be an area where MNR can identify some aspects of harmony in a quantitative way. This approach to control harmony will also be tested at Northrop by ground-based flight simulation.

Use of MNR Step Target Analysis to Develop Test Matrices

The correlations of MNR with the LATHOS data, and the understanding of inconsistencies in that data base that the MNR metric provides allows the method to be used to predict where further testing should be performed. By using the MNR metric for interpolation of the LATHOS data, areas of high expected pilot rating gradients can be identified for more thorough testing, while in areas of low sensitivity, testing can be reduced. In this way, time on simulators or test aircraft can be used to better advantage. Also, by testing along the gradients and the lines of apparent equal rating, better definitions of the boundaries of the flying qualities Levels can be obtained. By calibrating the MNR metric to any set of test data, this process can be employed to generate a well selected test matrix for further study. If a data base is unavailable, the method will still show where dense testing should be recommended, and where sparse testing should suffice.

NASA/Northrop Cooperative Program

Northrop is currently under contract to NASA Dryden Flight Research Facility to perform "A Cooperative Program for Investigation of Super-augmented Aircraft Lateral Flying Qualities." Ten flights using the Digital Fly-By-Wire F-8 aircraft will be performed at DFRF, and Northrop will provide engineering support to develop specific test plans, analyze flight test data and document the entire activity. The technology presented above is currently being used to generate the required test plans, and the resulting flight tests will extend the existing data base represented by the LATHOS program.

The basic dynamical interplay among the lateral flying qualities parameters is between control system transport time delay and the roll mode time constant T_R. Therefore the test plan will establish a baseline test matrix and an extended matrix. The baseline test objectives are:

1) Confirm LATHOS.

2) Adequately extend LATHOS.

3) Test small amplitude motions to avoid lateral acceleration N_{yP} effects.

4) Avoid prefilters.

5) Be restricted to linear gearing.

Once this basic matrix has been established and tested, then the matrix will be extended as follows by by examining:

1) N_{yP} lateral acceleration ride qualities.

2) Prefilter and nonlinear gearing alleviation of acceleration detriments.

3) Roll ratcheting identification and boundary study.

4) Establish criteria and verify by air-to-air target tracking.

The relationship between these test objectives is shown graphically in Figure 13.

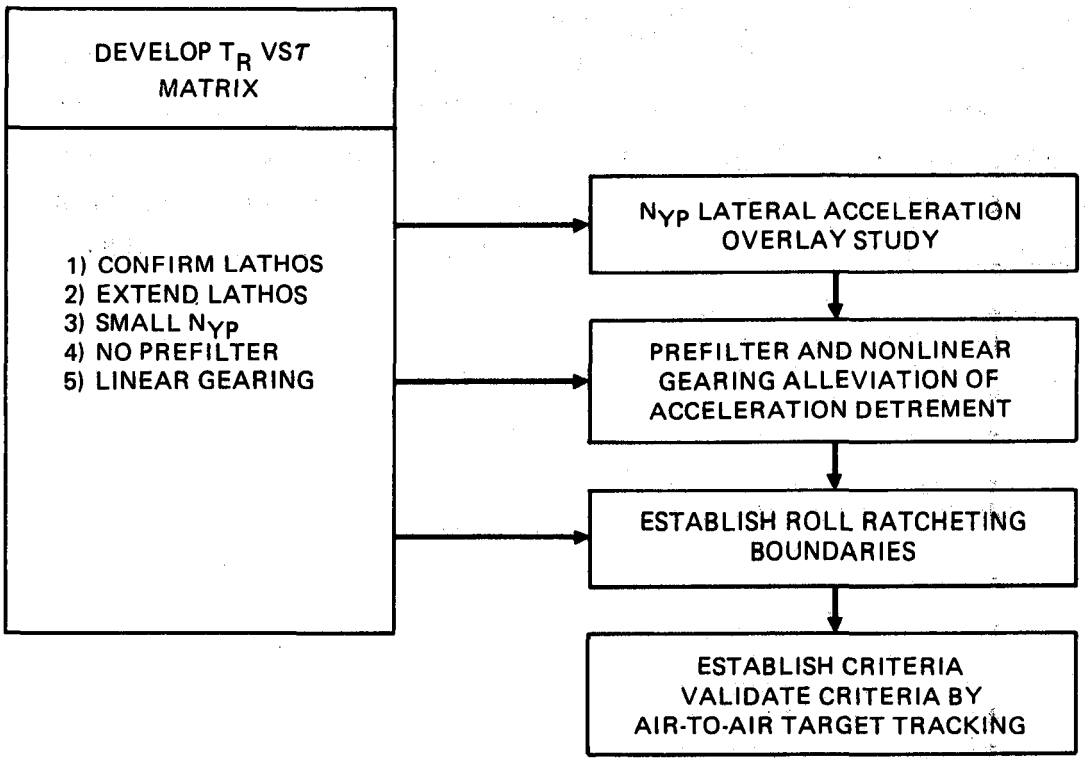

FIGURE 13. NASA/NORTHROP STUDY OBJECTIVES

VISTAS AND PROSPECTS

The data and analysis presented above in no way is offered as validation of any sort of pilot rating prediction method. What has been attempted, is to illustrate the utility of developing time domain models and metrics that can provide insight into some of the difficult aspects of control system development and flying qualities assessment. From this point of view, many more questions have been raised than answered. However, this general approach to the problem has demonstrated the following useful features:

- Ability to incorporate nonlinear system dynamics.
- Ability to incorporate discontinuous control dynamics and transient pilot control strategies.
- Ability to correlate with discrete task flight test data.
- Ability to analyze amplitude dependent flying qualities effects.

These together with the suggested areas of application in the study of rate limiting effects and control harmony demonstrate a need for continued

investigation of the basic step target methodology. Simulations and further analysis are in progress at Northrop, and the utility of this MNR metric is being demonstrated in developing suitable test matrices by interpolation of the LATHOS data base. These matrices are being evaluated by fixed-base flight simulation at the present time. Moving-base and in-flight simulation tests for the NASA/Northrop cooperative program will commence in mid 1984.

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