Fixed-Wing Flying Qualities Testing, Volume IV
Chapter 13
Closed Loop Handling Qualities Eval

Table of Contents

Fixed-Wing Flying Qualities Testing

Chapter 13

Closed Loop Handling Qualities Eval

Introduction

Discussions of aircraft *flying qualities* in previous chapters have been defined in clearly quantifiable terms. Standard stability and control tests were used to determine compliance to MIL-SPEC or FAR's. The criteria are just a means to an end however. The real question is "How well does the aircraft perform its intended mission and mission tasks?" The ultimate goal of any aircraft design should be good *closed loop handling qualities* for its mission. Closed loop handling qualities are judged predominantly by pilot opinion. They reflect the ease and precision with which a pilot can accomplish a specific task.

Because closed loop handling qualities are so important in determining an aircraft's acceptability, the role of a test pilot in making an accurate assessment is critical. Even with all the complex data recording and instrumentation devices now available to flight testers, pilot opinion remains as the primary evaluation method. More specifically, closed loop handling qualities (CLHQ) testing evaluates an aircraft for certain tasks. This approach is dramatically different from open-loop test techniques used for stability and control evaluations.

In this chapter, "open loop" refers to pilot-open-loop. This means that pilot inputs are made without regard to the aircraft response. Precision is not a factor in open loop evaluation. Open loop inputs are essentially pre-planned and may be combinations of impulses, steps, ramps or sinusoidal functions. They can be preprogrammed into subroutines in a fly-by-wire flight control system. As stated before, these inputs excite the airframe/flight control package so testers may evaluate its stability and control characteristics explicitly, but not its closed loop handling qualities. Military flying qualities specifications, as defined in MIL-STD-1797A, predominantly focus on open loop aircraft characteristics in an attempt to ensure satisfactory "closed loop handling qualities."

"Closed loop" refers to aircraft behavior with the pilot in the control loop. Such behavior is usually more complex because the pilot is continuously adjusting his or her inputs in an attempt to fly with some level of precision. An example of a *loose* closed loop task is cruising at some trim altitude and airspeed, while a high gain closed loop task (such as air-to-air gunnery) is more demanding.

Aircraft closed loop handling qualities is affected by open-loop quantifiable "stability and control" characteristics (Figure 13.1). Aircraft stability is expressed in both "static" and "dynamic" terms. Static stability is an aircraft's initial tendency once disturbed from equilibrium and dynamic stability is related to the time history of the aircraft open loop motion after a disturbance. "Control Power" is the capability of an aircraft to perform a maneuver commanded by the pilot.

The Flight Control System (FCS) is also an integral part of the handling of any aircraft. Important subjects are breakout forces, force & deflection gradients, and augmentation. Other Factors such as the pilot's task, atmospheric conditions and thrust also directly influence the pilot's ability to control the aircraft and the aircraft's closed loop handling qualities.

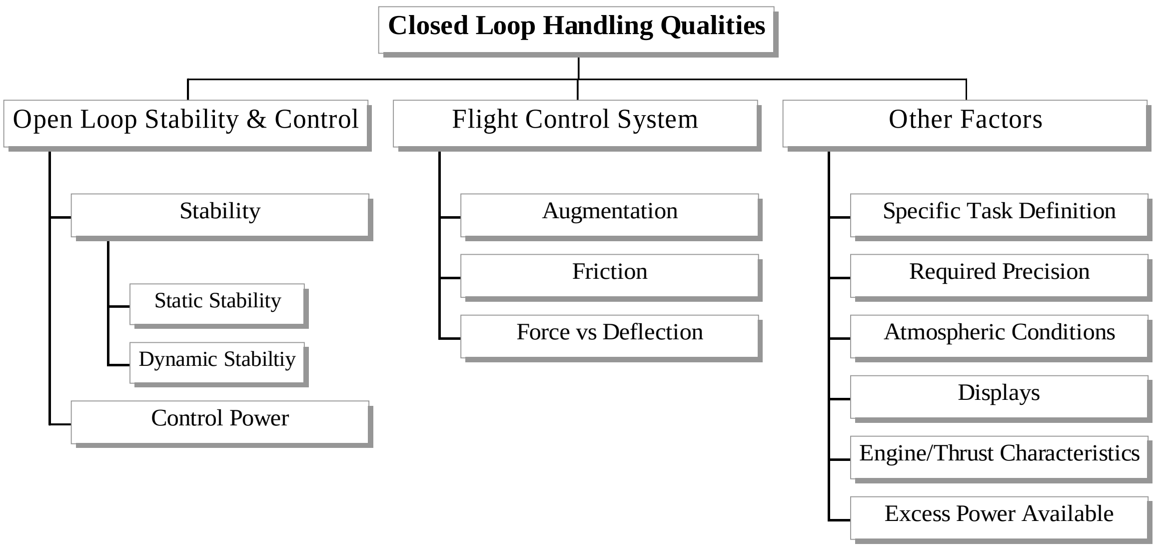

Figure 13.1 Elements of Closed Loop Handling Qualities

Pilot Compensation

The goal of any airframe/flight control system design should be to create a user-friendly aircraft with good closed loop handling qualities. This would allow the pilot to concentrate on mission tasks instead of having to devote his effort towards compensating for poor handling qualities. Pilot workload is thus decreased markedly and mission task performance is improved. An excellent contrasting example of good versus bad CLHQ for an air-to-air fighter aircraft would be the F-15 versus the F-4 for similar air-to-air combat mission tasks.

A simplified closed loop block diagram is shown in Figure 13.2. With the pilot in the loop, he continually adjusts control inputs, trying to accomplish a desired task. The question is, "How easily does the pilot performs the task?"

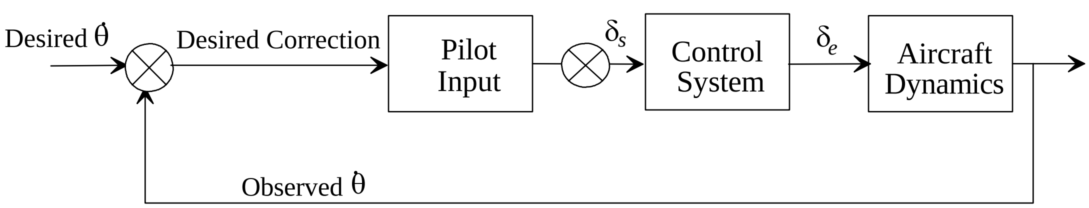

Figure 13.2 Aircraft Closed Loop Block Diagram

When flying aircraft, pilots are good adaptive gain actuators and can effectively compensate for deficiencies in the aircraft flight control system or in basic aircraft dynamics. In the first case illustrated in Figure 13.3 (a), actual aircraft response to a commanded step input is excessively fast and sensitive. To compensate and achieve the desired response, the pilot modifies his input with some "lag compensation" and makes a step input of only half magnitude and then gradually increases the magnitude of the input to the full amount. In the case of Figure 13.3 (b), a full step input results in a sluggish aircraft response. To compensate for this situation and achieve the desired response, the pilot now modifies his input with "lead compensation" and makes a large initial input and then backs off the input. The pilot can effectively compensate for both situations, under normal conditions. However, if the pilot is stressed, he may forget to compensate and under those conditions mission effectiveness can suffer.

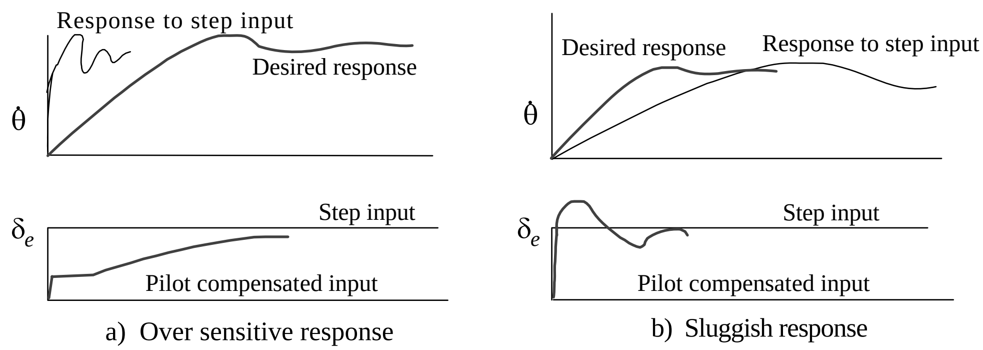

Figure 13.3 Pilot Compensation

MIL-STD 1797A Flying Qualities

Historically, aircraft developers and testers have determined that an aircraft's stability & controls characteristics influence its closed loop handling qualities. Depending on the mission of the aircraft, a specific blend of FCS and stability & control characteristics is necessary to optimize the aircraft handling qualities. In an effort to provide good handling qualities, many stability and control parameters have predefined levels of acceptability. These are based on flight test experience and have been developed over time. They do not guarantee good CLHQ, but they provide a first step for designers and for basic evaluation.

MIL-STD 1797A is based on its predecessor (8785C) and is rather lengthy because requirements vary depending on the class of aircraft, flight phase, and required level of handling qualities. Class I, II, III, IV denote light weight, medium weight, heavy weight (low to medium maneuverability), and highly maneuverable aircraft, respectively. Flight phase A designates high gain tasks such as aerial refueling or gunnery, phase B designates low gain tasks such as cruise or loiter, while C refers to takeoff and landing. The basic handling qualities levels are: Level 1 (clearly adequate); Level 2 (adequate), but with some increased workload; and Level 3 (safe to fly but not mission capable). Some example requirements will be shown in the following section to illustrate the wide variety.

Control System

First consider one element of the simplified flight control block diagram, the control system shown in Figure 13.4. The control system consists of the hydraulics & actuators; levers, cables & rods; and the controllers themselves - also known as the stick or wheel and pedals. Although the design of these components is infinitely variable, flight testers are concerned only with the response after the pilot's input, thereby simplifying the task to an evaluation of the controllers' effect on the aircraft.

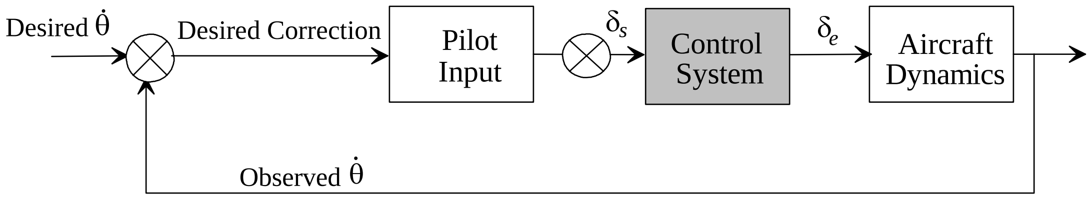

Figure 13.4 Control System Location

The design details of the controllers are quite important. Breakout forces, deflection vs. force gradients, etc. . ., all combine to greatly affect a pilot's opinion of an aircraft. These elements make up the control feel system. As an example, MIL-STD 1797A paragraph 4.2.8.5, "Pitch axis control breakout forces", puts limits on breakout forces (the forces required to start control surface movement in flight) as shown in Table 13.1. The values are for Levels 1 and 2, and less than twice these values for Level 3.

	Classes I, I-C, IV		**Classes II-L, III**	
Control	Min	Max	Min	Max
Center stick	1/2	3	1/2	5
Wheel	1/2	4	1/2	7
Sidestick	1/2	1	1/2	7

Table 13.1 Recommended Pitch Axis Breakout Forces (lbs)

Open Loop Dynamics Evaluation

The next element to consider is the inherent aircraft dynamics, which is the response to the control surface movements, Figure 13.5.

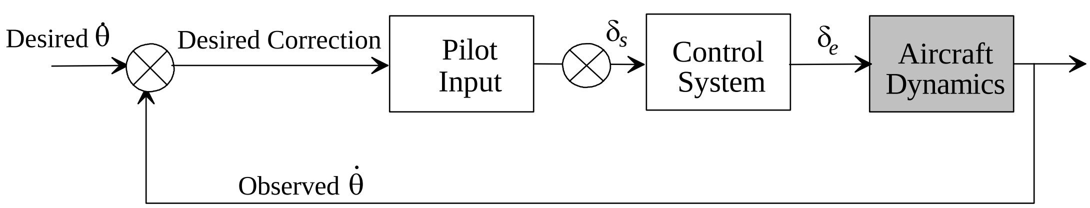

Figure 13.5 Aircraft Dynamics in the Closed Loop

The response is influenced by a number of factors including the static and dynamic stability. Experience has shown that there are certain characteristics which tend to give good handling. The appropriate parameters are detailed in 1797A; two examples are the short period mode frequency & damping and the dutch roll mode frequency and damping. These examples are highlighted below.

Frequency & Damping

The dynamic properties of frequency, damping, and time constant have particularly significant influences on handling characteristics. For example, through pilot opinion surveys and variable stability aircraft experiments, aircraft designers and testers have determined the best range of values for the short period natural frequency and damping ratio for a particular aircraft to accomplish a specific task (Figure 13.6). The optimum combination of short period frequency and damping ratio can be "designed in" to optimize an aircraft's longitudinal stability & control characteristics for its task. Frequency is a measure of the quickness of an aircraft motion whereas damping is a measure of how well motion decays. The influence of damping on aircraft handling characteristics is significant since too little damping results in an overly sensitive aircraft while too much damping results in sluggish responses.

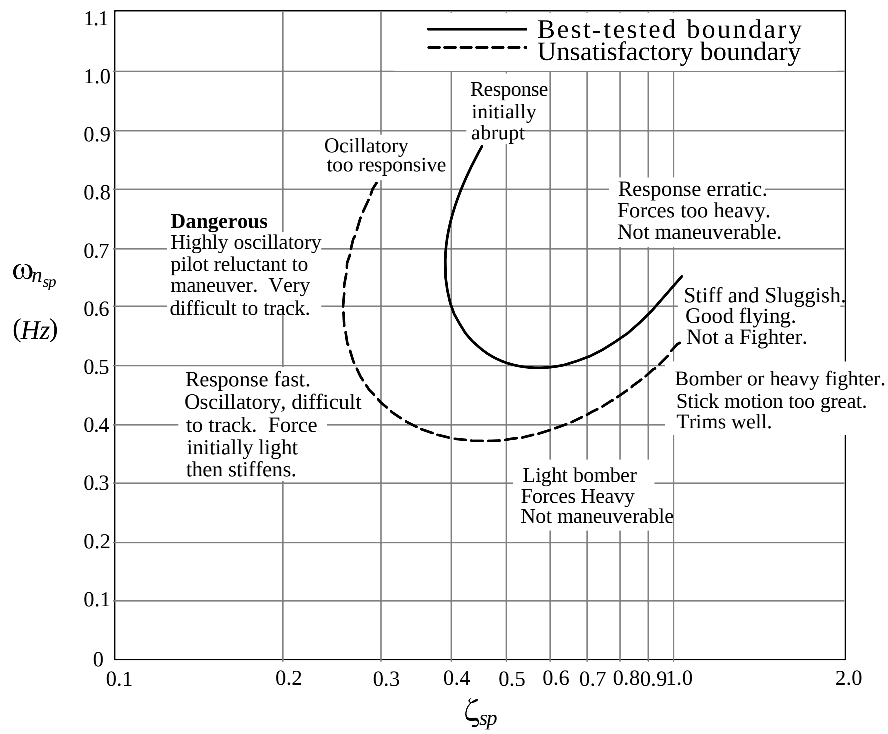

Figure 13.6 Optimum Short Period Frequency and Damping Based on Pilot Opinion

Based on this historical data and experience, MIL-STD 1797A, "Flying Qualities of Piloted Aircraft", provides guidance regarding acceptable values for open loop design parameters. This guidance assumes a second-order response and is therefore valid for the classic second order aircraft. Each parameter has distinct ranges of acceptability, depending on the desired level of flying qualities (i.e. Level 1, 2, or 3). Different criteria are also established for different phases of flight and category of aircraft.

Another example illustrates the dutch roll frequency and damping criteria. Just as certain combinations of short period frequency and damping ratio provide for optimum longitudinal handling qualities, there are optimum combinations of dutch roll frequency and damping that provide adequate lateral-directional flying qualities, Table 13.2. In addition to accounting for the aircraft mission by breaking out criteria by the class of aircraft, this table also breaks out criteria by mission task.

Flight Phase		**Class**	**Min ζ_d**	**Min $\zeta_d\,\omega_{nd}$ rad/sec**	**Min ω_{nd} rad/sec**
Level	**Category**				
1	A (CO and GA)	IV	0.4	---	1
	A	I, IV	0.19	0.35	1
		II, III	0.19	0.35	0.4
	B	AII	0.08	0.15	0.4
	C	I, II-C, IV	0.08	0.15	1
		II-L, III	0.08	0.1	0.4
2	All	All	0.02	0.05	0.4
3	All	All	0	---	0.4

CO - air-to-air combat **GA** - ground attack

Table 13.2 Open Loop Dynamic Specification Dutch Roll Frequency and Damping

Flight Path Stability

A third example illustrates that an aircraft *performance* characteristic such as flight path stability can influence closed loop handling qualities. Flight path stability is the slope of flight path angle versus velocity curve (Figure 13.7) at approach speed. Since flight path stability affects an aircraft's handling qualities during final approach, the military uses it as a criterion for power approach and landing handling qualities. Flight path stability is basically a measure of an aircraft's ability to maintain the glidepath (γ_{PA}, typically 3^o) at a defined approach speed (V_O), or require the glidepath and V_O if disturbed. The gradient is measured at V_{Omin}.

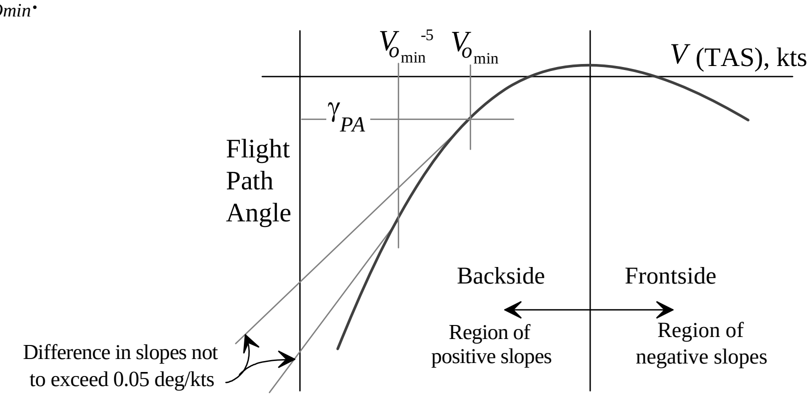

Figure 13.7 Aircraft Performance Specification Flight Path Stability

On the front side of the curve, speed reductions result in a shallower γ_{PA} and speed increases result in a steeper γ_{PA}. Therefore, the pilot can raise the nose to stretch the glide. This is intuitive. If the pilot wants to land farther down the runway he raises the nose. On the backside of the curve, however, speed changes will have the opposite effect. If disturbed from V_O, an aircraft with a positive slope at V_O will land shorter if the pilot raises the nose. If required to correct to glidepath or the desired V_O, aircraft with a highly unstable gradient at V_O will require greater power changes. Aircraft with a shallow γ_{PA} vs V slope at V_O will require smaller power changes. All of this directly influences the degree of pilot compensation required to conduct an acceptable landing approach.

Aircraft approach speed position on the front or back side of the curve dictates the best pilot technique for landing approach; on the front side, the pilot uses pitch for glide path control and power for airspeed control, and on the backside, he uses pitch for airspeed control and power for glidepath control. Criteria for flight path stability specifies that the slope be negative or less positive than specified positive gradients for Level 1, 2, and 3. Also, the gradient of the local slope at 5 knots below approach speed shall not be more than 0.05°/knot more positive than the slope at V_{Omin}.

Flight Control System Augmentation

SAS & CAS

To help compensate for deficient flying qualities, various stability augmentation systems (SAS) and command augmentation systems (CAS) have been devised and implemented. Stability augmentation systems modify the aircraft's basic open-loop characteristics. A simple example is illustrated in Figure 13.8 where the aircraft's immediate response is fed back to some part of the control system (mechanical or electrical) and converted to subsequent inputs.

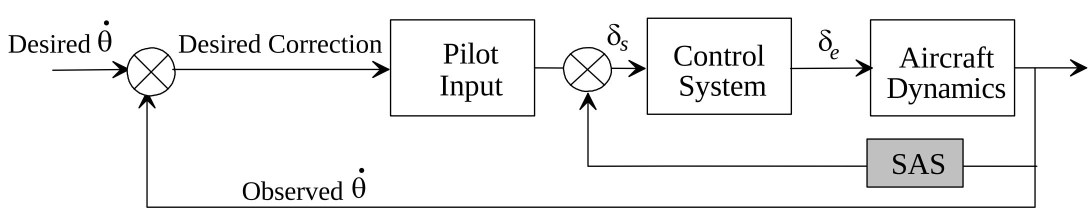

Figure 13.8 SAS within a Control System

A SAS is typically designed to sense motion such as pitch, roll or yaw rate and signal it back to the FCS to eliminate undesirable motions. They do not have a large amount of authority - the pilot still controls 80 to 90% of the control surface deflection. Examples include pitch and yaw dampers in the F-86, F-4, and KC-135 (Figure 13.9).

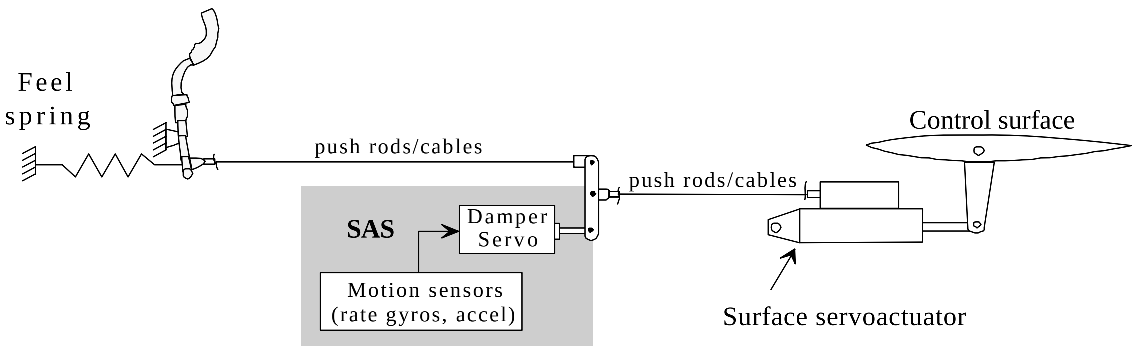

Figure 13.9 Stability Augmentation System

Until the late 1960's, augmentation systems were relatively simple, low authority stability augmentation systems. Since then, flight control systems have become increasingly more complex, powerful, and flexible with the ability to adaptively modify system gains, filters, etc., and significantly alter aircraft closed loop handling qualities.

A Command Augmentation System (CAS) goes beyond a simple SAS. It generates control surface movement and resultant aircraft motion in response to a specific **pilot command** such as load factor, attitude hold, or pitch rate. A CAS compares commanded versus actual aircraft response and continually works to eliminate any error. Basically, the pilot commands an aircraft response (i.e. pitch rate, roll rate, load factor).

Initially, command augmentation systems compensated for deficiencies in stick force-per-n_z and attitude rate response. Advances in flight control technology and system design have significantly improved aircraft handling qualities to the point where CAS configured systems provides total and predictable aircraft stability, control, and maneuverability throughout the flight envelope.

The upper example in Figure 13.10 illustrates an aircraft that responds too abruptly to a commanded pitch input. A lag filter inserted into the flight control system automatically slows the pitch rate input and response, thereby eliminating the undesirable abrupt response characteristic. This is transparent to the pilot and eliminates the requirement for him to apply "lag compensation" as illustrated in Figure 13.3(a).

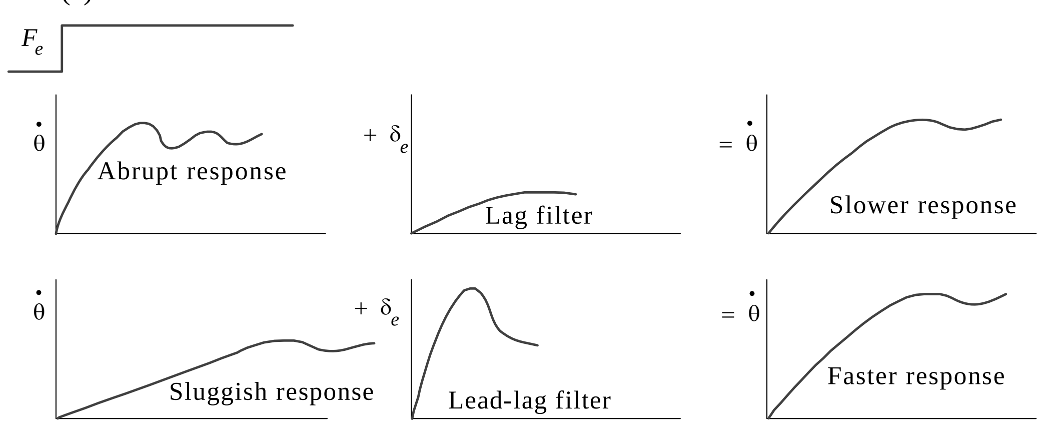

Figure 13.10 Flight Control System Compensation

The lower example in Figure 13.10 illustrates an aircraft that responds too sluggishly to a commanded pitch input. A lead-lag filter inserted into the flight control system automatically forces a more abrupt pitch rate response initially, then a slowed decrease in the response. Again, the pilot is no longer required to apply "lead compensation" as was required in Figure 13.3(b).

Figure 13.11 illustrates a fully augmented flight control system which has a redundant, high authority electrical augmentation system. Artificial feel is provided by springs and sensor feedbacks. There is also a direct mechanical link to the control actuators. The F-15 is an example of this type flight control system. It can be flown using either the mechanical controls or the electrical flight control system independently, or as an integrated system. The control authority of the CAS element is typically limited to approximately 50% of control deflection allowing the pilot to override the CAS if necessary. CAS equipped aircraft also include the F-111, A-7, and F-14.

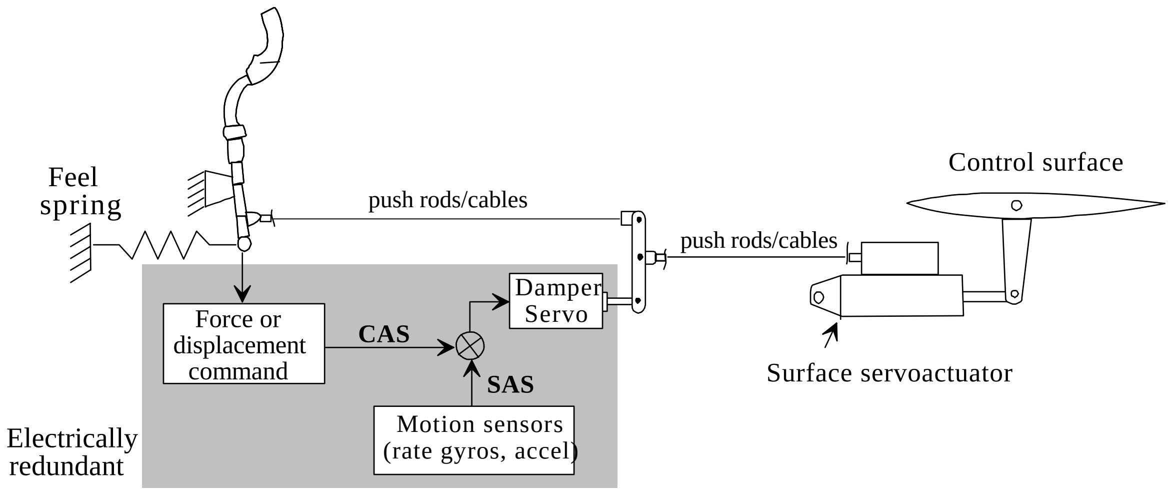

Figure 13.11 Fully Augmented Flight Control System

Full Authority Flight Control System

With sufficient redundancy built into the system, the CAS can be given full authority for each control system as in Figure 13.12. The flight control system, with it's electrical path between cockpit flight controls and control actuators is basically a "fly-by-wire" control system. The classical first and second-order dynamic responses are typically masked by the CAS. In addition to this masking, a full authority control system introduces new higher order dynamic characteristics which add to the basic airframe dynamics arriving at a totally new dynamic response. This response is a sum of all its components; the pilot, the displays, the airframe, and the full authority control system (Figure 13.13).

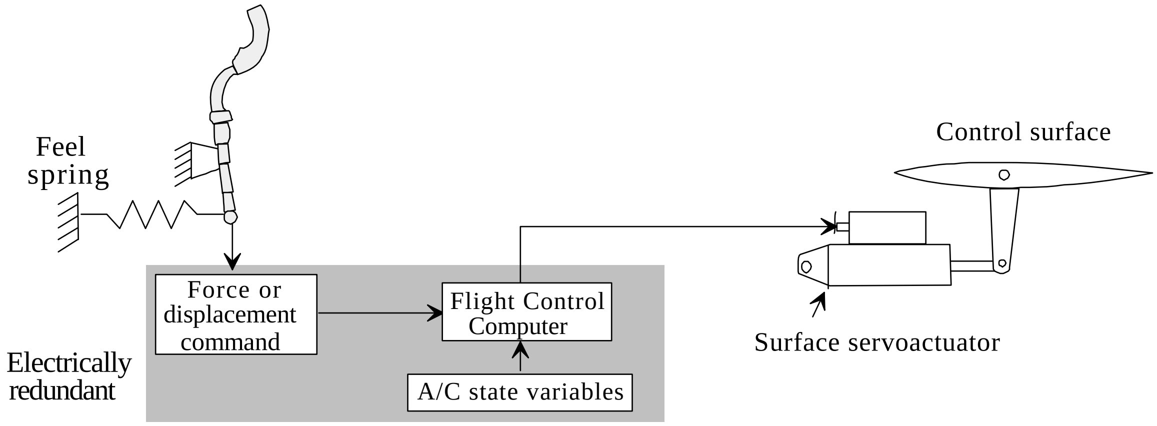

Figure 13.12 Fly By Wire Flight Control System

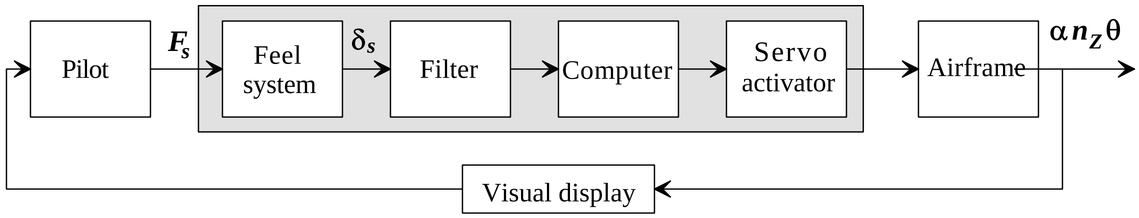

Figure 13.13 Full Authority Control System Response Factors

Modifying basic aircraft dynamics has proven to be extremely beneficial in improving aircraft handling qualities. Static stability can be relaxed allowing for improved performance and maneuverability. Previously unstable aircraft can be made stable. Flight control laws can be tailored to optimize specific mission tasks. Flight control systems can now be effectively integrated with fire control and propulsion control systems to enhance the overall aircraft operation and handling qualities.

Even though full authority flight control systems have demonstrated considerable utility and payoff since being introduced, there are unique disadvantages. The desired control surface dynamic response for a responsive full authority aircraft is typically high frequency, therefore requiring high frequency servo actuators. Unfortunately, time transport delays, where the output response lags the input command, are often inherent in many full authority control systems. Transport time delays are pure time delays which result in a phase shift in the output signal (Figure 13.14).

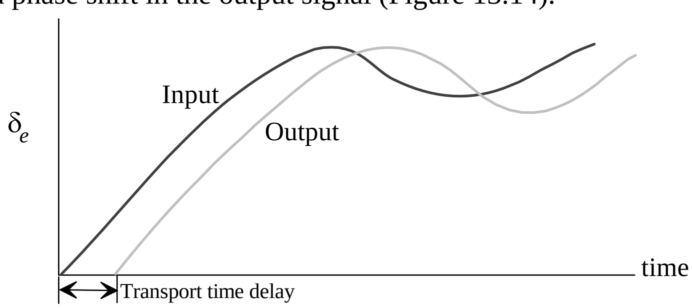

Figure 13.14 Transport Time Delay

The delays are typically very small in magnitude, and can result from such things as sample times, cycle times, and computational delays in digital control systems. Even though individual elements of time delay may be very small, the sum of all elements can have a significant effect on aircraft dynamics, particularly during high gain tasks. Transport time delays in high frequency systems have often been factors in pilot induced oscillations for aircraft with full authority control systems.

With full authority control systems, the aircraft response to a pilot input may no longer be a classic first or second-order dynamic response, but more likely a higher order dynamic response (Figure 13.15).

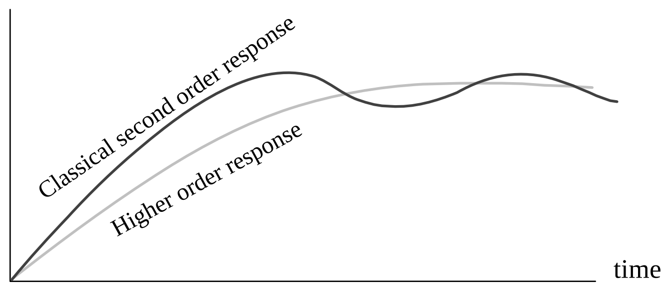

Figure 13.15 Higher Order Dynamic Response

A step input generates a second-order airframe response in a non-augmented aircraft. The same input into a higher order system may result in new and unique dynamic characteristics, which include the dynamics of all elements of the flight control system; the pilot, the displays, and the airframe. This presents a considerable problem: Classical handling qualities parameters and flight techniques used to define handling qualities for first and second-order aircraft are no longer applicable. In this case, the historical data base in MIL-STD-1797A are no longer useful; something else is required.

Alternate Evaluation Methods

Equivalent Second Order System

The Equivalent Aircraft Criterion, an open-loop measurement, was devised to satisfy this requirement. Basically, it attempts to reduce the higher order transfer functions to an equivalent first or second-order response. Best curve fit computer matching techniques take higher order dynamic flight control phase shifts into consideration by using time delay constants, Figure 13.16.

Second-order frequency and damping parameters are derived from classic open loop tests and evaluated against handling qualities criteria similar to MIL-STD-1797A criteria. Unfortunately, although there exist a wide variety of mathematical techniques and computer programs that reduce higher order responses to equivalent second order responses, different equivalent frequencies and damping ratios result from different techniques and programs; and the question then becomes "which one is most correct?" Consensus between the tester/developer and customer on the cost function and fidelity of the second order fit is a necessity.

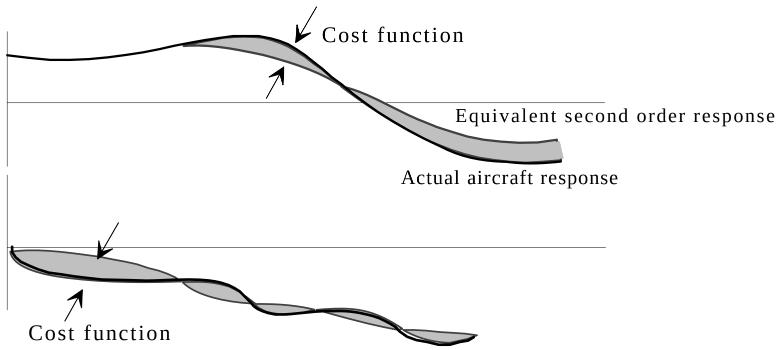

Figure 13.16 Equivalent Aircraft Criterion

The next level of sophistication in predicting CLHQ addresses the transfer function between the pilot input ant aircraft response. A transfer function is the mathematically expressed relation between input and output. Several criteria have been developed and are at least partially useful, but none yield an authoritative answer. The objective of these criteria is to provide a method for a designer to predict handling qualities characteristics. Numerical measurements of handling qualities characteristics should be standardized, and they should correlate well with qualitative pilot assessments. In short, they must consistently and accurately identify and discriminate between good and bad handling qualities. Three examples of these are the C* Criterion, the Neal-Smith Criterion, and the Smith-Geddes Criterion. The first and simplest is discussed here. The latter two address the phase angle between inputs and outputs.

C* Criterion

The C* Criterion used pilot ratings to define acceptable C* response boundaries to an open loop step input.   The C* response is a function of stick force, load factor, center of gravity, pitch rate and pitch acceleration and is defined by the following equation

$$\frac{C^*}{F_S} = \left[\frac{n}{F_S} + \frac{l_p}{g}\left(\frac{\ddot{\theta}}{F_S}\right) + \frac{400}{g}\left(\frac{\dot{\theta}}{F_S}\right) \right]$$

where F_S is stick force, n is load factor, l_p is distance between pilot and cg; $\dot{\theta}$ and $\ddot{\theta}$ are pitch rate and acceleration. For acceptable handling qualities, the C* response, obtained by the above equation, must be within the defined pilot rating boundaries depicted in Figure 13.17. This criterion has a major shortcoming however in that the data, used to define the boundaries of the C* envelope did not account for control system dynamics (it assumed control system dynamics were negligible). Therefore this criterion is not valid in cases where control system dynamics would influence the pilot ratings.

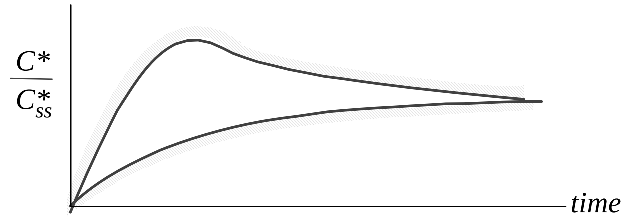

Figure 13.17 C^* Criterion Response Envelope Example

Closed Loop Handling Qualities Testing

Performance and handling qualities testing techniques presented up to now have been open loop. Quantifiable data on an aircraft's characteristics are gathered to determine compliance to military standards or FARs. There are situations, however, where a system may meet it's specifications and be qualitatively unsatisfactory, or not meet specifications and still be satisfactory. The military standards, FARs, and other quantifiable criteria are just a means to an end; the real question is "How well does the aircraft perform its intended mission and mission tasks?"

Closed loop handling qualities (CLHQ) testing qualitatively determines the acceptability of a system for performing mission tasks. Pilot *opinion* is the primary method of evaluating interactions between aircraft handling qualities and pilot performance/workload. To use this approach, specific tasks and performance criteria must be established. This process begins by examining tasks that a pilot may need to perform. Table 13.3 illustrates an example of a mission profile.

Ground Operations/Taxi
Takeoff
Climb Out/Level Off
Cruise
Mission Tasks
~ subsonic, transonic, supersonic cruising flight
~ air refueling
~ air-to-air combat
~ air-to-ground combat
~ low level flight
~ formation flying
Descent & Approach
Landings

Table 13.3 Typical Fighter Mission Profile

Table 13.4 provides an example of a detailed task analysis for one of the mission elements within this profile. Included in this table are lists of qualities the test pilot should evaluate.

Airspeed/AOA Control
~ speed stability, speed cues, flight path stability, engine response, turbulence effects
Flight Path Control
~ attitude, aim point, alignment control, high gain PIO tendencies
Attitude Control
~ control harmony & sensitivity, friction & breakout, predictability & precision, PIO tendencies, gust susceptibility, flare & landing characteristics, lateral-directional stability in cross control
Touchdown
~ predictability, precision, repeatability
Landing Gear Dynamics on Touchdown
Crosswind Effects & Control
Overhead Traffic Patterns
Instrument References
~ readability, dynamics, lag, and sensitivity of HUD, AOA, attitude & airspeed
Applied Techniques
~ front side, back side, AOA or airspeed, crab or wing low
Pilot Visibility & Access to Control

Table 13.4 Detailed Task Analysis for Approach and Landing

A CLHQ test closely examines one or more of these subjects. The basic approach of CLHQ testing is to force the test pilot to aggressively fly at least one of the above tasks with great precision. While attempting to do this, he must continually analyze and report on the aircraft's performance and or his workload required.

This reporting includes;

1) pilot evaluation of the capability of the aircraft system to *accomplish* a mission related task
2) the pilot *workload* necessary to accomplish that task
3) assignment of standardized *pilot ratings* of the aircraft's capability to accomplish that task

They key ingredients to this testing are aggressive flying and precision flying. By forcing the pilot to do both, pilot/vehicle interface deficiencies are illuminated.

CLHQ Test Requirements

In designing any test in which CLHQ rating data is to be used, several key requirements exist:

1). An explicit **mission definition** is probably the most important factor in obtaining an objective pilot evaluation. Define what the pilot is required to accomplish with the aircraft. Identify the circumstances and conditions must he operate.

2). Define appropriate mission **tasks**. Consider the importance of each task relevant to the intended mission and how task performance is measured. The tasks should be repeatable, they should require sufficient control input frequency to stress the system, and they should be of adequate duration to differentiate transient from steady state responses.

3). Establish **desirable** and **acceptable** criteria regarding task performance and mission suitability. Criteria established should be quantifiable, recordable, and realistic. Desirable criteria specify a satisfactory level of performance. Acceptable criteria specify the level of performance that is marginally adequate.

4). Realistically structure the test to include typical **distractions and disturbances** anticipated during an actual mission. It's understood that not all elements of an actual mission can be simulated as part of the test, but the relationship of the test scenario to an actual mission and the test limitations should be explicitly understood. Test participants should know what is left out of an evaluation, and also what elements might be included in an evaluation that normally wouldn't exist in an actual mission scenario.

5). Plan the actual measurement and recording of task **performance** relative to the criteria established in step 3. This includes data recording systems, cockpit video, tape recorders, and/or pilot observations and comments. To be of maximum use, qualitative observations and comments should be recorded during or immediately after each evaluation.

6). Plan the measuring and recording of pilot **workload** and compensation. The assessment of pilot workload is as critical as quantifying and recording the performance.

To insure that all these requirements are properly considered, adequate pretest preparation and planing is essential. CLHQ evaluations are one of the most difficult, and most important, tasks for a test pilot. CLHQ output data is only as good as the care taken in designing and executing the test, and in analyzing and reporting on the results. To preclude testing prejudice or bias, it's also important that the pilot have no foreknowledge of specific characteristics being tested. This does not limit adequate preparation for the test, but it does exclude specific knowledge of aircraft characteristics which might bias his evaluation.

In executing a CLHQ test, it's imperative the test be executed as planned. Also its important that the pilot make a strong attempt to obtain the ***desired*** level of performance. The difference between getting desired performance and "almost" getting desired performance may uncover a handling qualities "cliff", the point at which acceptable or satisfactory handling qualities quickly and dangerously degrade while the pilot is involved in a high gain task. If a pilot finds himself backing out of a task or decreasing aggressiveness to obtain better results, it also may be indicative of handling qualities problems.

Two types of output data define CLHQ evaluations; ratings and comments. The rating is an overall summation of the pilot observations regarding the ability of a system to perform a mission task. However, the rating does not represent the entire qualitative assessment of the system's ability to do a task. Ratings are meaningless without supporting comments substantiating why the system received a certain rating and what the deficiencies were. Pilot comments will also help determine to what degree the pilot objections are mission-related. To be most meaningful, ratings and comments should be given on the spot, either during or immediately after an evaluation. Comments should be simple and relevant; what is observed, what difficulties are encountered in executing a specific task, and what workload is required.

Cooper-Harper Rating Scale

The 10-point Cooper-Harper Handling Qualities Rating Scale has become the rating scale most widely used today. Figure 13.18 illustrates the basic decision tree and relation between words and rating numbers.

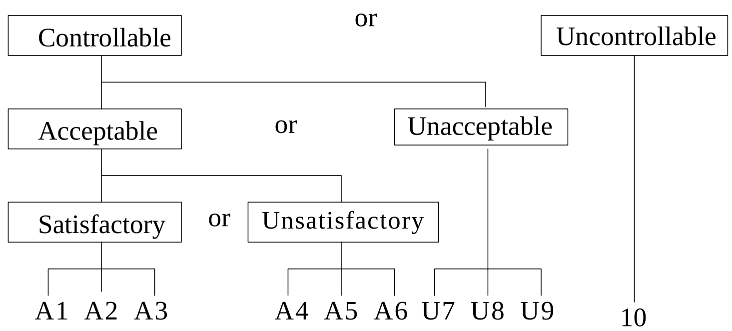

Figure 13.18 Pilot Ratings

It's important that the rating decisions be made sequentially through the process described in Figure 13.19, using the specific adjective descriptions instead of going directly to a numerical rating. The pilot must first determine the basic category of handling qualities. They are: uncontrollable, unacceptable (but controllable), unsatisfactory (but acceptable), and satisfactory.

The first decision is whether the aircraft is controllable or **uncontrollable.** Controllability must be determined within the context of the task. Uncontrollable doesn't necessarily mean the aircraft is destroyed during the task, but it does mean that flight manual limitations may be exceeded during the task or that the pilot may predict loss of control before he reaches that level of aggressiveness necessary to perform the task. If uncontrollable in the mission task or the pilot has to abandon the task to retain aircraft control, the aircraft is rated a 10.

If controllable, the next question is whether adequate performance is attainable with a tolerable pilot workload. A clear definition of "adequate" and "tolerable" are needed for this. A "No" answer (unacceptable) doesn't necessarily mean that the mission can't be accomplished, but it does mean that the pilot workload is so large that mission performance is inadequate. The aircraft is **unacceptable** and the noted deficiencies require improvement.

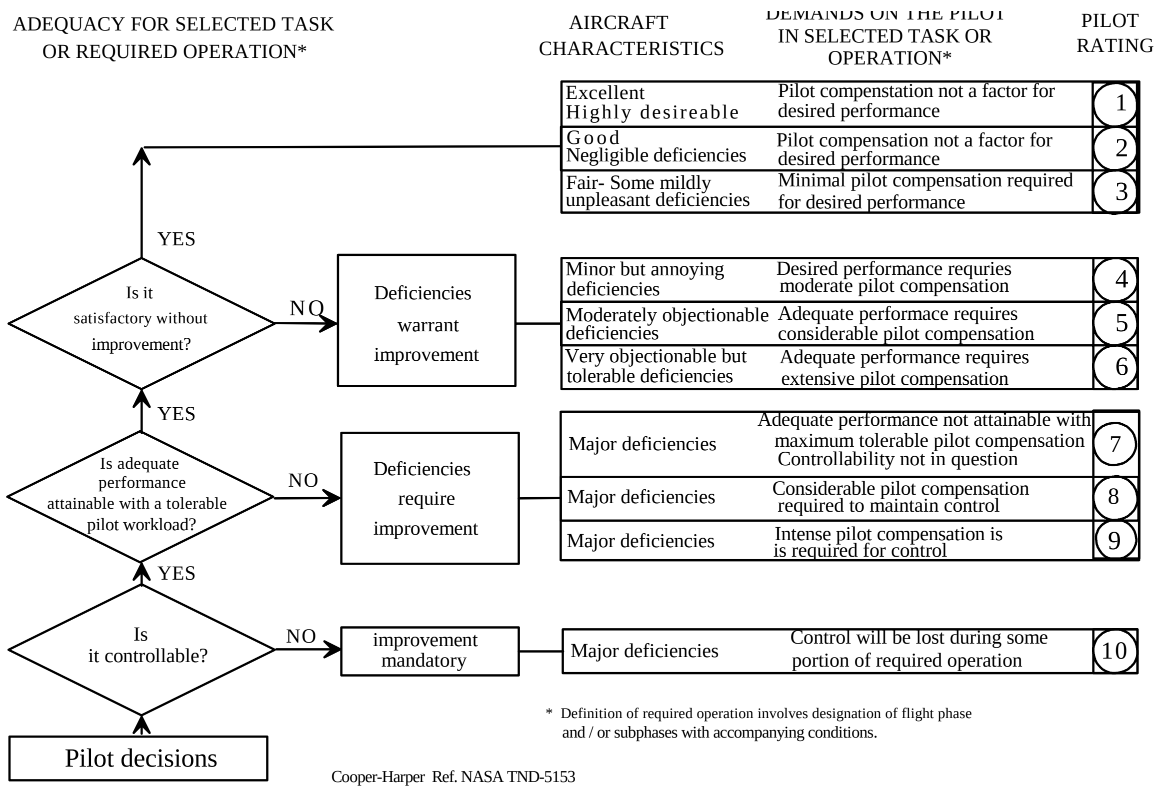

Figure 13.19 Cooper Harper Rating Scale

If adequate mission performance *is* attainable with a tolerable pilot workload, then it is acceptable. In this case, the next question is whether the aircraft is satisfactory without improvements or not. If the system has deficiencies that warrant improvement, then it is **unsatisfactory - but** acceptable. If improvements are not needed, then it is **satisfactory.** The question is not "Is it perfect without improvement?", but "Is it good enough that any deficiencies don't need to be fixed?"

Once the basic category of unacceptable, unsatisfactory, or satisfactory is determined, the pilot uses Figure 13.19 again to arrive at a specific rating. If the aircraft handling qualities for the task are satisfactory, the pilot must choose a rating of 1, 2, or 3. If pilot compensation is required, even minimally, and mildly unpleasant deficiencies are present, then a rating of 3 is appropriate. If compensation is not a factor, then good aircraft characteristics yield a pilot rating of 2. Excellent or highly desirable characteristics lead to a pilot rating of 1. Note that the pilot must achieve the more stringent "desired" performance to qualify for level one.

If the handling qualities are unsatisfactory but acceptable, the pilot must choose a 4, 5, or 6 rating. If merely moderate compensation is required to achieve the "desired" performance, then the pilot rating is 4. If only "adequate" performance is achievable, then the rating will be 5 or 6 depending on the degree of pilot compensation: considerable (PR = 5) or extensive (PR = 6).

If the handling qualities are unacceptable, the pilot must select a 7, 8, or 9 rating. If controllability is not in question, then a 7 rating is assigned. If controllability is in question, then the difference between "considerable" or "intense" pilot compensation will determine an 8 or 9 rating respectively. When assigning a rating, half ratings should be avoided, although half ratings within categories is acceptable. Half ratings between categories (3 1/2 or 6 1/2) should never occur because they indicate a degree of uncertainty in answering the basic directive questions.

Handling Qualities During Tracking

Handling Qualities During Tracking (HQDT) is one test technique for CLHQ testing. Recommendations for changes or improvements normally follow for all ratings below a 3. If the rating is in the 4, 5, 6 range, the recommendation would use the helping verb "should" as in: "The dutch roll damping in landing configuration *should* be increased." If the rating is below a 6, then the recommendation would use the helping verb "must" as in: "The stick force per g *must* be increased." This technique has been used extensively on fighter test & evaluation programs such as the F-15 and F-16, and more recently on tasks such as C-17 air refueling. The test technique is based on requiring the pilot to very precisely fly a high gain tracking task using a fixed pipper (something like a circular crosshair) with no tolerance for error. This technique is used throughout the flight envelope to increase the pilot's gain and highlight any handling qualities deficiencies that may not be apparent in a low to medium-gain task. The primary difference between HQDT and operational tracking is that HQDT seeks to artificially drive up the gain by tolerating no errors. Statistical tracking results are then computed from gun camera film or video and presented in HQDT plots. These can show pipper position time histories (Figure 13.20a and b), tracking error distributions (c), cumulative tracking errors (d), and root mean square (RMS) error data as well pilot comments and ratings (e).

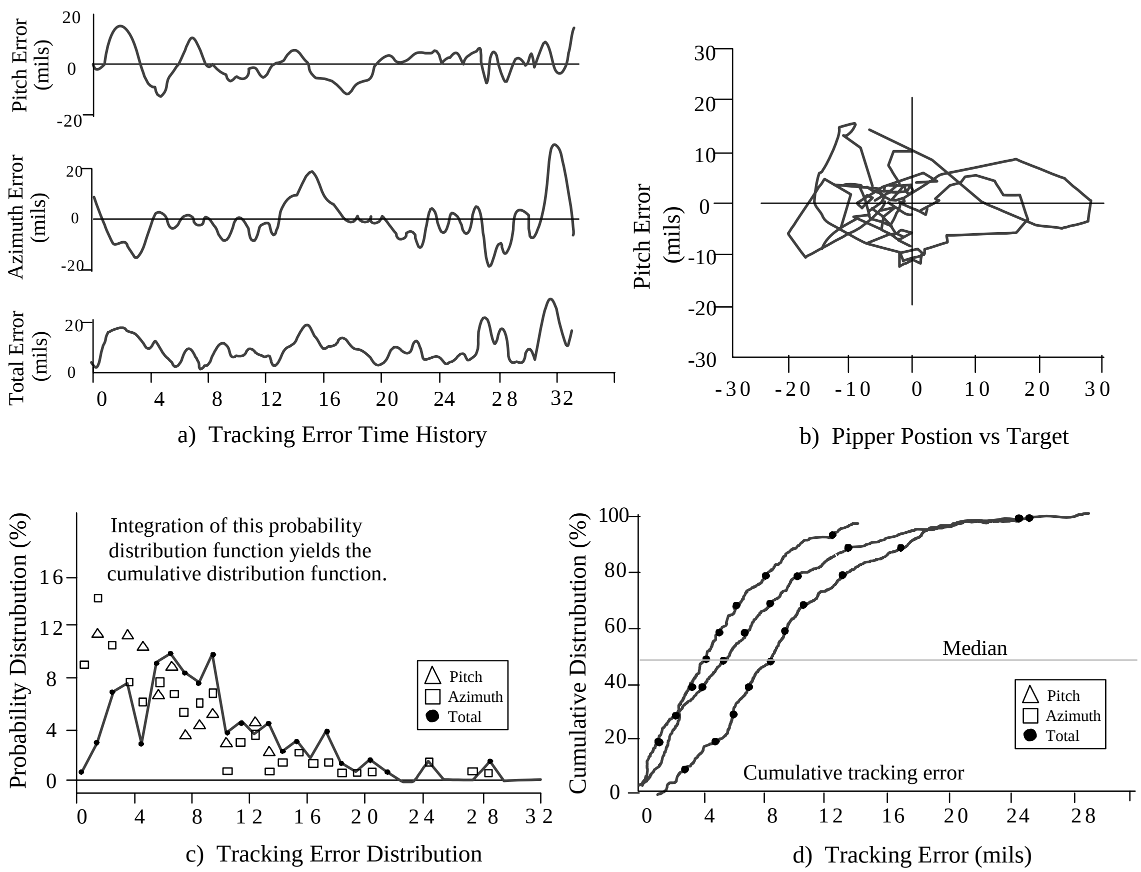

Figure 13.20 HQDT Plots

Summary

In summary, designers and flight testers should use the large historical database to provide an approximation of the aircraft's handling qualities. This is done first by knowing the basic open loop parameters such as static and dynamic stability. The next step is to compare the aircraft to more sophisticated open loop parameters such as the C*, Neal-Smith, and Smith-Geddes criteria. As a final check on handling qualities, testers should evaluate individual tasks using CLHQ and HQDT methods. Each test is aircraft and task specific and not dependent on historical results.

This evaluation process is intermixed with modifications to develop aircraft characteristics that allow a pilot to accomplish a task with ease and precision. The goal is a user-friendly aircraft with good handling qualities which allow the pilot to concentrate on mission tasks instead of having to devote his efforts toward compensating for poor handling qualities.

References

13.1 USAF Test Pilot School, *Flying Qualities Phase*, Vol.1 Edwards AFB, October 1990,

13.2 Twisdale, Thomas R. USAF, "Tracking Test Techniques for Handling Qualities Determination", Edwards AFB, CA. AFFTC-TO-75-1, May 1980

13.3 Cooper G.E., Harper R.P., "The Use of Pilot Rating in the Evaluation of Aircraft Handling Qualities" NASA Technical Note D-5153

13.4 Smith, Ralph H. "The Smith-Geddes Handling Qualities Criteria", 1994 SAE Conference April 20, 1994

13.5 Roberts, Sean C., *Flying Qualities Flight Testing of Light Aircraft*, Flight Research Inc., Mojave CA, 1981